Energy Research and Development Division
FINAL PROJECT REPORT

TRANSMISSION GRID RESEARCH

Appendices H-K

Prepared for: California Energy Commission
Prepared by: California Institute for Energy and Environment

FEBRUARY 2012
CEC-500-2013-098-APH-K

PREPARED BY:

Primary Authors:
Merwin Brown
Larry Miller
Lloyd Cibulka
Alexandra Von Meier
Lorraine Hwang

California Institute for Energy & Environment
University of California
2087 Addison Street, Second Floor
Berkeley, CA 94704
510 643-0038
www.uc-ciee.org

Contract Number: 500-07-037

Prepared for:

California Energy Commission

Jamie Patterson
Contract Manager

Fernando Piña
Office Manager
Energy Systems Research Office

Laurie ten Hope
Deputy Director
Energy Research and Development Division

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warranty, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

The CIEE Electric Grid Research team - Merwin Brown, Lloyd Cibulka, Jim Cole, Gilda Garcia, Lorraine Hwang, Larry Miller, and Sascha von Meir - is grateful to the other researchers and their institutions – MCEER, Pacific Earthquake Engineering Research Center, Pacific Northwest National Laboratory, and Virginia Tech – for their expertise and dedication in conducting the research and development accomplished in this effort. The team also wants to thank the many advisors, especially Policy Advisory Committee (PAC) and the Technical Advisory Committees (TAC) which support it. Committee membership was composed primarily of personnel from the 3 major investor owned utilities (IOU) in California – Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE)–and the California ISO (CAISO,) and chaired by an Energy Commission commissioner. Additional participants were often included to share knowledge on the meeting's focus including the Assistant Secretary of the Office of Electricity for the U.S. Department of Energy, a representative of the Bonneville Power Association, and the Utility Variable-Generation Integration Group.

This work was funded by the California Energy Commission PIER program under Contract 500-07-037. CIEE is especially grateful for this financial support which has made a significant contribution to advancing the technology needed for the modernization of California's electric grid for meeting California's energy policy goals. Electric Grid Research at CIEE is creating technologies for new tools to modernize the grid and maximize its ability to meet customer needs and California's aggressive energy-policy goals. The vision is a smarter, more responsive, more robust grid — the heart of California's quest to reduce greenhouse gases, improve energy efficiency, and deploy more renewable energy, all while satisfying the new and growing ways customers use electricity. With funding and direction from the California Energy Commission's Public Interest Energy Research (PIER) program, CIEE has worked, and is prepare to continue working, to make these new technologies reality through research. This report was prepared by the CIEE. CIEE makes no warranties as to the suitability of this product for any particular purpose.

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

Energy Research and Development Division funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Transmission Grid Research is the final report for the Transmission Grid Research project (Contract Number 500-07-037) conducted by the California Institute for Energy and Environment. The information from this project contributes to the Energy Research and Development Division's Energy-Related Environmental Research Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

This report presents results from 11 public interest research projects that advance science and technologies related to the electric power transmission grid. These projects fall within three focus areas: infrastructure, real-time operations, and planning and environmental activities. Three projects summarized current status, research gaps, and recommended research for each focus area. In the infrastructure area, two projects evaluated the seismic issues associated with transformer bushings and substation insulators and made recommendations for adoption by the Institute for Electrical and Electronics Engineers Standard 693, which specifies testing of these components. Three projects focused on real-time operations. The wide area energy management storage systems project analyzed the combination of fast and slow storage over two balancing areas. A project on oscillation detection developed new algorithms for measuring oscillations in real time. The project on modal analysis for grid operation on the Western Interconnection developed a decision support tool to suggest mitigation steps for poorly damped wide area oscillations. In the planning and environmental areas, two projects were completed. The adaptive relay project studied four different applications of the use of synchrophasor data to improve protective systems. The online tools for wind and solar project developed tools for use by the California Independent System Operator to forecast system demands for ramping and regulation and possible congestion over the following 24-hour period. Finally, the technology transfer research project focused on disseminating research results and encouraging further commercialization of the research.

Keywords: electric transmission, renewables, renewable energy integration, greenhouse gases (GHG), emissions, reliability, renewable penetration, energy efficiency, electric power system, Smart Grid, infrastructure, renewable portfolio standard (RPS), transmission and distribution (T&D), transmission planning, transmission operations, transmission infrastructure, once though cooling, technology transfer

Please use the following citation for this report:

Brown, Merwin; Miller, Larry; Cibulka, Lloyd; Von Meier, Alexandra; Hwang, Lorraine. (California Institute for Energy and Environment). 2012. ***Transmission Grid Research,*** California Energy Commission. Publication Number: CEC-500-2013-098-APH-K.

TABLE OF CONTENTS

Acknowledgements i

PREFACE ii

ABSTRACT iii

TABLE OF CONTENTS iv

APPENDIX H: Transmission Planning and Environmental Research Final Report H-1

APPENDIX I: Adaptive Relaying Technology Development Final Report I-1

APPENDIX J: Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation Final Report J-1

APPENDIX K: Technology Transfer Activities Final Report K-1

APPENDIX H:
Transmission Planning and Environmental Research Final Report

Arnold Schwarzenegger
Governor

FUTURE TRANSMISSION PLANNING AND ENVIRONMENTAL RESEARCH REPORT

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
California Institute for Energy and Environment

July 2009

Prepared By:
California Institute for Energy and the Environment
Project Manager: Merwin Brown
Authors: Lorraine Hwang, Merwin Brown
Sacramento, CA 95814
Commission Contract No. 500-07-037
Commission Work Authorization No:

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Jamie Patterson
Contract Manager

Pedro Gomez
Program Area Lead
Energy Systems Integration

Mike Gravely
Office Manager
Energy Systems Research

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Melissa Jones
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Future Transmission Planning and Environmental Research Report is the Task 4.0 final report for the contract number 500-07-037 conducted by California Institute for Energy and Environment (CIEE). The information from this project contributes to PIER's Energy Systems Integration Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

Please cite this report as follows:

Hwang, Lorraine, and Merwin Brown. 2009. *Future Transmission Planning and Environmental Research Report,* California Energy Commission, PIER Energy Systems Integration Program.

Table of Contents

Preface 1
Table of Contents 2
Abstract 3
Executive Summary 4
1.0 Purpose 10
2.0 Introduction and Process 12
3.0 Engagements with Stakeholders, Researchers and Technology Developers 14
4.0 Problem Statement 16
5.0 Initial Transmission Planning and Environmental Research Candidates 22
5.1. Enhance Acceptance of New Transmission by Facilitating Transmission Approval Process 22
5.2. Enhance Acceptance of New Transmission by the Deployment of New Technologies 22
5.3. Improve Understanding of Value of Transmission. 22
5.4. Markets Impacts. 22
5.5. Advanced Planning. 23
5.6. Accommodation of Distributed Renewable Energy Generation and Demand Response. 23
5.7. Controlled/Strategic Islanding: 23
5.8. Wind Generation-PHEV Partnership: 24
5.9. N-1 Reliability in a Renewable Generation Environment: 24
5.10. Impact of Intermittent Renewables on LMP Volatility: 25
5.11. Congestion Planning in an Expanded Renewables Deployment Environment: 25
6.0 References 26
7.0 Glossary 28

Abstract

California has adopted aggressive energy policy goals to significantly reduce greenhouse gases, improve energy efficiencies and deploy increased penetrations of renewable energy generation. Substantial increases in the generation of electricity from renewable resources that are located remote from customers will be necessary to achieve Renewable Portfolio Standard goals, and must rely on adequate, economical and reliable transmission for delivering renewable electricity to consumers. The current system will be challenged in performing its roles in meeting these goals. New transmission technologies offer the prospect of providing a substantial portion of the new or expanded capabilities to supplement traditional solutions.

This report contains the approach, framework and initial plan for achieving the goal for Task 4.0 Transmission Planning and Environmental Research Report of Contract 500-07-037, which is to identify new or expanded transmission operations research activities that

1. Increase the transmission of electricity from renewable resources
2. Increase the efficiency of the transmission system and
3. Reduce the emissions of greenhouse gases (GHG) that are associated with the transmission system

The report addresses but is not limited to a description of what future transmission planning and environmental research activities could be conducted in the context of the following:

- Technologies to provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- Methodologies and analytical techniques to provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- SmartGrid technologies for the inclusion into the planning process for transmission to increase the transmission of electricity from renewable resources.
- Variations of transmission planning methods to improve efficiency and reduce GHG.

Keywords: transmission planning, transmission siting, transmission upgrades, transmission construction, reducing environmental impacts, renewable energy integration, greenhouse gases (GHG) reduction, reliability, energy efficiency

Executive Summary

Purpose

This report contains the approach, framework and initial plan for Task 4.0, "Transmission Planning and Environmental Research Report," of the California Energy Commission Contract 500-07-037, which is to identify new or expanded transmission operations research activities that:

1. Increase the transmission of electricity from renewable resources,
2. Increase the efficiency of the transmission system, and
3. Reduce the emissions of greenhouse gases (GHG) that are associated with the transmission system

The report addresses but is not limited to a description of what future transmission planning and environmental research activities could be conducted in the context of the following:

- Technologies that provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- Methodologies and analytical techniques to provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- SmartGrid technologies for the inclusion into the planning process for transmission to increase the transmission of electricity from renewable resources.
- Variations of transmission planning methods to improve efficiency and reduce GHG.

This report also lists research activities identified to date for this research area.

Introduction

California has adopted aggressive energy policy goals to significantly reduce greenhouse gases, improve energy efficiencies and increased penetration of renewable energy generation. The electric transmission and distribution (T&D) system in California is a factor in being able to meet each of these goals. Although fractionally small, there are substantial energy losses in transporting electricity, which could be reduced with efficiency improvements. While T&D *per se* contributes relatively little to increasing GHG on a sustained basis, there are opportunities to reduce emissions in design, construction, operations and maintenance. Perhaps most significantly, however, T&D is absolutely essential to meet the state's renewable portfolio standard (RPS) goals. Substantial increases in the generation of electricity from renewable resources in remote locations will be necessary to achieve the RPS goals, and must rely on adequate, economical and reliable T&D for delivering renewable electricity to consumers. The current T&D system will be challenged in performing its roles in meeting these goals.

Meeting these challenges will require new or expanded capabilities for the grid. New transmission technologies offer the prospect of providing a substantial portion of the new or expanded capabilities to supplement traditional solutions. These technologies can be classified

among three broad categories: a) infrastructure, b) real time systems operation, and c) transmission planning, uncertainty analysis and environmental research. This Future Transmission Planning and Environmental Research report addresses the third of these.

Many of these new technologies will require additional development before they can be commercially or routinely deployed. The process for identifying the research activities of most value starts with identifying the most critical issues facing the electric industry community, and matching new technologies to address those issues. However there are often gaps between the current and desired status of each technology. These gaps have been identified along with the research, development and demonstration to work toward closing the gaps. The degree of success of this process depends largely on obtaining the best and latest policy, industry and technology knowledge by engaging public and private stakeholders and technology developers.

Stakeholder Engagement

A significant amount of situational analysis, technology identification, and evaluation of research and development needs, have been, and will be, accomplished by means of meetings that include representatives of key public and private stakeholders, and research and technology developer organizations. CIEE has found that the most effective means to obtain comprehensive and meaningful information about promising new research avenues is to meet at stakeholder and researcher sites so as to be accessible to a wide array of scientific, engineering, and business personnel to solicit their viewpoints and ideas. Where feasible, this is the preferred approach. It will be augmented by telephone conversations and interviews; participation in industry conferences, symposia and workshops; and other means as appropriate and feasible.

In addition, CIEE also holds Technical Advisory Committee meetings, typically "brainstorming-types" of meeting to discuss stakeholder and CIEE perspective on new planning and environment needs. Follow-up meetings are sometimes warranted to discuss draft versions of the major findings.

The following are organizations which hold meetings that could contribute to the development of the technical information described in this report. This is not an exclusive list; indeed, many additional, unanticipated meeting and conference opportunities are expected to arise, some on relatively short notice.

- **North American SynchroPhasor Initiative (NASPI)**
  CIEE is an active participant in NASPI Working Group Meetings and has played a significant, ongoing role in projects funded by PIER. These also represent opportunities to meet with key stakeholders, technology developers, and leading researchers that routinely attend these meetings.
- **Electric Power Research Institute (EPRI) Workshops**

  EPRI has a number of research program areas that directly relate to transmission research, including:

  - Underground Transmission Technologies Workshop

Underground Transmission Technologies have been identified as another key technology and are particularly relevant to efforts to facilitate the siting and approval of new transmission lines. CIEE TRP is in the planning stages of hosting a Workshop to assist in developing recommended new avenues of research.

- Meetings with CEC Transmission Planning, IOUs and CAISO

  In general, meetings with these entities will be scheduled on an ad-hoc basis, as needed to meet with key engineers and researchers at stakeholder sites, to develop the information necessary for defining the needed research in transmission planning and the environment.

- Topical Conferences and Workshops

  Public notices of workshops and conferences related to transmission planning and environment will be watched for relevant opportunities.

Problem Statement

Renewable resources within California are extensive and varied, and California has established aggressive RPS goals to increase the fraction of electricity made from renewable energy resources and to decrease greenhouse gas emissions under AB 32. By 2010, 20% of California's electricity is to come from renewables, and by 2020, perhaps 33%. Most of the new sources are expected to connect to the transmission system in remote locations and to exhibit properties quite different from traditional generation and loads, posing special challenges for providing timely adequate grid delivery capacity, maintaining reliability, and avoiding economic inefficiencies. We refer collectively to these challenges as the problem of Renewables Integration (RI), and it is often cited as the major barrier to achieving the renewable goals of the state. New technologies will be required to provide the functional capabilities required for success.

These new technologies can be applied in the context of providing three new or expanded broad capabilities: (1) Provide physical access for each new power plant, (2) Reliably accommodate any unique renewable generator behaviors, and (3) Increase the grid's power carrying capacity to handle the additional electric power flows. As solutions are developed through research to address the issues raised in meeting these three main state policy goals of renewable generation deployment, GHG reduction and energy efficiency improvements, the transmission community must continue to assure that transmission meets the critical requirements for adequacy, reliability, affordability, security, safety, and environmental protection.

Initial Transmission Planning and Environmental Research Candidates

Examples of the types of technologies and technology platforms that would qualify for examination include (but are not limited to) the following:

- **Enhance Acceptance of New Transmission by Facilitating Transmission Approval Process**

New transmission siting is highly complex, with diverse stakeholders and jurisdictions, and no integrated process for generation and transmission planning. Research focusing on information and tools that facilitate the public debate which support regional planning and transmission-corridor assessment would help bring consensus amongst these stakeholders on major transmission projects.

- **Enhance Acceptance of New Transmission by the Deployment of New Technologies**
  A major objection to new transmission is its visual and environmental impact. Reducing the visual profile and other environmental and siting impacts can help mitigate these concerns. The value and benefits including the impact on GHG, of undergrounding, HVDC and HVDC light, using existing right of ways and other methods to minimize these impact need to be integrated into planning tools

- **Improve Understanding of Value of Transmission**

  The acceptance of new transmission and technologies can be increased if its costs and values are understood. Methods to incorporate cost allocation and strategic value of transmission and new technologies such as advanced power flow devices (e.g. FACTS, DC transmission), energy storage, demand side options and capacity additions can help to inform decision making.

- **Markets Impacts**

  Intermittent renewables are expected to increase LMP volatility since their scheduling is dependent on variable (e.g. wind and sun) behavior as well as plant economics. Market simulation and market-power analysis, application of uncertainty analysis and techniques, and economic modeling and evaluation of cost of trade across market seams may help to better characterize renewable market participation and perhaps mitigate their effects.

- **Advanced Planning**

  Advanced long-range planning tools need to incorporate the uncertainties in expanding the transmission to serve new renewable generator plants to increase reliable power transfer capacities into major customer load centers. It is also anticipated that to meet RPS goals, wind generation will be imported from outside of California and will magnify congestion costs as well as impact grid reliability. High renewable penetration will require complementary energy resources for shaping and firming the variability of renewable resources.

- **Accommodation of Distributed Renewable Energy Generation and Demand Response**

  Distributed renewable energy is generally installed at the distribution level, but there is an interaction between distributed generation, demand response and transmission. At higher penetration levels, net energy produced finds it way back to the transmission level creating unprecedented operational, protection, interconnection, reliability, and market issues. However, through integration with multiple distribution sources, systems

could become a dispatchable electric supply on the transmission system. The development of a smart grid is a prerequisite for success of this concept.

- **Controlled/Strategic Islanding**

  When a disturbance is detected that may escalate into a wide-area cascading blackout, adaptive and corrective control strategies offers the potential to split the WECC system into self-sustaining islands.

- **Wind Generation-PHEV Partnership**

  Time of day wind generation profiles do not follow system load. Charging of plug-in hybrid electric vehicles may be conveniently managed to mitigate the minimum load issue of wind generation in the electric grid in California as well provide distributed energy storage.

- **N-1 Reliability a Renewable Generation Environment**

  The increasing penetration of variable as well as non inertial resources from renewable generation is hypothesized to have significant impact on grid reliability. Classic n-1 reliability criteria may no longer adequately protect the grid from extreme events.

- **Impact of Intermittent Renewables on LMP Volatility**

  Intermittent renewables are expected to increase LMP volatility since their scheduling is dependent on variable (e.g. wind and sun) behavior as well as plant economics. Market simulation and market-power analysis, application of uncertainty analysis and techniques, and economic modeling and evaluation of cost of trade across market seams may help to better characterize renewable market participation and perhaps mitigate their effects.

Benefits to California

This work benefits California by addressing how new technologies can be developed for helping the electric transmission and distribution system (T&D) perform its role in meeting the three main state policy goals of renewable generation deployment, GHG reduction and energy efficiency improvements, while continuing to assure that transmission meets the critical requirements for adequacy, reliability, affordability, security, safety, and environmental protection. California has adopted aggressive energy policy goals to significantly reduce greenhouse gases, improve energy efficiencies and increase penetration of renewable energy generation. The electric T&D system in California is a factor in being able to meet each of these goals, but currently faces many challenges in performing its roles in achieving them. Meeting these challenges will require new or expanded capabilities for the grid, and new transmission technologies offer the prospect of providing a substantial portion of the new or expanded capabilities to supplement traditional solutions. This report identifies the drivers and rationales that create the needs for new technologies, and describes the most promising new technologies and the research activities needed to help bring them to productive deployment and commercial reality in a manner that meets California needs in a timely fashion.

1.0 Purpose

This report contains the approach, framework and initial plan for achieving the goal for Task 4.0 , "Transmission Planning and Environmental Research Report," of Contract 500-07-037, which is to identify new or expanded transmission operations research activities that

1. Increase the transmission of electricity from renewable resources
2. Increase the efficiency of the transmission system and
3. Reduce the emissions of greenhouse gases (GHG) that are associated with the transmission system

The report addresses but is not limited to a description of what future transmission planning and environmental research activities could be conducted in the context of the following:

- Technologies to provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- Methodologies and analytical techniques to provide improvements to the upgrading, siting, construction, and installation of transmission equipment to increase the integration of renewables.
- SmartGrid technologies for the inclusion into the planning process for transmission to increase the transmission of electricity from renewable resources.
- Variations of transmission planning methods to improve efficiency and reduce GHG.

This report also lists research activities identified to date for this research area.

2.0 Introduction and Process

California has adopted aggressive energy policy goals to significantly reduce greenhouse gases, improve energy efficiencies and deploy increased penetrations of renewable energy generation. The electric transmission and distribution (T&D) system in California is a factor, in varying degrees, in being able to meet each of these goals. Although fractionally small, there are substantial energy losses in transporting electricity, which could be reduced with efficiency improvements. While T&D *per se* contributes relatively little to increasing GHG on a sustained basis, there are some opportunities to reduce emissions in design, construction, operations and maintenance. Perhaps most significantly, however, T&D is absolutely essential for meeting the state's renewable portfolio standard (RPS) goals. Substantial increases in the generation of electricity from renewable resources that are located remote from customers will be necessary to achieve the RPS goals, and must rely on adequate, economical and reliable T&D for delivering renewable electricity to consumers. The current T&D system will be challenged in performing its roles in meeting these goals.

Meeting these challenges will require new or expanded capabilities for the grid. For example, at higher RPS levels, the conventional "build" solutions, namely extending new lines or expanding the capacity of existing transmission gateways to load centers using traditional technologies, and building conventional power plants for support, will prove inadequate by themself, either because they are not the most cost effective, or obtaining the necessary permits will be very difficult. New transmission technologies offer the prospect of providing a substantial portion of the new or expanded capabilities to supplement these traditional solutions. These technologies can be classified among three broad categories: infrastructure, real time systems operation, and transmission planning, uncertainty analysis and environmental research. This *Future Transmission Planning and Environmental Research Report* addresses the third of these, and addresses algorithms, and analytical, planning and modeling tools for grid and market operations and infrastructure expansion, for use by T&D owners, planners, operators, regulators and policy makers.

Many of these new technologies are at an immature stage of development, and will require additional development before they can be commercially or routinely deployed to provide their benefits to the grid. The process for identifying the research activities of most value starts with identifying the most critical issues facing the electric industry community, and matching new technologies that enable enhanced or new capabilities to address those issues. However there are often gaps between the current and desired status of each technology. These development gaps are barriers to achieving the needed transmission capabilities, and are often the result of deficiencies in materials; mathematical, scientific, engineering or process knowledge; system design and integration; standards setting and performance verification; scale; user confidence; understanding policy impacts, etc. The final step is to identify what research, development and demonstration efforts are needed in each case to work toward closing the gaps. The degree of success of this process depends largely on obtaining the best and latest policy, industry and technology knowledge by engaging public and private stakeholders and technology developers.

Section 3, "Engagements with Stakeholders, Researchers and Technology Developers," provides examples of planned engagements with stakeholders, researchers and technology developers who can contribute the most to updating and identifying new issues, technologies, and the needed research and its importance. These engagements often take the form of targeted meetings with several representatives of key stakeholders, researchers and technology developers; technical advisory committee and research, development, and demonstration (RD&D) scoping meetings; and T&D industry, government, and university workshops and conferences attended by leading researchers, technology developers and stakeholder representatives. While some of these meetings can be conducted or attended via telecommunications media when practical, it is expected that other meetings, e.g., interactive meetings using "flipcharts and white board" discussions, viewing transmission system equipment and facilities, or involving complex technical discussions, will require participation on location in order to achieve mutual understanding in a time effective manner resulting in an acceptable outcome.

Section 4, "Problem Statement," is an initial situational analysis that provides the starting point context for engaging stakeholders and technology developers in identifying changes in market, policy and technology drivers, that create or will create, T&D issues that might be addressed through development and application of new technologies.

Section 5, "Current Technology Candidates and Research Activities," lists the most current technology candidates and research activities that will make significant contributions to achieving required grid functionality for achieving California's energy policy goals. This list reflects the latest knowledge obtained in the process described above, and the understanding and experience acquired from CIEE participation in the existing PIER Transmission and related RD&D programs. It will be amended as warranted following the engagements with stakeholders and technology developers and analysis of findings.

3.0 Engagements with Stakeholders, Researchers and Technology Developers

A significant amount of situational analysis, technology identification, and research and development needs evaluation is and will be done through meetings (by telecommunications or onsite) that include representatives of key public and private stakeholders, and research and technology developer organizations. Candidates usually include, but are not limited to, the organizations represented on the TRP Policy Advisory Committee (PAC): CAISO, SCE, PG&E, SDG&E, BPA and UWIG; selected research organizations such as EPRI, CERTS, PSERC, DOE, National Laboratories; the IEEE, particularly its Power Engineering Society T&D Committee; and leading universities involved in electric systems research. CIEE has found that the most effective means to obtain comprehensive and meaningful information about promising new research avenues for transmission planning and environment of interest to stakeholders is to meet at stakeholder and researcher sites so as to be accessible to a wide array of scientific, engineering, and business personnel to solicit their viewpoints and ideas. Where economically warranted and feasible, this approach will be the preferred approach with selected candidates. It will be augmented by telephone conversations and interviews; participation in industry conferences, symposia and workshops; and other means as appropriate and feasible.

In addition, CIEE also holds Technical Advisory Committee meetings, typically "brainstorming-types" of meeting to discuss stakeholder and CIEE perspective on new technology, planning, operations and environmental needs. Follow-up meetings are sometimes warranted to discuss draft versions of the major findings.

The following are organizations which hold meetings that could contribute to the development of the technical information described in this report, and therefore are under consideration for attendance by CIEE personnel. This is not an exclusive list; indeed, many additional, unanticipated meeting and conference opportunities are expected to arise, some on relatively short notice.

- **North American Synchrophasor Initiative (NASPI) Work Group Meetings**
  The mission of the North American SynchroPhasor Initiative is to improve power system reliability and visibility through wide area measurement and control. The NASPI community is working to advance the deployment and use of networked phasor measurement devices, phasor data-sharing, applications development and use, and research and analysis. NAPSI Task Teams include Data & Network Management, Operations Implementation, Performance and Standards, Planning Implementation, and Research Initiatives. NASPI holds several workshops a year around the country with different themes.
- **Electric Power Research Institute (EPRI) Workshops**
  EPRI has a number of research program areas that directly relate to transmission research, including:

- Transmission & Distribution Environmental Issues
- Grid Operations, Planning, Markets and Risks with Task Forces in Situation Awareness, Online Stability & Control, Modeling & Standardization, Reliability Assessment, Engineering Study & Economic Assessment, Controlled Separation & System Restoration
- The CIEE TRP has participated in EPRI Working Groups, Task Forces, and Project Advisory Groups, and will continue to do so, as it is advantageous to leverage EPRI's activities with TRP's. Some of these meetings will be local, i.e., requiring travel to Palo Alto or other in-state locations. Others will be out-of-state, and in rare cases will be held at international venues.

- **Underground Transmission Technologies Workshop**
  Underground Transmission Technologies have been identified as another key technology that can potentially provide near-term benefits to the California transmission system, and are particularly relevant to efforts to facilitate the siting and approval of new transmission lines, such as those contemplated for new, central station power plants. CIEE TRP is considering hosting a Workshop, either in Sacramento or the Bay Area, with utilities, technology developers, researchers and other industry stakeholders. The purpose of this workshop will be to gain better definition of the benefits, costs and implementation barriers to wider use of underground transmission in California, and develop recommended new avenues of research as indicated.
- **Meetings with CEC Transmission Planning, IOUs and CAISO**
  In general, meetings with these entities will be scheduled on an ad-hoc basis, as needed to meet with key engineers and researchers at stakeholder sites, to develop the information necessary for defining the needed research in transmission planning and the environment. It is anticipated that most of these meetings will be in-state in Northern or Southern California as appropriate.
- **Topical Conferences and Workshops**
  Public notices of workshops and conferences related to transmission planning and environment will be watched for relevant opportunities.

4.0 Problem Statement

Renewable resources within California are extensive and varied, and California has established aggressive RPS goals to increase the fraction of electricity made from renewable energy resources and to decrease greenhouse gas emissions under AB 32. By 2010, 20% of California's electricity is to come from renewables, and by 2020, perhaps 33%. This new generation will be integrated into the electric grid at both the transmission and distribution levels, but most of it is expected to connect to the transmission system in remote locations. Some of this renewable generation will exhibit properties quite different from traditional generation and loads, which poses special challenges for providing timely adequate grid delivery capacity, maintaining reliability, and avoiding economic inefficiencies. We refer collectively to these challenges as the problem of Renewables Integration (RI), and it is often cited as the major barrier to achieving the renewable goals of the state.

The renewable resources for larger, central station renewable power plants tend to be located remote from load centers and other generation resources, and therefore are remote from the existing electric transmission system. Extension of new transmission capacity is expensive and often takes many years getting siting approved. Given the relatively short construction times for many types of renewable generation, having transmission available when the power plant is ready to make its contribution toward meeting the renewable goals is problematic and threatens the ability to meet the RPS goals. Furthermore, adding new generation without upgrading existing transmission capacity or adding new capacity can result in more economic inefficiencies such as higher congestion costs for consumers.

At the other extreme, some of these renewable generators will be located, and integrated into the grid, near or at the electric loads. Prime examples are photovoltaic panels mounted on building roof-tops, and small biomass-fueled generators located at the community level. These "distributed" generators, in contrast to "central station," are usually connected at the distribution level, which in general was not designed to connect generation resources of any kind, and can cause some safety and operational issues. And while some of the power from a distributed generator might be fed to a neighboring load by the grid, some, if not most, of the power will be consumed locally, creating an ambiguous role as a new kind of generator acting as a negative load, at least from a transmission perspective.

From a transmission operational dynamics perspective, geothermal and biomass energy are similar to traditional power generators, especially base-load, and therefore do not pose much concern about their operational behavior within the power grid, though some biomass resources vary seasonally. Some types of renewable generation, however, are "fueled" by variable, or intermittent, energy sources like wind and sunshine, i.e., insolation, which are controlled by weather and rotation of the earth. These intermittent renewables can create renewable energy power plant behaviors for which the grid was not designed and that are quite unfamiliar to grid operators and outside their control. Relatively small penetrations of intermittent renewables are expected to have "operational implications significant but manageable" ("California Independent System Operator Integration of Renewable Resources," David Hawkins & Clyde Loutan, CAISO, November 2007). For greater penetration levels,

however, transmission infrastructure expansion, improved wind and solar forecasting, increased ancillary services for the grid, and new technologies for a smarter, more flexible grid will be required.

Not all the news associated with increased use of renewable generation integrated into the grid is negative. In addition to the obvious reduction in greenhouse gas reductions, inherent in renewable generation is a hedge against volatility in fuel prices and reliance on imported fossil fuels. Certain renewable resources, such as solar, have a reasonably strong correlation with load temporal profiles in California, and therefore might help with meeting peak load demands, and, especially for distributed forms, reducing congestion costs, deferring grid infrastructure investment and perhaps providing local voltage support. The non-intermittent renewable resources, such as geothermal and biomass, of course can add to a growing need for baseload generation capacity. Proper integration among renewable resource types and across geographical regions might further enhance renewables' contribution to a stable, reliable and affordable grid.

The successful integration into the electric grid of the renewable generation required to meet state RPS goals needs coordination among many public and private sector stakeholders in the renewable and electric grid communities. But new technologies will also be required to provide the functional capabilities required for success.

These new technologies can be applied in the context of providing three new or expanded broad capabilities: (1) Provide physical access for each new power plant, (2) Reliably accommodate any unique renewable generator behaviors, and (3) Increase the grid's power carrying capacity to handle the additional electric power flows.

New technologies to provide faster access for new renewable plants, in general, will need to put new transmission lines in a better light. One aspect of this capability is to use new technologies, such as underground cable, to reduce the visibility of transmission infrastructure, since that issue seems to be a major barrier for gaining public acceptance of new transmission expansions. The other aspect is to enhance the understanding by all interested parties of the need for, and relative economic and strategic value of, new transmission infrastructure through interactive planning and advanced analysis tools, so that siting and permitting decisions can be made on fully informed, objective and inconclusive.

New technologies to accommodate the unique renewable generator behaviors, in general, will need to enable a smarter and more flexible, and fast-acting grid to handle such behaviors as ramp following and intermittency. This "Smart Grid" capability needs to span timeframes ranging from milliseconds for automated, and seconds to hours for manual, operations to days for markets and short-term planning, and needs to span the topology of the whole interconnection, from generators – central and distributed - to the customers electric meters, and their appliances and equipment.

In a similar fashion, new technologies can increase transmission capacity by optimizing the grid for greater power flow. Because of operational uncertainties regarding stability and thermal limits, the grid power flow limits are conservatively set, leaving considerable transmission

capacity "on the table." Various new Smart Grid technologies can be developed and deployed to provide more accurate, real-time measured and predicted grid status conditions and margins over a wide area that could potentially be used to relax some of these constraints and free up additional transmission capacity in the existing system. Other technologies can provide the capability to control the grid better and faster allowing it to be operated closer to the real margins without jeopardizing reliability, again freeing up additional transmission capacity in the existing system. Other technologies, especially new technologies, can upgrade the existing infrastructure to handle higher power flows in the same pathway. Finally long range system planning tools that consider congestion management many years into the future can increase the capacity of new system expansions.

New planning technologies, such as statistical and probabilistic analysis and planning tools, are particularly well suited to the needs of the T&D system under growing uncertainty. Changes in generation and loads require new data and modeling capabilities. Also, new web-based tools can enable enhanced communication and interactive planning within the transmission community and the public. The enhanced or new transmission capabilities that may be achieved with these new technologies represent feasible and potentially cost-effective solutions to the challenges of transmission capacity and controllability resulting from renewable deployment, and reduction of electric losses and GHG.

While the transmission system's largest impact on the reduction of GHGs is its ability to integrate renewables, there are some other aspects to consider such as GHGs produced in construction activities, operations and maintenance. The release of SF_6 - a GHG that is about 20,000 times more potent than CO_2 - from various electric components is one example. The CO_2 released by transportation for maintenance activities and in conjunction with earthmoving equipment during construction is another. Likewise, electricity delivery losses, e.g., those resulting from Ohm's Law effects, will decrease the amount of renewable energy delivered to the customer by approximately 10%, and will correspondingly increase the amount of fossil fuel burned to deliver a given amount of electricity to a customer. Some new infrastructure technologies and improved operations and long range planning have the potential to reclaim some of these electrical energy losses.

Of the total amount of energy generated in the grid, approximately 7–10% is lost as heat due to resistance in transmission lines, transformers and other equipment. A comparable amount of energy (approximately 5–10%) is lost in the distribution system. Reducing system losses translates into energy production cost savings and reduced GHG. Methods for optimum real-time configuration and operation of the grid will likely produce a much greater percentage efficiency improvement than is attainable from focusing on resistive losses, especially on a per dollar invested basis.

In power system planning, utility engineers are very much aware that transmission system inefficiency is correlated with low system voltages, congestion or overloading, lack of operating flexibility, or other negative impacts. Proper planning and design generally tend to result in a more efficient system, both in the physical system and how it is operated. The optimal power

flow analysis, which is widely used, basically allows planners and operators to design and operate the transmission system with the highest efficiency.

However, from an overall system perspective, because losses cannot be directly measured, only calculated as the total system generation minus net delivered load, and will vary as line loadings change, it has historically been very difficult to pinpoint specific lines as candidates for economic upgrade based on losses alone.

Principal drivers for transmission system efficiency are:

- Enable renewable generation to meet RPS goals.
- Reduce the use of fossil fuels.
- Reduce greenhouse gas (GHG) production.
- Reduce costs to ratepayers.
- Maintain overall system reliability.
- Enable efficient energy markets.

There are two major areas regarding transmission efficiency:

1. Resistive and inductive losses, primarily in lines and transformers (physical efficiency).
2. Optimal configuration and operation of the grid (operational efficiency).

Resistive/inductive losses can be reduced by:

- Using larger diameter conductors
- Adding/bundling conductors
- Using advanced low-loss conductors
- Using low-loss transformers
- Installing series capacitors in lines (reduces line inductance, and current magnitude)
- Installing shunt and series capacitors to optimize voltage profiles
- Optimizing generation dispatch to minimize peak loading on lines
- Uprating line voltages, e.g., converting a 115kV line to 230kV
- Installing storage at strategic locations to minimize congestion and peak line loading, optimize voltages, etc.
- Use HVDC lines instead of AC lines

These measures may or may not be cost-effective solely on the basis of reducing losses.

Operational methods to increase transmission system efficiency are:

- Intelligent management systems, e.g., Smart Grid
- Optimal power flow applications

Finally, as solutions are developed through research to address the issues raised in meeting these three main state policy goals of renewable generation deployment, GHG reduction and

energy efficiency improvements, the transmission community must continue to ensure that transmission meets the critical requirements for adequacy, reliability, affordability, security, safety, and environmental protection.

5.0 Initial Transmission Planning and Environmental Research Candidates

The goal of this step is investigate different methodologies and technologies to help close identified developmental gaps for issues in transmission planning and environment and identify candidate research activities that will enhance the performance of the transmission system for meeting policy goals in renewable generation, GHG emission reductions and efficiency improvements.

Examples of research areas for further analysis and development that may be examined include but are not limited to the following:

5.1. Enhance Acceptance of New Transmission by Facilitating Transmission Approval Process.

New transmission siting is highly complex, with diverse stakeholders and jurisdictions, and no integrated process for generation and transmission planning. Hence the institutional challenges to transmission planning far outweigh the technical challenges. The planning process is subject to both non-technical stakeholder concerns and federal/state laws and policies. Research focusing on information and tools that facilitate the public debate which support regional planning and transmission-corridor assessment would help bring consensus amongst these stakeholders on major transmission projects.

5.2. Enhance Acceptance of New Transmission by the Deployment of New Technologies.

A major objection to new transmission is its visual and environmental impact. Paths for new transmission often cross environmentally sensitive lands and urban corridors. Identification of Technologies that reduce the visual profile and other environmental and siting impacts of a transmission line and other grid infrastructure can help mitigate these concerns. The value and benefits including the impact on GHG, of undergrounding, HVDC and HVDC light, using existing right of ways and other methods to minimize these impact need to be integrated into planning tools.

5.3. Improve Understanding of Value of Transmission.

The acceptance of new transmission and technologies can be increased if its costs and values are understood. Methods to incorporate cost allocation and strategic value of transmission and new technologies such as advanced power flow devices (e.g. FACTS, DC transmission), energy storage, demand side options and capacity additions can help to inform decision making.

5.4. Markets Impacts.

Intermittent renewables are expected to increase locational marginal pricing (LMP) volatility since their scheduling is dependent on variable (e.g. wind and sun) behavior as well as plant economics. Market simulation and market-power analysis, application of uncertainty analysis and techniques, and economic modeling and evaluation of cost of trade across market seams

may help to better characterize renewable market participation and perhaps mitigate their effects.

5.5. Advanced Planning.

Advanced long-range planning tools need to incorporate the uncertainties in expanding the transmission to serve new renewable generator plants to increase reliable power transfer capacities into major customer load centers. The RETI process and the identification of CREZ will help identify paths and properties of optimal renewable resources. It is also anticipated that to meet RPS goals, wind generation will be imported from outside of California will magnify congestion costs as well as impact grid reliability. Improvements in congestion management and extreme event analysis for use in transmission expansion include the applications of probabilistic and risk management principles, incorporation of statistical techniques in extreme event analysis, strategic islanding, rapid outage restoration, evaluation of n-1 criteria for high penetration of renewables, using community activity room approach to enhance reliability, assessment of new infrastructure technologies for improved power flow control and related investigations into linkages to markets (e.g. LMP) and policy.

Large quantities of renewable resources can be successfully integrated into power system operations if the system also has complementary energy resources required for shaping and firming the variability of renewable resources. The addition of transmission and generation requires complementary resources to accommodate ramp rates, assess the need for load following capacity, regulation capacity, and voltage control/VAR. [CAISO, February 6, 2009]

5.6. Accommodation of Distributed Renewable Energy Generation and Demand Response.

While renewable energy distributed generation is generally connected to the electric grid through electric distribution, there is an interaction between distributed generation, demand response and transmission. At lower penetration levels, from a transmission perspective they act as a negative load. At higher penetration levels, net energy produce finds it way back to the transmission level creating unprecedented operational, protection, interconnection, reliability and market issues. However, with additional penetration and optimization through integration with multiple distribution sources, systems could become a dispatchable electric supply on the transmission system. The development of a smart grid is probably prerequisite for success of this concept.

Planning and environmental research candidates include, but are not limited to, the following research activities.

5.7. Controlled/Strategic Islanding:

When a disturbance is detected that may escalate into a wide-area cascading blackout, adaptive and corrective control strategies offers the potential to split the WECC system into self-sustaining islands.

- Major Goals Addressed: Increase the integration of renewable generation, deployment of smart grid technologies
- Major Issues Addressed: Maintain reliability
- Major Developmental Gap(s): Approach, assessment and algorithm development; prototype testing; lack of confidence
- R&D Activity: To (1) Identify islanding strategies for mitigating dynamic grid problems, (2) conduct value quantification of various technology approaches, and (3) develop a roadmap for the best sequence of actions going forward.
- A promising slow coherency based generation grouping algorithm described in a recent IEEE paper is ready for Stage 3 research and prototype testing. If the results of this Stage 3 project are promising, a Stage 4 technology development and field test experiment might be recommended for funding in cooperation with the CAISO and other WECC entities.

5.8. Wind Generation-PHEV Partnership:

Time of day wind generation profiles do not follow system load. Charging of plug-in hybrid electric vehicles may be conveniently managed to mitigate the minimum load issue of wind generation in the electric grid in California as well provide distributed energy storage

- Major Goals Addressed: Increase the integration of renewable generation, deployment of smart grid technologies
- Major Issues Addressed: Maintain reliability, enable deployment of renewable, economic inefficiencies
- Major Developmental Gap(s): Analysis of concept, interaction between distributed resources and transmission, use of storage, value of export
- R&D Activity: Feasibility study investigating potential uses of PHEV as a grid resource and identification of technology gaps including system interface and control issues and operational issues at increasing penetrations.

5.9. N-1 Reliability in a Renewable Generation Environment:

The increasing penetration of variable as well as non inertial resources from renewable generation is hypothesized to have significant impact on grid reliability. Classic n-1 reliability criteria may no longer adequately protect the grid from extreme events.

- Major Goals Addressed: Increase the integration of renewable generation
- Major Issues Addressed: Maintain reliability
- Major Developmental Gap(s): Analysis of variable renewable impacts on grid reliability
- R&D Activity: To investigate the validity of using the classic "n-1" transmission reliability criteria with a substantial penetration of intermittent renewable generation, and modifications required.

5.10. Impact of Intermittent Renewables on LMP Volatility:

Intermittent renewables are expected to increase LMP volatility since their scheduling is dependent on variable (e.g. wind and sun) behavior as well as plant economics. Market simulation and market-power analysis, application of uncertainty analysis and techniques, and economic modeling and evaluation of cost of trade across market seams may help to better characterize renewable market participation and perhaps mitigate their effects.

- Major Goals Addressed: Increase the integration of renewable generation, reduce costs to ratepayers
- Major Issues Addressed: Enable deployment of renewables, accelerate new transmission, maintain system reliability
- Major Developmental Gap(s): Quantification of pricing impacts under MRTU
- R&D Activity: To investigate the effect of intermittent renewable generation on LMP volatility and methods for modeling it.

5.11. Congestion Planning in an Expanded Renewables Deployment Environment:

Develops planning tool methodology to accelerate new transmission capacity for transmission congestion management, especially given intermittent renewable generation expansion. It is anticipated that to meet RPS goals, wind generation imported from outside of California will magnify congestion costs as well as impact grid reliability. A key concept to develop is "economic congestion levels".

- Major Goals Addressed: Increase the integration of renewable generation, increase efficiency, reduce costs to ratepayers.
- Major Issues Addressed: Accelerate new transmission, facilitate investment, understand transmission needs, increase capacity.
- Major Developmental Gap(s): Methodology and planning tools.
- R&D Activity: Developing planning tool methodology accounting for variable renewable generation expansion. The concept of "economic congestion levels" will be incorporated into planning so the longer term transmission investment decisions will consider the value of project deferral, expected congestion costs, system security, planned remedial actions, and market design implications. This activity would build on an earlier PIER TRP project conducted by EPRI.

The goal of this step is to determine the transmission planning and environment issues that enable enhanced or new capabilities for the T&D system to accelerate new transmission, facilitate investment, increase capacity and reliability as related to renewable deployment and reduction in electric losses and GHG emissions.

6.0 References

Brown, Merwin, et al, 2008. *Transmission Technology Research for Renewable Integration*, California Energy Commission, PIER Program Energy Commission-500-99-013.

California Renewable Portfolio Standard (RPS): cf. Senate Bill 1078 (2002) and Senate Bill 107 (2006), and Governor's Executive Order S-14-08 (November 17, 2008).

California Energy Commission, 2008. *2008 Integrated Energy Policy Report Update*, Sacramento: California Energy Commission.

7.0 Glossary

BPA	Bonneville Power Administration
CAISO	California Independent System Operator
CIEE	California Institute for Energy and the Environment
CREZ	Competitive Renewable Energy Zone
CERTS	Consortium for Electric Reliability Technology Solutions
DOE	Department of Energy
EPRI	Electric Power Research Institute
FACTS	Flexible Alternating Current Transmission Systems
GHG	Green house gas
HVDC	High Voltage Direct Current
IOU	Investor Owned Utility
IEEE	Institute of Electrical and Electronic Engineers
LMP	Locational Marginal Pricing
NASPI	North American Synchrophasor Initiative
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
PHEV	Plug-In Hybrid Vehicle
PSERC	Power Systems Engineering Research Center
PIER	Public Interest Energy Research
PAC	Policy Advisory Committee
RETI	Renewable Energy Transmission Initiative
RI	renewable integration
RPS	Renewables Portfolio Standard
R&D	Research and development
RD&D	research, development, and demonstration
SDG&E	San Diego Gas and Electric
SCE	Southern California Edison

STATCOM	static synchronous compensator
SVC	static VAR compensator
T&D	transmission and distribution
TRP	Transmission Research Program
UWIG	Utility Wind Integration Group
WECC	Western Electricity Coordinating Council

APPENDIX I:
Adaptive Relaying Technology Development Final Report

Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

Adaptive Relay Technology Development and Measurements

Prepared for: California Energy Commission

Prepared by: Virginia Polytechnic Institute and State University

NOVEMBER 2011

CEC-500-07-037

A

Prepared by:

Primary Author(s):
Virgilio Centeno
James Thorp
Arun Phadke
Jaime De La Ree
Anamitra Pal
Mutmania Tania
Santhosh Sambamoorthy
Kate Vance

Virginia Polytechnic Institute and State University
302 Whittemore Hall
Blacksburg, VA 24061
www.vt.edu

Contract Number: 500-07-037

Prepared for:

California Energy Commission

Cathy Turner
Contract Manager

Jamie Patterson
Project Manager

Mike Gravely
Office Manager
Energy Systems Research Office

Laurie ten Hope
Deputy Director
Energy Research and Development Division

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

The research team would like to express its appreciation for the valuable guidance and advice received from the members of the advisory team: Vahid Madani (PG&E), Farrokh Habibiashrafi (SCE), Damir Novesel (Quanta Technology), and Armando Salazar (SCE). The valuable information and advice provided by the advisory team was of great importance for the successful completion of this project. This project would have not been possible without the administrative guidance and patience of Larry Miller (CIEE).

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Adaptive Relay Technology Development and Measurements is the fina report for the Virginia Tech – CIEE Project on Advanced Protection Systems using Wide Area Measurements project contract number 500-07-037, grant number TRP-08-06 conducted by Virginia Tech. The information from this project contributes to PIER's Transmission Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

This report presents the results of four research tasks on the use of wide area measurement to implement adaptive relaying technology applied to the California system. The first task presents a scheme for supervising backup zones with remote PMU measurements to keep backup protection from operating when it is not appropriate. An exhaustive analysis reveals no cases of encroachments for single line and generators outage conditions.

The second tasks presents an approach for creating coherent groups for generators and finding the Loss of Field settings for the member generators which allows on-line identifying system conditions based on PMU measurements. The third task applies an Intelligent Load Shedding algorithm to detect loss of generation conditions before an appreciable change in frequency occurs and allows effective shedding of load. The power flow on major tie lines is monitored for major loss of generation. A loss of supply within California causes an increased power flow on the boundary lines. These tie lines are monitored with PMUs for a marked increase in flow, indicating the need for load shedding. The most effective loads to relieve the tie lines is determined by an offline load sensitivity analysis.

In the last task an integrated form of control using PMUs is proposed for damping of low frequency oscillations in the California system. The coordinated control is implemented through a Linear Matrix Inequality based polytopic model that guarantees pole placement for a variety of operating conditions. An algorithm is developed that reduces the size of the system to the relevant modes of oscillations. The algorithm is applied to a 127-bus equivalent model of the WECC System. The results indicate that the proposed control successfully damps the relevant modes of oscillations. The control is then effectively transferred to a California full model to test its performance.

Keywords: Protective Relaying, Wide Area Measurement Systems (WAMS), Adaptive Relaying, Zone 3 Relaying, Line Outage Distribution Factor, Loss of Field (LOF), Generator Protection, Stability Limit, Load Shedding, Islanding, Load Shift Factor (LSF), Area Control Error (ACE), Inter-area Oscillations, Linear Matrix Inequality (LMI) Control, Polytopic Model, Selective Modal Analysis (SMA

Please use the following citation for this report:

Centeno, Virgilio, James Thorp, Arun Pahdke, Anamitra Pal, Mutmania Tania, Santhosh Sambamoorthy, Kate Vance. (Virginia Tech). 2011. Final Report Adaptive Relay Technology Development and Measurements. California Energy Commission. CEC-500-07-037.

TABLE OF CONTENTS

Acknowledgements ..... **i**

PREFACE ..... **iii**

ABSTRACT ..... **iv**

TABLE OF CONTENTS ..... **v**

TABLE OF FIGURES ..... **x**

EXECUTIVE SUMMARY **16**

Introduction 16

Purpose 16

Objective 16

Conclusions 17

Chapter 1: Introduction **18**

1.1Motivation 18

1.2 Benefits of the research 18

1.3 Relationship to PIER Goals 18

1.4 Goals of the Project 19

1.5 Background 19

1.5.1 Develop techniques to supervise back-up zones 19

1.5.2 Intelligent load shedding 20

1.5.3 Adaptive loss-of-field 20

1.5.4 Phasor measurements for damping of low frequency oscillations 21

1.2 Summary of proposed work 23

Chapter 1 References 24

Chapter 2: Techniques for Supervise Overreaching zones **25**

2.1 Introduction 25

2.1.1 Study Scope 25

2.1.2 Zone 3- Relay Protection Criteria 25

2.2 Development and Test Plan 26

2.2.1 Selection of Appropriate Location for Back-up Protection 26

2.2.2 Line Outage Distribution Factors (LODF) 26

2.2.3 Test Plan 29
2.3 Implementation of LODF in the Full California Model 29
2.3.1 Formation of LODF Matrix for CA System and Identification of Critical Lines 29
2.3.2 Identification of Zone 3 Settings for Critical Lines and Encroachment of Protective Zone due to Single Contingency 29
2.2.3 Relay Settings for Multi-Terminal Lines 30
2.4 Multiple Contingency Studies 31
2.4.1 Inertial Re-dispatch of Generators 31
2.4.2 Comparison between CA and Full-Loop Study System 32
2.5 Project Results 34
2.5.1 Line Outage Distribution Factor Study 34
2.5.2 Single contingency Analysis and Xone 3 Enchroachment Study 34
2.5.3 Multiple Contingency Studies 34
Chapter 2 References 35
Chapter 3: Adaptive Loss of Field 36
3.1 Introduction 36
3.1.1 Background 36
3.2 Methodology 36
3.2.1 Loss-of-Field Relay Protection Criteria 36
3.2.2 Steady State Instability as Loss of Field Condition 40
3.2.3 Steady State Stability Limit Circle 42
3.3 Development and Test Plan 43
Chapter 3 References 45
Chapter 4: Intelligent Load Shedding 46
4.1 Introduction 46
4.1.1 Traditional Load Shedding Systems 46
4.1.2 Problems with Under Frequency Load Shedding (UFLS) Schemes 47
4.1.3 Loss of Generation within an Area 47
4.1.4 Application of WAMS for detecting loss of generation 47
4.1.5 Intelligent Load Shedding 48

4.3 Load Shedding Algorithm Development 48
4.3.1 Inputs for the Intelligent Load Shedding Algorithm 49
4.3.2 Identifying Loads for shedding 51
4.3 Intelligent Load Shedding Algorithm 53
4.3.1 Load Shift Factors 53
4.3.2 Flow Chart 53
4.3.3 Algorithm Coding 55
4.3.4 Arbitrary Parameters 55
4.3.5 Suggested Improvements 56
4.4 Simulation Results 57
4.4.1 Loss of Diablo 57
4.4.2 Loss of San Onofre Units 59
4.4.3 Loss of one Diablo Unit and InterMountain - Adelanto HVDC Line 60
4.4.4. Loss of InterMountain – Adelanto and one leg of Celilo – Sylmar PDCI 61
4.5 Summary 62
Chapter 4 References 63
Chapter 5: PMU Application for Damping Low Frequency Oscillations 64
5.1 Introduction 64
5.1.1 Need for Co-ordinated Control 64
5.1.2 Role of PMUs and WAMs 65
5.1.3 Conclusion 66
5. 2 Design of the Control 67
5.2.1 Linear Matrix Inequalities (LMI) 67
5.2.2 Selective Modal Analysis (SMA) 70
5.2.3 Proposed Modification to SMA 72
5.2.4 Conclusion 75
5.3 Testing and Evaluation if MATLAB Results 75
5.3.1 16-Machine System 75
5.3.2 The 29 Machine Model of the WECC System 84
5.3.3 Summary 102

5.4 Testing and Evaluation of PSLF Results 102
5.4.1 29-Machine Model of WECC System 102
5.4.2 New California Model 110
5.4.3 Application of Control to New Model 119
5.4.4 Section Summary 131
5.5 Summary 132
Chapter 5 References 134
Chapter 6: Conclusions and Recommendations 135
6.1 Techniques for Supervise Overreaching Zones 135
6.2 Adaptive Loss of Field 135
6.3 Intelligent Load Shedding 136
6.4 Damping Low Frequency Oscillations 137
Appendix A 140
Table A.1 Line Overload Results for 500 kV lines 140
Table A.2 Line Overload Results for 230 kV lines 145
Table A.3 Line Overload Results for 287 kV lines 199
Table A.4 Line Overload Results for 161 kV lines 200
Table A.5 Line Overload Results for 138 kV lines 202
Table A.6 Line Overload Results for 115 kV lines 209
Appendix B: LOF Settings 299
Appendix C: PSLF EPCL Code 325
Program ilsmain_v1.p 325
Program nilsin_v1.p 326
Program ilsin_v3.p 327
Appendix D: GSF in % for loads within California 336
Appendix E: System Details 356
E.1 16-Machine System 356
D.2 29-Machine System 365
Appendix F: Program Codes 381
F.1 MATLAB Programs 381

Program 1: Postpro 381
Program 2: SMA 383
Program 3: Simplepp 386
F.2 EPCL Programs 388
Program 1: Sample_main 388
Program 2: Sample_in 390

TABLE OF FIGURES

Figure 1.1 Supervision of Bach-up-zones 19

Figure 1.2 Intelligent Load Shedding 20

Figure 1.3 Adaptive Loss-of-Field 21

Figure 1.4 The model two area system 22

Figure 1.5 the power flow between areas when the PSS is inserted after 50 sec. 22

Figure 1.6 Performance of the collocated controller. 23

Figure 2.1: L1-3 in Service 27

Figure 2.2: L1-3 Out of service 28

Figure 2.3: Effect of infeeds on zone settings of distance relays 30

Figure 2.4: Flow chart for inertial re-dispatch of generators 33

Figure 3.1: Simple system for Steady-state stability analysis [2] 36

Figure 3.2: (a) A circle in the P –Q plane transforms into (b) a circle in the R–X plane [2] 37

Figure 3.3: (a) Generator connected to a power system. (b) The generator supplying the same power to a parallel load. (c) The generator supplying the same power to a series-connected load. This is the apparent impedance seen by an impedance relay [2] 39

Figure 3.4: The current and the phasor diagram of generator voltage and relationship between reductions in field current as field current decreases 41

Figure 3.5: The relationship between reduction in field current and the phasor diagram of the generator voltage and current. As the field current decreases, there are changes in the apparent impedance seen by a distance relay at the generator terminal [2]. 42

Figure 3.6: Graphical method for Steady State Stability 43

Figure 3.7: LOF Relay at Diablo machine terminal 44

Figure 4.1: Intelligent Load Shedding Scheme 48

Figure 4.2 Change in Major tie flows 50

Figure 4.2: Flow Chart for the ILS Algorithm 54

Figure 4.3: Change in intertie flow without and with ILS algorithm 58

Figure 4.4: Area Frequencies without and with ILS algorithm 58

Figure 4.5: Change in intertie flow without and with ILS algorithm 59

Figure 4.6: Area Frequencies without and with ILS algorithm 59

Figure 4.7: Change in intertie flow without and with ILS algorithm 60

Figure 4.8: Area Frequencies without and with ILS algorithm 60

Figure 4.9: Change in intertie flow without and with ILS algorithm 61

Figure 4.10: Area Frequencies without and with ILS algorithm 61

Figure 5.2.1: LMI Region for Pole Placement; The Damping ratio of poles lying in the region enclosed by the solid lines is at-least cosθ 68

Figure 5.2.2: LMI Control Design using a Polytopic system having three vertices 70

Figure 5.2.3: Block Diagram of SMA [4] 71

Figure 5.2.4: Flowchart of Proposed Control Technique 74

Figure 5.3.1: The 16 machine – 68 Bus System 76

Figure 5.3.2: Eigenvalues of the 16 machine system corresponding to the base case 78

Figure 5.3.3: Reducing system size for base case – 10 machine system 80

Figure 5.3.4: Applying control check described in Step 4 of algorithm to 10 machine system 80

Figure 5.3.5: Applying control check described in Step 4 of algorithm to 9 machine system 81

Figure 5.3.6: Closed-Loop eigenvalues for the 8 cases of the (15+1) machine system 82

Figure 5.3.7: Closed-Loop eigenvalues for the 8 cases of the (10+1) machine system 83

Figure 5.3.8: Root Locus plot for base case using the proposed algorithm 84

Figure 5.3.9: Single-Line Diagram of the 127-Bus WECC System 85

Figure 5.3.10: Eigenvalues of the 29 machine system corresponding to the base case 88

Figure 5.3.11: Reducing system size for base case – 21 machine system 90

Figure 5.3.12: Applying control check to 21 machine system..... 90

Figure 5.3.13: Applying control check to 20 machine system..... 91

Figure 5.3.14: Closed loop eigenvalues for reduced system under no control 92

Figure 5.3.15: Closed loop eigenvalues for reduced system under 3-element control 92

Figure 5.3.16: Closed loop eigenvalues for full-order system under 6-element control.. 97

Figure 5.3.17: Closed loop eigenvalues for reduced-order system under 6-element control 97

Figure 5.3.18: Root Locus plot for Case 1 using the proposed algorithm 98

Figure 5.3.19: Root Locus plot for Case 2 using the proposed algorithm 98

Figure 5.3.20: Root Locus plot for Case 3 using the proposed algorithm 99

Figure 5.3.21: Root Locus plot for Case 4 using the proposed algorithm 99

Figure5. 3.22: Root Locus plot for Case 5 using the proposed algorithm 100

Figure 5.3.23: Root Locus plot for Case 6 using the proposed algorithm 100

Figure 5.3.24: Root Locus plot for Case 7 using the proposed algorithm 101

Figure 5.3.25: Root Locus plot for Case 8 using the proposed algorithm 101

Figure 5.4.1: Generator angles for Base Case of 29 machine model of the WECC system 106

Figure 5.4.2: Oscillations due to a step input in the 29-machine system in absence of control 106

Figure 5.4.3: Oscillations due to a step input in the 29-machine system in presence of control 107

Figure 5.4.4: Generator angles of five machines with dominant inter-area modes of oscillations (Left: No control applied; Right: Twice the control applied)..... 108

Figure 5.4.5: Generator angles of seven machines with dominant local modes of oscillations (Left: No control applied; Right: Twice the control applied)..... 108

Figure 5.4.6: Lowest inter-area mode of oscillation present in 29 machine system (Left: No control applied; Right: Twice the control applied)..... 109

Figure 5.4.7: Second lowest inter-area mode of oscillation present in 29 machine system (Left: In absence of Control; Right: In presence of twice the control) 110

Figure 5.4.8: Changes in Equivalent Network in the East..... 113

Figure5. 4.9: Equivalent Network for Inter-area Exchange Control..... 114

Figure 5.4.10 PDCI as represented in Full Loop Model 115

Figure 5.4.11 Modifications to Celilo buses..... 116

Figure 5.4.12: Bus angles at High Voltage buses 118

Figure 5.4.13: Bus Angles after tripping Diablo I at t = 1 second 118

Figure 5.4.14: Comparison of damping w.r.t. Dominant Modes for Second Case 120

Figure 5.4.15: Comparison of damping w.r.t. Dominant Modes for Third Case 120

Figure 5.4.16: Comparison of damping w.r.t. Dominant Modes for Fourth Case 121

Figure 5. 4.17: Comparison of damping w.r.t. Dominant Modes for Fifth Case 121

Figure 5.4.18: Comparison of damping w.r.t. Dominant Modes for Sixth Case 122

Figure 5.4.19: Comparison of damping w.r.t. Dominant Modes for Seventh Case 122

Figure 5.4.20: Comparison of damping w.r.t. Dominant Modes for Eighth Case 123

Figure 5.4.21: Oscillations in tie-lines due to a step input to the new model (absence of control) 123

Figure 5.4.22: Oscillations in tie-lines due to a step input to the new model (presence of control) 124

Figure 5.4.23: Change in the power flow across PDCI in response to the applied control 125

Figure 5.4.24: Lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control) 126

Figure 5.4.25: Second lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control) 127

Figure 5.4.26: Third lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control) 127

Figure 5.4.27: Fourth lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control) 128

Figure5. 4.28: Sustained oscillations produced due to a negatively damped 0.35 Hz oscillation (Left: In absence of Control; Right: In presence of control) 129

Figure 5.4.29: Performance of proposed control on sustained oscillations (29-machine system)..... 130

Figure 5.4.30: Performance of proposed control on un-damped oscillations (New model) 131

EXECUTIVE SUMMARY

Introduction

The 2003 North East blackout, the 1996 West Coast blackouts, and other recent system blackouts throughout the world have shown the importance of a reliable power system in modern societies, and the enormous economic and societal impact a blackout can cause. Blackouts are the results of a cascading phenomenon where, in a large percentage of cases, some protection system misoperate and becomes an important contributing factor in the sequence of events leading to the blackout. This is known as "the hidden-failure phenomenon in protection systems". Other contributing factors to catastrophic failures are unexpected power system configurations which have not been foreseen when protection systems were set, errors in setting and calibration of relays, or undiscovered design flaws in the protection systems. Adaptive relaying and wide area measurement has been proposed as a possible solution to hidden failures. Adaptive relaying systems use digital relays that can change their settings to adapt to changing system conditions, either automatically by sensing the proper parameters, or in response to a control signal from an operator or wide-area control system.

Purpose

This three year research project developed and evaluated the use of adaptive protection to monitor, supervise, and modify the protection systems in real-time based upon the information about the state of the power system provided by the phasor measurements. Four aspects of the protection system supervision and control were selected for research, because they address principal concerns regarding protection system responses, and are inter-related and complementary in their scope. Such measures are within the capabilities of technology available today, and when successfully applied can reduce the frequency and intensity of power system blackouts.

This R&D effort was conducted in close cooperation with PG&E, and SCE. The studies was conducted using the validated California Power System Model developed in the Virginia Tech R&D project (MTX-06-03), and the results of the research are used to provide proofs-of-concept of the proposed project, as well as complete functional specifications for implementing these ideas on the California system.

Objective

The objective of this project was to use real-time synchronized phasor measurement data to provide improved protection system supervision in order to make it adaptive to prevailing system state. By using real-time wide area measurements, it is possible to determine optimum protection policies and settings for critically located relaying systems. The proposed three year Research Development and Demonstration (RD&D) project aimed at slow speed protection functions in which the latency involved in remote phasor measurements is not an obstacle. It is recognized that primary protection of power system equipment requires high speed decision making that is incompatible with delays of even tens of milliseconds. Such protection is unlikely to be adaptive to remote inputs. In particular, adaptive supervision of back-up zones, intelligent load shedding, adaptive loss-of-field relaying, and the use of remote phasor

measurements in the design of robust damping control of low frequency oscillations will be developed.

Conclusions

To fulfill the objectives the project team:

Developed a scheme for supervising back-up zones with remote phasor measurements so that back-up protection is not allowed to operate when it is not appropriate.

Developed a load shedding algorithm by simulating various contingency conditions on the California power system model, and assessed its efficacy of taking control action to prevent islanding.

Developed techniques to use wide area measurement systems to adjust the loss-of-field relay settings automatically as the system Thévénin impedance changes. Algorithms were developed to determine the proper method for setting these relays. Verification of the appropriateness of the developed logic by simulations.

Develop methodology to design robust damping controller using remote phasor measurements on a multi mode, multi DC line system for a large system along with suggested limits on the allowed delay. Methodology to extend the results to FACT devices and generator excitation systems as the control mechanism.

Future Work

This projected was a proof of concept of four adaptive protection enhancements aimed to improve the reliability of the California electric grid. The smart grid funding provided by the recovery act of 2009 has accelerated the deployment of wide area measurement devices increasing the short time feasibility of the proposed protection schemes.

This research has moved the proposed schemes from conceptual enhancements to proven concepts applicable to the California grid. The next logical step in this development is a laboratory test at the California utilities using on-line data from the real system. These tests will reveal additional details on the limitations of available commercial equipment and other possible limitations due to non-technical requirements in the availability and sharing of the required wide area data and information among the California utilities.

Chapter 1: Introduction

1.1Motivation

This final report presents the results of a series of projects performed at Virginia Tech to develop, demonstrate and evaluate adaptive relaying systems with the aim to enable the use of Synchrophasors in advanced operation and control strategies in the California transmission system. Adaptive relaying systems use digital relays that can change their settings to adapt to changing system conditions, either automatically by sensing the proper parameters, or in response to a control signal from an operator or wide-area control system. These relays with advanced data acquisition capabilities can also be exploited for use in advanced control and operations methodologies.

The research team at Virginia Tech has led the industry in the development of these ideas through their technical publications and field tests of computer relaying, hierarchical communication for supervision of protection systems, adaptive relaying and Synchrophasors for real-time monitoring of the power system. This 3 year research project, developed and evaluated the use of these technologies to monitor, supervise, and modify the protection systems in real-time based upon the information about the state of the power system provided by the phasor measurements.

1.2 Benefits of the research

The principal achievements of this research are to reduce the likelihood of false trips by protection systems based upon a correct assessment of the prevailing power system state. The four areas where benefits were achieved are:

Techniques to supervise over-reaching zones

Load shedding algorithms aimed to prevent islanding

Techniques to adjust the loss-of-field relay settings automatically

Technique for PMUs application for damping of low frequency oscillations

1.3 Relationship to PIER Goals

This research project meets the following PIER Goals:

- Improving the reliability and quality of California's electricity,
- Improving the energy cost/value of California's electricity

1.4 Goals of the Project

The goals of this project are to:

Develop and evaluate the operational performance of the four proposed protection system enhancement tools to meet California Independent System Operator (CA ISO) specifications,

Initiate the transfer of these prototypes to a CAISO vendor for implementation as production-grade operating tools

Communicate research results to PG&E, SCE and other entities involved in TRP program.

1.5 Background

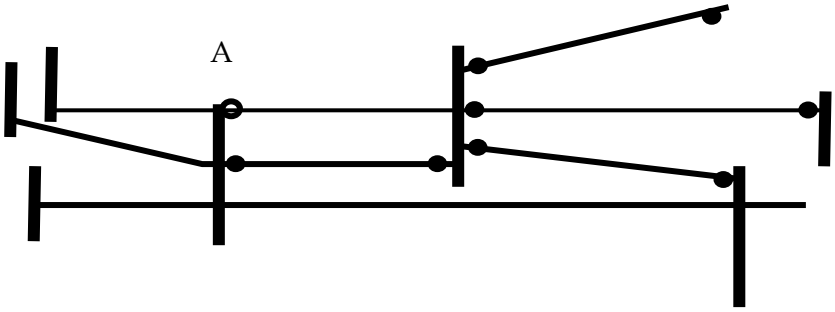
This three year project developed and evaluated the use of adaptive relaying to monitor, supervise, and modify the protection systems in real-time based upon the information about the state of the power system provided by the phasor measurements. Four aspects of the protection system supervision and control were selected for research, because they address principal concerns regarding protection system responses, and are considered to be within the capabilities of technology available today, and when successfully applied can reduce the frequency and intensity of power system blackouts.

The four research topics selected for this project are: adaptive supervision of back-up zones, intelligent load shedding, adaptive loss-of-field relaying, and the use of remote phasor measurements in the design of robust damping control of low frequency oscillations.

1.5.1 Develop techniques to supervise back-up zones

After major disturbances there have been calls to remove back-up protection such as zone-3 although relay engineers argued that zone-3 is required in certain situations. A solution may be to monitor other relays in the vicinity to supervise zone-3. That is, if an appropriate combination of zone-1 relays do not see a fault the zone-3 should be blocked. For example, in Figure 1, if zone-3 picks up at point A the issues are whether the fault seen at A is balanced and whether any of the relays at the indicated points see a zone 1 fault. If the fault is balanced and no relay sees a zone 1 fault the zone 3 trip is blocked.

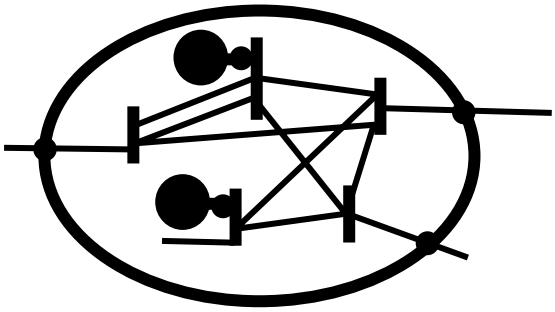
Figure 1.1 Supervision of Bach-up-zones



1.5.2 Intelligent load shedding

Under-frequency load shedding has been in use by power system engineers for many years, and has performed well when the thresholds of frequency and feeders assigned for tripping are allocated appropriately for credible contingencies. However, it is clear that this system does not operate unless the system breaks into islands, and there is an overall decay of system frequency. In many cases, this action is too late. It would be desirable to activate load shedding under supervisory control when significant loss of generation or load takes place, although no islands are formed and the frequency does not begin its decline. One thought worth exploring is to gather in real-time wide area measurements from tie-lines and generators in order to detect step changes in their real-power outputs. These changes are in response to loss of generation or load somewhere on the network. It is possible to determine ahead of time thresholds which would trigger load shedding ahead of a system break-up into islands. The dynamic ACE measures s the load needed to be shed to return to pre-disturbance state

Figure 1.2 Intelligent Load Shedding

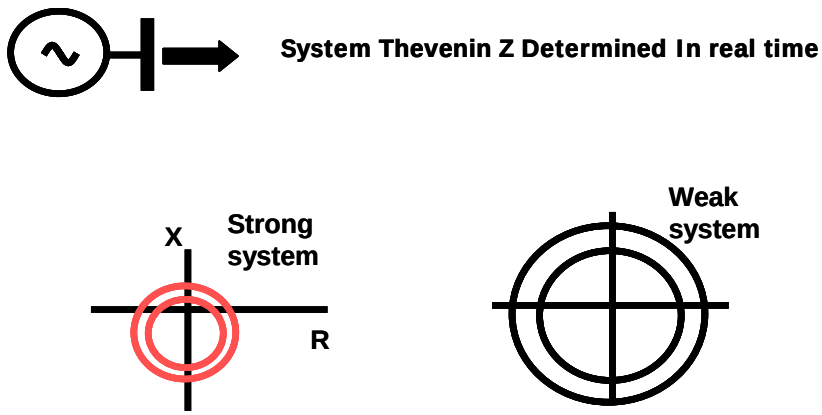


In essence, what needs to be measured is a dynamic Area Control Error (ACE), from which a short-fall or excess of generation on the network could be estimated. Algorithms need to be developed which would provide a correlation between changes in dynamic ACE and the necessary load (or possibly generation) drop. These actions will be preventive in nature, reducing the possibility of a system collapse and fragmentation into islands.

1.5.3 Adaptive loss-of-field

Loss-of-field relays on important generators are designed to keep the machine safe from steady-state instability. The limits of stability are expressed as settings in the R-X plane for distance relays installed at the terminals of the generator. There is an alarm setting (larger zone), as well as a setting which denotes violation of the steady state limit and leads to a trip of the unit. The setting of the loss-of-field relays is based upon generator voltage, generator impedance, and the Thévénin impedance of the system as seen from the generator terminals. Clearly the generator impedance is constant, but the system Thévénin impedance changes as the structure of the power system changes.

Figure 1.3 Adaptive Loss-of-Field



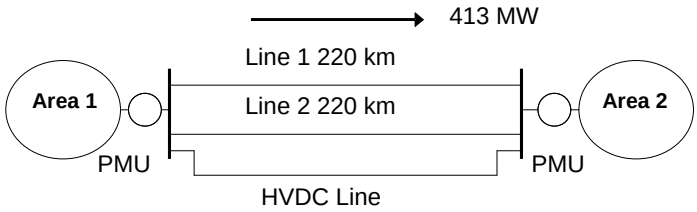
Consider a scenario where the power system is cascading towards a blackout. In this scenario, several important transmission lines are being lost, and eventually the system Thévénin impedance begins to increase – reflecting the evolving weakness of the power system. As the Thévénin impedance increases, the steady-state stability margin begins to shrink, and the out-of-step relay settings in place on the generators begin to become inappropriate. In certain cases of cascading failures, this may lead to a generator trip without getting a warning, further exasperating a worsening situation.

1.5.4 Phasor measurements for damping of low frequency oscillations

Existing approaches have been shown to lack robustness. A parallel to this problem exists in structures in both tall buildings and large space structures. In both cases it is desirable to damp vibrations without knowing precisely what form the vibrations will take. Earthquakes and unusual winds for tall buildings and unpredicted disturbances on the space station are examples. A common solution to the structures problem is the use of so called "collocated control". Such controls are present in modern buildings (Building 101 in Taipei, for example). It seems that phasor measurements can provide a similar solution to low frequency inter-area oscillations in power systems.

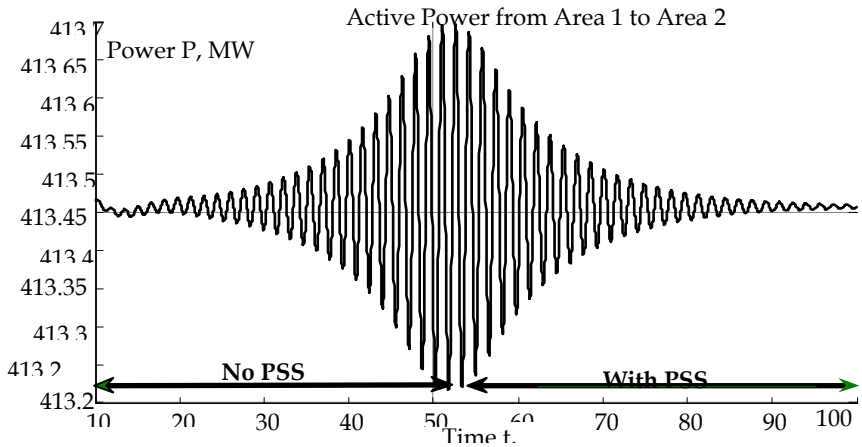
The Chinese power system which has a number of new HVDC systems has installed a "wide-area coordinated control of multiple HVDC systems" (WACCH) to damp low frequency oscillations [1]. The system uses a fast real-time Prony algorithm to determine the frequency of the oscillation. This is necessary since the frequency changes with changing system conditions and the control technique must know the oscillation frequency. A pole placement design is used for the initial control system and the parameters of the initial design are tuned as the oscillation frequency changes. The premise of the research proposed in this task is that such designs are unnecessary and that damping can be provided for an entire class of low frequency oscillations.

Figure 1.4 The model two area system



As an example the system in Figure 1.4 [2] is a four generator two area systems used as an example of a PSS design. The four generators are identical except for the inertias which are 6.5 s in Area 1 and 6.175 in area 2. The two areas are connected by two 220 km 230 kV lines. Without the stabilizer there is an unstable low frequency inter-area mode at 0.64 Hz. The system has been modified [3] by adding a parallel HVDC line connecting the two areas. In [3] an artificial situation is created to study the effect of collocated control using the HVDC line. The situation studied is a period with the PSS not in service and then after the 0.64 Hz. oscillation has grown the PSS is inserted to damp the oscillation. The power flow between the systems is shown in Figure 1.5.

Figure 1.5 the power flow between areas when the PSS is inserted after 50 sec.



The collocated control scheme is to modulate the power flow along the line proportional to the frequency difference between areas measured by the PMUs at either end of the line. The frequency measurement taken at the remote bus (Area 2) is subject to communications delay. Assuming a dedicated fiber-optic communication communications channel connecting Areas 1 and 2 it is reasonable to assume that delay is less than 50 milliseconds.

Delays up to 300 ms cause no noticeable degradation in the performance. The compelling reason to use the collocated scheme is its robustness. To test the robustness the following system changes were made without changing the control algorithm.

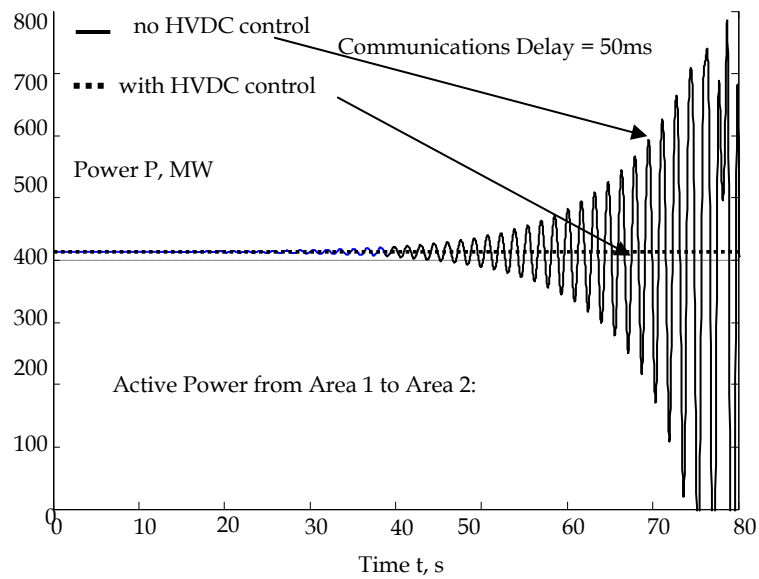
1) Increase system-wide loading by 50%:

2) Increase nominal power flow along DC tie by 100 MW

3) Change the lengths of the AC tie lines by 10%

4) Change the generator inertias:

Figure 1.6 Performance of the collocated controller.



For all these simulations the communications delay was kept at a constant 50ms. None of these systems changes had any noticeable effect on the performance of the controller.

1.2 Summary of proposed work

The technical objective of this project is to use real-time synchronized phasor measurement data to provide improved protection system supervision in order to make it adaptive to prevailing system state. By using real-time wide area measurements, it is possible to determine optimum protection policies and settings for critically located relaying systems. This three year Research Development and Demonstration (RD&D) project aimed at slow speed protection functions in which the latency involved in remote phasor measurements is not an obstacle. It is recognized that primary protection of power system equipment requires high speed decision making that is incompatible with delays of even tens of milliseconds. Such protection is unlikely to be adaptive to remote inputs.

Four aspects of the protection system supervision and control were selected for research, because they address principal concerns regarding protection system responses, and are inter-related and complementary in their scope. Such measures are considered to be within the

capabilities of technology available today, and when successfully applied can reduce the frequency and intensity of power system blackouts.

This R&D effort was conducted in close cooperation and supervision of PG&E, and SCE through the Project Advisory group lead by Vahid Madani from PG&E and Farrokh Habibiashrafi from SCE. The studies were conducted using a validated California Model developed in a preceding Virginia Tech R&D project (MTX-06-03). The results of the research are used to provide proofs-of-concept of the proposed project, as well as complete functional specifications for implementing these ideas on the California system.

Chapter 1 References

[1] J. H. Shi, P. Li, X. C. Wu, C. Lu, Y. Zhang, Y. K. Zhao, J. Hu, "Implementation of an adaptive continuous real-time control system based on WAMS" Monitoring of Power System Dynamics Performance, Saint Petersburg, 28-30 April 2008

[2] P. Kundur, , Power System Stability and Control. Example 12.6, p. 813 McGraw-Hill, 1994.

[3] http://phasors.pnl.gov/Meetings/2007_may/presentations/synch_freq_meas.pdf page 17 of the presentation

Chapter 2: Techniques for Supervise Overreaching zones

2.1 Introduction

After major disturbances there have been calls to remove back-up protection such as zone-3 although relay engineers argued that zone-3 is required in certain situations. A solution may be to monitor other relays in the vicinity to supervise zone-3 [1]. That is, if an appropriate combination of zone-1 relays do not see a fault the zone-3 should be blocked.

With participation of the TAG, the Virginia Tech team worked on a precise problem definition and identify research needs to achieve the goals of this task. There were two major tasks defined for this project, the development of the supervising scheme and the exhaustive testing of the schemes through simulations.

2.1.1 Study Scope

The goal of this project is to develop schemes for supervising back-up zones with remote phasor measurements so that back-up protection is not allowed to operate when it is not appropriate. There are two major tasks for this project,

a) The development of the supervising scheme and

b) The exhaustive testing of the schemes through simulations in the full California study system.

This technical report focuses on the development of the supervising scheme and the plans for testing it on the California system model.

2.1.2 Zone 3- Relay Protection Criteria

Even though the transmission line is fully protected with Zone 1 and Zone 2 relays, Zone 3 of a distance relay is used to provide the remote backup protection in case of the failure of its primary protection and is typically set to cover about 120-180% of the longest adjacent line [2]. This zone is given a delay time twice that associated with zone 2 operating time to achieve time selectivity, and the time delay is typically set in the range of 1–2 s. Sometimes it is necessary to coordinate the Zone 3 relay with over-current relays on tapped distribution load. The relay should detect any fault for which it is expected to provide backup and not limit the load carrying capability of the line. The setting of the Zone 3 relay ideally will cover (with adequate margin and with consideration for in-feed, if required) the protected line, plus all of the longest line leaving the remote station [3].

2.2 Development and Test Plan

2.2.1 Selection of Appropriate Location for Back-up Protection

To implement the supervisory protection scheme, the critical locations where the back-up will be needed have to be detected. This requires a thorough understanding of the system under study and of the critical elements of the system. Critical elements are those that when lost or tripped affect the stability of the power system. Since the aim is to supervise distance relay protection of transmission lines, identifications of critical lines is crucial for this task.

When a line trip in the power system, other lines try to make up for the power loss by transmitting power to the load that was fed by the tripped line. If a line is tripped which has a large portion of total power flow, this loss may not be quickly restored by the others as over-loading may occur. As a result, the frequency of the whole power system may decrease, and the whole system may be unstable. Protection of those lines is very important to ensure the system stability.

As a part of the steady state analysis, the method of line outage distribution factor (LODF) will be applied in this project to identify the critical lines. The goal is to find the line with large LODF, for one or multiple contingencies.

2.2.2 Line Outage Distribution Factors (LODF)

LODF gives the percent of flow from the outage line that ends up flowing on another line. As discussed before for a line outage, loss of power flow on one line is carried by other lines.

Figure 2.1 shows the power flows in a system prior to the removal of the line from bus 1 to 3. In Figure 2.2 the line from bus 1 to 3 is out of service, the figure shows the parts of the previous flow S1-3 being carried by other lines; the percentage of S1-3 is the distribution factor for that line L1-3.

2.2.2.1 Propose Technique of Determining Line Outage Distribution Factor

Before the line outage contingency occur, the impedance matrix, Z is computed considering the initial topology of the system. Post-contingency impedance matrix, Z' is formed considering the change of topology of the network due to the outage of a single line. Distribution factor Krs,pq represents the fraction of the power in the line p-q that goes out which ends up in line r-s after the outage. Z is impedance matrix before outage and Z' is the impedance matrix without line p-q (line p-q is out of service).

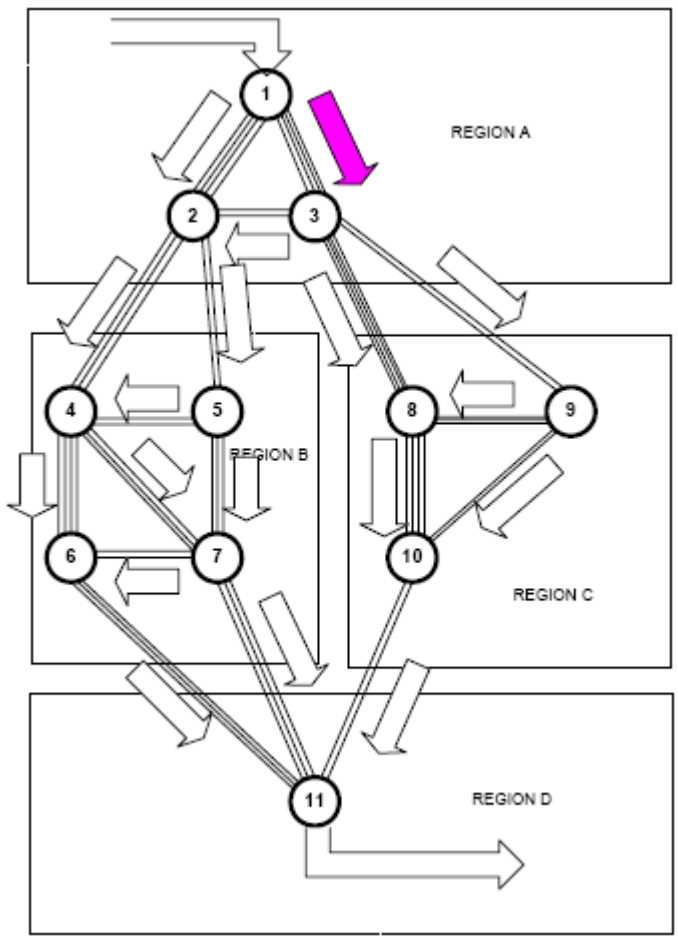
$$K_{rs,pq} = \frac{\left(Z_{pr}' - Z_{qr}'\right) - \left(Z_{ps}' - Z_{qs}'\right)}{z_{rs}} \tag{2.1}$$

If the distribution factors are expressed in terms of elements of Z (rather than element of Z'), the formula becomes,

$$K_{rs,pq} = \frac{Z_{pq}}{Z_{rs}} \cdot \frac{(Z_{pr} - Z_{qr}) - (Z_{ps} - Z_{qs})}{2 \cdot Z_{pr} - Z_{pr} - Z_{pp} - Z_{qq} + z_{pq}} \tag{2.2}$$

Where zpq is the impedance of the line p-q and Zpq is the pq'th element of impedance matrix Z [5].

Figure 2.1: L1-3 in Service

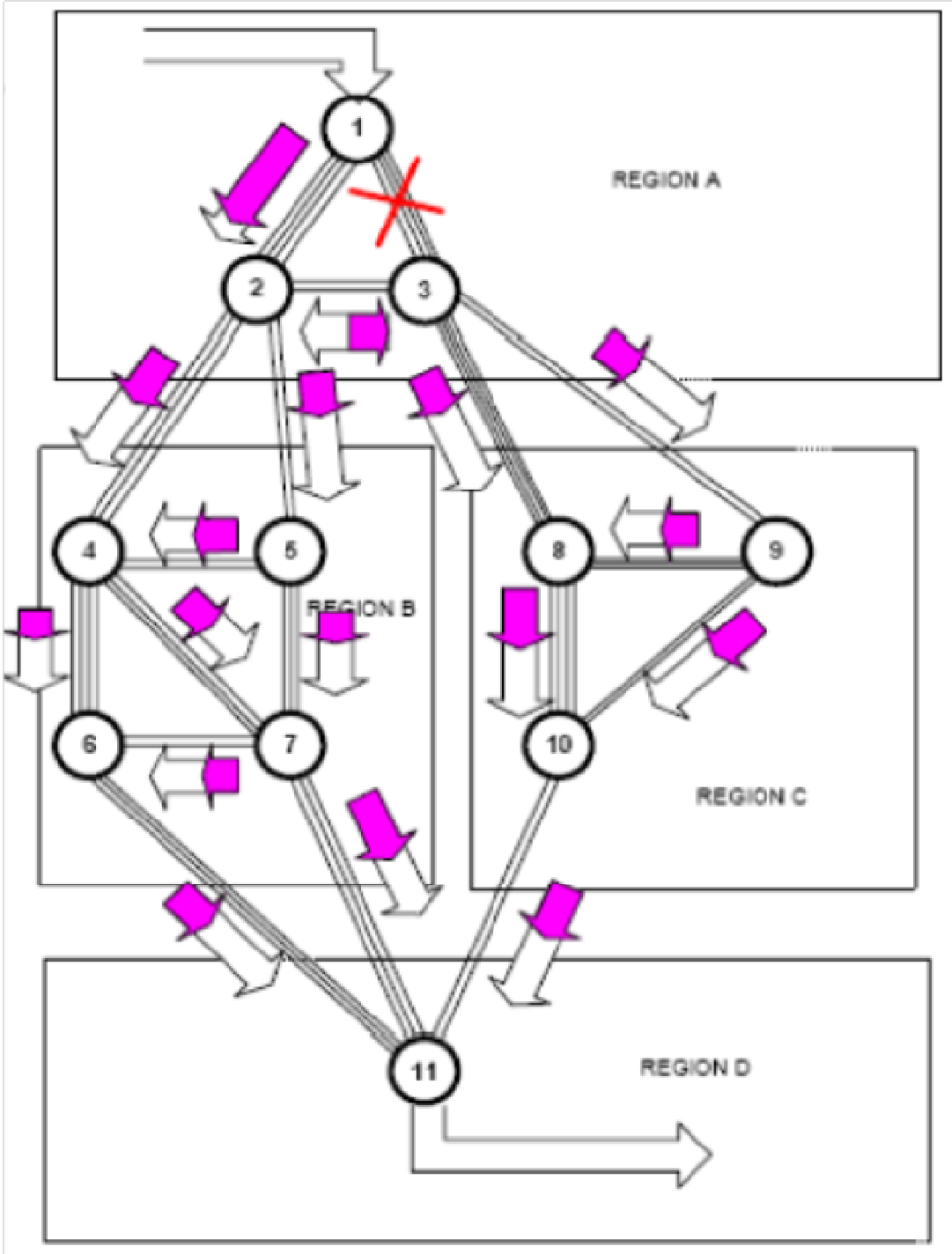


If the power on line r-s and line p-q is known, the flow on the line r-s, due to the outage of line p-q can be determined using the Krs,pq factors.

$$f_{rs} = f_{rs}^{0} + K_{rs,pq} \cdot f_{pq}^{0} \tag{2.3}$$

Where f_{rs} is the flow on line r-s after line p-q out, f0rs and f0pq are the pre-outage flows on the lines r-s and p-q, respectively [4].

Figure 2.2: L1-3 Out of service



2.2.3 Test Plan

The proposed criteria for distribution factor analysis will be tested with the full California Heavy summer power system model. Understanding of the system parameters and familiarization with PSLF (GE Positive Sequence Load Flow Software) are necessary as the system is modeled using the software. As LODFs are to be found in terms of bus impedance matrix or Zbus, bus admittance matrix, Ybus will be built for the California network, with 3852 buses and 4474 lines.

For this study (n-1) contingencies will be created and the corresponding critical lines monitored. The zone 3 setting of critical lines will be identified considering the apparent impedances is seen by the relays in normal condition. The apparent impedances seen by the relays due to the pre-determined overloads will be determined. For some value of line loading, the apparent impedance may cross into the zone of protection of a relay, and the relay will trip, this will be considered an encroachment of protective zone.

2.3 Implementation of LODF in the Full California Model

To apply the distribution factor analysis to the full California power system model, understanding of the system parameters and familiarization with PSLF (GE Positive Sequence Load Flow Software)are necessary as the system is modeled using the software. As LODFs are to be found in terms of bus impedance matrix or Zbus, bus admittance matrix, Ybus is built for the California network, with 3852 buses and 4474 lines. As we know for a power system [6],

$$Z_{bus} = [Y_{bus}] -1$$

2.3.1 Formation of LODF Matrix for CA System and Identification of Critical Lines

Using equations (2.1) and (2.2), distribution factors for each 3300 single contingencies are calculated and a 4474 X4474 dimensional LODF matrix is formed. As LODF gives the percent of flow from the outage line that ends up flowing on another line, distribution factor, Krs,pq represents the fraction of the power in the line (p-q) that goes out which ends up in line r-s after the outage. Using the equation (2.3), post-contingency power flows in the lines are calculated. Considering a power factor (0.8~0.9), the thermal capacity of the lines are compared with the post-contingency power flows in the lines and overloads are detected. Lines with 30% or more overloads are considered as critical lines (Results attached in Appendix A).

2.3.2 Identification of Zone 3 Settings for Critical Lines and Encroachment of Protective Zone due to Single Contingency

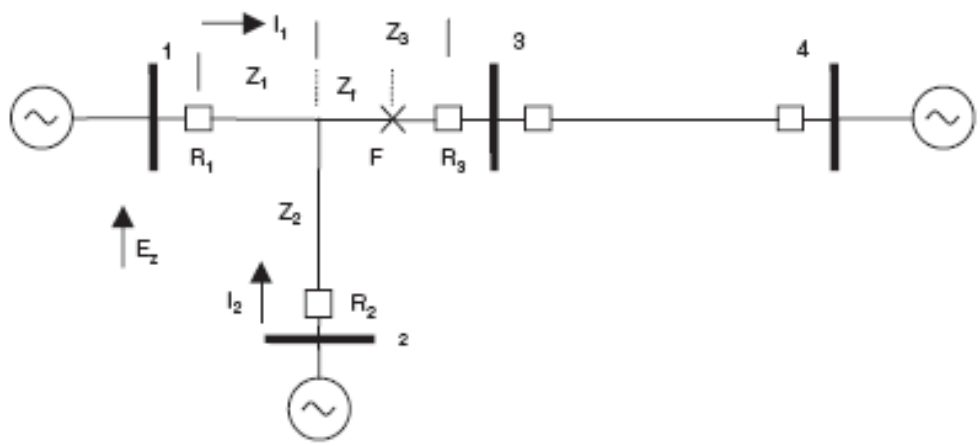
For this study (n-1) contingencies were created and the corresponding critical lines were monitored. The zone 3 setting of critical lines were identified considering Mho relays i.e. the apparent impedances is seen by the relays in normal condition. The apparent impedances seen by the relays due to the pre-determined overloads were determined. As the load on a line

increases, the apparent impedance locus approaches the origin of the R–X diagram. For some value of line loading, the apparent impedance may cross into the zone of protection of a relay, and the relay will trip, this is called an encroachment of protective zone.

2.2.3 Relay Settings for Multi-Terminal Lines

When the multi-terminal lines have sources of generation behind the tap points, or if there are grounded neutral wye-delta power transformers at more than two terminals, the protection system design requires careful study of infeed currents. Let's consider the three-terminal transmission line shown in Figure 2.3 [2] for this study.

Figure 2.3: Effect of infeeds on zone settings of distance relays



For a fault at F, there is a contribution to the fault current from each of the three terminals. (For the sake of simplicity, the system is assumed to be a single-phase system, although it must be understood that the interest is in three-phase systems, and the actual distance evaluations for each type of fault must be considered. This aspect of multi-terminal line protection is no different from the usual considerations of faults on a three-phase system). To determine the relaying current and voltage at relay R1, the voltage at bus 1 is related to the current at bus 1 by the equation

$$E_1 = Z_1 \cdot I_1 + Z_f \cdot (I_1 + I_2) \tag{2.4}$$

and the apparent impedance seen by relay R1 is

$$Z_{app} = \frac{E_1}{I_1} = Z_1 + Z_f \left(1 + \frac{I_2}{I_1}\right) \cdot f_{pq}^{0} \tag{2.5}$$

The current I2, the contribution to the fault from the tap, is known as the infeed current when it is approximately in phase with I1, completely arbitrary phase relationships are also possible, but in most cases the phase relationship is such that the current I2 is an infeed current.

Equation (2.5) shows that the apparent impedance seen by relay R1 is different from the true impedance to the fault: (Z1 + Zf). When the tap current is an infeed, the apparent impedance is greater than the correct value. Thus, if zone 1 setting of relay R1 is set at about 85% of the actual line length 1–2, for many of the faults inside the zone of protection will appear to be outside the zone of the relay, and the relay will not operate. It would be insecure to set zone 1 of the relay to a high value, in order that the apparent impedances for all faults inside the 85% point lie inside the zone setting. For such a setting, if the tap source should be out of service for some reason, faults beyond the 85% point will cause zone 1 operation [2].

On the other hand, zones 2 and 3 of relay R1 must reach beyond buses 2 and 3, respectively, under all possible configurations of the tap. Thus, for these (overreaching) zone settings, we must set the zones with all the infeeds in service. Then, even if some of the infeeds should be out of service, the impedance seen by the relay will be smaller, and will be definitely inside the corresponding zones. The principle of protecting a multi-terminal line may be summarized as follows: under reaching zones are set with infeeds removed from consideration, and overreaching zones are set with the infeeds restored [2].

2.4 Multiple Contingency Studies

Since the study was unable to find any encroachment of zone 3 protective zones with single contingencies, the study was expanded to overloads from multiple contingencies. The study started with contingencies like 500 KV line outage which created heavy overloads (30% or more of line capacity, max MVA rating) along with generator outages. When performing this contingency analysis, it was observed that for all generator outages, PSLS load flow add the MW losses in the system with the Swing Generators. In the CA Study system there are 2 swing generators, one located in the Northern boundary and the other in the Eastern boundary of CA. These swing generators are also modeled as equivalent generators outside CA. As a result of normal load-flow in PSLF, all generation mismatches were picked up by these two equivalent generators, but in the real system, the outage generations are to be distributed to the rest of the generators (in-service) according to their machine inertia. So an inertial re-dispatch for generator outage contingencies was performed.

2.4.1 Inertial Re-dispatch of Generators

From the swing equation [6] [7], we have,

$$J\omega_r \frac{d^2\delta}{dt^2} = P_m - P_e = P_a \tag{2.6}$$

Where, J is the Stored kinetic energy at synchronous a speed, ωr is Rotor angular velocity, δ is Power angle, Pm is Mechanical power output and Pe is the electrical power output. The inertial constant of a generator is known to be,

$$H = \frac{Stored\_kinetic\_energy\_at\_synchronous\_speed\_in\_megajoules}{Generator\_MVA\_rating}$$

or , $H = \frac{J\omega_s^{\ 2}}{2S_{rated}}$

from equation (2.6), the following equation is obtained

$$2H\frac{S_{rated}}{\omega_s^{\ 2}}\omega_r\frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

In steady state, the machine angular speed is equal to the synchronous speed and hence ωs (synchronous angular velocity) can replace ωr in the above equation and the swing equation becomes,

$$2H\frac{S_{rated}}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e = -\Delta P \qquad (2.7)$$

In steady state analysis ΔP α Srate is considered. After a generator outage contingency is created, the MW mismatch is made-up by re-dispatching the other generators in service based on their machine base, Srate . The post-contingency change in real power output in generators is found using the following equation,

$$\Delta P_x = \frac{S_{rated,x}}{S_{rated,total}} \cdot \Delta P_{total}$$

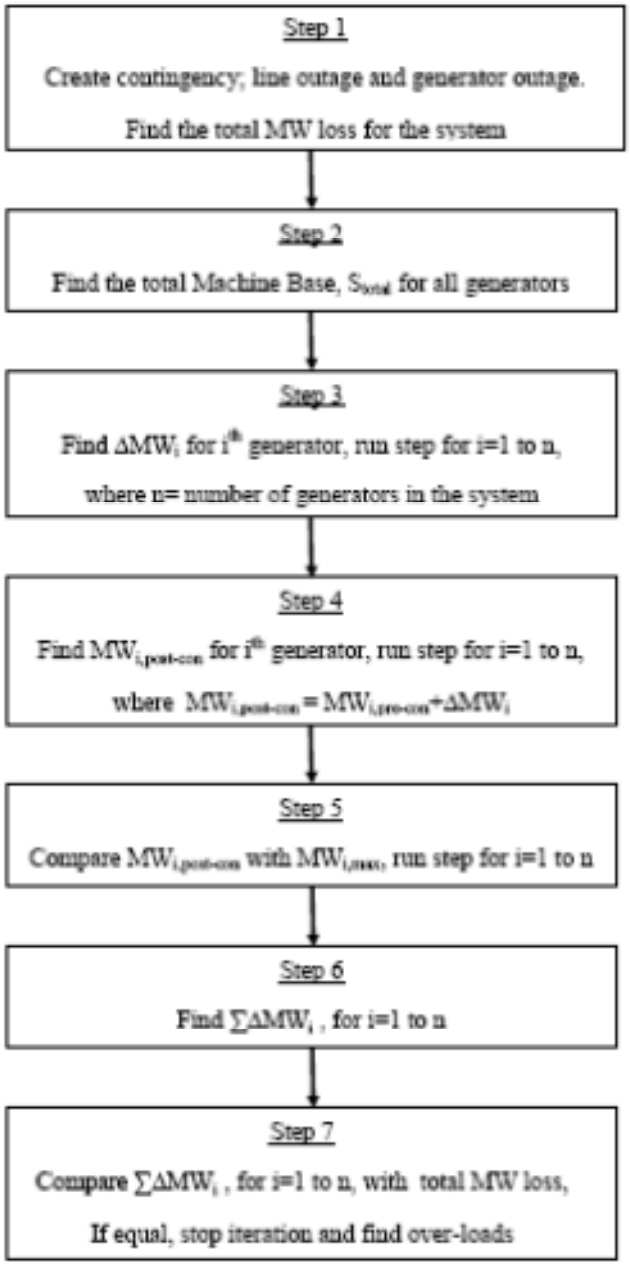
Where, is the change in MW in machine x, after re-dispatch, is the total loss in MW in whole system, before re-dispatch, is the machine base of machine x, and $S_{rated,total}$ is the total of Machine bases in whole system.

A multiple contingency analysis is performed, based on the algorithm in Figure 2.4 to find overloads and encroachments of back up zone (zone 3).

2.4.2 Comparison between CA and Full-Loop Study System

To verify the generator inertial re-dispatch algorithm, the same generator outage contingencies were performed in both the Full-loop study system, a complete model of WECC power system that has the actual generators outside CA included in it. But these generators are modeled as equivalents in the CA study system. It was observed that in the Full-loop model 66~70% of make-up generations come from generators outside CA and in the CA model 70~73% of losses were picked up by the equivalents modeled as generators outside CA. After validating the algorithm with the testing in both systems, the multiple contingency studies were performed.

Figure 2.4: Flow chart for inertial re-dispatch of generators



2.5 Project Results

2.5.1 Line Outage Distribution Factor Study

All overloads above 10% were found and lines with 30% and above overloads were considered as critical Lines.

2.5.2 Single contingency Analysis and Xone 3 Enchroachment Study

For single line outages, the critical lines did not have scenarios of encroachment of zone 3 protective zones

2.5.3 Multiple Contingency Studies

Inertial re-dispatch for machine outages was considered and contingencies of line and generator outages were studied. In normal operating conditions, no cases of zone 3 encroachments was found for single line and generators out of service. If severe contingencies are considered, the system collapses, before any occurrences of encroachment in the back-up zone. In further studies for the Phase III of the CA project, Adaptive loss-of-field, severe contingencies are being considered by creating bus faults in the 500KV buses, thus taking multiple lines out of service, and monitoring system conditions and limits of stability.

Chapter 2 References

[1] Phadke, A.G.; Novosel, D.; Horowitz, S.H., "Wide Area Measurement Applications in functionally integrated power systems", CIGRE B-5 Colloquium, Madrid, Spain, 2007.

[2] Horowitz, S.H.; Phadke, A.G., *Power System Relaying,* Research Studies Press, Taunton, Somerset, England, 1992

[3] IEEE Guide for Protective Relay Applications to Transmission Lines, IEEE Standard C37.113-1999, PSRC

[4] Wood, Allen J.; Wollenberg, Bruce J., *Power Generation, Operation and Control,* John Wiley & Sons, Inc, New York, 1996.

[5] Ilic-Spong, Marija; Phadke, Arun G.," Redistribution of Reactive Power in Contingency Studies." IEEE Transactions on Power Systems, Vol. PWRS-1, No. 3, August 1986, pp 266-274.

[6] Kundur, Prabha; *Power System Stability and Control,* McGraw-Hill Inc. 1994.

[7] Saadat, Hadi; *Power Systems Analysis*, McGraw-Hill Inc. 2002.

Chapter 3: Adaptive Loss of Field

3.1 Introduction

3.1.1 Background

Loss-of-field (LOF) relays on important generators are designed to keep the machine safe from steady-state instability. The limits of stability are expressed as settings in the R-X plane for distance relays. These relays are installed at the terminals of the generator. There is an alarm setting (larger zone), as well as a setting which denotes violation of the steady state limit and leads to a trip of the unit. The setting of the loss-of-field relays is based upon generator voltage, generator impedance, and the Thévénin impedance of the system as seen from the generator terminals. Clearly the generator impedance is constant, but the system Thévénin impedance changes as the structure of the power system changes. Let us consider a scenario where the power system is cascading towards a blackout. In this scenario, several important transmission lines are being lost, and eventually the system Thévénin impedance begins to increase. This reflects the evolving weakness of the power system. As the Thévénin impedance increases, the steady-state stability margin begins to shrink, and the out-of-step relay settings in place on the generators begin to become inappropriate [2]. In certain cases of cascading failures, this may lead to a generator trip without getting a warning, further exacerbating the situation.

1.2 Study Scope

The goal of this project is to implement adaptive LOF relays for generator protection with remote phasor measurements so that these generator protection schemes are not allowed to operate when it is not appropriate. There are two major tasks for this project:

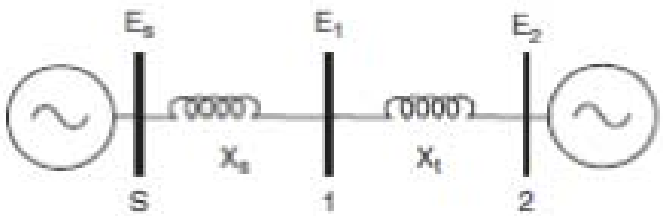
1. The development of the adaptive LOF relaying scheme.
2. The exhaustive testing of the relaying schemes through simulations in the full California study system which is then used to determine the system Thévénin impedance correctly using the PMU data.

3.2 Methodology

3.2.1 Loss-of-Field Relay Protection Criteria

Consider a simple system consisting of one machine connected to a power system as shown in Figure 3.1.

Figure 3.1: Simple system for Steady-state stability analysis [2]



The internal voltage of the machine is E_s and the machine reactance is X_s. The equivalent impedance (Thévénin) of the power system is X_t and power system equivalent voltage is E_2. Since we are considering a steady-state analysis, the voltage E_s is the field voltage E_f, and the reactance X_s is the the synchronous reactance X_d. The total reactance between the machine internal bus and E_2 is $X = X_s + X_t$. The electric power output at the machine terminals (at bus S or at bus 2) is given by Equation 3.1.

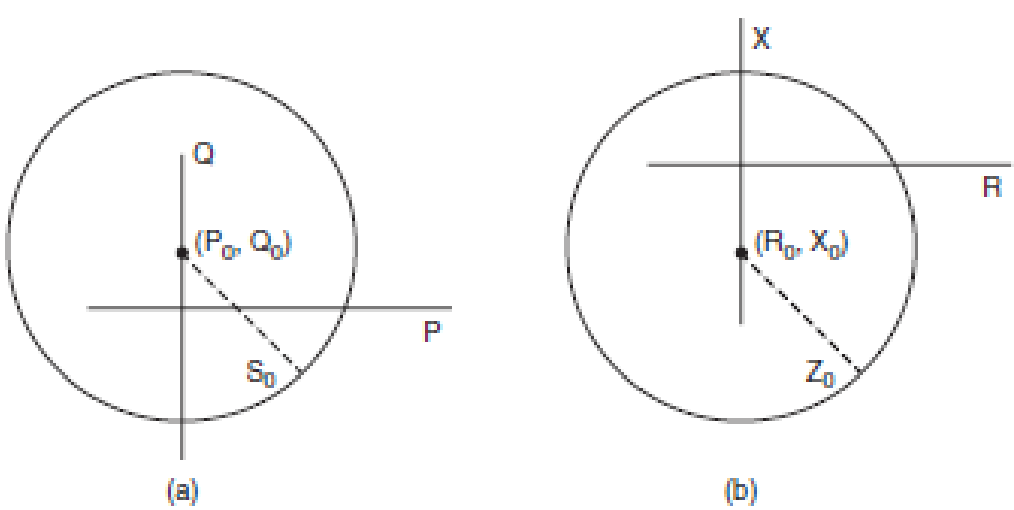
$$P_e = \frac{E_s E_2}{X} \sin \delta \tag{3.1}$$

where δ is the angle by which the machine internal voltage E_s leads E_0. The mechanical power input to the machine is P_m, and in steady state electrical power and mechanical power are in balance at a rotor angle δ_0 which is zero when the machine is operating in steady state at δ_0. The rate of change of the output power P_e with respect to δ is given by Equation 3.2.

$$\frac{dP_e}{d\delta} = \frac{E_s E_2}{X} \cos \delta \tag{3.2}$$

which remains positive for $-\pi/2 \leq \delta \leq +\pi/2$. This is the range of steady-state stability for the system. Because we need the generator to have a positive output, the steady-state stability limit of interest is $\delta = \pi/2$. This remains positive for $-\pi/2 \leq \delta \leq +\pi/2$. This is the range of steady-state stability for the system. Because we need the generator to have a positive output, the steady-state stability limit of interest is $\delta = \pi/2$.

Figure 3.2: (a) A circle in the P –Q plane transforms into (b) a circle in the R–X plane [2]



The real and reactive power outputs of the machine (as measured at the machine terminals) are given by Equation 3.3.

$$P_1 + jQ_1 = E_1 I_1 \tag{3.3}$$

At the steady-state stability limit of the machine, the rotor angle is $\pi/2$, and it can be shown that, at the stability limit, P_1 and Q_1 satisfy Equation 3.4.

$$P_1^2 + \left[Q_1 - \frac{E_1^2}{2}\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\right]^2 = \left[\frac{E_1^2}{2}\left(\frac{1}{X_d} - \frac{1}{X_q}\right)\right]^2 \tag{3.4}$$

This is an equation of a circle in the P_1 –Q_1 plane, as shown in Figure 3.2(a). When the machine is operating at its steady-state limit, we determine the response of a distance relay. We will next show that a circle in the P –Q plane maps into a circle in the apparent R–X plane. Whether or not a machine approaches a limit (such as a steady-state stability limit) defined by a circle in the P –Q plane can then be detected by the corresponding circle in the R–X plane, using a distance relay. Let us take a general circle in the P –Q plane, with its center at (P_0, Q_0), and a radius of S_0. This is given in Equation 3.5.

$$(P - P_0)^2 + (Q - Q_0)^2 = S_0^2 \tag{3.5}$$

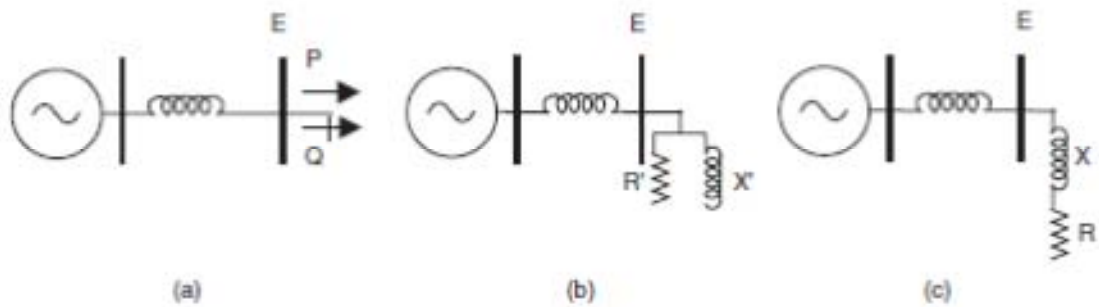
For example, in the case of the steady-state stability limit given in (2.4), these values are given by Equations 3.6-8.

$$P_0 = 0 \tag{3.6}$$

$$Q_0 = \frac{E_1^2}{2}\left(\frac{1}{X_d} - \frac{1}{X_q}\right) \tag{3.7}$$

$$S_0 = \frac{E_1^2}{2}\left(\frac{1}{X_d} - \frac{1}{X_q}\right) \tag{3.8}$$

Figure 3.3: (a) Generator connected to a power system. (b) The generator supplying the same power to a parallel load. (c) The generator supplying the same power to a series-connected load. This is the apparent impedance seen by an impedance relay [2]



Consider the three circuits shown in Figure 3.3. Figure 3.3(a) shows a generator with output $P + jQ$ with a terminal voltage E. Figure 3.3(b) shows the generator with the same terminal conditions but now supplying an impedance load R and X connected in parallel at the generator terminal. The parallel impedances are next converted to series-connected R and X, which are related to the terminal conditions by Equations 3.9-10.

$$R = \frac{E^2 P}{P^2 + Q^2} \tag{3.9}$$

$$X = \frac{E^2 Q}{P^2 + Q^2} \tag{3.10}$$

Substituting (2.9) into (2.10), we obtain Equations 3.11.

$$(R - R_0)^2 + (X - X_0)^2 = Z_0^2 \tag{3.11}$$

We get an equation of a circle in the R–X plane with its center at (R_0, X_0) and a radius of Z_0 as in Figure 3.2(b) where these parameters are given by Equations 3.12-14.

$$R_0 = \frac{Z_0 E^2}{R_0^2 + X_0^2 - Z_0^2} \tag{3.12}$$

$$X_0 = \frac{Z_0 E^2}{R_0^2 + X_0^2 - Z_0^2} \tag{3.13}$$

$$Z_0 = \frac{Z_0 E^2}{R_0^2 + X_0^2 - Z_0^2} \tag{3.14}$$

The circle in the impedance R–X plane for the steady-state stability limit is shown in Figure 3.2(b). For this case, we may substitute the values for P_0, Q_0 and S_0 from (3.6-8) using E for the machine terminal voltage, rather than E_1. We then obtain the LOF relay settings given in Equations 3.15-17.

$$R_0 = 0 \tag{3.15}$$

$$X_0 = \frac{X_m + X_m}{2} \tag{3.16}$$

$$Z_0 = \frac{-(X_m - X_m)}{2} \tag{3.17}$$

3.2.2 Steady State Instability as Loss of Field Condition

Now we try to explain why the steady-state instability is referred to as a loss-of-field condition. Figure 4 shows the phasor diagram of the terminal voltage, stator current, and the internal voltage of the generator E_f. Also shown is the field circuit with a field current I_f.

Neglecting the effects of machine saturation, the voltage E_f and the field current I_f are proportional to each other. We may use the phasor E_f (magnitude) to represent the field current. If the field current of the generator decreases for whatever reason, the output power P is not affected. Since the power P is equal to $EI \cos \theta$, where θ is the power factor angle, the projection of the stator current I_1 on the axis of E_1 must be constant as the field current changes. This is designated as 'x' in Figure 3.4. Now consider a reduction in the field current I_f. In order to maintain the phasor relationship between E_f, E_1 and I_1 under these conditions, as E_f changes (drops in magnitude) it must travel along the dashed horizontal line and the current I_1 must travel along the dashed vertical line as shown in Figure 3.4. This keeps the output power

constant at *P*, while the stator current goes from a lagging power factor angle to a leading position. The machine thus absorbs reactive power when the field current decreases [1].

Figure 3.4: The current and the phasor diagram of generator voltage and relationship between reductions in field current as field current decreases

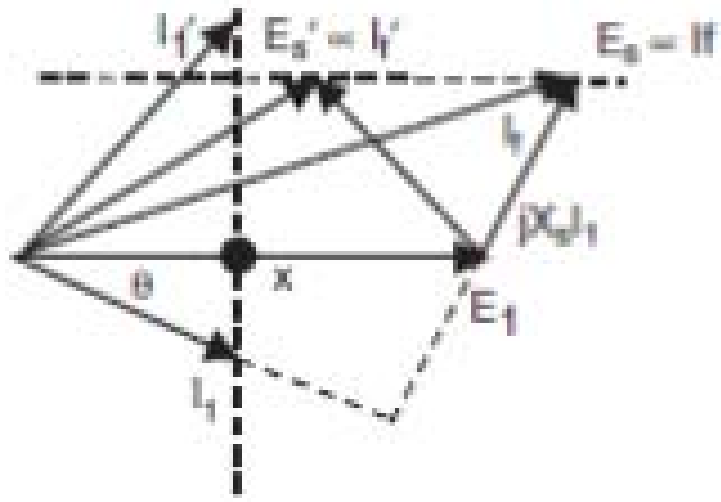
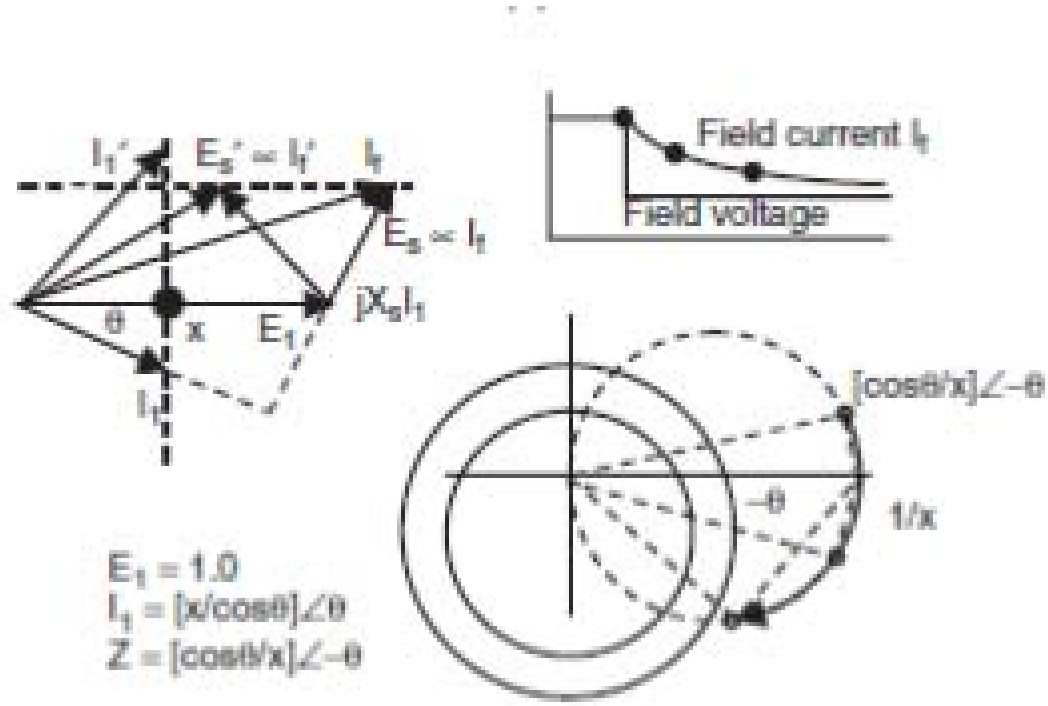


Figure 3.5: The relationship between reduction in field current and the phasor diagram of the generator voltage and current. As the field current decreases, there are changes in the apparent impedance seen by a distance relay at the generator terminal [2].

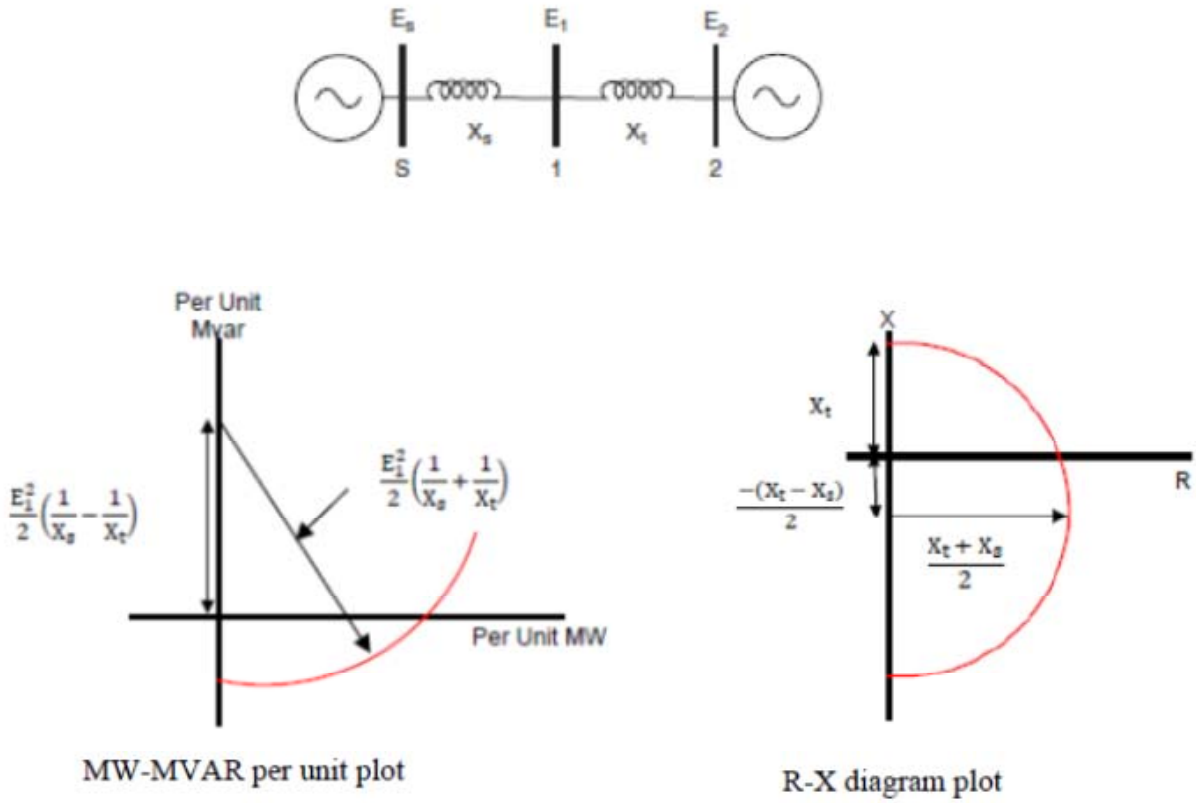


The ratio of E_1 to I_1 is the apparent impedance (R + jX) seen by a distance relay connected at the terminals of the generator. If 'x' is constant, the apparent impedance travels along the circle, crossing over from the first quadrant to the fourth quadrant. The characteristics of the impedance relays which define the steady stability boundary are also shown in Figure 3.5. It should be clear that as the field current of the generator drops, the generator goes from a lagging power factor to a leading power factor, and the apparent impedance seen by a distance relay approaches the steady-state stability boundary [2].

3.2.3 Steady State Stability Limit Circle

The steady state stability limit, as explained in the previous section, reflects the ability of the generator to adjust for gradual load changes. The steady state stability limit is a function of the generator voltage and the impedances of the generator, step-up transformer and system (Th´evenin equivalent impedance). This method assumes field excitation remains constant (no AVR) and is conservative. When making the calculations, all impedances should be converted to the same MVA base, usually the generator base. The steady state stability limit is a circle defined by the equations shown in Figure 3.6 below [4]:

Figure 3.6: Graphical method for Steady State Stability



In traditional LOF protection, the size of the steady state stability limit circle is unchanged once the relay is commissioned. However, in a practical system, the size of the steady state stability limit circle is related with the system operating modes and changes from time to time as the loading of the system changes or due to an event [5].
As previously mentioned, the steady state stability limit boundary impedance locus is a circle as shown in Figure 6. The center of the impedance circle is located at $(0, -j(X_t-X_s)/2)$ and the radius is $(X_t+X_s)/2$. From Figure 6, it can be seen that the center and the radius of the steady state stability limit circle are related to the system's Thévénin equivalent impedance since the impedance of the generator and the transformer remain constant. When the system impedance increases, the radius gets larger and the center moves up. At the same time, the new steady static stability impedance circle becomes larger, covering the previous area. When the system impedance decreases, the radius gets smaller and the center moves down.

3.3 Development and Test Plan

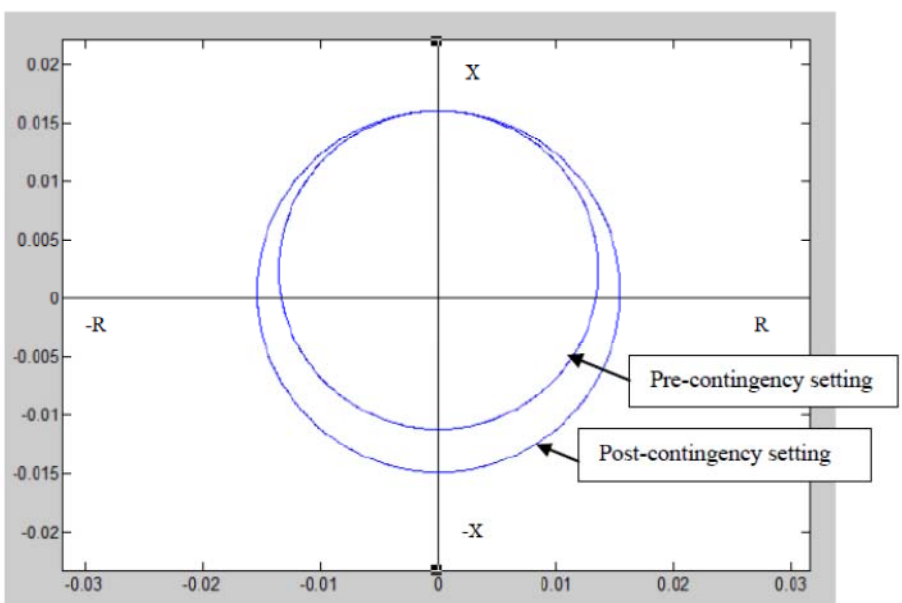
The scheme as explained in the previous section uses an impedance relay as the measuring element for loss of field for a generator. The application for this project is based on the behavior of the system impedance as seen from the generator terminals for various under-excited conditions or contingencies in the system. The primary indicator that a generator or a machine has lost its excitation is the high reactive flow into the machine [2]. So the final impedance after

an under-excitation condition lies in the fourth quadrant of the R–X diagram. Any relay characteristic that will initiate an action in this quadrant is applicable [3]. Once again, the question of whether to trip or to alarm for this condition must be addressed. In almost every case, an alarm is provided early in the locus of the impedance swing so the operator can take the appropriate corrective action.

For the purpose of the relay being adaptive, we determined the required change of the relay characteristic after creating possible contingencies, i.e. changing the operating condition that could possibility impact the equivalent impedance (Thévénin) of the power system, X_t. We know that the LOF relay settings depend on the synchronous reactance X_d and Thevenin reactance of the power system, X_t at the generator terminal. Since any topology change close to that terminal will change the value of X_t, we planned to train the relay to adapt to these topology changes and create a LOF relay setting group for each generator or generator groups. Each members of LOF relay setting group will be representing the LOF settings for a specific operation conditions. After identifying the current operation condition, the relay will adapt to the system. In the California study system, a few generators are connected to the system through their step-up transformers which are referred as the generator groups.

In Figure 3.7 below, we are showing an example of the relay settings at the terminal of generators at Diablo. As we can see in the figure, the radius increased showing that the LOF relay setting changed from its normal conditions after a contingency. This contingency was a line outage from Midway to Diablo. With this scenario, the pre-contingency and post-contingency X_t values need to be calculated. Additionally, it should be noted that the Thevenin reactance of the power system at the machine terminal changes significantly.
The results and the relay settings are attached in the Appendix B.

Figure 3.7: LOF Relay at Diablo machine terminal



Chapter 3 References

[1] Mason, C.R. "A new loss-of-excitation relay for synchronous generators", AIEE Trans. Part II , 68, 1240–5, 1949.

[2] Horowitz, S.H.; Phadke, A.G., *Power System Relaying,* Research Studies Press, Taunton, Somerset, England, 1992.

[3] Loss-of-Field Relay Operation during System Disturbance Working Group Report - June 1971, W. F. Mackenzie, J. A. Imhof, C. Dewey, S. H. Horowitz et al, IEEE Transactions on Power Apparatus systems, vel. PAS-94, no. 5 , September/October 1975.

[4] "Protective Relaying Theory and Applications" edited by Walter A. Elmore, ABB Power T&D Company Inc. Coral Springs, FL, 1994.

[5] Bi, Tianshu, Sui, Jiayin, Yu, Hao, Yang, Qixun, " Adaptive loss of field protection based on phasor measurements", Power and Energy Society General Meeting, 2011 IEEE, Detroit, MI, USA, October 2011.

Chapter 4: Intelligent Load Shedding

4.1 Introduction

The technical objective of the project is to detect loss of generation within a given network defined by a boundary and shed loads intelligently before there is a decline in frequency. The availability of Wide Area Measurement Systems (WAMS) has opened up the possibility of observing the power network that is spread over a vast geographical area in near-real time. By observing the real power flow across the tie lines that connect the given network to the rest of the power grid, we can detect a loss of major generation, especially within the network being monitored.

As we know, at a steady state operating point, the supply and the demand are always balanced. When there is a loss of generation within an area, an imbalance is created. The spinning reserves and other generators within and outside the area, try to pick up the lost generation, resulting in a gradual slowing down of the generators. This leads to a steady drop in grid frequency. So long as this loss is small the frequency recovers quickly to its nominal value. If there is a loss of a major supply source, the decline in frequency may be greater. If this frequency decline is not arrested immediately, it could lead to tripping of other generators due to low frequency resulting in the system breaking up into uncontrolled islanding and potentially a cascading blackout. Shedding loads is usually the last resort used to arrest declining frequency.

4.1.1 Traditional Load Shedding Systems

One of the most commonly employed schemes for load shedding is the under frequency load shedding scheme. If the electrical network is "undergenerated," it leads to a rapid frequency decline unless additional generation is brought online. Demand-supply gap can also be bridged by shedding adequate load.

In order to prevent an islanded area from operating at low frequency for a long duration, under frequency load shedding (UFLS) schemes are employed to reduce connected load so that the available generation can effectively supply the load at nominal frequency. The UFLS relays operate, when the system frequency drops to a certain level, to shed preset amount of load. The operation is staggered in such a way that more loads gets shed as the frequency continues to depreciate. To shed a larger amount of load, Frequency Trend Relays (FTR) that operate on both frequency and rate of frequency are employed [1].

The UFLS relays are set after extensive study of frequency decline in an area due to overloading/undergeneration. A typical load shedding system in the California network operates in multiple stages as follows:

- Drop 5.8% of load at a bus at 59.5 Hz
- Drop 5.7% more load at 58.9 Hz
- Drop 5.6% more load at 58.7 Hz
- Drop 7.1% more load at 58.5 Hz
- Drop 6.0% more load at 58.3 Hz

4.1.2 Problems with Under Frequency Load Shedding (UFLS) Schemes

UFLS Schemes are usually employed as the last resort to restore the system frequency to nominal value in an islanded area after an appreciable decline in frequency. This implies that the interconnection has already started to disintegrate into islands, with some islands having excess generation while others having excess load. Thus UFLS schemes cannot be relied upon for keeping the interconnection together.

Another important disadvantage of UFLS is that the nature of load shedding – both location and amount, is not necessarily optimal. Such schemes may shed more load than necessary or may require multiple stages until the system frequency can be stabilized.

With the rapid expansion of the network with a spurt in loads and addition of generation, the UFLS systems need to be tuned offline as often as needed, in order to ensure that the scheme is dependable and secure. The setting of these relays requires extensive load flow and dynamic studies.

4.1.3 Loss of Generation within an Area

Let us consider an interconnection consisting of multiple areas. Each area consists of local generation and loads. These areas are connected to each other through tie lines. The advantage of having such an interconnection is that, it is sufficient that load and generation be balanced at the interconnection-level and not within every area. Such an arrangement allows us to operate the electric grid economically. In a typical area, the load and generation are not matched and this difference in real power is compensated for by importing or exporting real power through the tie lines. Thus change in real power flow on the tie lines indicates the extent of generation-load mismatch within an area. In Power Systems engineering parlance, this disturbance in inter-area power transfer is described as the Area Control Error (ACE).

NERC defines ACE as the "instantaneous difference between net actual and scheduled interchange of a balancing authority, taking into account the effects of frequency bias." When there is a sudden increase in load or loss of generation, a load-generation mismatch occurs. Under normal circumstances, the generation reserve within the area would correct this mismatch. If the reserve is insufficient, this mismatch is corrected by other areas in proportion to their reserve capacity, reflected by the ACE [1]. This results in a deviation of system frequency from the pre-disturbance value. The change in frequency is proportional to the magnitude of the mismatch. If a major generator is lost, the decline in frequency may be significant.

4.1.4 Application of WAMS for detecting loss of generation

With the advance of Wide Area Measurement Systems (WAMS), it is now possible to capture a snapshot of a power network spread across a vast geographical expanse. This allows us to monitor any major changes in the network on a near-real time basis.

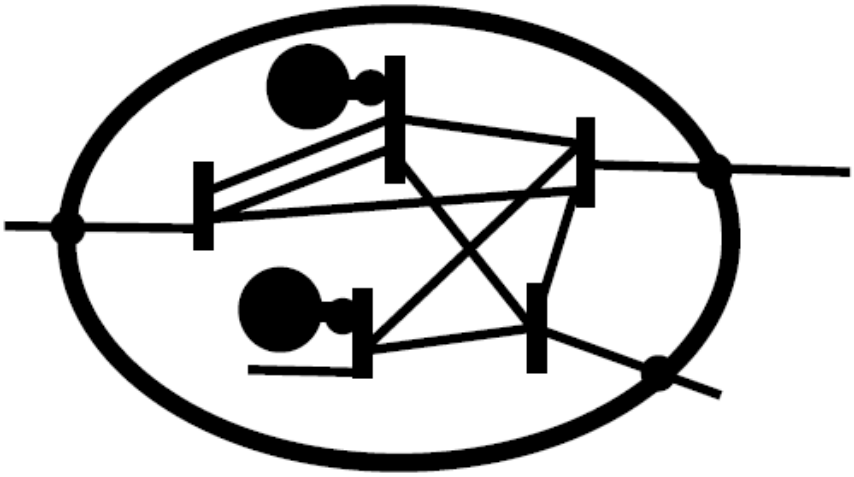
When the boundaries of an electrical network within a larger interconnection are defined, we can employ WAMS to monitor the tie lines that connect them, to detect any major event. When a generator within the area is lost, there will be a sudden unscheduled increase in the tie line flow. This increase in tie flow is proportional to the size of generation lost. If the load-

generation mismatch within the area is reduced by disconnecting loads we could effectively prevent any major frequency decline.

4.1.5 Intelligent Load Shedding

The main objective of the proposed Intelligent Load Shedding (ILS) scheme is to detect an unscheduled change in tie line flow and shed loads so as to prevent any decline in frequency. Thus, the ILS algorithm monitors the intertie flows through PMU-based WAMS, for real time control. For developing the current algorithm, California was taken as a single area. However, it is actually comprised of five regions, Imperial California, SDG&E, SCE, LADWP and PG&E. This area is connected to the rest of the WECC network by 8 major tie lines, each at 500kV.

Figure 4.8: Intelligent Load Shedding Scheme



Another aspect of the proposed scheme is its selectivity and adaptability. The load shedding is made selective by the use of a sensitivity analysis to identify the location of the loads that best relieves excess flow on a tie line. This is achieved by the computation of Generator Load Shift Factors. Load Shift Factors (LSFs) are calculated for each load with respect to every major tie line.

The algorithm is also adaptive in that the amount of load to be shed is determined from the observed tie line changes. As shown in the Interim report, the magnitude of the tie line flow change is directly proportional to the magnitude of generation lost. This allows us to vary the amount of load to be shed based on the amount of generation lost, as reflected on the interties.

4.3 Load Shedding Algorithm Development

The proposed algorithm detects step changes in the real-power outputs of the tie-lines and the generators from real-time wide area measurements, and shed loads accordingly. These actions

will be preventive in nature, reducing the possibility of a system collapse and fragmentation into islands. The changes observed on the tie lines and the generators are in response to a loss of generation or load in the network. Thus these two parameters serve as suitable inputs for the algorithm.

4.3.1 Inputs for the Intelligent Load Shedding Algorithm

4.3.1.1 Dynamic ACE:

The dynamic Area Control Error (ACE) measures the load needed to be shed to return to pre-disturbance state. Thus a measurement of the dynamic Area Control Error (ACE), a short-fall or excess of generation on the network could be estimated. Hence the dynamic ACE is being used as the input for the Intelligent Load Shedding Algorithm to be developed. The algorithm provides a correlation between changes in dynamic ACE and the necessary load (or possibly generation) drop.

The ACE represents the shift in an area's generation required to restore the frequency to the nominal value and the net interchange to their desired values.

$$ACE = \Delta T - B\,\Delta F$$

Where ΔT is the change in the tie line flow

B is called the frequency bias factors, given by $B = (1/R) + D$

ΔF is the change in the frequency of the area

As shown in the above equation, changes in the tie line flows is a very important factor. Since the proposed algorithm is intended to prevent a change in frequency($\Delta F=0$), the dynamic ACE effectively reduces to being the change in the tie line flows. In order to assess the effect of loss of generation on the tie line power flows, contingency analysis was performed on the California-only model. In the California-only model, the network representing California is represented in detail by a 4000+ bus system, while the rest of the WECC network is represented by two equivalent generators. There are seven major tie lines that connect the California network with the two equivalent generators, representing about 7 GW of inflow into California.

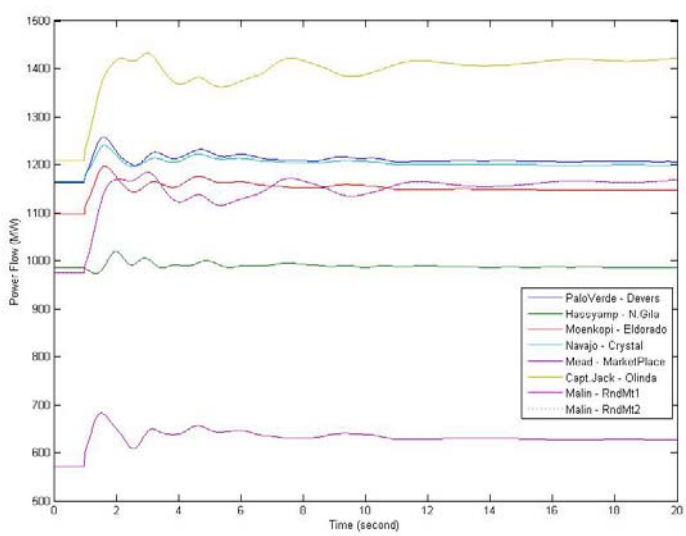
The change in the tie line flows for a loss of a generator within California was recorded using dynamic simulations in PSLF. The generators to be removed were selected based on their real power output. The following seven generators have a real power output of over 500MW and hence were selected.

Table 4.1 Major Generators within California

BUS-NO	NAME1	PGEN	QGEN
36405	MOSSLND6	720	42
36406	MOSSLND7	720	42.1
36411	DIABLO 1	1180	2.2
36412	DIABLO 2	1200	15.5
24107	ORMOND1G	750	215.8
24108	ORMOND2G	749	216.8
24129	S.ONOFR2	1070	223.4
24130	S.ONOFR3	1080	223.4

These generators were removed one at a time and the change in tie line power was observed. The simulation result for tripping of Diablo1 is shown below.

Figure 4.9 Change in Major tie flows



In all of the above cases, it was found that change in tie line power flows had a direct correlation with the amount of generation that was lost inside California.

4.3.1.2 Generator Output Changes

Another input for the proposed algorithm is the change in the real power output of the generators. A loss of generation causes the other units connected to the network to slow down. This leads to the governors increasing the output of the generators until the units seek a new common operating frequency. Usually the governor action takes a few seconds before the new

set point is reached. The amount of load that the generators pick up is directly proportional to the slope of the droop characteristics of the individual generators. Thus any change in the load or generation connected to the network, is reflected on the generator outputs. By measuring these changes, it is possible to estimate the amount of generation that was lost.

In order to study the effect of loss of generation, dynamic simulations were performed using the California-only model described above in PSLF. Since we would like the algorithm to act before there is a decline of frequency, the simulations were carried out without any governors. Since the governors were removed, the change in frequency and output of the generators is due only to the inertial response of the machines. The simulation was repeated for major generators inside California, listed in Table 1.

4.3.2 Identifying Loads for shedding

The next step in developing the algorithm is to identify the optimum amount and location of the load to be shed, to arrest a change in frequency. This process can be very tedious, since it requires extensive contingency studies even at initial levels, to develop the algorithm. One of the easier ways is to calculate the generator shift factor (GSF). Generation Shift Factor is one of the two types of linear sensitivity factors. These factors give a correlation of the change in line flows and the generation on the network.

4.3.2.1 Generator Shift Factor (GSF)

Generator Shift Factor (GSF) is a ratio of the change in power flow on a line(in MW) to a change in generation at a certain bus.

$$GSF_{li} = \frac{\Delta T_l}{\Delta P_i}$$

where ΔT_l is the change in the power flow on a line, l

ΔP_i is the change in generation at a bus, i

The GSF represents a sensitivity of the flow in the line l, to a change in generation at bus i. The GSF can be used to calculate the change in the power flow in a line, after a loss of generation, given its GSF. The GSF is a linear estimate and hence the effects of simultaneous changes on several generating buses can be calculated using superposition.

4.3.2.2 Load Shedding as a "GSF problem"

GSF can be modified as the sensitivity of a flow in a line to a change in the load at a bus. With this definition, it is possible to deduce a direct correlation between a change in the load and a corresponding change in the tie line flows. Thus it is easy to identify the loads that are best located to relieve the excessive power flow through a tie line.

When there is a loss of generation inside California, the demand is greater than the generation. This difference between load and generation causes a surge in the tie line flows. The change in the tie line flow is directly proportional to the amount of generation that was lost. Given the real time tie line flows and the GSF for all the loads, it is easy to identify the loads that can best normalize the tie line flows, after a generator is lost.

4.3.2.3 Simulations for computing GSF

The on-going simulations involve calculation of the GSF for all the loads within California. Seven major tie lines were identified. The load is increased at all the buses within California, one at a time. This increase in load results in a change in the operating points of all the generators inside and outside California, and also a change in the power flow in the tie lines. The GSF for each line and bus combination is calculated using these changes in real power flows. Dynamic simulation program in PSLF is used for running these simulations. A reduced model of the WECC network was used for initial simulations. The reduced model consists of the California network represented in detail and the 'Outside-of-California' network represented by an equivalent 24-machine network. The Heavy Winter version of the full loop model was used for verification and more detailed simulations. In the Heavy Winter model, California constituted by the five utilities, PG&E, SCE, Imperial California, SDGE and LADWP is connected to the rest of the WECC systemby 8 major interties.

The results from one of the simulations on the WECC Heavy Winter model are presented below. The load at bus 36416 ST MARIA 9.11kV located within the PG&E network is increased from 2 MW to 102 MW (a load increase of 100MW) and the change in generator outputs and change in tie flows is determined. The ratio of the change in tie line flow over the change in load(100MW) gives the generator shift factor for the tie line for that particular load.

Tie Line	Real Power Flow before Load increase (MW)	Real Power Flow after Load increase (MW)	Change in Tie Flows (MW)	Generator Shift Factor
Capt.Jack - Olina	1208.5	1221.8	13.3	0.133
Malin – RndMt.1	985.4	987.8	2.4	0.024
Malin – RndMt.2	997.9	1000.3	2.4	0.024
PaloVerde – Devers	1176.3	1167.6	-8.7	-0.087
Moenkopi – Eldorado	1097.5	1103.6	6.1	0.061
Hassyampa – N.Gila	985.5	986.5	1	0.01
Crystal – Navajo	1165.2	1169.6	4.4	0.044
Mead – Marketplace	571.5	577.8	6.3	0.063

Similarly, each load in California is increased by 100MW and the generator shift factors are calculated. The PSLF EPCL Code used for performing the above simulation is included in Appendix C. The Generator Shift Factors(in %) for loads within California with respect to the 8 major tie lines area-wise is included in Appendix D.

4.3 Intelligent Load Shedding Algorithm

This section describes the Intelligent Load Shed Algorithm developed as part of Task 4. The algorithm is written in Engineer's Process Control Language (EPCL) executable by the GE Positive Sequence Load Flow (PSLF) program. EPCL programs allow us to interact with the electrical network model in PSLF directly and intuitively.

4.3.1 Load Shift Factors

Load Shift Factor (LSF) is the ratio of change in power flow on a line to a change in the load at a certain bus. LSF indicates how much the power flowing in a line changes due to a change in a load at a bus. PSLF simulations were used to compute the Load Shift Factors for each load within California with respect to each of the eight major tie lines. From these calculations, we can conclude that:

- Any change in load anywhere within California, except San Diego Gas & Electric, is contributed by the California-Oregon Intertie (COI) comprising of the three Northern tie lines.
- The loads located in Pacific Gas & Electric are best suited for relieving excess flow in the COI
- The loads located in San Diego Gas & Electric are best suited for relieving excess flow in the Hassyampa - North Gila tie line
- Although the interties, Palo Verde – Devers, Moenkopi – El Dorado and Navajo – Crystal contribute 1GW of power and Mead – Marketplace brings in about 0.5GW of power into California, they do not contribute significantly to a change in loading within California.

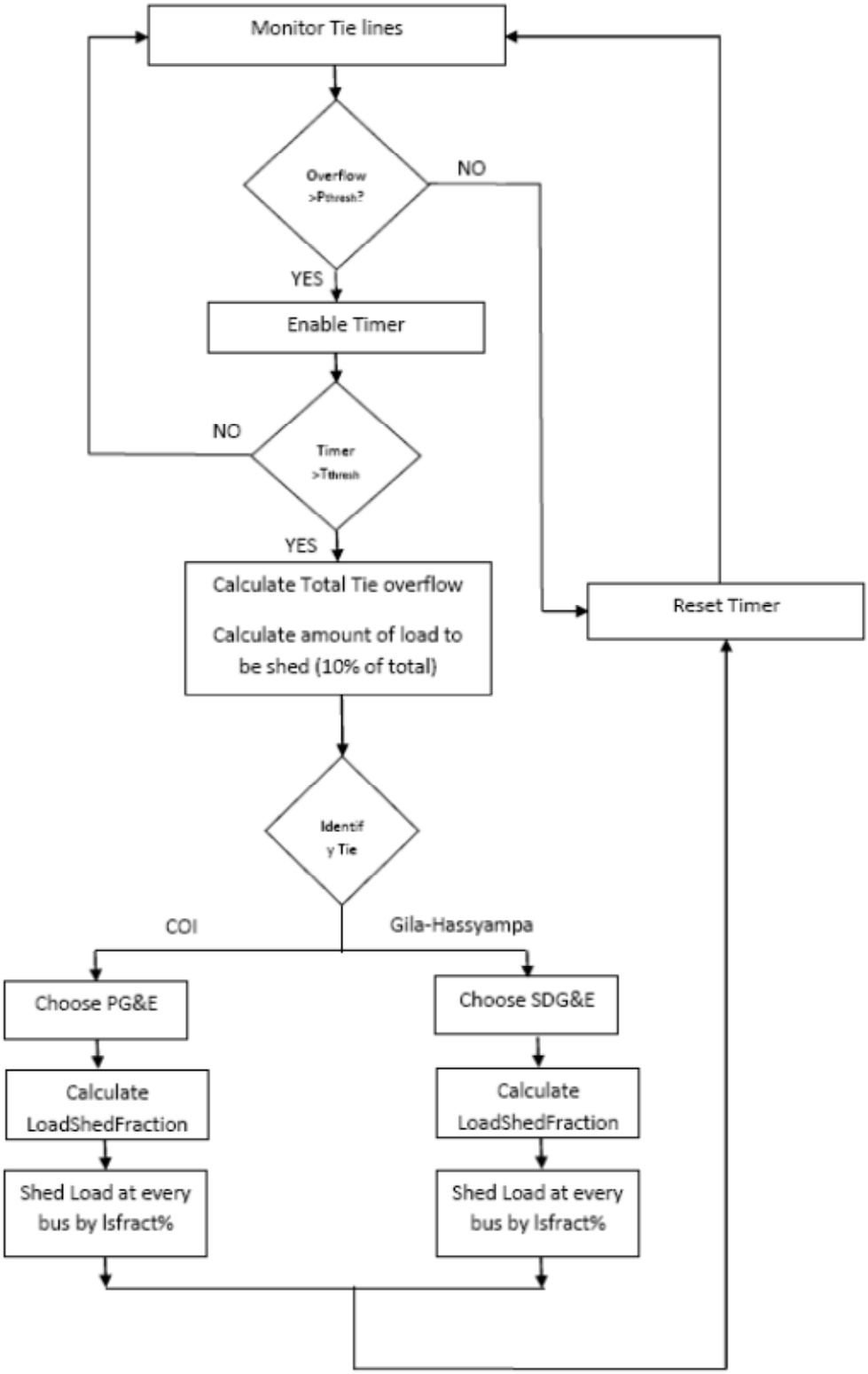
Based on the above conclusions, it was decided that the COI and the Hassyampa – North Gila would be monitored for detecting a loss of generation within California, while a sum total of excess flows along every tie line would be used to calculate the amount of load to be shed. The following logic has been used for deciding the location of the load.

- If Hassyampa – North Gila were to report an excessive flow, the loads located within San Diego Gas & Electric would be shed.
- For an excessive flow along the COI, the loads located within Pacific Gas & Electric would be shed. As the Load Shift Factors suggest, it is expected that comparable results could be achieved if the loads were to be shed across every utility in California.

4.3.2 Flow Chart

The following flowchart describes the logic of the Intelligent Load Shedding algorithm. As shown, the eight major tie lines are continuously monitored for an increase in intertie flow. When an excessive flow is detected, a timer is initiated. For our simulations, this excessive flow threshold is set at 10%. The timer is used to avoid initiating load shedding due to power swings. The timer is set to be timed out, if the tie flows remain above 10% of nominal flow for over 2 seconds.

Figure 4.10: Flow Chart for the ILS Algorithm



Once a tie line times out, the total overflow into the California network through the eight tie lines is calculated. The amount of load to be shed is calculated as 10% of the above value, if the total overflow is less than 3000MW. If the overflow is above 3000MW, a load equal to half of the overflow value is shed. This helps us to stabilize the system faster by shedding a larger amount of load.

After the amount of load to be shed is calculated, the location of the load is determined using the above conclusions from the study of Load Shift Factors (LSFs). The fraction of load to be shed at each load bus is calculated as a ratio of the amount of load to be shed to the total connected within the area.

After the location of the load and the percentage of load to be shed at each load bus are determined, the load shedding is initiated. This is followed by resetting all the timers and other variables and the tie lines are monitored again for excessive flows.

4.3.3 Algorithm Coding

The algorithm consists of two EPCL files that are run simultaneously through the PSLF EPCL Compiler. The actual algorithm is coded in an "inrun EPCL program", while the "main EPCL program" is used to simulate contingencies. The Inrun program, referred to as "$inrun1"within the main program, is invoked by the main EPCL program every time step. The main program titled "ilsmain_v1.p" and the inrun program titled "ilsin_v3.p" are provided herewith.

At the end of execution, three text files are created as an output. The output text file "FlowILS.txt" records the changes in the eight tie line flows for every time step and is referred to as "$output1" within the inrun EPCL program. The second output text file, "FreqILS.txt" records the bus frequencies at the Area Swing Generators of the 21 utilities that consist of the entire WECC network. This file is referred to as "$output2" within the inrun program. A third text file titled "LoadILS.txt" and referred to as "$output3" within the inrun program records the total overflow recorded, the calculated load shed fraction and the amount of load that was shed along with the time instant at which the ILS algorithm was invoked.

Another inrun program titled "nilsin_v1.p" referred to as "$inrun2" within the main program is also provided. This Inrun program simply records the flows ("FlowNILS.txt") and area frequencies ("FreqNILS.txt") during the contingencies specified in the main program.

4.3.4 Arbitrary Parameters

As discussed in section 1.2.2., there are three parameters that have been arbitrarily set in the algorithm:

- Overflow Threshold - % flow above the nominal flow
- Timer Threshold – duration for which the flow has to be above Overflow Threshold that would invoke the ILS algorithm
- Load Shed Amount - % of the overflow that is determined as the amount of load to be shed

4.3.4.1. Overflow Thresholdt

In the ILS algorithm developed, the overflow threshold was arbitrarily set at 10%. This parameter along with the Timer Threshold determines the algorithm bias on the Security/Dependability scale. When this value is lowered, the ILS algorithm tends to be biased towards Dependability and thus is very sensitive to even small changes in tie line flows. When set to a higher value, the ILS algorithm would wait for a major change in tie line flows before it would act. This parameter is referred to as "@overflow" in the inrun program.

4.3.4.2. Timer Threshold

Along with Overflow Threshold, the Timer Threshold determines the Security/Dependability bias of the algorithm. In addition, the Timer Threshold also aids in tiding through power swings. The Timer Threshold has been set at 2 seconds arbitrarily. When this value is lowered, the ILS algorithm is invoked more quickly after a persistent overflow is detected. When this value is increased, the ILS takes longer to act. By varying the Timer Threshold and Overflow Threshold, the Security/Dependability bias can be greatly altered. The Timer Threshold setting can be improved by opting for an inverse time characteristic. This will be discussed later. This Timer Threshold can also be eliminated by employing an external arming/disarming signal, based on extensive analysis of the system's current operating condition. This parameter is referred to as "@tcutoff" in the inrun program.

4.3.4.3. Load Shed Amount

This parameter, referred to as "@ovrflwsh" in the inrun program, determines the % of overflow that is taken as the amount of load to be shed. It is arbitrarily set as 10% for overflows totaling less than 3000MW and 50% for overflows totaling over 3000MW. The value was initially set at 50% but was reduced to 10% by trial and error, so as to minimize amount of load is shed without compromising on the effectiveness of the ILS algorithm. It was also found that for major contingencies that cause an import of huge amount of power (3000MW), this value needs to be greater and hence was retained at the initial 50%. When the value of this parameter is reduced, the ILS algorithm would have to be invoked more often for the same contingency.

4.3.5 Suggested Improvements

In order to improve the performance of the ILS algorithm, the following improvements are suggested.

4.3.5.1 Arming/Disarming Signal

The current algorithm is dependent on the Overflow Threshold and Timer Threshold parameters for determining at what level of overflow and when would the ILS algorithm be invoked. Although these settings seem to be satisfactory for all contingency cases identified, the reliability of the algorithm can be improved by replacing these parameters with arming/disarming signal that can be generated based on system operating point.

4.3.5.2 Zone-wise Load Shedding

In PSLF, each utility is represented as an area and each area is further divided into smaller zones. Currently, the algorithm determines the location of loads to be shed, area-wise. This can be changed to shed loads zone-wise based on Load Shift Factor calculations, to ensure better selectivity. Although this does not affect the quantum of load that is shed, it does affect the percentage of load that is reduced at any single bus. Since the zones contain smaller number of loads than areas (utilities), the percentage of load that needs to be shed at each bus will be higher.

4.3.5.3 *Co-ordination with Other Existing Schemes*

In the simulation results shown in the following section, it can be seen that for major contingency cases, the ILS algorithm operates alongside the existing schemes. The other schemes include Under Voltage and Under Frequency Load Shedding and result in a high loss of load. However, it should be noted that without the ILS algorithm the system would have been driven to a cascading outage. Further study can be conducted into coordinating the ILS algorithm along with existing schemes.

4.4 Simulation Results

This section discusses a few of the test cases that were used to test the ILS algorithm. In each of the simulations below, the dynamic simulation was run without any contingency for 1 second and then the contingency was created and the simulation was run for 30 seconds. The first contingency is loss of the largest generator within California and represents the least severe of cases that the ILS algorithm acts upon. The last contingency is a double contingency that is the most severe of contingencies for which the ILS algorithm restores the system to a stable state. For each test case below, the change in tie flows and area frequencies are plotted with and without the ILS algorithm. A brief discussion of the results is also provided.

4.4.1 Loss of Diablo

Diablo Nuclear Power Plant has two of the largest machines making it the largest power station within California. Each of the Diablo plants has an output of 1150MW.

Figure 4.11: Change in intertie flow without and with ILS algorithm

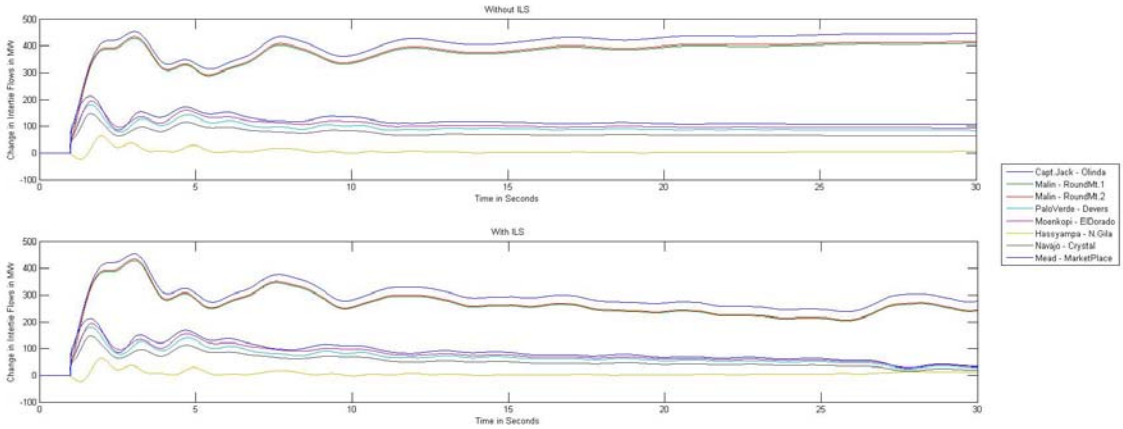
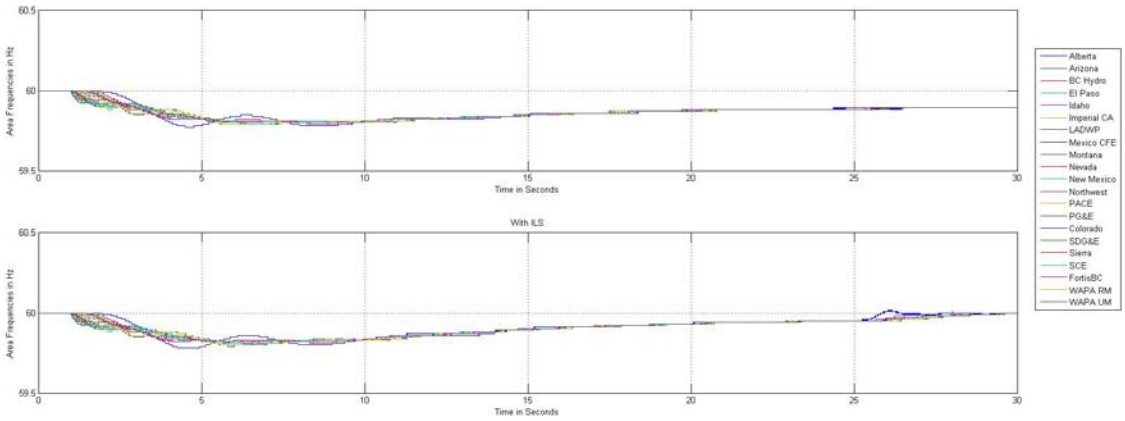


Figure 4.12: Area Frequencies without and with ILS algorithm



As shown, the ILS algorithm helps the system to stabilize faster and recover quickly, while keeping the intertie flows close to their scheduled values.

4.4.2 Loss of San Onofre Units

San Onofre Nuclear Power Plant is one of the largest generating stations with two large machines of 1070MW each.

Figure 4.13: Change in intertie flow without and with ILS algorithm

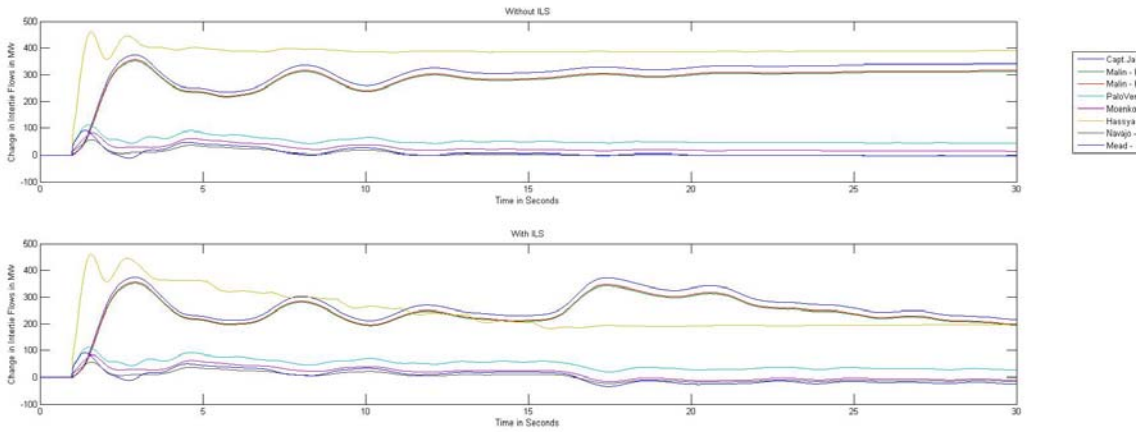
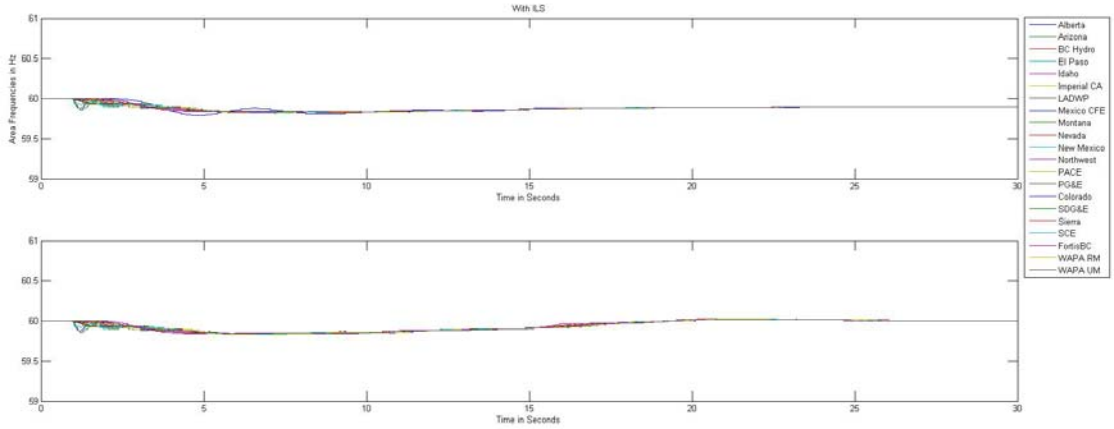


Figure 4.14: Area Frequencies without and with ILS algorithm



4.4.3 Loss of one Diablo Unit and InterMountain - Adelanto HVDC Line

The InterMountain – Adelanto HVDC line carries close to 1.7GW of power into California. This is a double contingency case involving a loss of one Diablo unit and the HVDC line.

Figure 4.15: Change in intertie flow without and with ILS algorithm

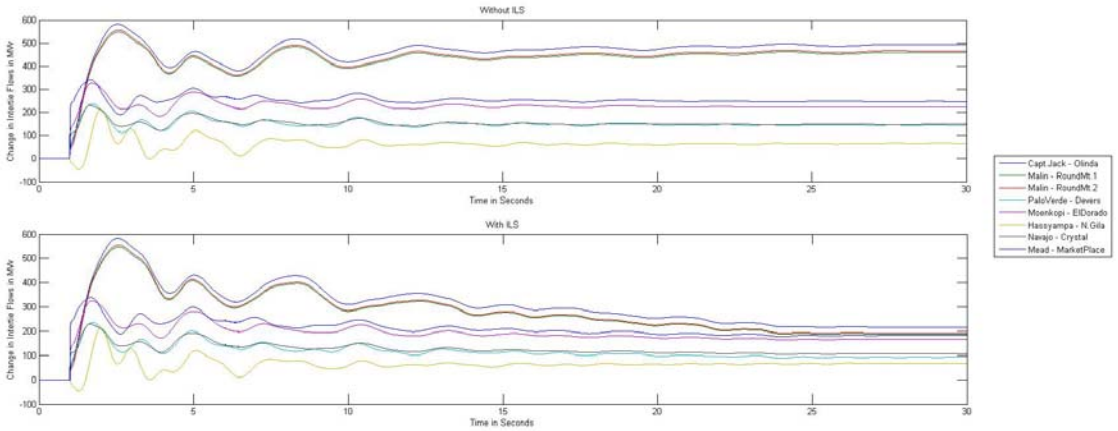
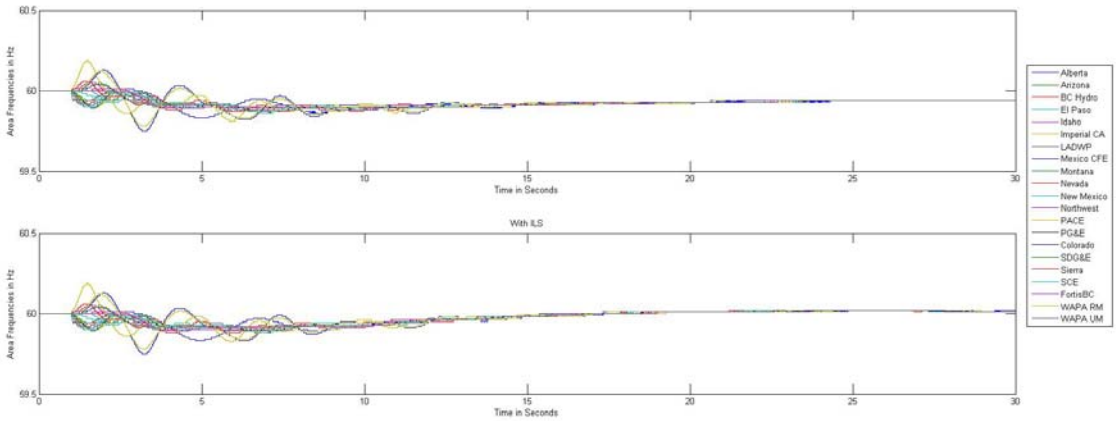


Figure 4.16: Area Frequencies without and with ILS algorithm



4.4.4. Loss of InterMountain – Adelanto and one leg of Celilo – Sylmar PDCI

The California network is supplied by two HVDC networks. The InterMountain – Adelanto HVDC network brings in about 1.7 GW; the other network, the Pacific DC Intertie (PDCI) runs parallel to the California Oregon Intertie bringing in about 2.2GW power into California. The PDCI consists of two parallel networks and each leg originates from two Celilo substations and ends in a different Sylmar substation. Effectively, one of the parallel networks can be switched off without affecting the steady state operation of the other. In this case the InterMt. – Adelanto HVDC line and one of the two PDCI networks was taken out of service, resulting in a net loss of 2.8GW. This is a very serious contingency since both the HVDC systems culminate within LADWP – one of the largest load centers.

Figure 4.17: Change in intertie flow without and with ILS algorithm

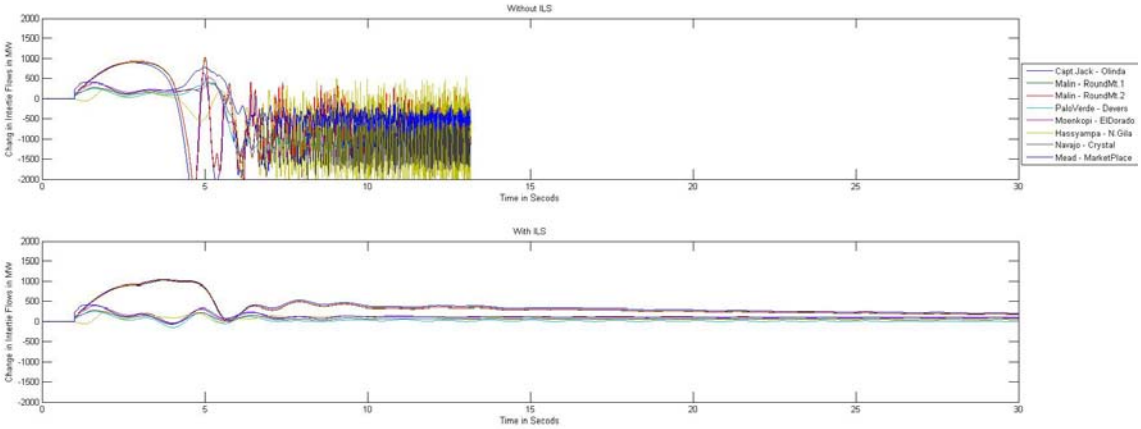
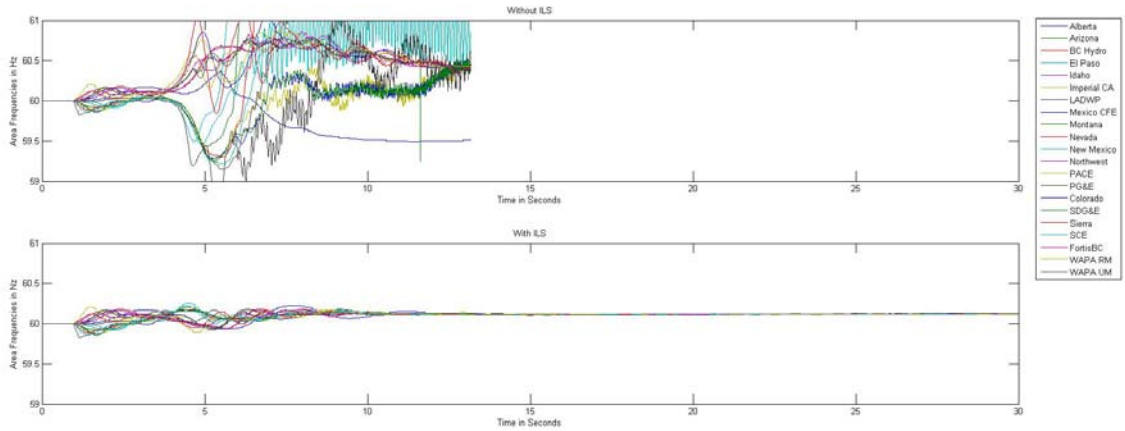


Figure 4.18: Area Frequencies without and with ILS algorithm



The severity of the contingency is obvious from the fact that, without the ILS algorithm, the network collapses resulting in several islands. When the same case is run with the ILS algorithm in place, the system is actually restored to a stable operating point, albeit with a slightly higher

nominal frequency. Such overshedding can be avoided by coordinating the ILS scheme with the existing UFLS and UVLS schemes.

4.5 Summary

The main objective of this task is to demonstrate the use of WAMS for shedding loads intelligently, where "intelligent" meaning preventative, selective and adaptive. Through the simulation results presented above, it can be shown that the ILS algorithm arrests decline in frequency and restores system frequency to nominal value much more quickly than it would take for UFLS schemes or by the system itself without the aid of any of these schemes. Although these cases in isolation may seem to point at an over-active ILS scheme, such a response may be very desirable when the system is on the verge of islanding. Extended periods of recovery can also result in wider swings, as witnessed in the frequency plot of Alberta in the above cases. With the improvements suggested in section 1.2.5, we hope that the ILS scheme can act as the first line of defense against under frequency operation, with the UFLS scheme as a back-up scheme.

Chapter 4 References

[1] Kundur, Prabha. *Powre System Stability and Control*. McGraw-Hill Education (India) Pvt. Ltd, 1994.

Chapter 5: PMU Application for Damping Low Frequency Oscillations

5.1 Introduction

The Electric Power System is a dynamic entity. For its smooth and stable operation it has to be constantly monitored and its ailments have to be taken care of as promptly as possible. One of the oldest problems that the power system suffers from are oscillations at low frequencies, collectively termed *"Low Frequency Oscillations (LFOs)"*. These oscillations are primarily related to the small signal stability of the power system. They are detrimental to the goals of maximum power transfer and power system security.

The most critical of these oscillations and the primary concern of power engineers all over the world are the inter-area modes of oscillations which are associated with machines in one part of the system oscillating at very low frequencies against machines in other parts of the system. The natural frequency of these oscillations in the WECC is in the range of 0.1-0.7 Hz. Traditional damping methods (like Power System Stabilizers) cannot provide adequate damping over a variety of operating conditions. Thus, there is an urgent need for a robust damping controller that can integrate different control mechanisms in a co-ordinated manner to damp these oscillations. This project uses remote phasor measurements in the design of robust damping control of low frequency oscillations in general and the inter-area modes of oscillations in particular.

5.1.1 Need for Co-ordinated Control

With the deregulation of power systems, many tie-lines between control areas have come to operate near their maximum capacities, especially the ones serving heavy load centers. Such stressed operating conditions have increased inter-area oscillations between different control areas and even led to major disturbances [1]. Study of these outages has shown how critical a reliable power system is to modern society, and the enormous economic and social damage a blackout can cause to it. It is therefore of utmost importance to develop control techniques which can damp system oscillations over a wide variety of operating conditions.

Over the past few decades, attention has been focused on designing controllers to damp the inter-area modes of oscillations. The traditional method of damping these oscillations is through the use of PSSs that control the excitation of generating units [2]. However local PSSs alone cannot guarantee adequate performance of the generator when the operating point changes. An inappropriate coordination among the local controllers has caused serious problems. The need to retune PSSs frequently has prompted investigation of techniques that can adapt to changing system conditions.

With the growing implementation of PMUs across the power grids, it is now possible to observe and analyze system wide dynamic phenomena in real-time. PMUs capture dynamic data of power systems through synchronized measurements enabled by GPS satellites. A controller

based on such remote signals can enhance damping of inter-area oscillations and improve overall dynamic performance. In recent times, use of HVDC lines, FACTS devices and Energy Storage Devices (ESDs) as potential forms of control have been investigated. It is therefore desirable to develop an integrated form of control that uses WAMs to coordinate PSSs, DC lines, FACTS devices, and ESDs for stabilizing inter-area oscillations.

5.1.2 Role of PMUs and WAMs

Oscillations are due to the natural modes of the system and therefore cannot be completely eliminated. However, their damping and frequency can be modified. As power systems evolve, the frequency and damping of existing modes change and new modes emerge. The main source of ''negative'' damping is the power system controls, primarily excitation system AVRs. Power System Stabilizers (PSSs) are the most commonly used devices for enhancing the damping of the inter-area modes of oscillations. A PSS in combination with an AVR uses the auxiliary stabilizing signals for producing a damping torque component which controls the excitation system of the generating units. Commonly used signals for the PSS include changes in shaft speed, terminal frequency and output power [2].

A PSS provides supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. Once the oscillations are damped, the thermal limit of the tie-lines in the system may be approached. Since the exciter and the generator usually exhibit frequency dependent phase and gain characteristics, the PSS transfer function has appropriate phase compensation circuits to compensate for the phase lag between the exciter input and the electrical torque output. In the ideal case, with the phase characteristic of the PSS being an exact inverse of the exciter and generator phase characteristics to be compensated, the PSS would come up with a pure damping torque at all oscillating frequencies.

However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS on the rotor. The reason for this is that PSSs are tuned around a steady-state operating point. Their damping effect is only valid for small excursions around this operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism in an attempt to control its excitation field. Moreover, a traditional PSS uses local measurements of power and frequency and is tuned to act on a single mode. Therefore, in its efforts to damp a local mode of oscillation, the PSS can negatively damp an inter-area mode of oscillation and vice-versa. It has also been observed that a PSS that is expected to damp oscillations over a broad range of frequencies is not able to sufficiently damp the critical low frequency modes that might be excited in the system. It therefore becomes obvious that the application of a PSS alone falls short of the goal of damping local and inter-area modes of oscillations over a broad range of operating points.

The conflicting requirements for stability of local and inter-area modes of oscillations under both small signal and transient conditions have led to many different approaches for the control and tuning of PSSs. However, the most sophisticated digital PSSs still use local measurements of power and frequency and are aimed at a single mode of oscillation. One way to overcome

this limitation is to provide remote measurements to PSSs in a coordinated multi input environment using PMUs and Wide Area Measurements. A new PSS using two signals, the first, to damp the local mode in the area and the second, global signal, to damp inter-area modes is proposed in [3].

An alternate approach that has been followed for controlling LFOs has been the introduction of passive or active control elements other than PSSs into the power system. These devices include special modulation controls for HVDC-links, Energy Storage Devices (ESDs) and Static VAR Compensators (SVCs) installations in the system, as well as other FACTS devices such as Thyristor-Controlled Series Capacitors (TCSCs), Unified Power Controllers (UPCs) and Thyristor-Controlled Dynamic Brakes. Supplementary Damping Controllers (SDCs) for FACTS devices have been found to show great potential in damping inter-area oscillations. It has also been proven that controlling the flow of HVDC lines can help in damping small signal oscillations, increasing power transfer capability and improving transient stability of AC/DC hybrid systems. Thus, the most ambitious approach for damping low frequency oscillations would be to coordinate PSSs, FACTS devices, and DC lines using Wide Area Measurements.

One way of implementing such an integrated form of control is through the development of an LMI polytopic model of the system where time delays are modeled as uncertain parameters, unmeasured portion of the system are represented by un-modeled dynamics, and LMI techniques are used to design robust controllers. The advantage of the polytopic approach is that the span of the model uncertainty is considered within the design itself. Although the LMI approach appears to give good results for small sized systems, its direct application to bigger systems has been limited due to its computational complexity [4]. The technique proposed here appears to alleviate this problem by reducing the size of the system to the relevant modes of oscillations. The size of the system is reduced using a technique called Selective Modal Analysis (SMA). While there exist a number of other techniques for forming reduced order models to study inter-area modes, SMA was chosen since it fit the LMI Matlab environment.

5.1.3 Conclusion

The long history of inter-area oscillations in power systems all over the world clearly identifies inadequate/negative damping as the primary factor leading to system separation and eventually blackouts. The amount of damping and the frequency of oscillation vary with system operating conditions. The operating range of a power system is usually very wide, requiring an oscillation damping control strategy that is effective over the whole range. To develop such a control successfully, it is necessary to have comprehensive modeling and analysis techniques of all the components that may interact to produce oscillations. In accordance with this realization, this project delves upon the idea of using Linear Matrix Inequalities (LMIs) in conjunction with Wide Area Measurements and Selective Modal Analysis (SMA) to come up with a robust control that is effective over a wide range of system conditions. The next chapter explains the mathematical basis of these two methods.

5. 2 Design of the Control

As described in the previous section, an optimum control for damping Low Frequency Oscillations (LFOs) in general and inter-area modes in particular, can be formulated by using wide area measurements to coordinate PSSs, ESDs, FACTS devices, and DC lines. One way of implementing such an integrated form of control is through the development of an LMI polytopic model of the system where time delays are modeled as uncertain parameters, unmeasured portions of the system are represented by un-modeled dynamics, and LMI techniques are used to design robust controllers. The advantage of the polytopic approach is that the span of the model uncertainty is considered within the design itself.

5.2.1 Linear Matrix Inequalities (LMI)

An LMI is any constraint of the form [5]:

$$A(x) := A_0 + A_1 x_1 + A_2 x_2 + \cdots + A_n x_n < 0 \tag{5.1}$$

Where, $x = x_1, x_2, \ldots x_n$ is an unknown vector comprised of the optimization variables; $A_0, A_1, \ldots A_n$ are known symmetric matrices. The inequality < 0 implies that the A matrices are negative definite. This means that the largest eigenvalue of $A(x)$ is negative. The LMI constraint defined in (5.1) is a convex constraint on x as $A(y) < 0$ and $A(z) < 0$ will imply $A\left(\frac{y+z}{2}\right) < 0$. Moreover, a system of LMI constraints can be thought of as a single LMI problem whose block-diagonal matrix has the system matrices of those individual systems as its diagonal elements.

The pole-placement in LMI regions looks to evaluate the convex sub-sets D described by,

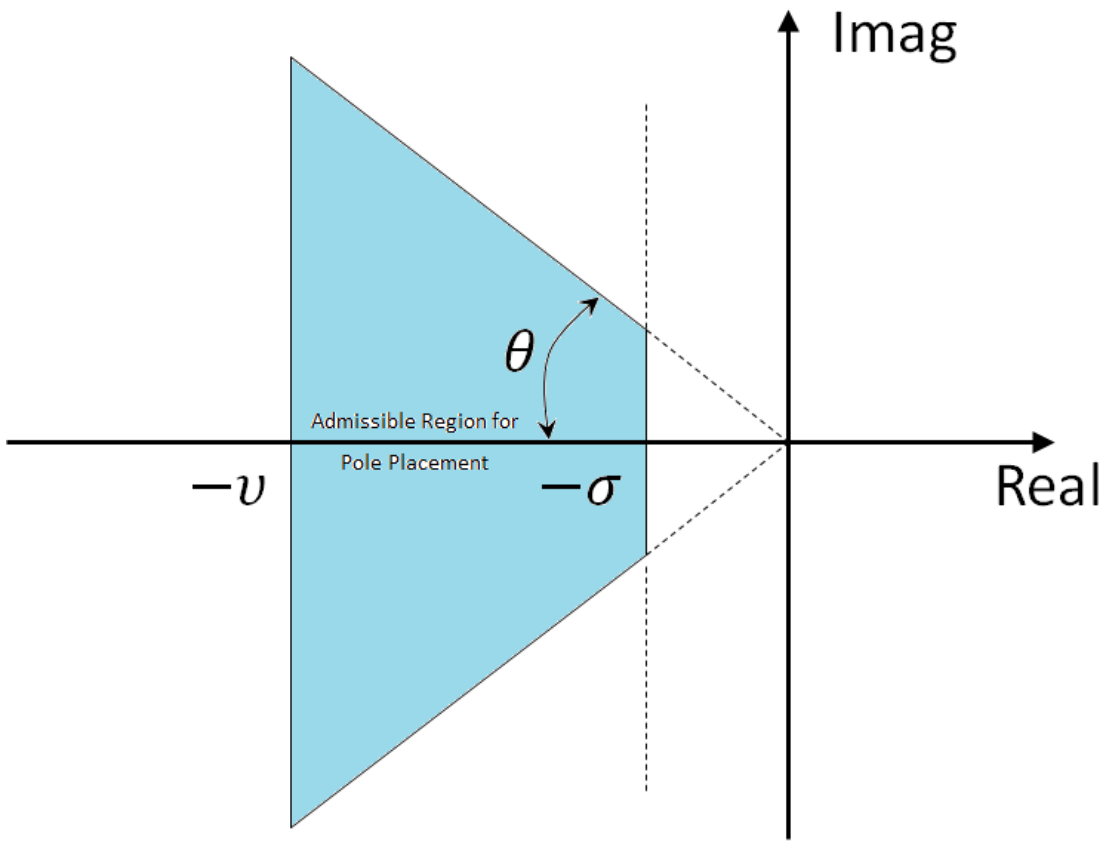
$$D = \{z \in \mathbb{C} : L + Mz + Mz^{T} < 0\} \tag{5.2}$$

Where M and $L = L^T$ are fixed, real matrices. The characteristic function of this region is given by,

$$f_D(z) := L + Mz + Mz^{T} \tag{5.3}$$

The LMI Control Toolbox in Matlab also provides the option of defining a region of one's choice so as to provide additional constraints on the optimization. Figure 5.2.1 depicts a typical LMI region for Pole Placement consisting of a conic section and a vertical barrier. The shaded portion depicts the region where the eigenvalues should lie.

Figure 5.2.1: LMI Region for Pole Placement; The Damping ratio of poles lying in the region enclosed by the solid lines is at-least



The design of a robust WAMs based control of Inter-Area oscillations is posed in terms of Polytopic systems. The polytopic systems approach is a part of the MATLAB LMI toolkit. The polytopic formulation is posed with state space models of the form,

$$
\begin{aligned}
\dot{x} &= Ax + B_1 u + B_2 w \\
z_\infty &= C_1 x + D_{11} u + D_{12} w \\
z_2 &= C_2 x + D_{22} u \\
y &= C_{m} x + D_{m1} u + D_{m2} w
\end{aligned}
\tag{5.4}
$$

Where is the state of the system, is the control, is a disturbance, and are for the optimizations and is the output. The cases that would be used to test the robustness of the controller for a power system application such as tie-line outages, load changes, changes in line flows, etc., all have their own version of the system denoted by (5.4). These systems are then the vertices of the polytope.

The such system denoted by is of the form:

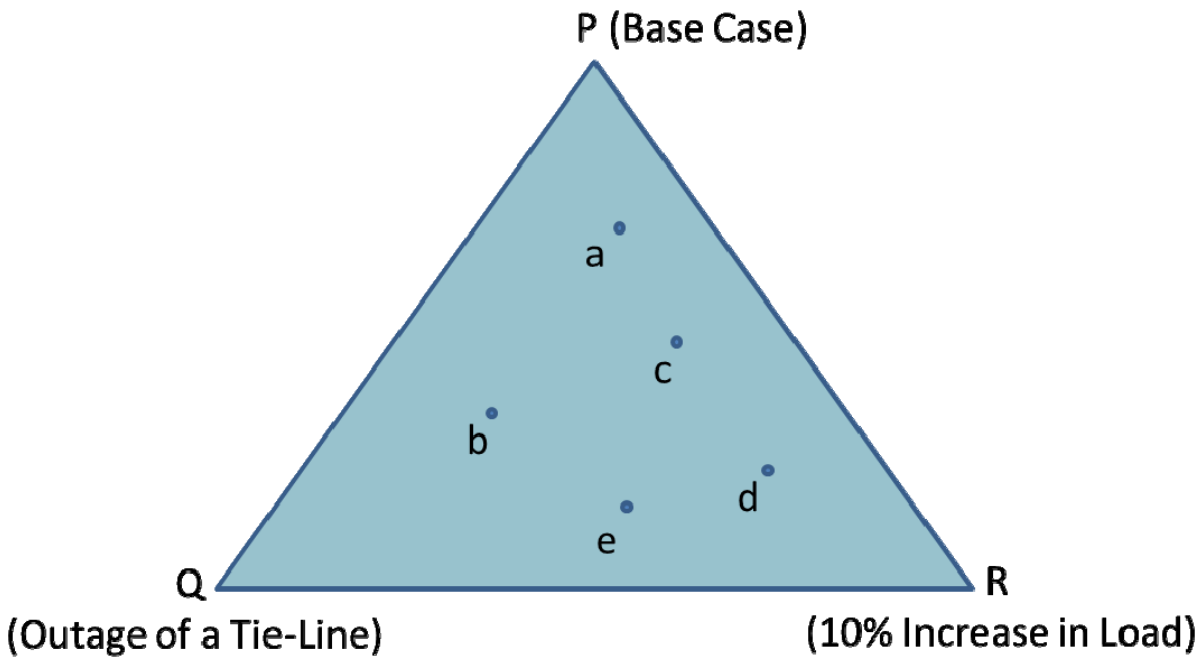
$$\mathcal{B}_{\mathcal{M}} = \begin{bmatrix} \mathcal{B}_{\mathcal{M}} & \mathcal{B}_{\mathcal{M}1} & \mathcal{B}_{\mathcal{M}2} \\ \mathcal{B}_{1} & \mathcal{B}_{\mathcal{M}11} & \mathcal{B}_{\mathcal{M}12} \\ \mathcal{B}_{\mathcal{M}2} & 0 & \mathcal{B}_{\mathcal{M}22} \\ \mathcal{B}_{\mathcal{M}\mathcal{M}} & \mathcal{B}_{\mathcal{M}\mathcal{M}1} & \mathcal{B}_{\mathcal{M}\mathcal{M}2} \end{bmatrix} \tag{5.5}$$

The convex combination of the systems is given by,

$$\mathcal{B}\{\mathcal{B}_1, \mathcal{B}_2, \ldots \mathcal{B}_{\mathcal{M}}\} = \left\{ \sum_{\mathcal{B}=1}^{\mathcal{M}} \mathcal{B}_{\mathcal{M}} \mathcal{B}_{\mathcal{M}}; \sum_{\mathcal{B}} \mathcal{B}_{\mathcal{M}} = 1, \mathcal{B}_{\mathcal{M}} \geq 0 \right\} \tag{5.6}$$

The non-negative numbers $\alpha_1, \alpha_2, \ldots, \alpha_k$ are called the polytopic co-ordinates of S. Many of the convex combinations in (5.6) have simple explanations. If S_1 is the base case and S_2 represents the outage of a tie-line then $\alpha S_1 + (1 - \alpha) S_2$ can be thought of as continuously increasing the impedance of the tie-line until it is open. Figure 2.2 describes this concept with a simple illustration. The three terminals (P, Q and R) represent the base case (no contingency case), an outage of a tie-line and a 10% increase in the loads respectively, whereas the edges represent the trajectory followed by the system for moving from one condition to the other. The points a, b, c, d, and e denote different operating conditions. For example, operating condition 'a' can imply a 2% increase in the loads and a slight decrease in the power flowing through the tie-line. Similarly condition 'b' can denote a larger decrease in tie-line power flow and a 7.5% increase in load and so on. In such a scenario, the LMI control states that all operating conditions lying within the enclosed area (i.e. a, b, c, d, and e) can be simultaneously optimized by a single control law.

Figure 5.2.2: LMI Control Design using a Polytopic system having three vertices



5.2.2 Selective Modal Analysis (SMA)

A closer look at (5.6) makes it clear that many of the sub-matrices in do not depend on for any given application. Most of the applications only involve changes in the system matrix . Even for a modest system the matrix and hence can become large when detailed machine models, exciters, PSSs, and the states involved in controls are considered. In such a scenario, the optimization problem can become unwieldy even for a small example. A reduced order model is therefore necessary to minimize the size of the problem. Selective Modal Analysis (SMA) developed by I. J. Perez-Arriaga, G. C. Verghese, and F. C. Schweppe in 1982 is a novel method for creating such reduced-order systems [6-7]. While there exist a number of other techniques for forming reduced order models to study inter-area modes, SMA was chosen since it fit the LMI Matlab environment.

A particular organization of the dynamic equations for the reduced order model can be described as:

$$= \begin{matrix} 0 & 0 & 0 & 0 \\ 21 & 22 & 23 & 24 \\ 31 & 32 & 33 & 34 \\ 41 & 42 & 43 & 44 \end{matrix}, = \begin{matrix} 0 \\ 0 \\ 0 \\ 2 \end{matrix}, = \begin{matrix} \\ \\ 3 \\ 4 \end{matrix} \tag{5.7}$$

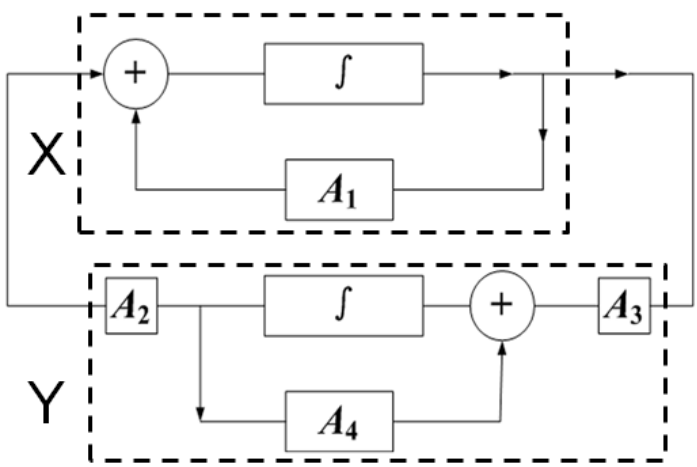
Where and are differences from values at the reference machine-a large external equivalent. Also, denotes all the remaining machine states (fluxes, exciters and PSSs) and denotes the states associated with the controls. The matrices are formed by numerically perturbing the load flow equilibrium using the Matlab suite PST. The matrix corresponds to the control signals

for the DC lines, the ESDs and the SVCs. Both angles and frequencies are used as feedback signals for these controls. Equation (2.4) can be partitioned in the SMA form as follows:

$$A = \begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix};\ A_1 = \begin{bmatrix} 0 & A_{12} \\ A_{21} & A_{22} \end{bmatrix};\ A_2 = \begin{bmatrix} 0 & 0 \\ A_{23} & A_{24} \end{bmatrix};\ A_3 = \begin{bmatrix} A_{31} & A_{32} \\ A_{41} + A_{21} & A_{42} + A_{22} \end{bmatrix};\ A_4 = \begin{bmatrix} A_{33} & A_{34} \\ A_{43} & A_{44} \end{bmatrix} \quad (5.8)$$

The block diagram in Figure 5.2.3 is the key to SMA. The block X denotes the "relevant" portion of the system whose dynamics is of interest. The block Y denotes the "less relevant" part of the system which has been collapsed in such a manner that it does not interfere with the dynamics of the portion of interest. Therefore in accordance with this logic, block X contains the matrix A_1 which has the angles and speeds of the generators as its elements; while block Y contains the matrices A_2, A_3 and A_4 which have information of all the remaining machine states and the states associated with the controls.

Figure 5.2.3: Block Diagram of SMA [4]



The transfer function of the system in the feedback path denoted by the block Y is,

$$H(s) = A_2(sI - A_4)^{-1}A_3 \quad (5.9)$$

The above equation can be thought of as a combination of two equations as shown below:

$$\begin{aligned} H(s) &= H_1(s) + H_2(s) \\ H_1(s) &= A_2(sI - A_4)^{-1}\begin{bmatrix} A_{31} & A_{32} \\ A_{41} & A_{42} \end{bmatrix} \\ H_2(s) &= A_2(sI - A_4)^{-1}\begin{bmatrix} 0 & 0 \\ A_{21} & A_{22} \end{bmatrix} \end{aligned} \quad (5.10)$$

The SMA process is an iterative method beginning with the eigenvalues and eigenvectors of A_1. Using $H_1(s)$ to illustrate, if the left eigenvalues and eigenvectors of A_1 are d_i and v_i then w_i, the ith column of the matrix W is formed by

$$[illegible]_m = [illegible]_2([illegible] - [illegible]_4)^{-1}\begin{bmatrix} [illegible]_{31} & [illegible]_{32} \\ [illegible]_{41} & [illegible]_{42} \end{bmatrix}[illegible]_m \tag{5.11}$$

A first correction to A_1 is then formed by,

$$[illegible]_{1\,[illegible]} = [illegible]_{1\,[illegible]} + [illegible]_1\,[illegible]_1 = [illegible]^{-1} \tag{5.12}$$

In (5.12), V^{-1} is the inverse of the matrix of left eigenvectors. The process is repeated with the eigenvalues and eigenvectors of $A_1 + M_1$. A few iterations give a good estimate to the eigenvalues of the A matrix. Given the presence of B in (5.10), the right eigenvectors of A_1 are more appropriate for H_2. The result is a reduced order system of the form in (5.13) where M is an approximation to H_1, N is an approximation to H_2 and K is the gain matrix obtained as the output of the LMI control.

$$[illegible]_1 = ([illegible]_1 + [illegible] + [illegible])[illegible]_1 \tag{5.13}$$

Thus, (5.13) is an approximation to the closed loop eigenvalues using the fixed matrices M, N and K.

5.2.3 Proposed Modification to SMA

A polytopic system using SMA to reduce the system size to twice the number of machines present in the system with respect to the swing machine was developed in [4]. The system model denoted by (5.13) had been used for the polytopic design. However, it was observed that if the generator angles (δ) and generator speeds (ω) of all the machines with respect to the swing machine are kept in A_1, the size of A_1 would still be an issue for large systems. An algorithm was then developed which uses SMA to systematically reduce A_1 to its smallest possible size. The proposed approach is described below.

A flowchart describing the proposed control technique is illustrated in Figure 5.2.4. This procedure is to be followed after the traditional SMA approach described earlier has been used to obtain an A_1 matrix containing the δ and ω modes of all the machines. The steps to be followed are:

Step 1: Compute for the oscillatory modes of the system and identify machines primarily responsible for those modes on the basis of their Participation Factors. Arrange them in descending order of frequency (top-to-down) and participation percentage (left-to-right).

Step 2: Drop the machine which (a) is largely responsible for the highest frequency of oscillation amongst all the oscillatory modes and (b) has significantly low participation for the low frequency inter-area modes. A more detailed description of this step is given later.

Step 3: Perform iterations in SMA for this reduced order model of the system and check for its convergence. The convergence of SMA ensures that the reduced model has the same dynamic response as the full model.

Step 4: If SMA converges, then perform an elementary check of the control. This check detects any possible negative damping of the local modes, thereby preventing excessive reduction in the size of the system.

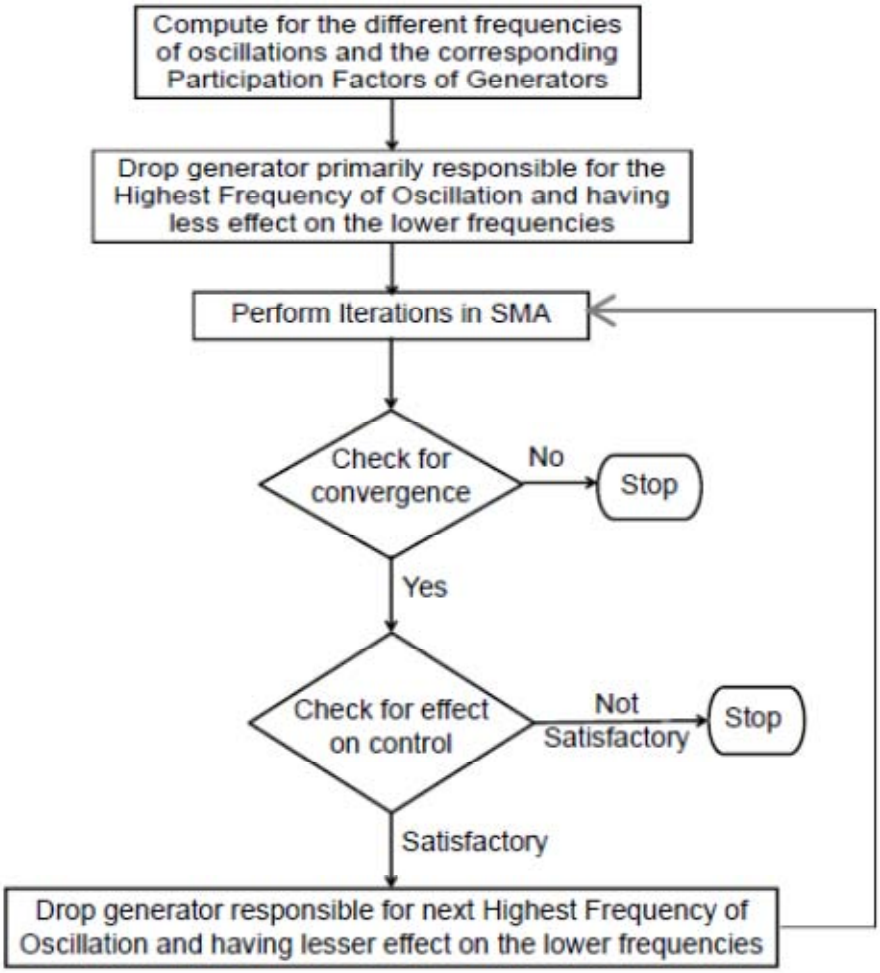
Step 5: If the control is also found to be satisfactory, then drop the next machine in the sequence and repeat Steps 3 and 4. If SMA is not found to converge or the control is not found to be satisfactory, then the stable and converged system obtained one level before is the smallest possible size of A_1.

The primary objective of this algorithm is to reduce the system size further than what was achieved using the traditional SMA approach, without affecting the control of the inter-area modes of oscillations. Although, control of some of the local modes can be slightly affected, Step 4 of the algorithm ensures that the system as a whole remains stable throughout this process.

The logic that is to be used for selecting the sequence of machines to be dropped (Step 2 of the proposed algorithm) is illustrated in more details below –

- Select the machine which has the maximum participation percentage to the highest frequency of oscillation
- Check for its participation in the pre-defined frequency range, i.e., if dropping that machine from control results in the low frequency modes moving to the right then it implies that *that* machine has high participation for the low frequency modes and should not be dropped from control
- If its participation percentage appears to be low, then drop that machine; if not, select the machine that has the next highest participation percentage to the highest frequency of oscillation and perform the check
- Once a selected machine is dropped, go back to the machines corresponding to the higher frequencies of oscillation and check for the convergence of SMA after dropping them, one at a time
- If it so happens that dropping a machine results in the corresponding frequency losing control from all the other machines, then that machine should not be dropped

Figure 5.2.4: Flowchart of Proposed Control Technique



Reduction factor: This is used to determine the relationship between the dimensions of the full-order and the reduced-order systems and the computational time required for the LMI control to work on both the systems. This is a quantitative measure of the efficiency of the proposed technique. If S_1 denotes the dimension of the full-order system and S_2, the dimension of the reduced-order system, then mathematically, the reduction factor n can be defined as,

$$n = \frac{\ln(S_1) - \ln(S_2)}{\ln(T_1) - \ln(T_2)} \tag{5.14}$$

Where T_1 and T_2 denote the computation time for the full-order and reduced order systems

Typically, the reduction factor was found to be in the range of 4-5. It was found to decrease slightly as the size of the optimization problem was increased.

5.2.4 Conclusion

This chapter describes the mathematical concepts of the two techniques that have been used in this thesis, namely Linear Matrix Inequalities (LMIs) and Selective Modal Analysis (SMA). Wide Area Measurements in combination with LMIs appears to provide a robust damping control for all kinds of oscillations. The size of the polytopic system appears to be an issue for large systems, but the use of SMA appears to alleviate this problem. Initially, SMA had been used to reduce the size of the system to twice the number of machines present [4], but the algorithm developed here suggests that one can go further than that. The proposed method reduces the size of the polytopic system to its smallest possible stable state thereby alleviating the issue of computational complexity which prevents application of LMI control to larger systems. The next chapter summarizes the results obtained when this technique is applied to three different systems – a 16 machine, 68 bus system equivalent model of the New England-New York interconnected power system, a 29 machine highly reduced model of the WECC system and a relatively detailed 4000 Bus+ model of the WECC system.

5.3 Testing and Evaluation if MATLAB Results

In this chapter, the proposed technique is first tested on a 16 machine, 68 bus model of the New England-New York interconnected power system in which DC lines and SVCs are acting as the control elements. As the results were found to be encouraging, the algorithm was next applied to a 29 machine equivalent model of the WECC system. The initial control designed using the HVDC lines and SVCs already present in the model was not robust enough for damping all the low frequency inter-area modes of oscillations present in the larger system. Three more controllers in the form of Energy Storage Devices (ESDs) are introduced into the system to get the desired effect. The theory of controllability indices is used to find the optimum locations for the ESDs. The results indicate that by having six controllers in the system, all the low-frequency inter-area modes of oscillations can be adequately damped along with most of the local modes.

5.3.1 16-Machine System

A benchmark model consisting of 16-machines, 68-buses and five-areas, shown in Figure 5.3.1, is used as the study system for the damping control design. The first nine machines (G1–G9) are a simple representation of the New England Test System (NETS) generation. Machines G10–G13 denote the New York Power System (NYPS) generation. The last three machines (G14–G16) are the dynamic equivalents of the three neighboring groups connected to the NYPS. The tie-lines connecting NETS and NYPS carry 700 MW. Area #5 exports 1550 MW to NYPS and imports 24 MW from Area #4 while 610 MW flows from Area #3 to NYPS and 175 MW from Area #3 to Area #4. The detailed description of this system including network data and dynamic data for the machines, buses, and branches can be found in Appendix E.1. In order to damp the

inter area modes and study the effectiveness of the polytopic control, the test system is modified by adding parallel DC lines and SVCs.

The three DC lines are added in parallel with the tie-lines (Bus 41 to Bus 42, Bus 42 to Bus 52, and Bus 46 to Bus 49). SVCs are installed at Buses 26, 46, and 51. All machines have simple exciters and turbine models. Machine 16 is the reference, and all machines except machines 1, 2, 7, 14, have PSSs as described in [8]. The WECC load model is assumed at all the load buses. The real power is 80% constant current, the reactive power is 80% constant admittance and all loads have the remaining 20% as an induction motor load. The eight cases selected for this test are described in Table 3.1. In all the cases apart from the base case (no-contingency case), tie-line 1-27 is assumed to be out of commission in addition to the particular contingency under test. This is done to increase the severity of the contingency and to further test the robustness of the control.

Figure 5.3.1: The 16 machine – 68 Bus System

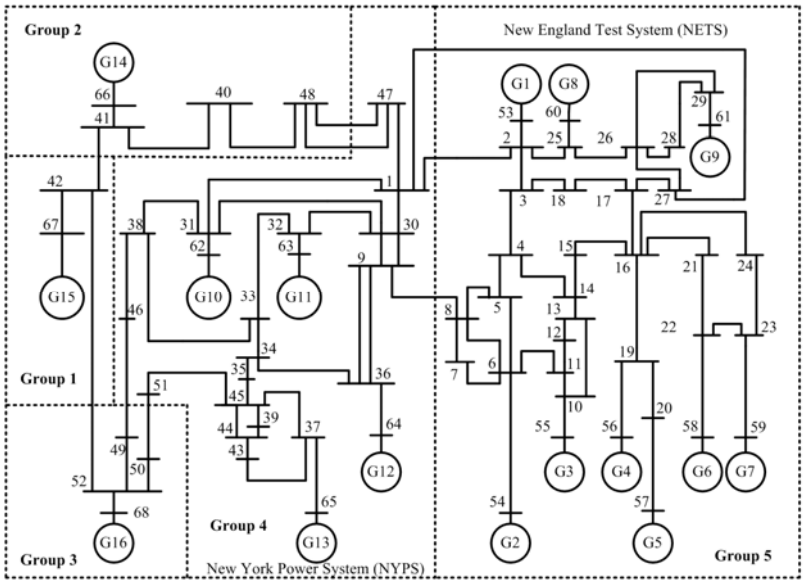


Table 5.3.1: Case Bank for the 16 machine NE-NY system

Case Number	Case Details
1	No-Contingency Case
2	Flow in Line 50-52 increased from 700 MW to 900 MW
3	Flow in Line 50-52 decreased from 700 MW to 100 MW
4	Outage of Tie-line 1-2
5	10% decrease in inertial equivalent at Machine 14 (Bus Number 66)
6	10% increase in inertial equivalent at Machine 14 (Bus Number 66)
7	All Loads reduced to 90% of their original value, keeping generation constant
8	All Loads raised to 110% of their original value, keeping generation constant

The A matrix for each of the eight cases is 129×129. Figure 3.2 shows a portion of the eigenvalues corresponding to the no-contingency case highlighting all the oscillatory modes along with some of the non-oscillatory ones. The black dots represent the eigenvalues of the A matrix whereas the red circles denote the eigenvalues of the A_1 matrix obtained after applying SMA to this system. The low frequency inter-area modes of oscillations are of particular interest and have been identified in the figure. The figure also shows the local modes of oscillations present in the system and the real eigenvalues (non-oscillatory modes) which correspond to the other states and controls. From the figure, it also becomes clear that the traditional form of SMA described in the previous chapter is able to correctly identify all the oscillatory modes within three iterations.

In order to apply the proposed algorithm, Table 3.2 was constructed to denote the participation percentage of the generators for the different frequencies. The sequence which is to be followed for dropping control of the machines for this system is shown in Table 3.3. It is important to note here that although this sequence was generated corresponding to the no-contingency case, it works perfectly well for the rest of the cases. The reason for this was that the contingencies being tested were sufficient to test the robustness of the control but not severe enough to make the system collapse.

The selection of the eigenvalues in accordance with the proposed algorithm is depicted in Figure 5.3.3. Figure 5.3.4 shows the effect of applying a rudimentary control (LQR optimization) to the system obtained in Figure 5.3.3. The red dots denote the feedback to the reduced-order

system, whereas the green circles denote the feedback to the complete system. The blue squares denote the starting positions. It becomes clear from the figure that the proposed control obtained from the reduced-order system successfully moves all the low–frequency modes of oscillations to the left, thereby increasing the damping of the inter-area modes. Although some of the high frequency local modes of oscillations move towards the right, none of them cross the imaginary axis. Figure 5.3.5 illustrates the effect of dropping one more machine on the control for the system. It is clear from these figures that the smallest number of machines that is to be controlled for a stable operation of this system is 10. That is, using the developed technique, the first five machines mentioned in Table 5.3.3 could be safely dropped from the LMI control.

The system size reduction performed above for the no-contingency case was then applied to the remaining seven cases. By doing so, all the eight cases were reduced to have a matrix. In essence, this implied that the system had been reduced from a 15 machine system to a 10 machine one (with one machine being the reference). Every matrix now contained the angles and frequencies of only those machines which corresponded to the significant modes of oscillations. Therefore, we are now in a position to apply the LMI control to this reduced-order system.

Figure 5.3.2: Eigenvalues of the 16 machine system corresponding to the base case

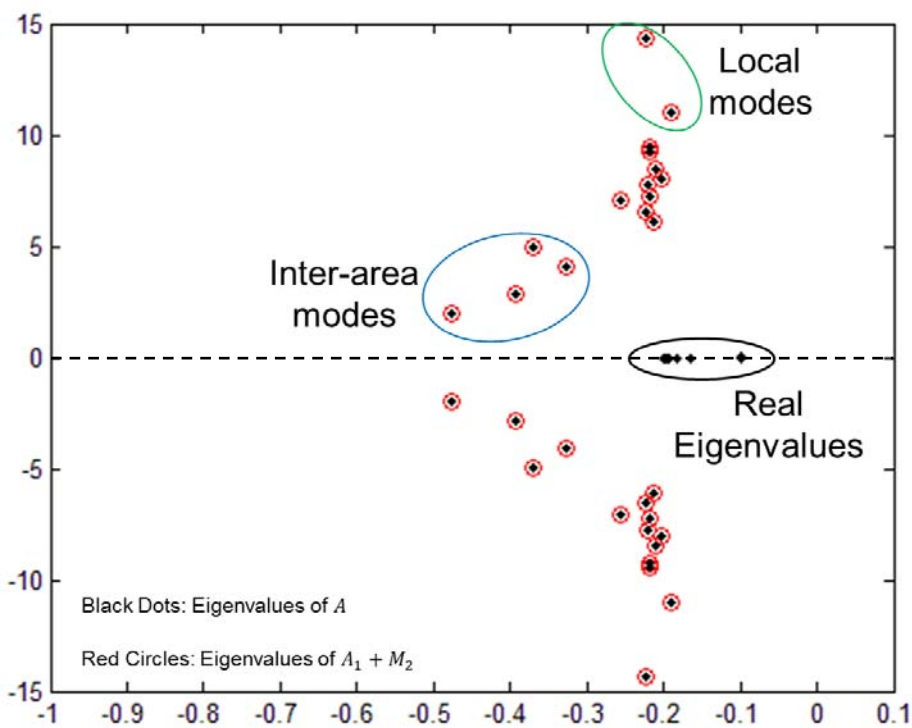


Table 5.3.2: Frequency-Participation Percentage for Base Case of 16-machine system

Serial Number	Frequency (in Hz)	Bus Number based on Participation Factor Percentage															
1	1.8309	63	62	53	64												
2	1.6314	53	60	62	56	63											
3	1.5371	56	59	57	58	60											
4	1.5214	59	58	56	57	60											
5	1.3491	62	60	53	64	61	63	58	54	57	55	59					
6	1.2958	62	60	53	64	55	61	54	63	58	57	59					
7	1.2897	54	55	60	62	53	64										
8	1.2003	57	58	59	56	54											
9	1.1727	64	65	62	55	54	63	60	53	61							
10	1.0794	55	54	57	58	56	59	64	65	62	53	60	63	61			
11	0.9793	61	57	58	56	59	55	54	60								
12	0.7876	67	66	68													
13	0.5999	65	61	58	59	56	57	55	54	53	60	64	67	62	68	63	66
14	0.5213	68	66	67	65												
15	0.3351	65	67	66	68	64	58	61	55	53	56	57	54	59	60	63	62
16	0.0038	65	68	66	67	64	53	55	58	61	62	54	63	56	59	57	60

Table 5.3.3: Sequence to be followed for dropping machines for the 16-machine system

Serial Number	Machine Number
1	63
2	53
3	62
4	57
5	61
6	60

Figure 5.3.3: Reducing system size for base case – 10 machine system

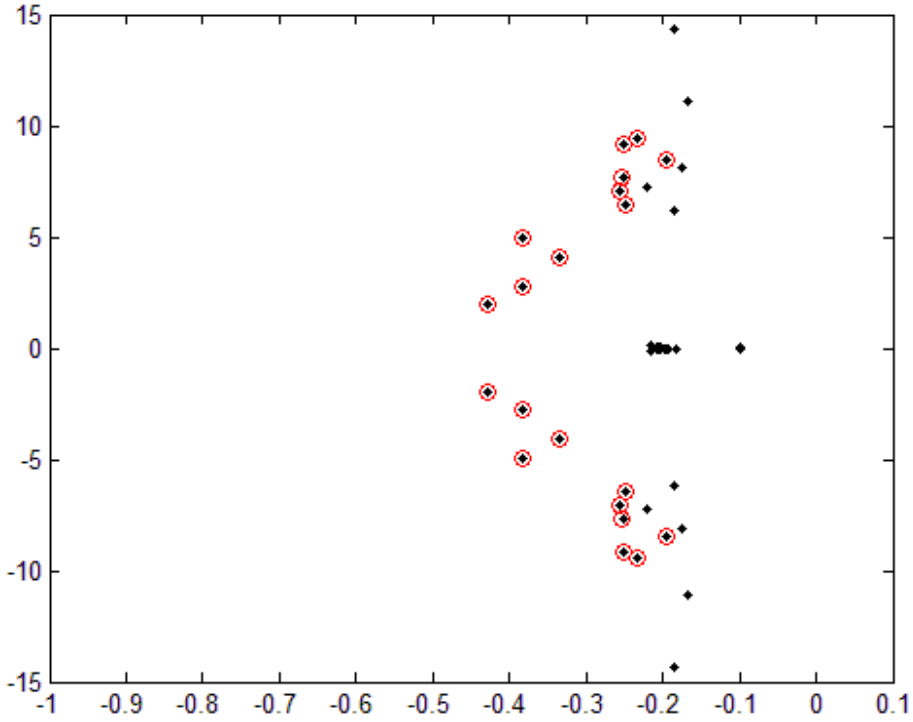


Figure 5.3.4: Applying control check described in Step 4 of algorithm to 10 machine system

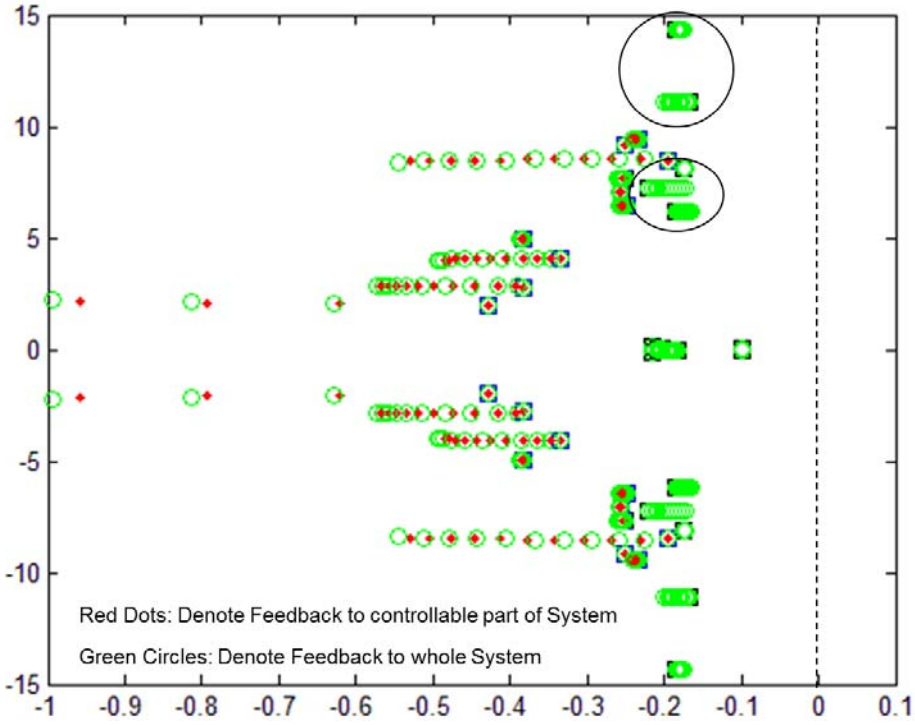
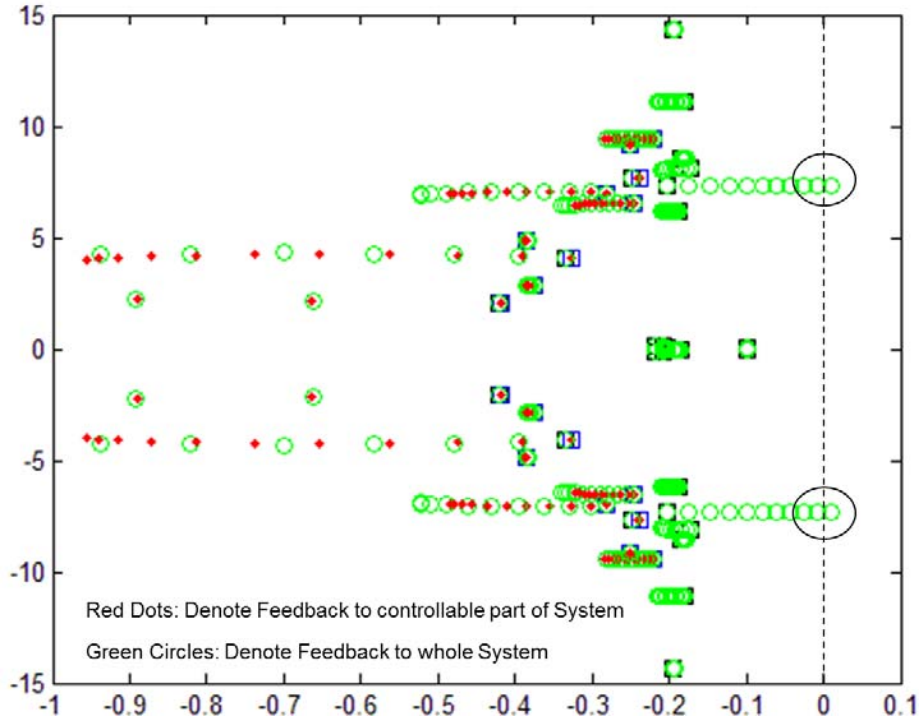


Figure 5.3.5: Applying control check described in Step 4 of algorithm to 9 machine system



Each of the LMI problems with 20 retained states is described by a LTI system. The collection of the eight cases results in a polytopic system while the closed loop system has a size of . The LMI optimization yields a single feedback gain matrix for all the eight cases defined above. Table 5.3.4 gives a comparison of the LMI control to this system when the traditional SMA approach is applied with that which is obtained when the proposed algorithm is applied to it. From the results it becomes clear that by reducing the system to two-thirds of its initial size the computational time has been reduced by a factor of eight.

Table 5.3.4: Comparison results for 16 machine system

	Traditional SMA + LMI Control	Proposed Algorithm + LMI Control
System Size ( )		
Size of individual LTI system		
Size of Polytopic System		
Size of Closed Loop System		
CPU Time*** (seconds)		

*** The computations were performed on an Intel (R) Core ™ i5 Processor having a speed of 2.40 GHz and an installed memory (RAM) of 5.86 GB

The reduction factor n for the 16-machine system is found to be –

$$n = \frac{\ln(606.328895) - \ln(75.493861)}{\ln(15) - \ln(10)}$$

$$=> n \approx 5.14$$

Figures 5.3.6 and 5.3.7 show the eigenvalues of the closed loop matrices for the eight cases denoted in Table 5.3.1 for the full-order and the reduced-order systems respectively. Fewer eigenvalues appear in Figure 5.3.7 because of the proposed algorithm. The conic region is used as the LMI region for pole placement. It is obvious from Figure 5.3.7 that all the closed-loop poles lay in the LMI region.

Figure 5.3.6: Closed-Loop eigenvalues for the 8 cases of the (15+1) machine system

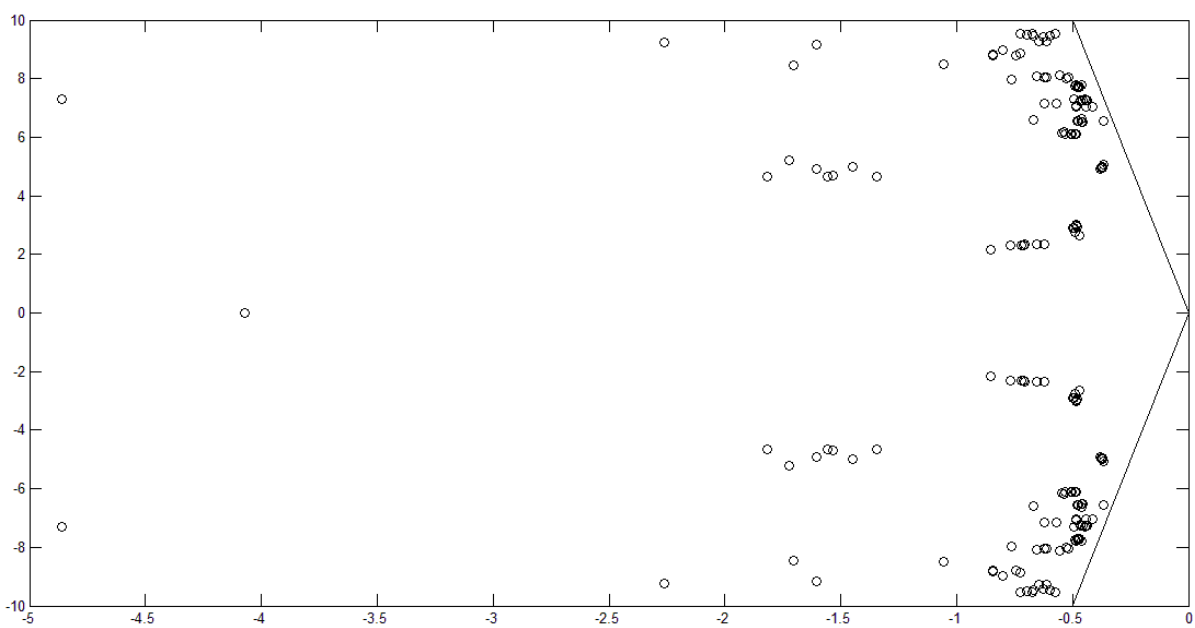
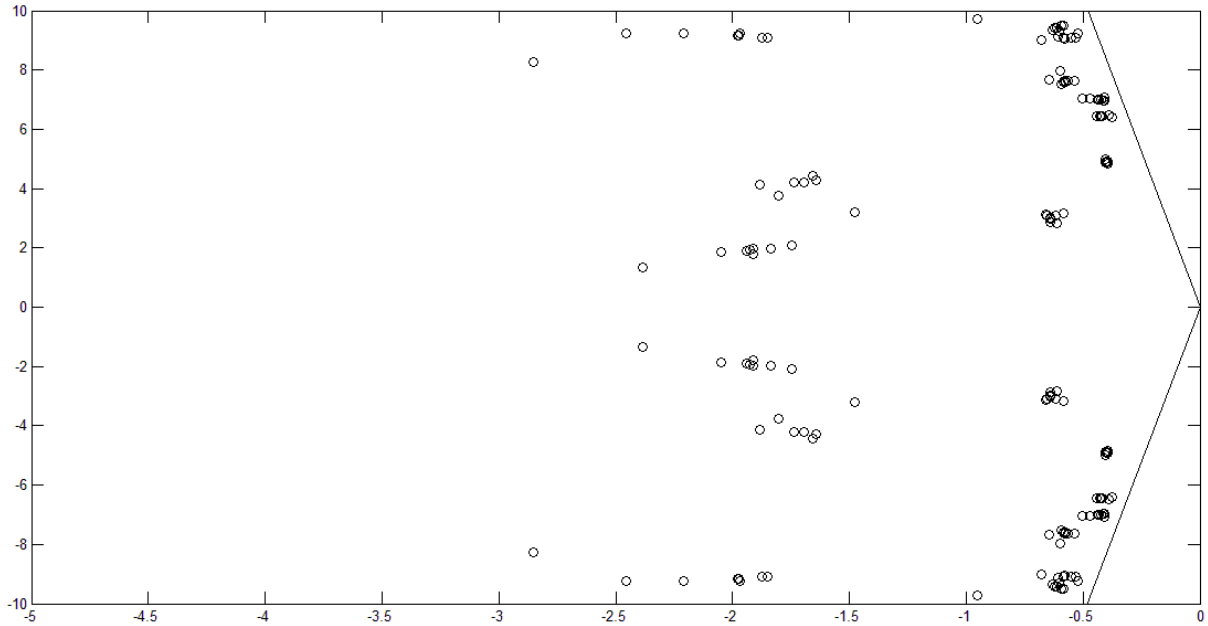
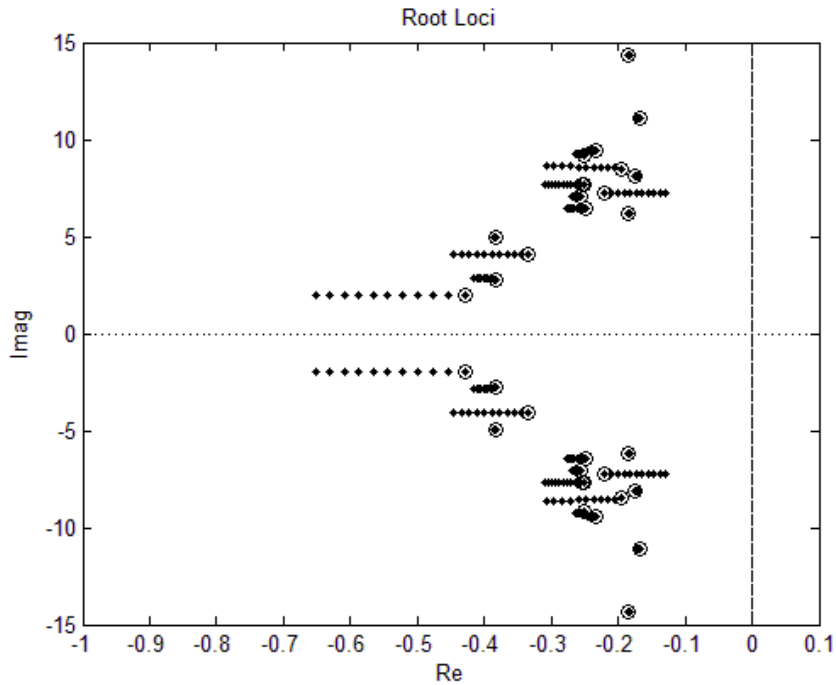


Figure 5.3.7: Closed-Loop eigenvalues for the 8 cases of the (10+1) machine system



The root loci starting at the eigenvalues of the original system as the feedback gain is increased to its final values for the base case of the reduced order system is shown in Figure 5.3.8. The circles denote the starting positions and the dots represent the trajectory followed as the gain is increased. Similar plots were obtained for the other seven contingency cases [9]. The plots confirm the fact that the proposed control successfully damps all the low frequency inter-area modes of oscillations present in the this system. Some of the local modes do move towards the right but none of them become unstable. Thus, it can be inferred that although one-third of the machines originally present in the system have been removed, the proposed control is robust enough to keep the system stable under a wide variety of contingencies. Also, the fact that the computational complexity has been reduced by a large factor implies that this technique can be readily applied to bigger systems.

Figure 5.3.8: Root Locus plot for base case using the proposed algorithm

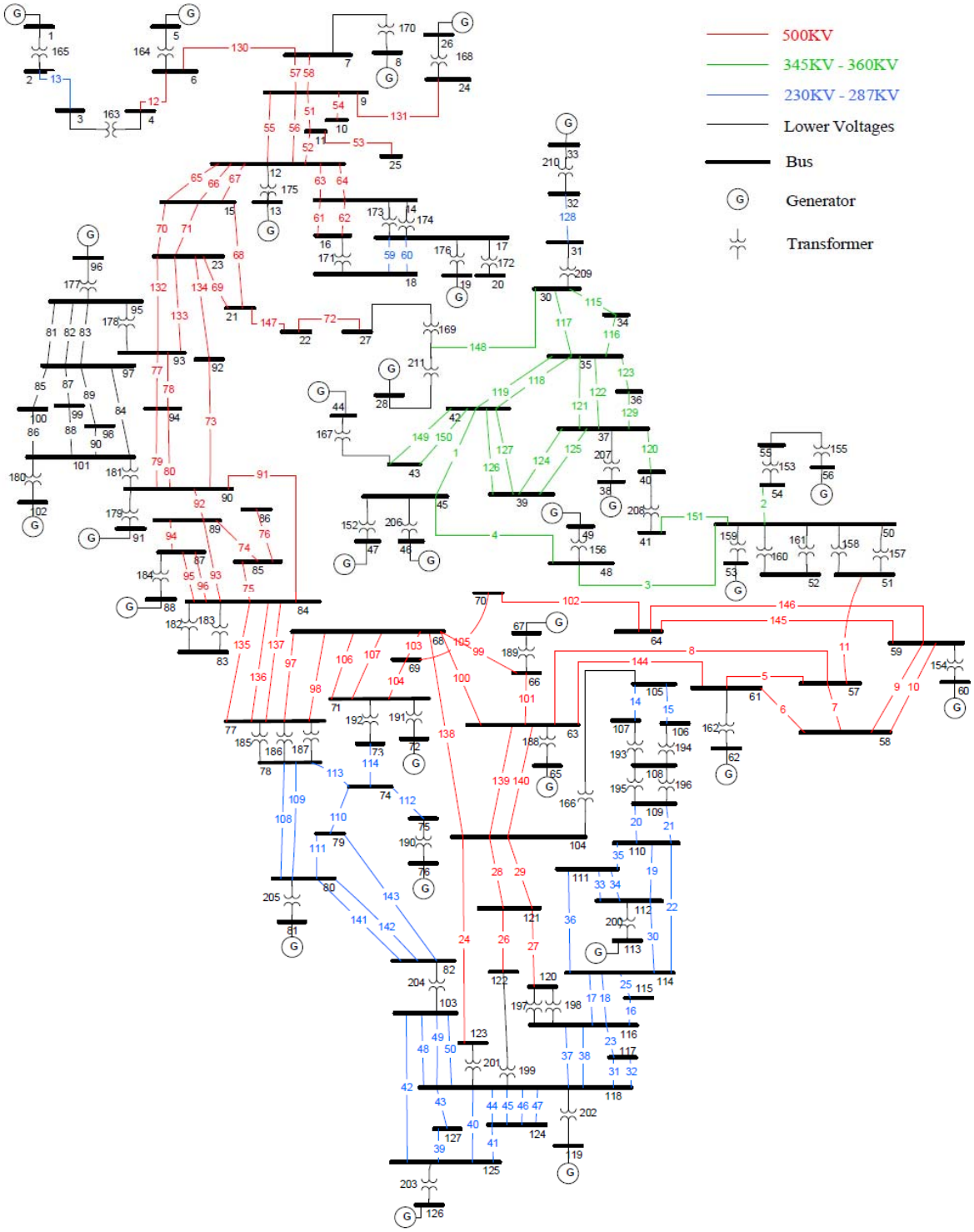


5.3.2 The 29 Machine Model of the WECC System

The system consists of 29 machines, 127 buses and 215 lines. It has a generating capacity of 61.4 GW with a load of 60.8 GW, the difference between the two being accounted for by the losses of the system. It contains two HVDC lines extending from Celilo in the North to Sylmar in the South and from Inter-mountain in the East to Adelanto in the South-West. An SVC is also located at Adelanto. The single-line diagram of the system is shown in Figure 5.3.9. It is a relatively older network that was developed in [10] for analyzing the low frequency interaction phenomena between DC links and the electro-mechanical stability cases. Typical line and machine parameters were adopted and the controllers tuned to guarantee a stable base-case. A detailed description of the system is provided in Appendix E.2.

Figure 5.3.9: Single-Line Diagram of the 127-Bus WECC System

(Courtesy of Dr. David Elizondo)



The machines depicted in this system are equivalents of the actual machines present in the real system. The California model is represented by a 12 machine, 60-bus network whereas the "rest of WECC" is depicted by a 17 machine, 67-bus network. The inter-ties connecting California with the "rest of WECC" were identified as the critical tie-lines of the system. The HVDC lines of the network were modeled as constant PQ loads at Celilo and Sylmar (representing the Pacific DC Intertie) and at Inter-Mountain & Adelanto (representing the Inter Mountain-Adelanto HVDC line). The list of inter-ties present in this model is summarized in Table 5.3.5.

Table 5.3.5: List of Interties in 29-machine model

Interties	Real Power (MW)	Reactive Power (MVAR)
Malin – RoundMt 1	982	66.7
Malin – RoundMt 2	971	78.4
Malin – Olinda	1150	-35.4
Moenkopi – Eldordo	993	-57.4
Navajo – Eldordo	843	98.4
PaloVerde – Devers 1	903	45.6
PaloVerde – Devers 2	903	45.6

The control developed for this system had two main objectives –

- Ensure a specified percentage of damping on all the low frequency modes of oscillations. For e.g., if the minimum damping of all the modes was at least 5%, then the minimum damping percentage of all the modes after the application of the control should be at-least 7.5%
- Provide more damping to the inter-area modes of oscillation. For e.g., if the minimum damping of the inter-area modes was 5%, then after the application of the control, it should be around 15%

In order to test the proposed control along these objectives, a variety of contingency cases were identified. These included outage of critical tie-lines, changes in line flows of important lines, increase/decrease of loads in key areas etc. A polytope comprising of

these cases was then used for the development of the control. The eight cases that were selected to test the robustness of the control are summarized in Table 5.3.6.

Table 5.3.6: Case Bank for the 29 machine WECC system

Case Number	Case Details
1	No-Contingency Case
2	Outage of one Tie-line between PaloVerde and Devers
3	Outage of one Tie-line between Midway and Vincent
4	Outage of one Line between Grizzly and John Day
5	Flow in one Line between Big Eddy and John Day decreased by 250 MW
6	Flow in one Line between Big Eddy and John Day increased by 250 MW
7	Loads at Buses Canada and North decreased by 10%
8	Loads at Buses Canada and North increased by 10%

Since two HVDC lines and one SVC were already present in the system, they were chosen as the preferred forms of control. The A, B, C, and D matrices for this system had dimensions of 171×171, 171×6, 29×171, and 29×6 respectively. Using the traditional SMA approach described in Chapter 2, the A matrix was partitioned into A_1, A_2, A_3 and A_4, each having dimensions of 56×56, 56×115, 115×56, and 115×115 respectively.

Figure 5.3.10 shows a portion of the eigenvalues of the A matrix corresponding to the no-contingency case highlighting the oscillatory modes for this system. The black dots represent the eigenvalues of the A matrix whereas the red circles denote the eigenvalues of the A_1 matrix. It becomes clear from the figure that the traditional SMA approach has been successful in identifying the oscillatory modes present in the system. In order to apply the proposed algorithm, Table 5.3.7 was constructed to denote the participation percentage of the generators for the different frequencies similar to what was done for the 16 machine example system. The machines to be dropped from the LMI control logic are summarized in Table 5.3.8.

Figure 5.3.10: Eigenvalues of the 29 machine system corresponding to the base case

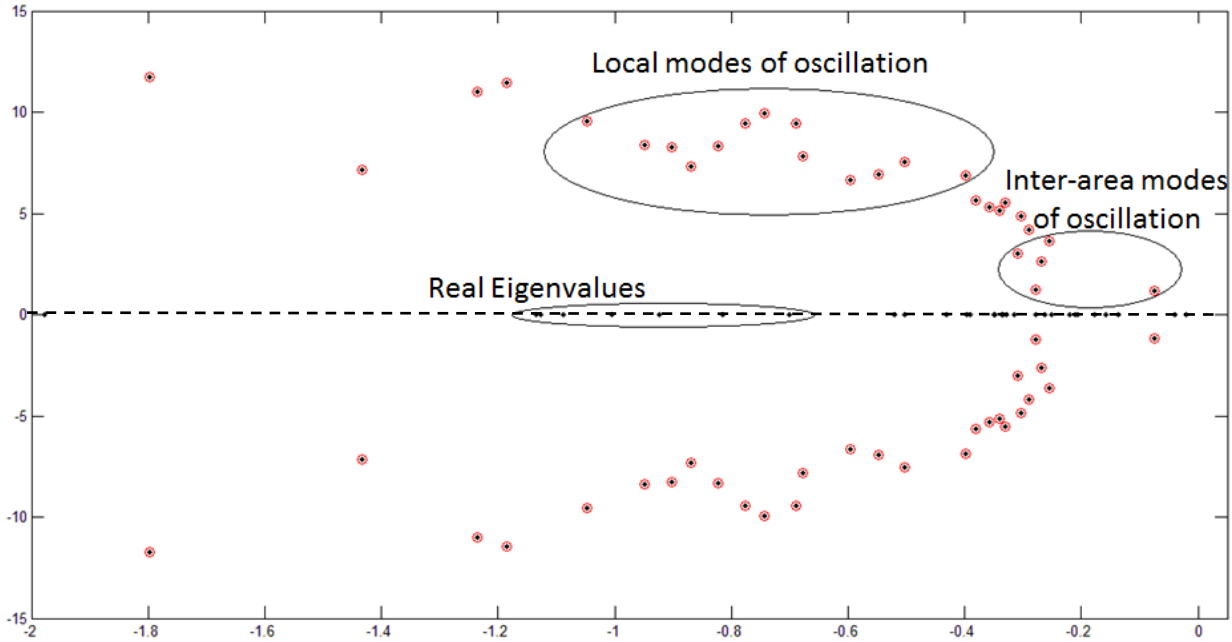


Table 5.3.7: Frequency-Participation Percentage for Base Case of 29-machine system

Serial Number	Frequency (in Hz)	Bus Number based on Participation Factor %																											
1	1.9415	119	81																										
2	1.7999	46	47	49																									
3	1.7443	49	53	46	47																								
4	1.7267	19	33																										
5	1.5622	38	44																										
6	1.4531	113	72	81	126	62																							
7	1.3933	81	126	72	62	67	113																						
8	1.3446	72	126	81	113	62	88	28	76	67	53	13	56	49															
9	1.3384	102	91																										
10	1.3112	62	53	126	67	49	56	60	72	65	88																		
11	1.2584	28	13	44	91	38	88	72	8	126	96	33	67	81	62														
12	1.2352	56	53	49	62	67	126	60	44	65	47	72	88	81	91														
13	1.1910	88	126	81	72	113	91	67	96	76	56	102	62	119	65	13	53												
14	1.1552	91	13	96	102	8	28	88	126	67	19	26	113	72	5	44	81	38	76	56									
15	1.1001	33	44	38	96	13	56	47																					
16	1.0996	96	13	33	19	44	102	38	28	126	8	67	91	81															
17	1.0765	88	67	126	81	72	76	113	96	65	8	91	56	28	13	62	119	26	5	44	33								
18	1.0434	65	67	81	88	126	72	76	60	113	13	96	62	91	56														
19	0.9595	8	13	5	96	91	65	28	76	19	33	44	38	102	72	113	88	126											
20	0.8761	56	65	53	49	67	47	8	60	33	46	76	5	44	38	81	72	126	28	88	113	91							
21	0.8676	76	60	65	67	47	62	46	91	56	53	26	72	81	96	113	49	44	13	38									
22	0.8340	60	65	67	56	53	76	47	49	46	8	5	62	81	72	88	113	126											
23	0.8220	33	47	44	38	46	5	8	91	28	60	76	13	65	102	96	67	88	81	19									
24	0.7966	5	13	91	28	47	96	60	19	46	102	76	33	53	56	8	44	38	49	26	1	88							
25	0.6648	26	76	47	91	60	46	38	53	44	28	56	49																
26	0.5318	47	46	44	38	76	60	33	26	53	65	49	67	56	28	5	81	62	72	8	126	88	113	91					
27	0.4435	5	8	60	13	76	1	26	91	65	62	67	53	56	28	47	19	96	49	72	81	46	102	126	113				
28	0.2138	1	60	76	65	62	67	91	26	53	72	47	81	5	49	56	13	38	88	44									
29	0.0000	1	8	60	5	91	76	13	65	67	62	26	72	81	53	28	88	47	38	44	49	56	96	102	19	126	46	113	33	119

Table 5.3.8: Sequence to be followed for dropping machines for the 29-machine system

Serial Number	Machine Number
1	119
2	19
3	33
4	113
5	126
6	102
7	65
8	81

The selection of the eigenvalues in accordance with the proposed algorithm is depicted in Figure 5.3.11. Figure 5.3.12 shows the effect of applying a rudimentary control (LQR optimization) to the system obtained in Figure 5.3.11. The red dots denote the feedback to the reduced-order system whereas the green circles denote the feedback to the complete system. The blue squares denote the starting positions. It becomes clear from the figure that the proposed control obtained from the reduced-order system successfully moves all the low–frequency modes of oscillations to the left thereby increasing the damping of the inter-area modes. Although some of the high frequency local modes of oscillations move towards the right, none of them cross the imaginary axis. Figure 5.3.13 illustrates the effect of dropping one more machine, on the control for the system. It is clear from these figures that the smallest number of machines that is to be controlled for a stable operation of this system is 21. That is, using the developed technique, the first seven machines mentioned in Table 5.3.8 could be safely dropped from the LMI control.

The system size reduction performed above for the no-contingency case was then applied to the remaining seven cases. By doing so, all the eight cases were reduced to have a 42×42 A_1 matrix. In essence, this implied that the system had been reduced from a 28 machine system to a 21 machine system (with one machine being the reference). Every A_1 matrix now contained the angles and frequencies of only those machines which corresponded to the significant modes of oscillations. Therefore, we were now in a position to apply the LMI control to this reduced-order system.

Figure 5.3.11: Reducing system size for base case – 21 machine system

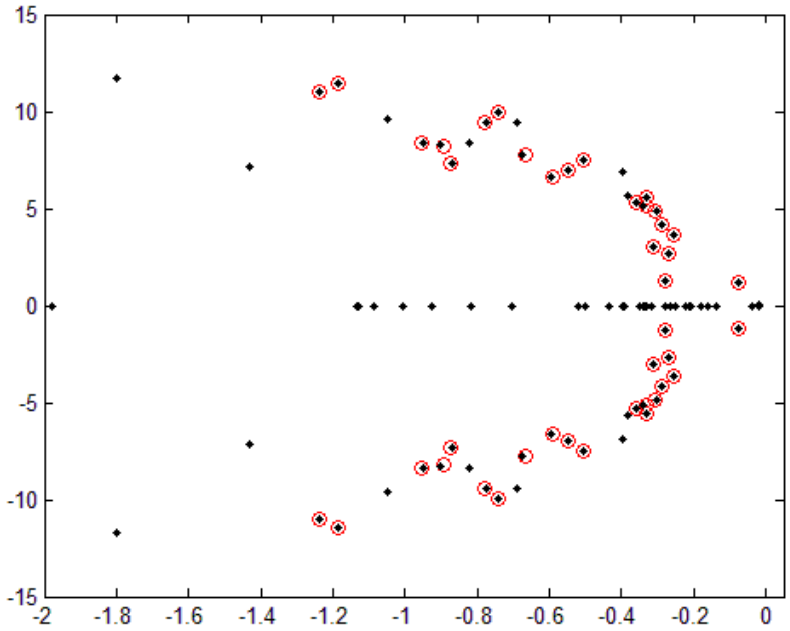


Figure 5.3.12: Applying control check to 21 machine system

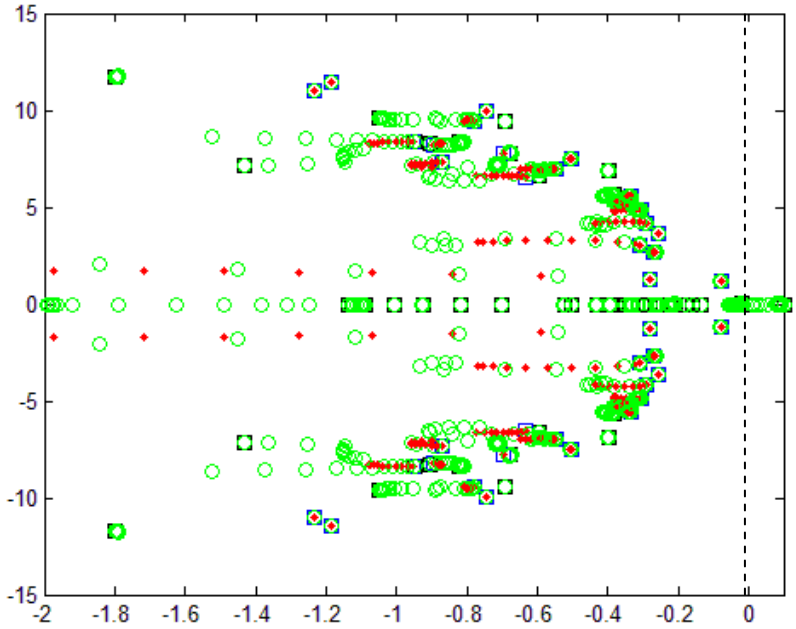
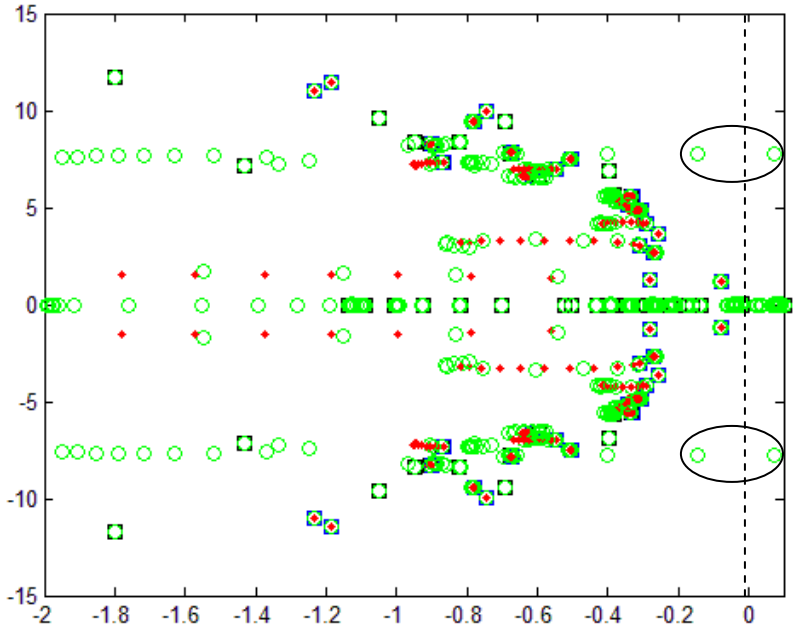


Figure 5.3.13: Applying control check to 20 machine system



Each of the LMI problems with 42 retained states is described by a 65 × 49 LTI system. The collection of the eight cases results in a 65× 401 polytopic system while the closed loop system has a size of 65 × 377. The LMI optimization yields a single feedback gain matrix for all the eight cases defined in Table 5.3.6. Figure 5.3.14 shows the eigenvalues of the closed loop matrices for the reduced-order system when the control has not been forced. Figure 5.3.15 depicts the same reduced-order system when the three-element control has been forced onto it.

On comparing the two figures, it is realized that although all the eigenvalues attain the minimum desired amount of damping (7.5%) on the application of the control, some of the more critical modes remain relatively unaffected. The most acute amongst the latter group being the lowest frequency inter-area mode which had much less damping (≈8%) than what it was expected to have (about 15%) on the application of the control. The inference drawn from these results was that the three elements used for the control were not enough for providing the requisite amount of damping to all the low frequency inter-area oscillations present in the system. Therefore, it became necessary to add more number of controls into the system.

Figure 5.3.14: Closed loop eigenvalues for reduced system under no control

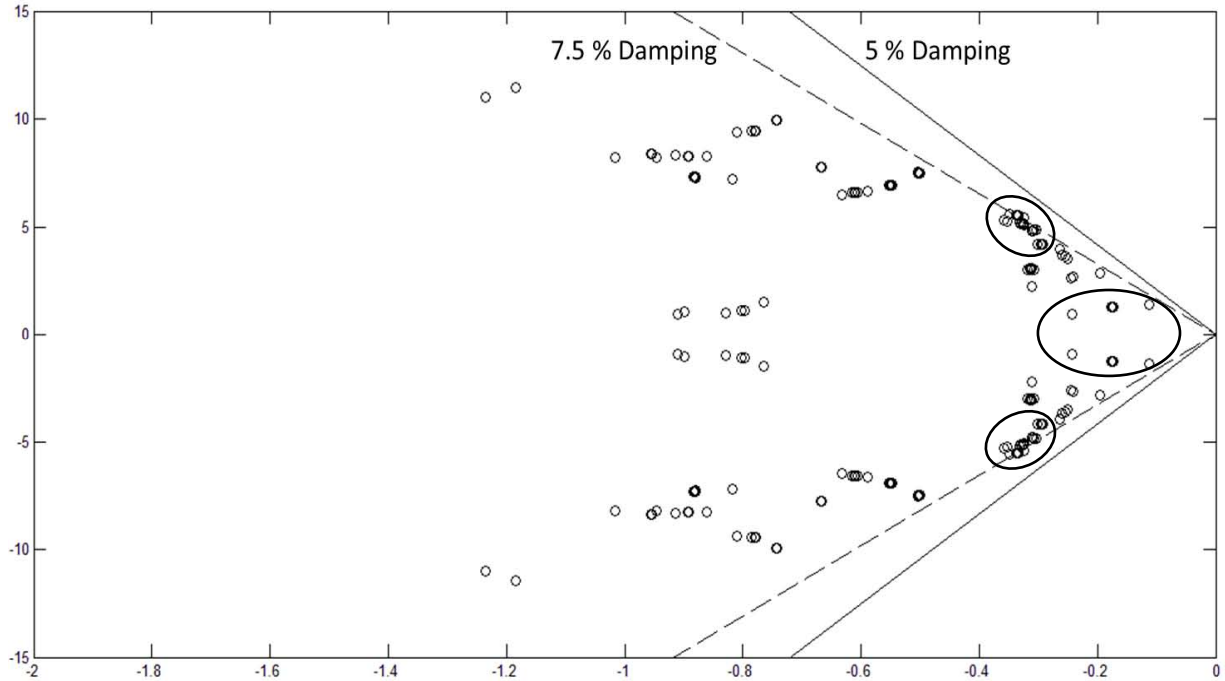
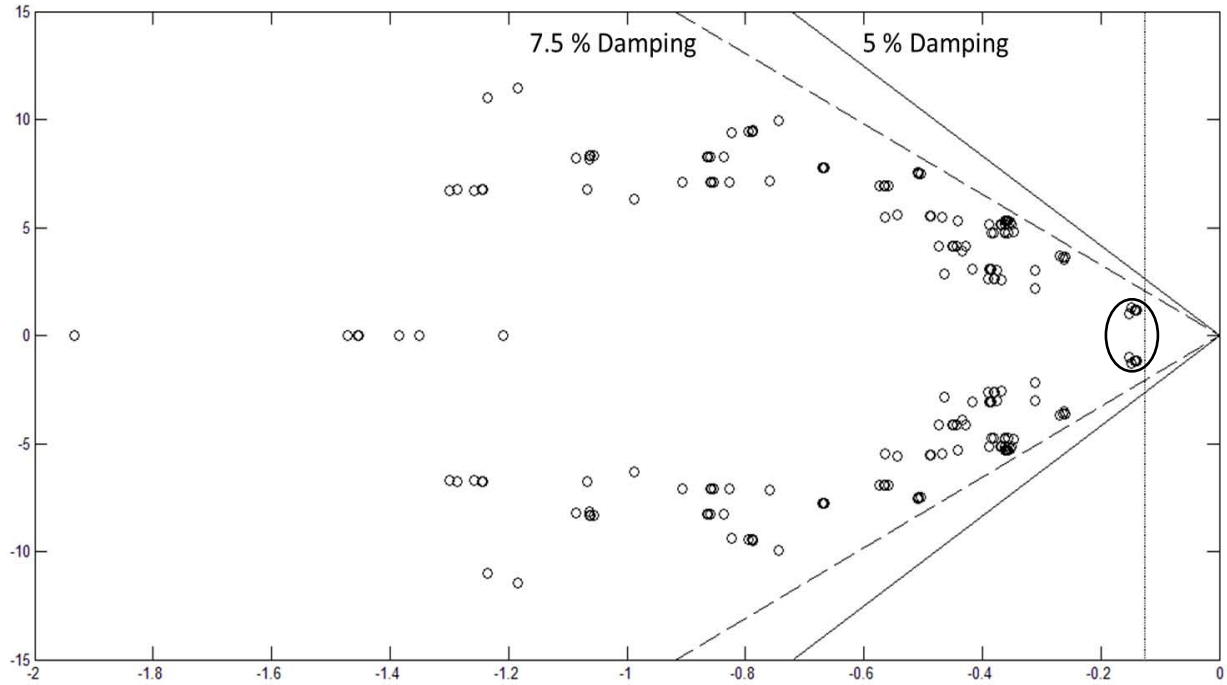


Figure 5.3.15: Closed loop eigenvalues for reduced system under 3-element control



The inference that was drawn from the analysis performed previously was that for the 29 machine model of the WECC system, the three elements selected for control purposes were not enough for providing the requisite amount of damping to the various low frequency inter-area modes of oscillations present in the system. Therefore, in order to achieve the desired control objectives, there is a need for introducing more controls. The solution is to add Energy Storage Devices (ESDs) into the system.

Use of ESDs as a form of control has been proposed for quite some time now. While they do not necessarily represent energy sources, these devices provide valuable added benefits to improve stability, power quality, and reliability of supply. To illustrate, when power system disturbances occur, synchronous generators are not always able to respond rapidly enough to keep the system stable. If a high-speed real or reactive power control is available, load shedding or generator dropping may be avoided during the disturbance. Flexible AC Transmission Systems (FACTS) devices make high speed reactive power control possible, but their role in the control of real power is limited. In such situations, a better solution is to introduce ESDs into the systems which have the ability to rapidly vary real power without impacting the power circulation. Thus, they can play a very important role in maintaining system reliability and power quality [11].

In recent times, with the significant reduction in the capital cost of ESDs, they are becoming a viable solution for modern power applications. Being composed of static elements, they have a much faster dynamic response when compared to other storage devices. The four types of ESDs which have been reckoned to have great potential in the domain of power systems are –

Super-conducting Magnetic Energy Storage (SMES) Systems

Battery Energy Storage Systems (BESS)

Advanced Capacitors (AC)

Fly-wheel Energy Storage (FES) Systems

Although several of these technologies were initially envisioned for large-scale load-leveling applications, they are now been seen more as a tool to enhance system stability, aid power transfer, and improve power quality in power systems. Additionally, it has now been recognized that ESDs can also be used to increase the system damping of undesirable inter-area oscillations as a cost-effective damping controller.

Similar to other types of controllers proposed earlier, local or un-coordinated control strategies can cause destabilizing interactions among the ESDs. The damping of oscillations can be adversely influenced by negative interactions within the ESD controls. In addition, the controllers might fail to produce adequate damping due to variations in generation and load patterns and changes in transmission networks. However, the co-ordinated form of control proposed here appears to perfectly counter such adverse effects. Therefore, with the aid of PMUs and WAMs, it is proposed that ESDs can be used in the integrated control design just like the DC lines and the other FACTS devices described herein.

An important issue that needs to be addressed before using ESDs as a form of control is the criteria for "site selection". The intended system application influences the required number of installations. A judicious choice of locations is necessary to meet the criteria of cost and intended applications. Therefore, the focus is on damping many inter-area modes with fewer ESDs. Courtesy WAMs, it is now possible for a relatively small number of synchronized stabilizing signals from different locations of power systems to be coordinated to damp a relatively large number of inter-area modes. Moreover, it has also been proved that remote signals are more effective than local signals for damping out inter-area oscillations. Keeping this in mind, the concept of controllability indices described in [12] is used here to identify the best locations for the ESDs. The Geometric Measure of Controllability (GMC) associated with the inter-area mode k is given by,

$$\text{GMC}_k(i) = \cos\left(\alpha(\psi_k, b_i)\right) = \frac{|b_i^T \psi_k|}{\|\psi_k\| \|b_i\|} \tag{5.15}$$

Where b_i is the ith column of the input matrix B, ψ_k is the left-eigenvector associated with the mode k, and $\alpha(\psi_k, b_i)$ is the geometric angle between the ith input vector and the kth left eigenvector. $\|\psi_k\|$ and $\|b_i\|$ are the Euclidean Norms of ψ_k and b_i respectively whereas $|b_i^T \psi_k|$ denotes the modulus of $b_i^T \psi_k$. Then, in accordance with the concept of controllability indices, the most suitable locations of ESDs with respect to the critical inter-area modes were found to be the generators with the highest GMC [12].

The results obtained by applying this concept to the 29 machine WECC System is shown in Table 5.3.9. From the table, it is realized that buses 1, 5 and 76 (highlighted in bold) are the best locations for adding the ESDs into the system. Since the system matrix had to be modified to incorporate the presence of the three ESDs, the dimensions of all of its derivative matrices had to be recomputed. The new dimensions of A, B, C, and D matrices were found to be 174×174, 174×12, 29×174, and 29×12 respectively. Similarly, the new dimensions of A_1, A_2, A_3 and A_4, were found to be 56×56, 56×118, 118×56, and 118×118 respectively. However, since the addition of ESDs into the system did not change the participation factors of the machines or the frequencies of the oscillations, Table 3.7 and 3.8 remained the same.

By applying the proposed algorithm in a manner similar to what was done for the three-element control, the A_1 matrix of all the eight cases was reduced to a dimension of 42×42. Then, each of the LMI problems with these 42 retained states is described by a 65×55 LTI system. The collection of the eight cases results in a 65×449 polytopic system while the closed loop system has a size of 65×401. The LMI optimization yielded a single feedback gain matrix for all the eight cases defined in Table 5.3.6. Table 5.3.10 gives a comparison of the LMI control to this system when the traditional SMA approach is applied with that which is obtained when the proposed algorithm is applied to it. From the results, it becomes clear that by reducing the system to three-fourths of its initial size the computational time has been reduced by a factor of about four.

Table 5. 3.9: Normalized GMCs corresponding to the three lowest inter-area modes

Mode 1		Mode 2		Mode 3	
Bus Number	**GMC**	**Bus Number**	**GMC**	**Bus Number**	**GMC**
1	**1.0000**	**5**	**1.0000**	**76**	**1.0000**
91	0.0169	8	0.1353	60	0.4967
5	0.0161	1	0.0501	67	0.3292
60	0.0154	91	0.0293	126	0.3106
19	0.0136	60	0.0239	88	0.2315
44	0.0135	126	0.0173	62	0.2255
126	0.0118	76	0.0162	72	0.1820
76	0.0115	81	0.0145	91	0.1277
8	0.0114	88	0.0120	102	0.1114
81	0.0099	72	0.0116	113	0.0943
72	0.0088	44	0.0112	81	0.0827
38	0.0064	65	0.0093	44	0.0815
113	0.0063	113	0.0091	53	0.0645
102	0.0055	26	0.0083	28	0.0489
65	0.0051	62	0.0083	65	0.0394
62	0.0046	67	0.0080	38	0.0365
28	0.0045	28	0.0060	119	0.0333
96	0.0045	38	0.0027	19	0.0333
88	0.0044	96	0.0017	49	0.0299
67	0.0043	119	0.0017	8	0.0183
26	0.0026	102	0.0012	26	0.0151
33	0.0012	56	0.0010	96	0.0073
119	0.0012	19	0.0008	46	0.0072
46	0.0008	47	0.0008	47	0.0050
49	0.0006	33	0.0004	33	0.0044
53	0.0006	53	0.0004	56	0.0022
56	0.0004	46	0.0002	1	0.0021
47	0.0000	49	0.0001	5	0.0017

Table 5.3.10: Comparison results for 29 machine system (with 6 controls)

	Traditional SMA + LMI Control	Proposed Algorithm + LMI Control
System Size (A_1)	56×56	42×42
Size of individual LTI system	86×69	65×55
Size of Polytopic System	86×561	65×449
Size of Closed Loop System	86×513	65×401
CPU Time*** (seconds)	5435.701939	1543.530256

*** The computations were performed on an Intel (R) Core ™ i5 Processor having a speed of 2.40 GHz and an installed memory (RAM) of 5.86 GB

The reduction factor n for the 29-machine system was found to be –

$$n = \frac{\ln(5435.701939) - \ln(1543.530256)}{\ln(28) - \ln(21)}$$

$$=> n \approx 4.3761$$

Figures 5.3.16 and 5.3.17 show the eigenvalues of the closed loop matrices for the eight cases denoted in Table 4.1 for the full-order and the reduced-order systems respectively. Fewer eigenvalues appear in Figure 5.3.17 because of the proposed algorithm. The conic region is used as the LMI region for pole placement. It is obvious from Figure 5.3.17 that all the closed-loop poles lay in the LMI region.

The root loci starting at the eigenvalues of the original system as the feedback gain is increased to its final values for all the eight cases for the reduced order system are shown in Figs. 5.3.18-5.3.25. The circles denote the starting positions and the dots represent the trajectory followed as the gain is increased. The plots confirm the fact that the control described here successfully damps all the low frequency inter-area modes of oscillations present in this system. Some of the local modes do move towards the right but none of them become unstable. Thus, it can be inferred that although one-fourth of the machines originally present in the system have been removed, the proposed control is robust enough to keep the system stable under a wide variety of contingencies.

Figure 5.3.16: Closed loop eigenvalues for full-order system under 6-element control

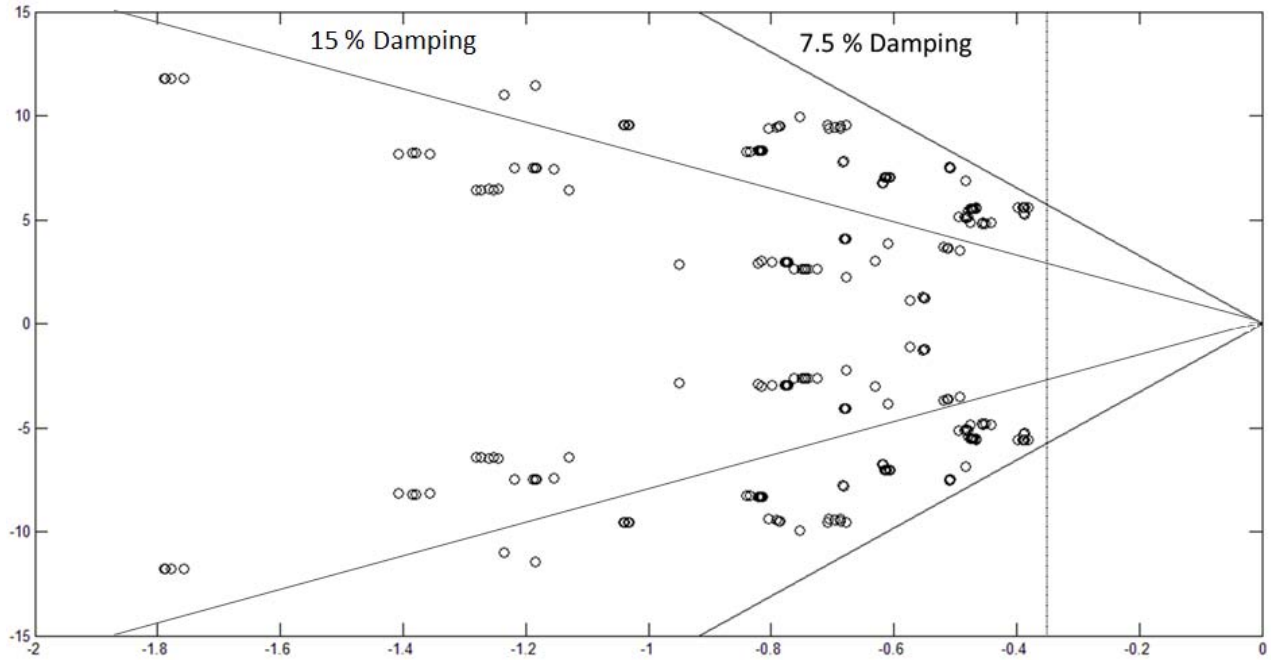


Figure 5.3.17: Closed loop eigenvalues for reduced-order system under 6-element control

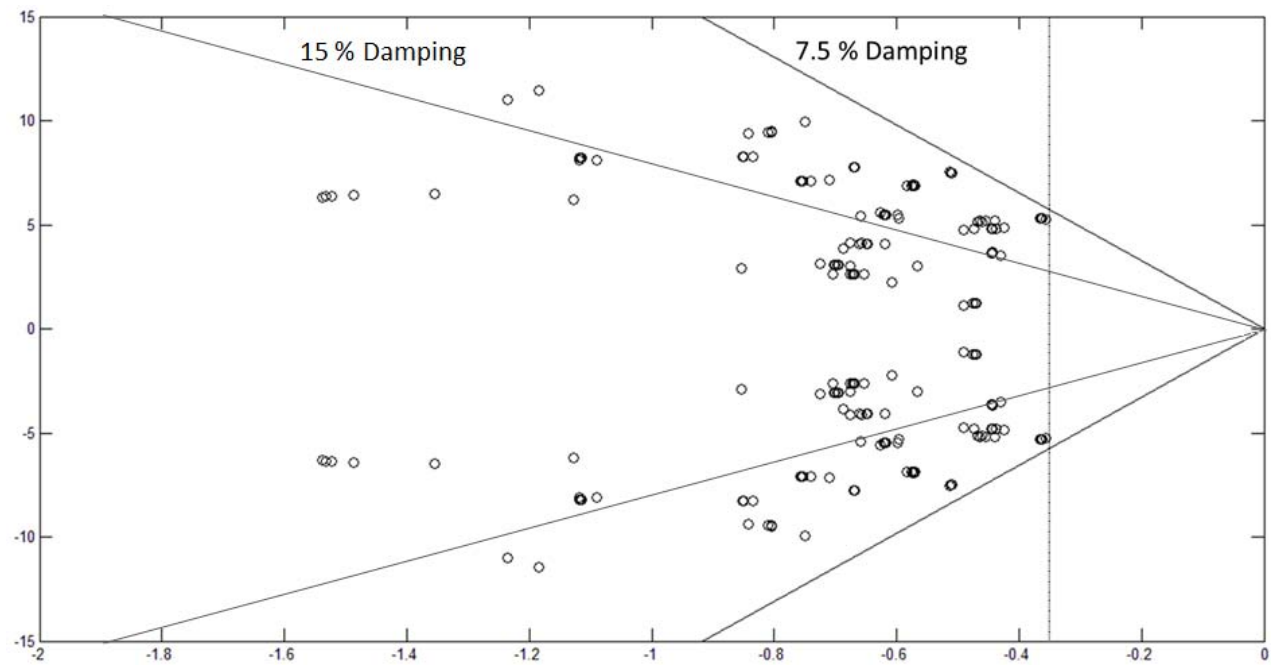


Figure 5.3.18: Root Locus plot for Case 1 using the proposed algorithm

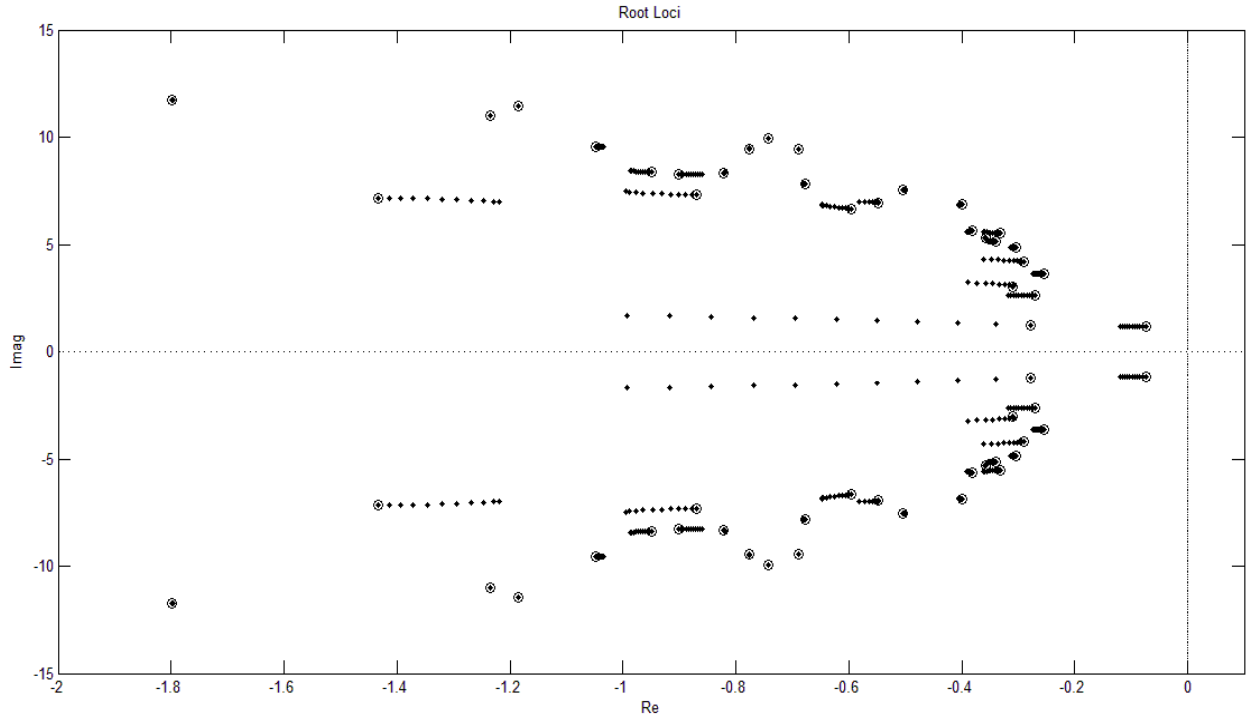


Figure 5.3.19: Root Locus plot for Case 2 using the proposed algorithm

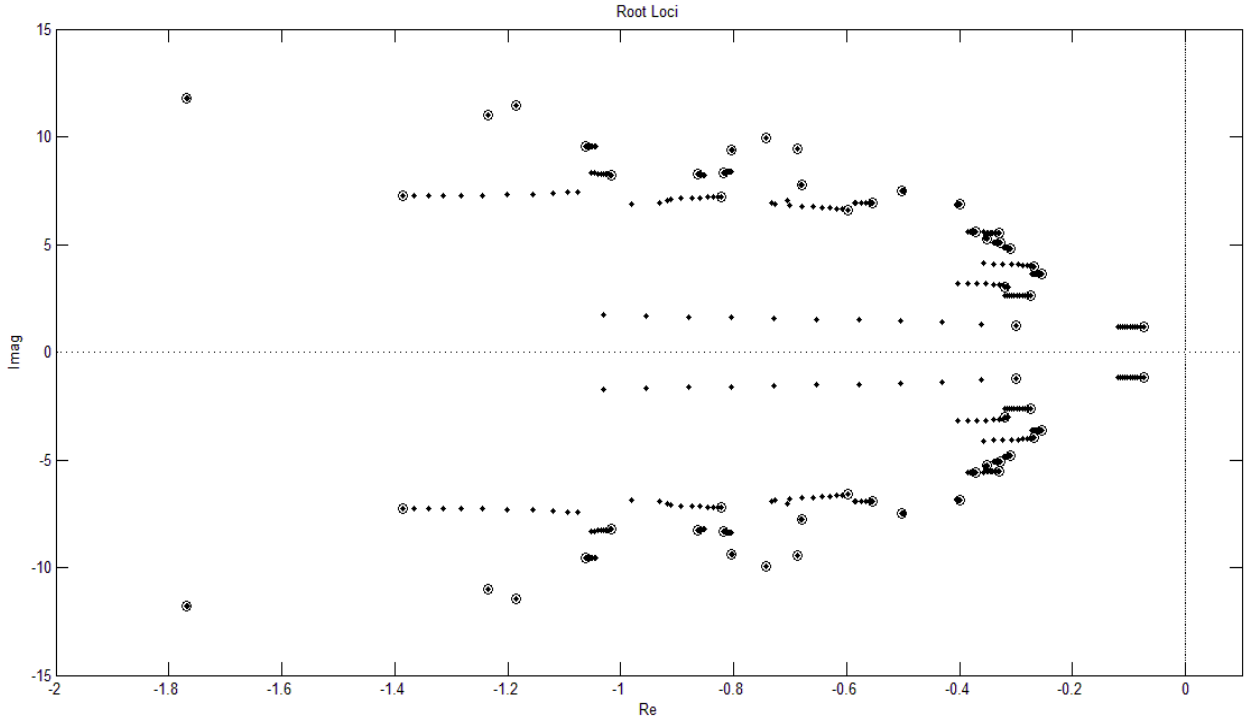


Figure 5.3.20: Root Locus plot for Case 3 using the proposed algorithm

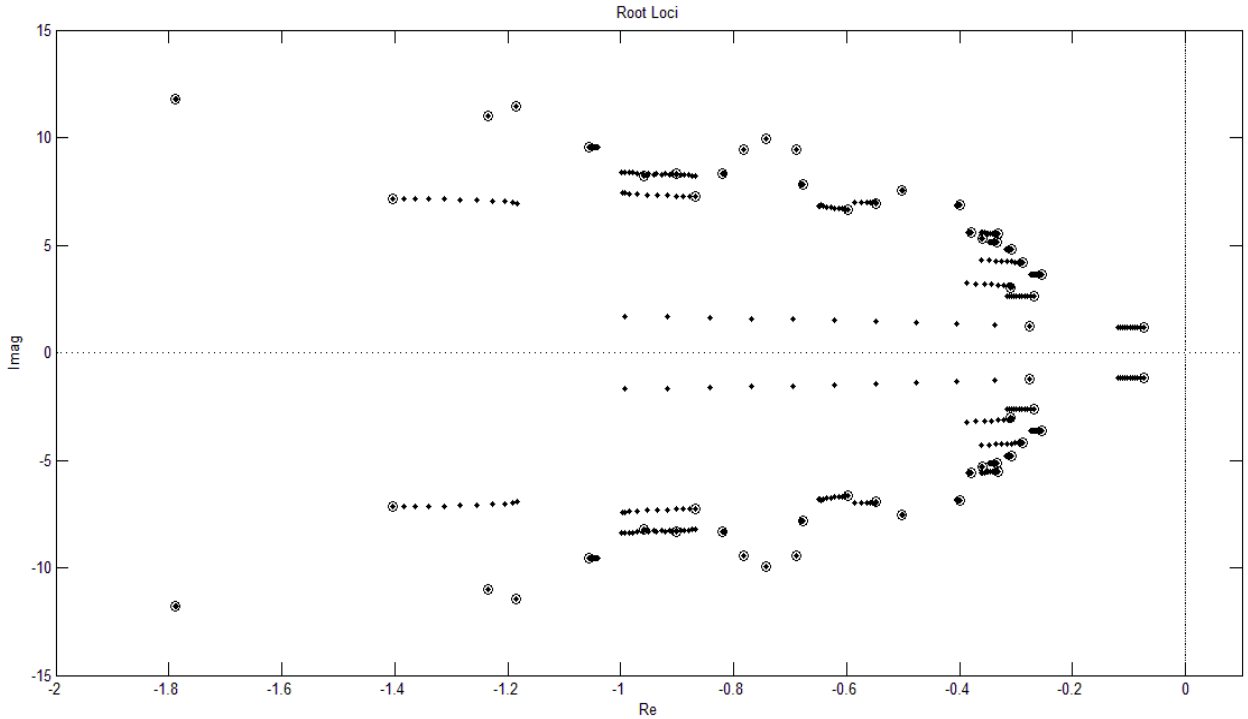


Figure 5.3.21: Root Locus plot for Case 4 using the proposed algorithm

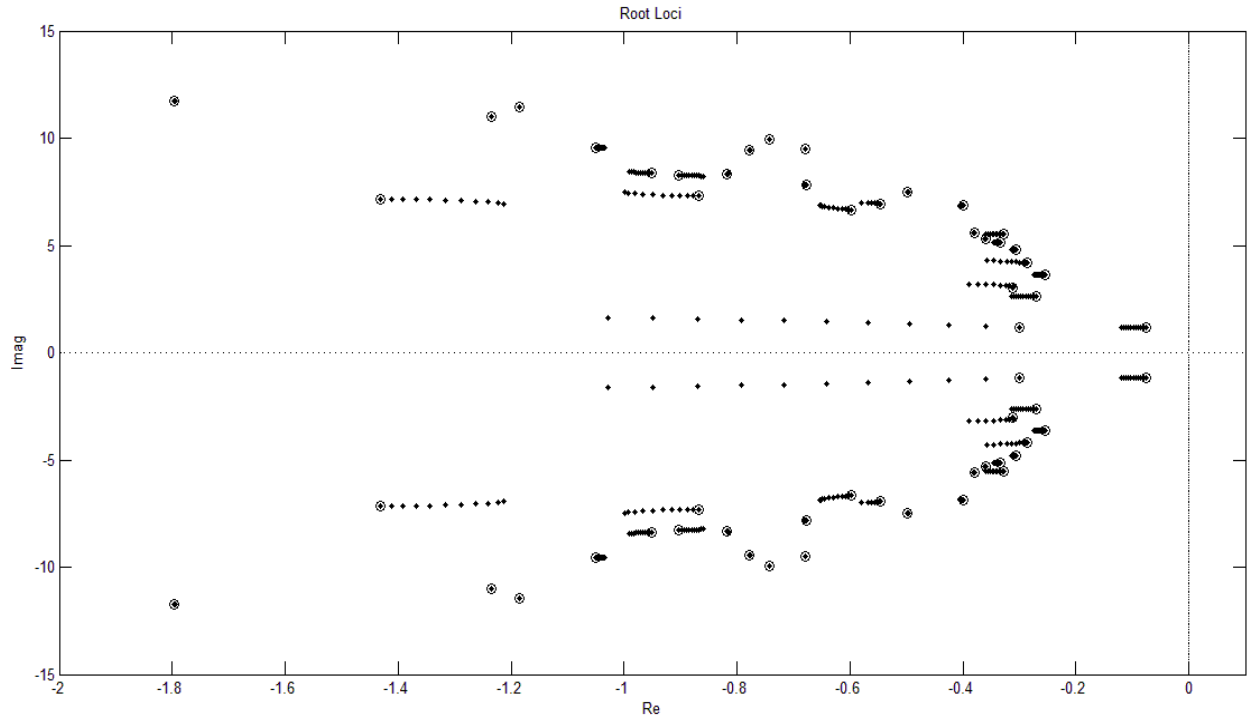


Figure5. 3.22: Root Locus plot for Case 5 using the proposed algorithm

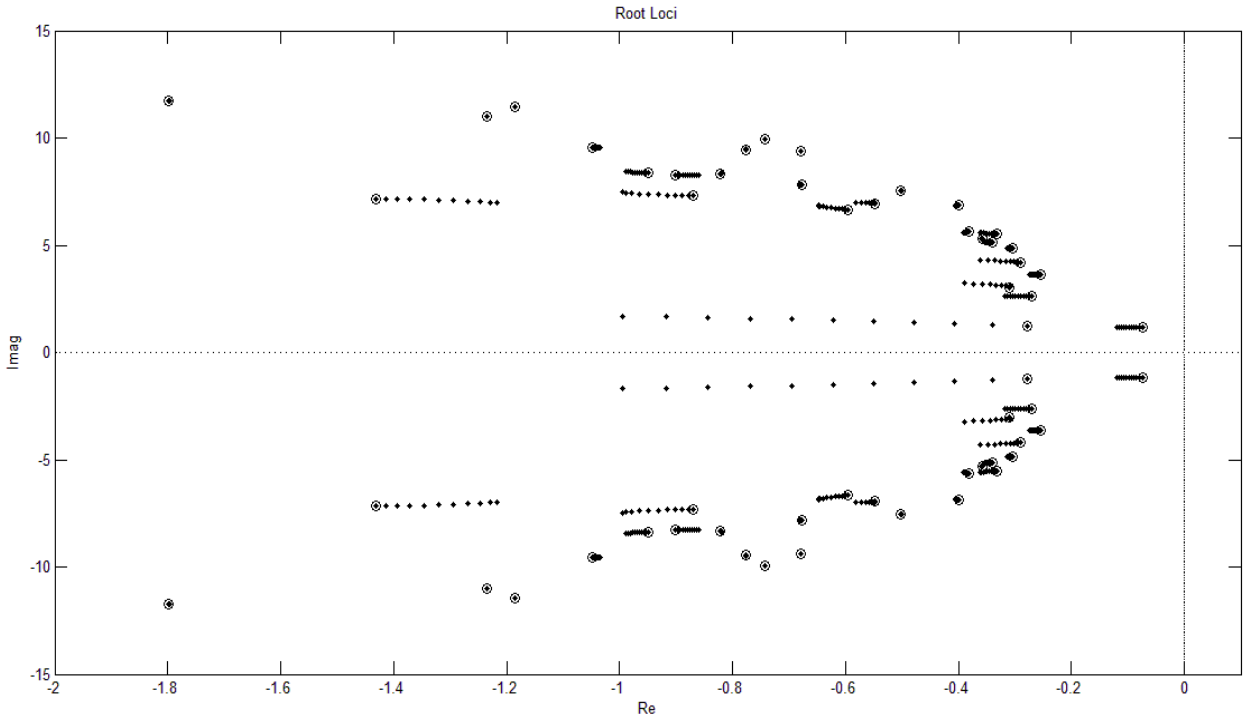


Figure 5.3.23: Root Locus plot for Case 6 using the proposed algorithm

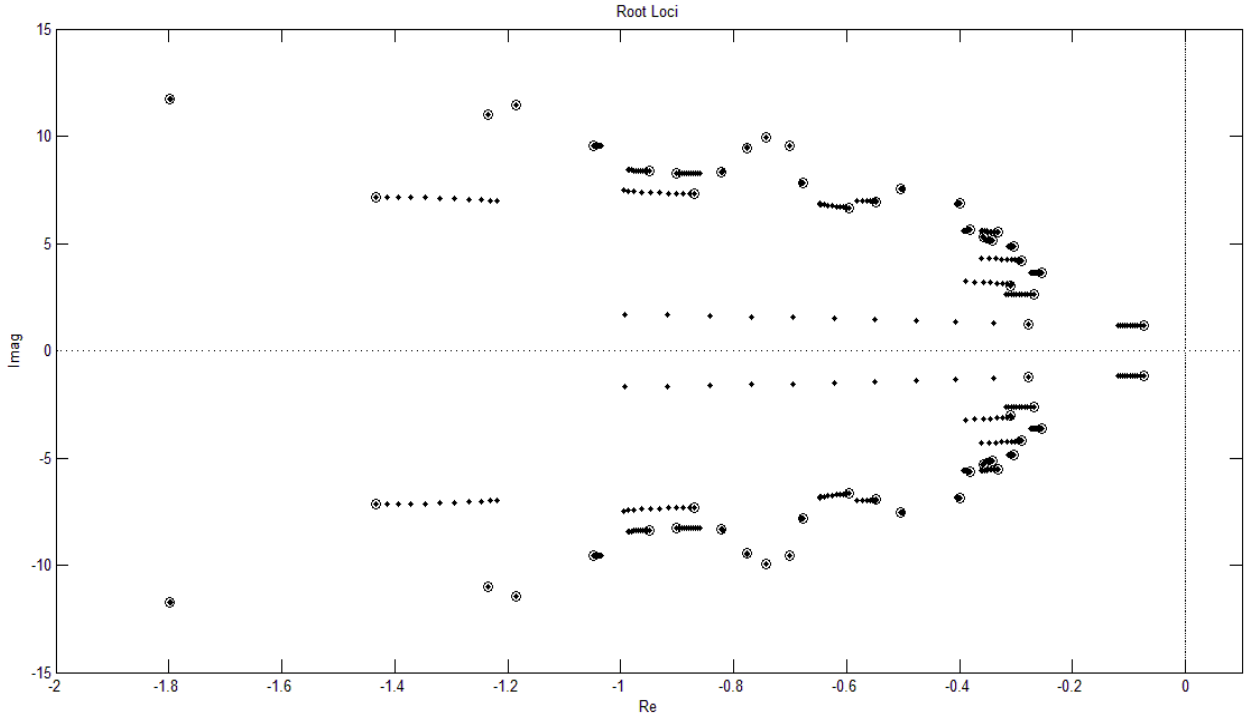


Figure 5.3.24: Root Locus plot for Case 7 using the proposed algorithm

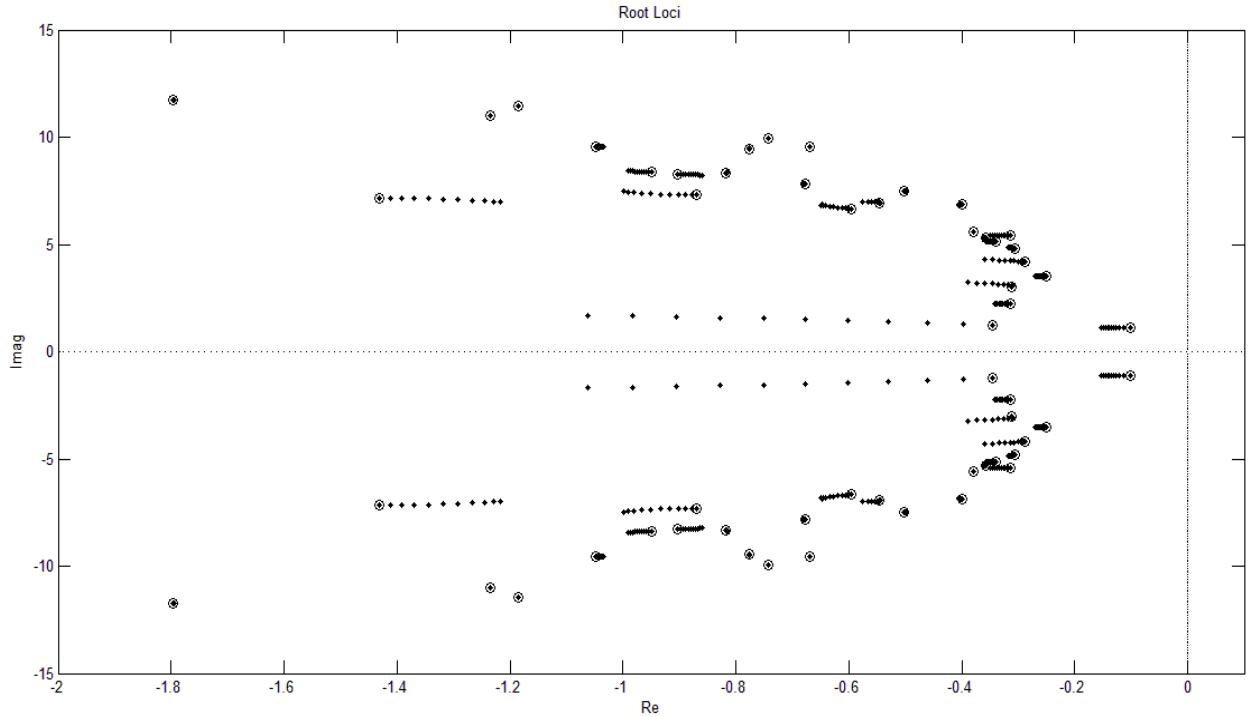
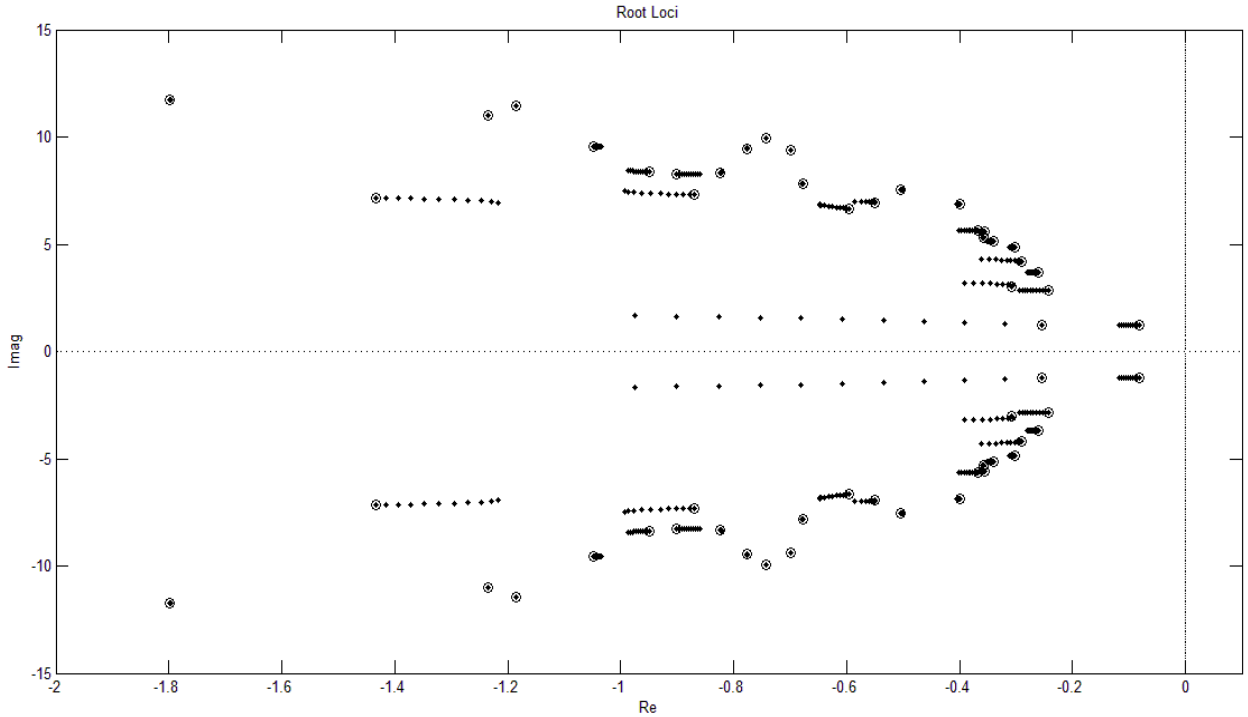


Figure 5.3.25: Root Locus plot for Case 8 using the proposed algorithm



5.3.3 Summary

This section applies the proposed algorithm to two power system problems – a 16 machine, 68 bus system model of the New England-New York inter-connected power system and a 29 machine, 127 bus equivalent model of the WECC system. The system size is reduced to the relevant modes of oscillations in both cases, and the polytopic model develops the control from the reduced system. The results show that all the low-frequency inter-area modes of oscillations are adequately damped along with most of the local modes. The flexibility of the proposed method is made obvious by its ability to combine different types of controllers to develop an integrated form of control. Finally, the fact that such a reduced version of the original system is capable of producing such good control is a clear indication of the robustness of the method developed herein. Matlab had been used till now for performing the simulations. The next chapter describes how this control can be transferred to other power system simulators.

5.4 Testing and Evaluation of PSLF Results

The simulations till now had been performed in Matlab, but as the model of the actual system was in PSLF, the proposed control had to be transferred to PSLF to implement it on the real system. In order to do this, an intermediate 29 machine system was created in PSLF which was similar to the system in Matlab but was closer to the actual system currently in existence. The control developed in Matlab was then applied to this system in PSLF. The gain of the control had to be adjusted to produce the desired effect on the inter-area modes of oscillations. However, the local modes were found to be relatively unaffected. The reason for this was attributed to the fact that the models in Matlab and PSLF were not identical to each other. It is suggested that if the two models are made more exact, the control results can also be made more alike.

The control developed for the 127-bus equivalent system in PSLF was then applied to the new model of the WECC System that was created in PSLF. In this big system, California is represented in detail by a 4000+ bus system whereas the "rest of WECC" is represented by a 67-bus equivalent network extracted from the 127-bus model. Since the "rest of WECC" was similar to that extant in the 127-bus model, the control for that portion of the big system remained the same. The only change needed was to find real measurements for the California region in the big system corresponding to the equivalent measurements obtained in the 127-bus system. This chapter summarizes the procedure followed for creating the new model and the results subsequently obtained.

5.4.1 29-Machine Model of WECC System

The output of the LMI control developed in the Matlab suite Power System Toolbox (PST) is a gain matrix K. Its rows correspond to the number of controls present in the system whereas its columns correspond to twice the number of machines that are to be controlled. The reason for it being two times the number of controlled machines is that the first half is associated with the

generator angles (δ) whereas the second half is associated with the generator speeds (ω). Therefore, the K matrix for the 29 machine model has a dimension of 6×42 as it has 6 controls and 21 machines that are controlled, as illustrated in the previous chapter.

Now, the control vector (u) corresponding to the gain matrix (K) and the state vector (x) is given by,

$$u = -Kx \tag{5.16}$$

For the ith control, the increment in the control can be denoted as,

$$\Delta u_i = -[k_{i1} \quad k_{i2} \quad \dots \quad k_{i42}] \begin{bmatrix} \Delta \delta \\ \Delta \omega \end{bmatrix} \tag{5.17}$$

Also, let the initial load at the bus corresponding to the ith control be $P_i + jQ_i$. Then, based on the type of controller, the following changes can occur.

Case 1: When the ith control is a SVC

Since an SVC controls the voltage magnitude, it primarily affects the reactive power of the bus on which it is placed. Now, if the reactive power output of that bus at time step t be Q_i^t, then the new output at time step $t+1$ can be found to be,

$$Q_i^{t+1} = Q_i^t + \Delta Q_i^t \tag{5.18}$$

Where,

$$\Delta Q_i^t = -[k_{i1} \quad k_{i2} \quad \dots \quad k_{i42}] \begin{bmatrix} \Delta \delta_i^t \\ \Delta \omega_i^t \end{bmatrix} \tag{5.19}$$

In (4.4), $\Delta\delta_i^t$ and $\Delta\omega_i^t$ represent the change in the generator angles and the generator speeds of the machines being controlled. Mathematically, they are expressed as,

$$\Delta \delta_i^t = \delta_i^t - \delta_i^{t-1} \tag{5.20a}$$

And,

$$\Delta \omega_i^t = \omega_i^t - \omega_i^{t-1} \tag{5.20b}$$

As the control is fed back after one time-step, it is necessary that the time step be small for the control to remain effective. This condition is satisfied during the modeling in PSLF by setting the time-step to be approximately 4 milliseconds.

Case 2: When the ith control is an ESD

As ESDs were modeled to control the real power outputs, they primarily affect the real power of the bus on which they are placed. Then, proceeding in a manner similar to that in the previous case, if the real power output of that bus at time step t be P_i^t, then the new output at time step $t+1$ is found to be,

$$P_i^{t+1} = P_i^t + \Delta P_i^t \tag{5.21}$$

Where,

$$\Delta P_i^t = -\begin{bmatrix} P_{i1} & P_{i2} & \dots & P_{i42} \end{bmatrix} \begin{bmatrix} \Delta P_1^t \\ \Delta P_2^t \end{bmatrix} \tag{5.22}$$

Case 3: When the ith control is a HVDC Line connecting buses (say) A and B

As the HVDC lines were modeled as active and reactive power injections, they affect both the real as well as the reactive powers of the buses which they connect. The modeling is done in a manner such that the real power enters through one end of the line and exits from the other end, whereas the reactive power enters the line at both ends. The reactive power input is set at approximately 30% of the real powers at either ends. Then, proceeding in a manner similar to that in the previous cases, if the real and reactive power outputs of the connecting buses A and B at time step t be $P_{i\ A}^t$, $Q_{i\ A}^t$, $P_{i\ B}^t$, and $Q_{i\ B}^t$ respectively, then the new outputs at time step $t+1$ are found to be,

$$P_{i\ A}^{t+1} = P_{i\ A}^t + \Delta P_i^t \tag{5.23}$$

$$Q_{i\ A}^{t+1} = Q_{i\ A}^t + 0.3 \times \Delta P_i^t \tag{5.24}$$

$$P_{i\ B}^{t+1} = P_{i\ B}^t - \Delta P_i^t \tag{5.25}$$

$$Q_{i\ B}^{t+1} = Q_{i\ B}^t + 0.3 \times \Delta P_i^t \tag{5.26}$$

Where,

$$\Delta P_i^t = -\begin{bmatrix} P_{i1} & P_{i2} & \dots & P_{i42} \end{bmatrix} \begin{bmatrix} \Delta P_1^t \\ \Delta P_2^t \end{bmatrix} \tag{5.27}$$

This completes the transfer process of the control.

In order to simulate the proposed control on the 127-bus model of the WECC system, an equivalent system was created in PSLF corresponding to the one developed in the Matlab suite PST. The two DC lines were modeled as power injections whereas the ESDs and SVCs were modeled as real and reactive power inputs respectively. The system was made more realistic by adding exciters and turbo-governors to the generators similar to that present in the real system. The reason for doing so is that the detailed model of the system had all the other elements in

place (exciters, power system stabilizers, turbo-governors etc). To make the control more effective in that system, it had to be tested on something similar to it, but not as complex.

It is important to note here that the presence/absence of exciters or turbo-governors did not affect the control developed in Matlab as the use of SMA had made the system sensitive to only the generator angles (δ) and the generator speeds (ω). Finally, a program was created in the Control Language Processor of PSLF i.e. EPCL, which performed the control transfer process described in the previous section. The generator angles obtained for the stable base case are shown in Figure 4.1.

In order to test the effectiveness of the control, a hitherto untested contingency (which was not part of the case bank used to develop the control) was applied to this system. The contingency that was simulated was a step change of 20% in the North-South HVDC Line extending from Celilo to Sylmar (Pacific DC Intertie), at time t = 1 second and lasting for 10 cycles. The reason for using this particular case was that previous studies on the 29 machine WECC model had shown that this particular contingency excited all the low frequency inter-area modes of oscillations present in the system. The oscillations produced in the system corresponding to this step input are shown in Figure 5.4.2.

For the development of the control, the differences in generator angles ($\Delta\delta$) and the generator speeds ($\Delta\omega$) for two consecutive time-steps were used as feedbacks. The loads of the control buses were updated based on whether the control was from a SVC, or an ESD, or a HVDC line. The plot of the generator angles at every time step was used as the response. Since PSLF does not compute the eigenvalues of the system, the success of the control was tested on the basis of the time-domain plots generated by the simulator. Also, PSLF can only plot six variables at a time. Therefore, in order to plot all the modes of oscillations and get a global view of the performance of the control, the output file of PSLF was synchronized with Matlab to generate the figures seen below.

Figure 5.4.1: Generator angles for Base Case of 29 machine model of the WECC system

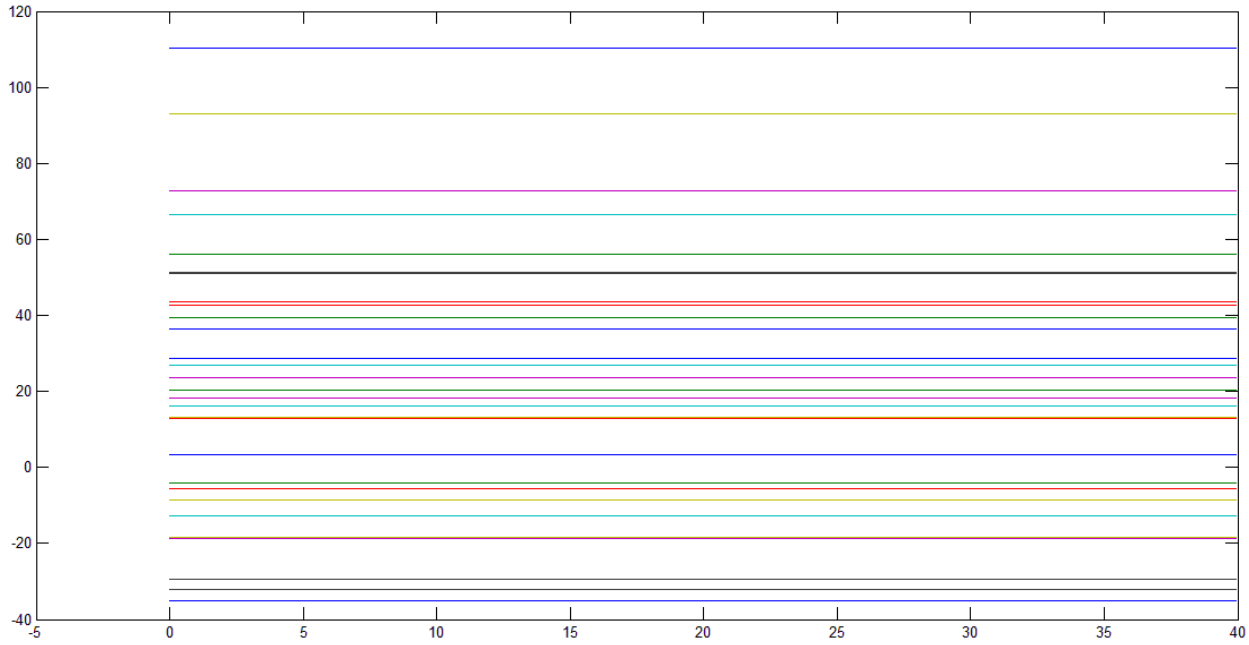
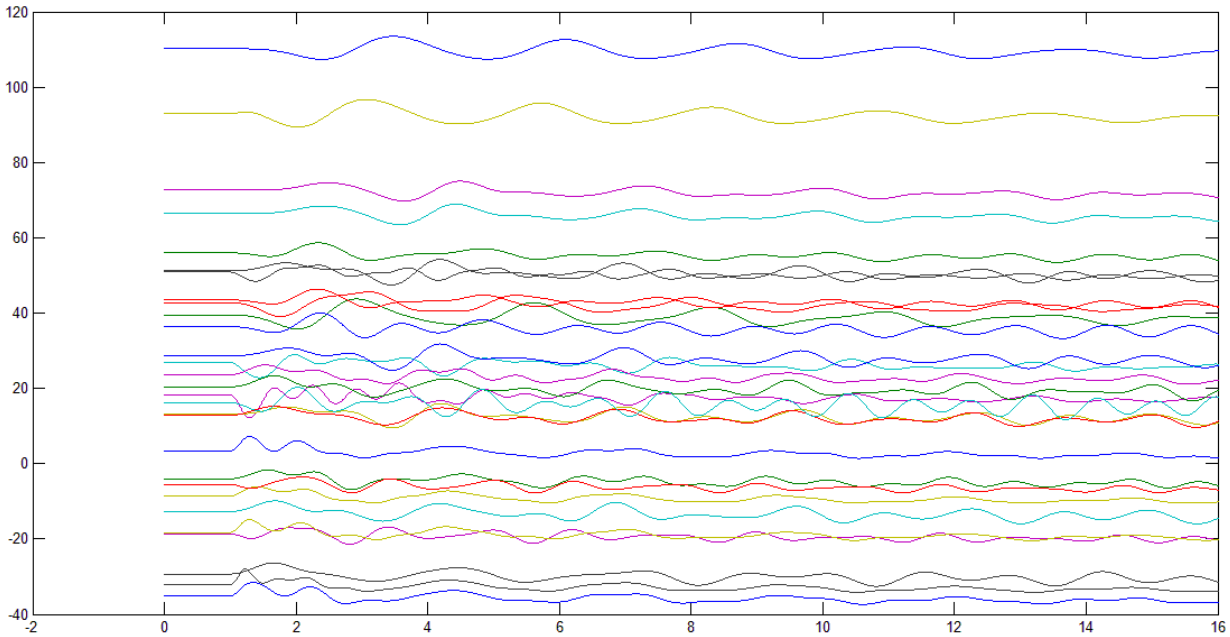


Figure 5.4.2: Oscillations due to a step input in the 29-machine system in absence of control



When the six-element control developed in Matlab was applied to this system, it was observed that the control did not have much influence on the damping of the oscillations. Therefore, in order to force the control further, the gain of the control was multiplied by a factor of two. The resulting plot obtained shown in Figure5.4.3, shows prominent signs of damping. Thus, the control was acting in the correct direction but it had lost some of its potency due to the

difference in the two models. Another fact which becomes clear from this analysis is that even though the gain of the control is doubled, none of the oscillations increase substantially, implying that there was no negative interaction amongst the controllers.

Figure 5.4.3: Oscillations due to a step input in the 29-machine system in presence of control

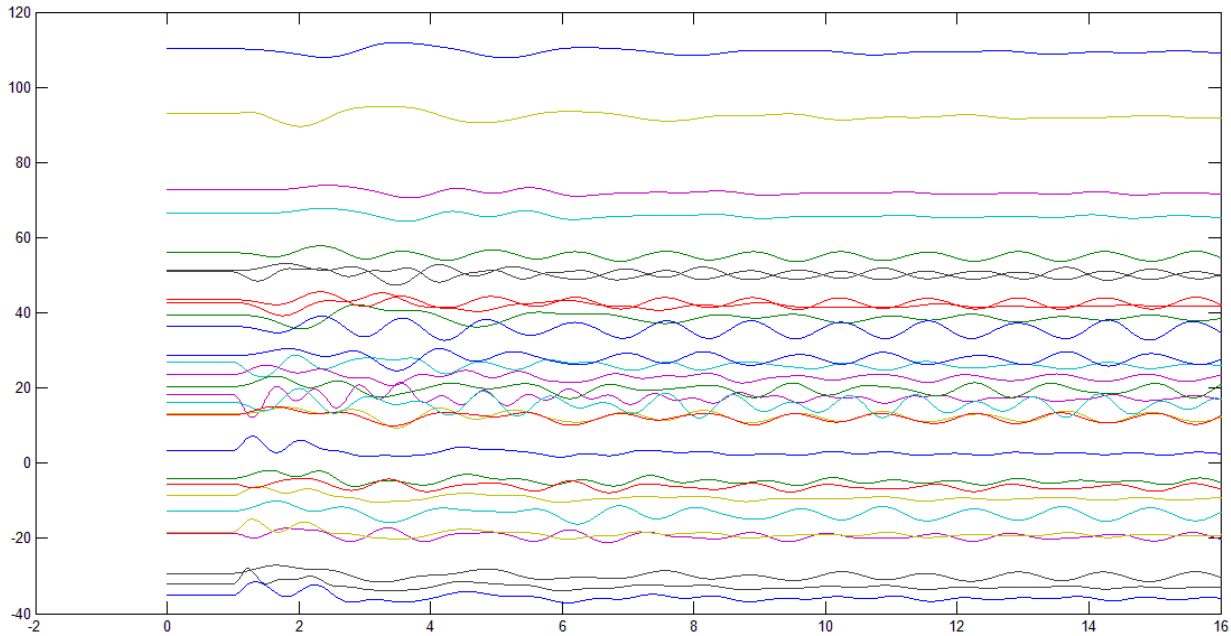


Figure 5.4.4 depicts the generator angles of five machines which had dominant inter-area modes of oscillations. The plot on the left is obtained when the control is absent whereas the one on the right is obtained when the proposed six-element control with twice the gain is applied to this system. From this figure, it can be inferred that by multiplying the gain by two, the control is able to –

- Reduce the number of ripples present in a given time frame
- Decrease the magnitude of the individual ripples

Figure 5.4.5 shows the generator angles of some of the machines which had dominant local modes of oscillations. As expected, although damping of some of the local modes either remains the same or is slightly decreased (due to the doubling of the gain), none of them become sufficiently high to make the system unstable. The fact that the local modes could not be damped as much as they had been in Matlab was attributed to the differences in the two models used. The inference that is drawn from this analysis is that if the two models are made more similar to one another, the results can also be made to look more alike.

Figure 5.4.4: Generator angles of five machines with dominant inter-area modes of oscillations (Left: No control applied; Right: Twice the control applied)

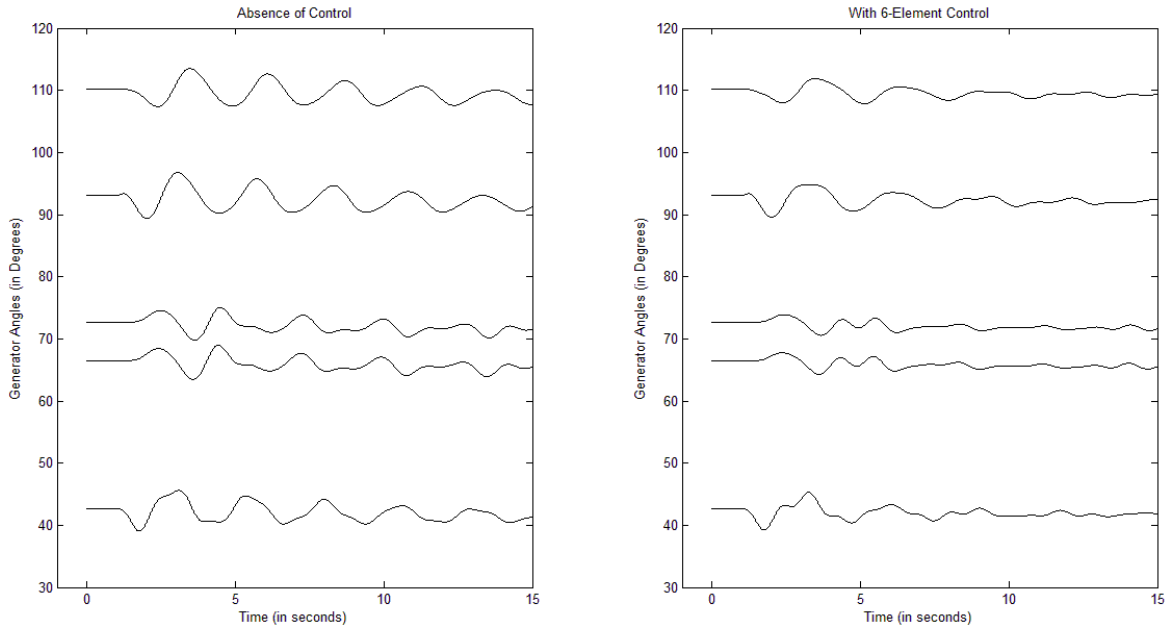
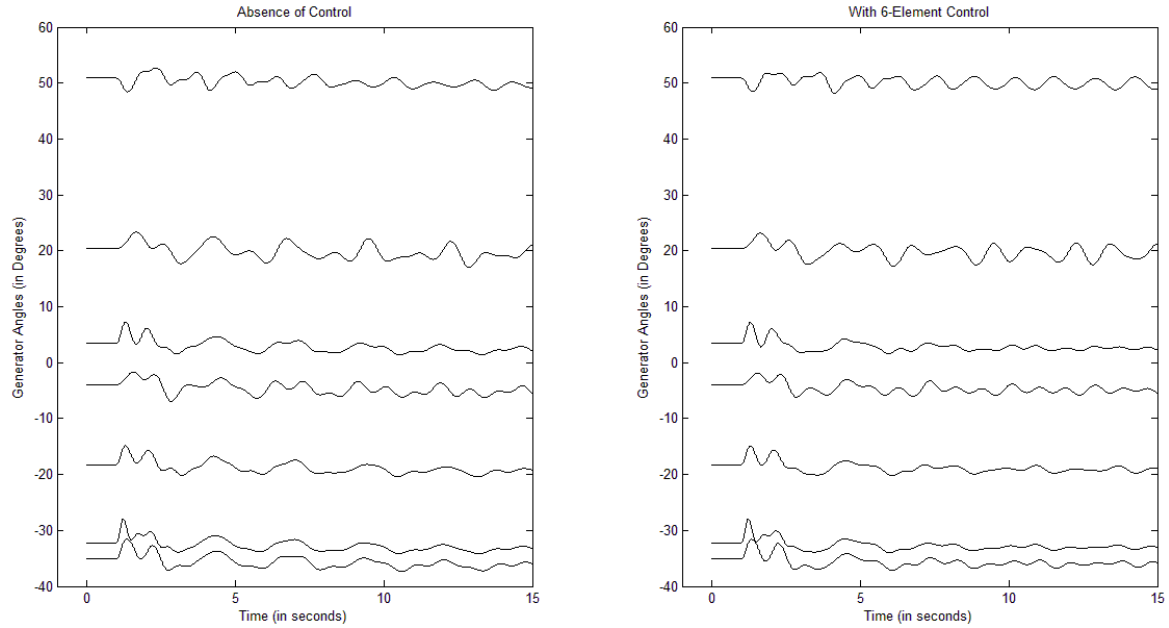


Figure 5.4.5: Generator angles of seven machines with dominant local modes of oscillations (Left: No control applied; Right: Twice the control applied)



In order to better examine the effect of the control on the inter-area modes, Prony Analysis was done on the uncontrolled and controlled waveforms. Prony extracts valuable information from a uniformly sampled signal and builds a series of damped complex exponentials or sinusoids. As compared to other oscillatory signal analysis techniques (such as Fourier), Prony has the

advantage of estimating damping coefficients apart from frequency, phase and amplitude. Moreover, it best fits a reduced-order model to a high-order system both in time and frequency domains [13]. It has been widely used in the areas of power systems, biomedical monitoring, radioactive decay, radar, sonar, geophysical sensing, speech processing etc. Figures 5.4.6 and 5.4.7 depict the two most critical inter-area modes of oscillations present in this system as identified by Prony Analysis. Similar results were obtained for the other inter-area modes. From these results, it becomes clear that the proposed control (with twice the gain) has been able to significantly improve the damping of all the inter-area modes of oscillations present in the system.

Figure 5.4.6: Lowest inter-area mode of oscillation present in 29 machine system (Left: No control applied; Right: Twice the control applied)

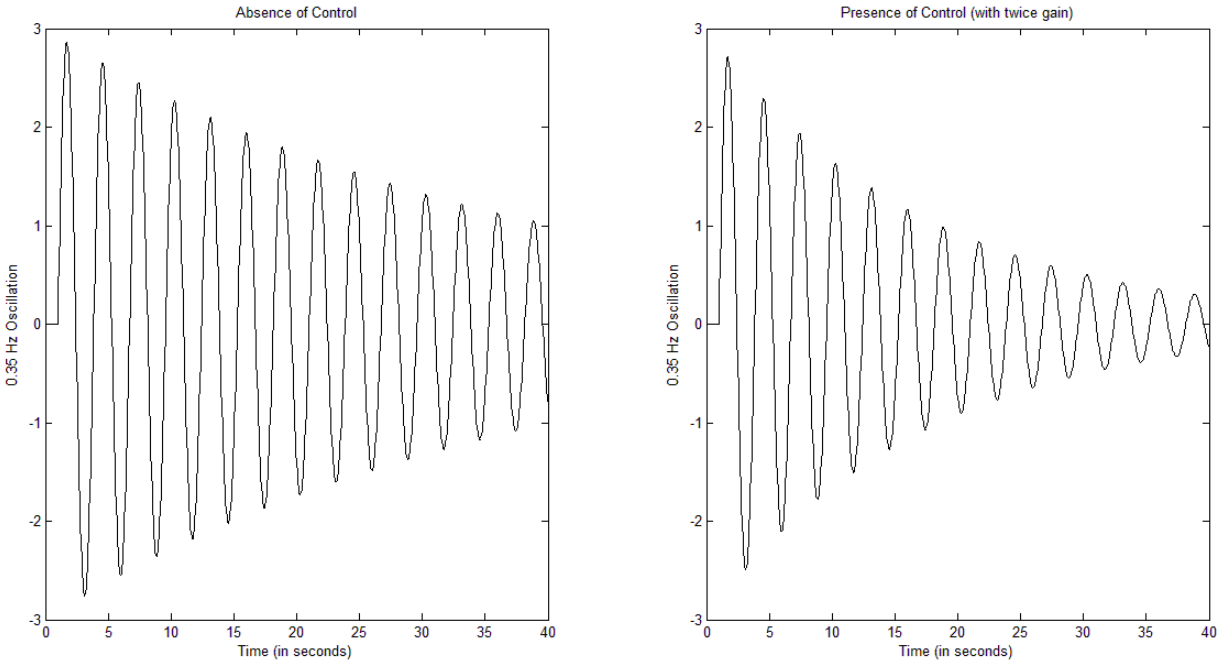
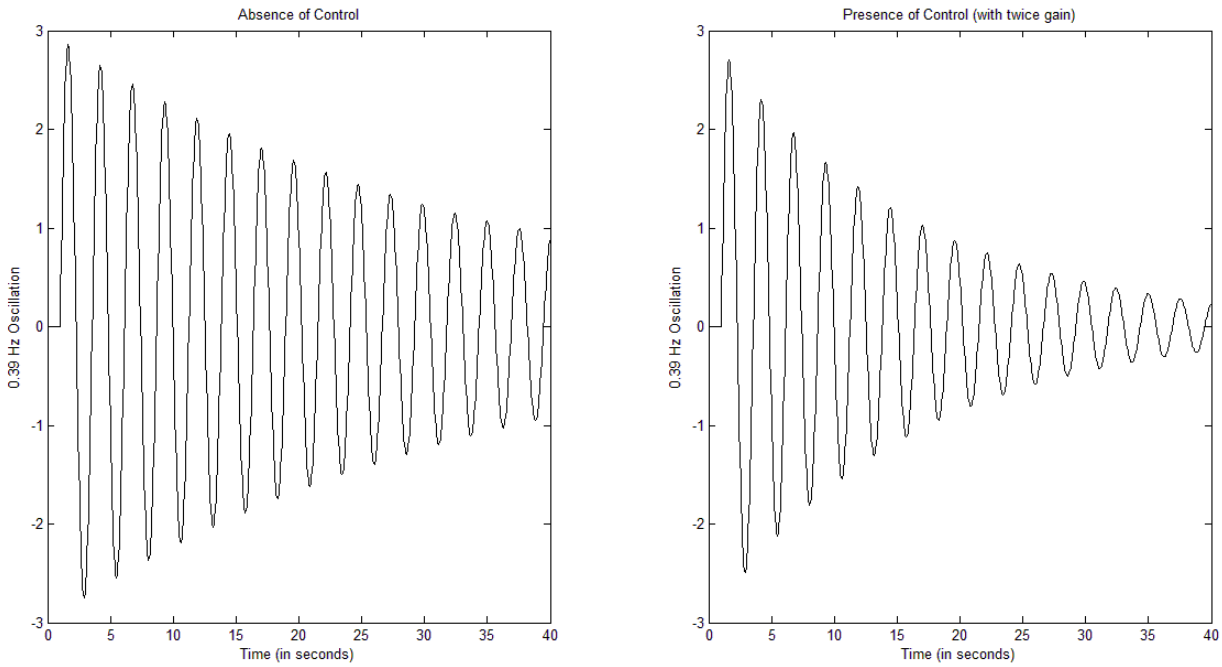


Figure 5.4.7: Second lowest inter-area mode of oscillation present in 29 machine system (Left: In absence of Control; Right: In presence of twice the control)



5.4.2 New California Model

There are three PSLF models of WECC that are currently available – the 127-bus Equivalent Model, the 4000+ bus California-only model(CA-only) and the 15000+ bus full loop model. The CA-only model has a detailed representation of the electric grid in California, whereas the rest of WECC is represented by 2 equivalent generators. Since a study of the modes of oscillations requires additional details (inclusion of generators that take part in the oscillation) outside California, it was decided that a new model be created. In the new Model of WECC, California is represented in detail by a 4000+ bus system and the rest of WECC is represented by a 67-bus equivalent network extracted from the 127-bus model. The 15000+ bus full loop model was used as a benchmark against which the new model was compared.

Modeling the California Network: The California network, being our area of interest, is modeled in detail. To ensure that the new model is as accurate, the California network was extracted from the 15000+bus model. The California grid is represented by the areas Imperial California (21), San Diego Gas & Electric (22), Southern California Edison (24), Los Angeles Department of Water and Power (26) and Pacific Gas & Electric (30). The buses that are represented by areas other than the utilities listed above were removed from the full loop model. A list of 28 tie lines that connect California to the WECC was compiled. The tie lines that carried power of 1 GW and above were retained in the new model also, whereas the other smaller interties were modeled as equivalent generators, since we have only a limited number of buses outside California with which to connect.

Table 5.4.1: List of Interties in Full Loop Model

Major Interties	From	To	MW	MVAR
Malin -RoundMt 1	BPA	PG&E	967	-17
Malin - RoundMt 2	BPA	PG&E	978	-148
Capt. Jack - Olinda	BPA	PG&E	1194	-295
Moenkopi – Eldordo	Arizona	SCE	1098	-29
PaloVerde - Devers	Arizona	SCE	1162	18
Navajo - Crystal	Arizona	LADWP	1165	-32
Hassyamp – N. Gila	Arizona	SDG&E	985	166
Net Inflow			7549	

The remaining 21 interties were modeled as generators. To avoid any complications in the dynamic response of the network, these generators are converted into constant PQ loads, during dynamic simulation.

Modeling the "Rest of WECC' Network: The "rest of WECC" network is extracted from the 127-bus equivalent model of the WECC system. The interties connecting California and the rest of WECC in the equivalent model were identified. They are summarized in Table 5.3.5 in the previous chapter and are repeated here for convenience.

Table 5.4.2: List of Interties in 29-machine model

Major Inter-ties	Real Power (MW)	Reactive Power (MVAR)
Malin – RoundMt 1	982	66.7
Malin – RoundMt 2	971	78.4
Malin – Olinda	1150	-35.4
Moenkopi – Eldordo	993	-57.4
Navajo – Eldordo	843	98.4
PaloVerde – Devers 1	903	45.6
PaloVerde – Devers 2	903	45.6
Net Inflow	6745	

The 127-bus model is a relatively older model. When comparing Table 5.4.1 and Table 5.4.2, two issues become obvious:

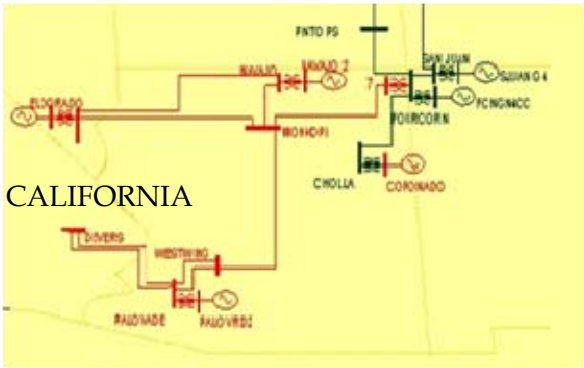
a) Buses North Gila, Hassyamp and Crystal are absent in the Equivalent model, and

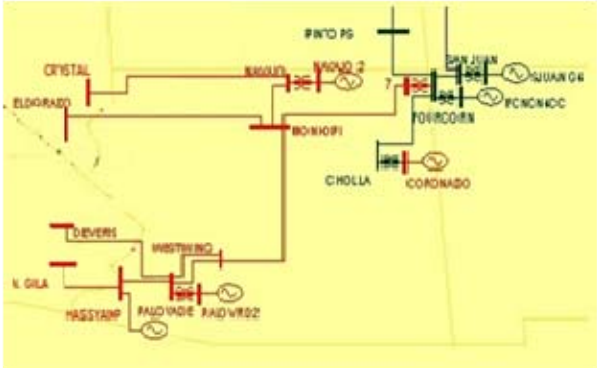
b) The net inflow is much less in the equivalent model.

These issues are addressed below.

Absence of important buses: North Gila, Hassyamp and Crystal are relatively newer substations, that are absent in the older 127-bus model. Since the inflows at these buses from Arizona is very significant (about 1 GW at each bus), inclusion of these buses is very important for obtaining an accurate model. Since there was no estimate of the equivalent for transmission lines connecting these buses with the rest of the equivalent network, the actual line parameters from the full loop model were taken as the initial values. These lines were made equivalents by performing Short Circuit analysis on these buses. The fault current on every transmission line connecting each of these buses, for a three phase fault was calculated from the full loop model. A three phase fault was placed on these buses in the Equivalent model, and the parameters of the new transmission lines were varied until the desired short circuit currents were obtained. These line parameters then represented the missing transmission lines. The changes made to the Equivalent network in the East of California are shown below.

Figure 5.4.8: Changes in Equivalent Network in the East



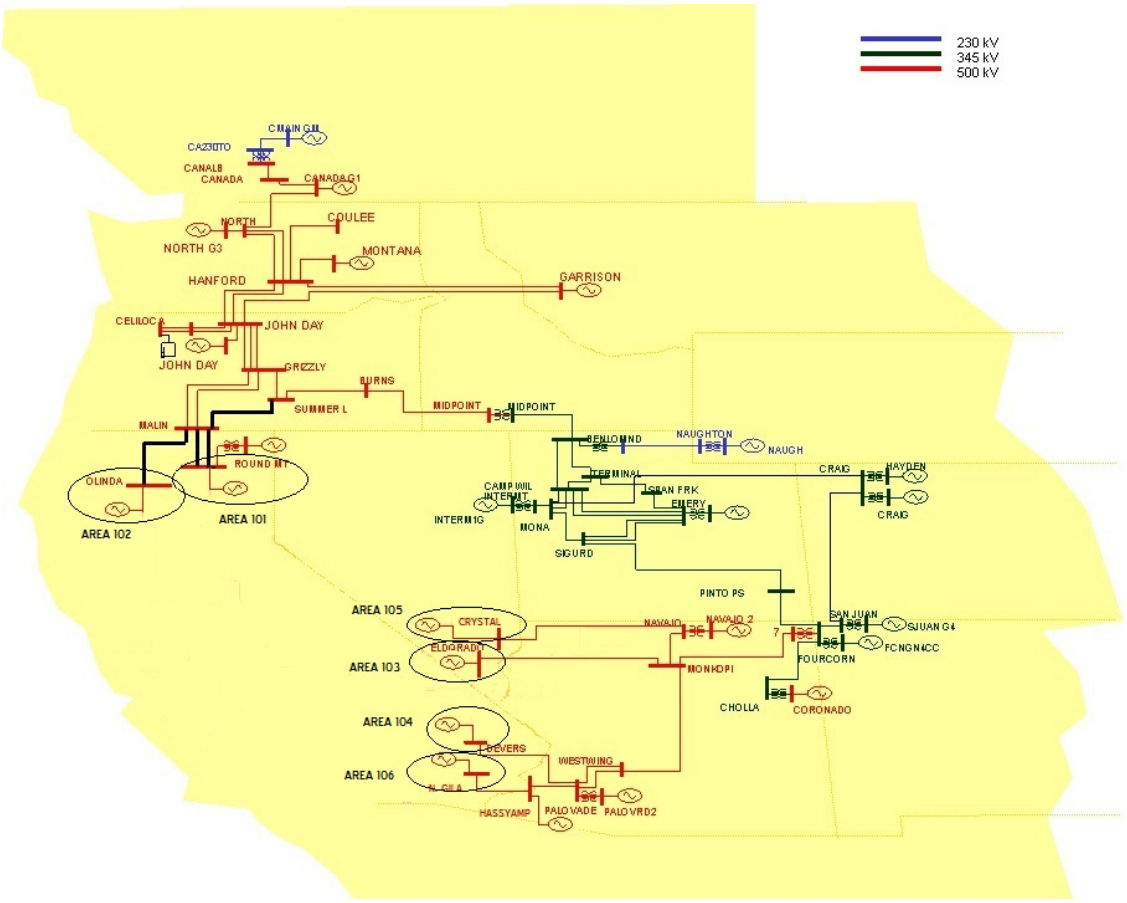


Reduced Inflows into California: In order to achieve the required inflows, the values of real power generation, P and Voltage magnitude, V at the generator buses in the equivalent network have to be modified. The new values of P & V at the generator buses were determined by performing a multiple swing bus load flow. The multiple swing bus load flow was achieved using the "Inter-area Exchange Control" tool of the PSLF. For using the Inter-area Exchange control, the following modifications were made to the equivalent network.

- The buses that belong to California (buses number 63 and above) were removed, except the boundary buses (RoundMt, Eldordo, Olinda & Devers) and the newly created Hassyamp, N. Gila & Crystal buses.
- A generator was connected to each of the 6 boundary buses. The real and reactive power generated by these generators is the same as the required intertie flows at these buses. Thus effectively, these 6 equivalent generators represent the California network.
- Each boundary bus and its generator were marked as an area. The buses are declared as area swing buses.
- The voltage profiles of the boundary buses were set the same as the voltage profiles of these buses in the Full Loop model. Since these buses were declared as swing buses, their voltage magnitude and angles was not changed.
- The real power and reactive power limits on all the generators and the voltage limits on all the buses were removed to enhance the possibility of achieving a working load flow.

Thus, the equivalent network has been split into 7 areas, including the rest of WECC as Area 0. The problem of adjusting the inflows into California has been modeled into a problem of achieving the required inter-area exchange flows between the 7 areas. The resulting equivalent network is shown in Figure 5.4.9.

Figure5. 4.9: Equivalent Network for Inter-area Exchange Control



The load flow is solved in PSLF with the Inter-area Exchange Control Tool. The real power output of the generator is modified to match the inter area exchange requirements. The values of the loads in the equivalent network are also adjusted. This procedure is repeated until the required intertie flows are as close to the desired values as possible. New loads were added on the equivalent end of the interties to adjust for the reactive power flow.

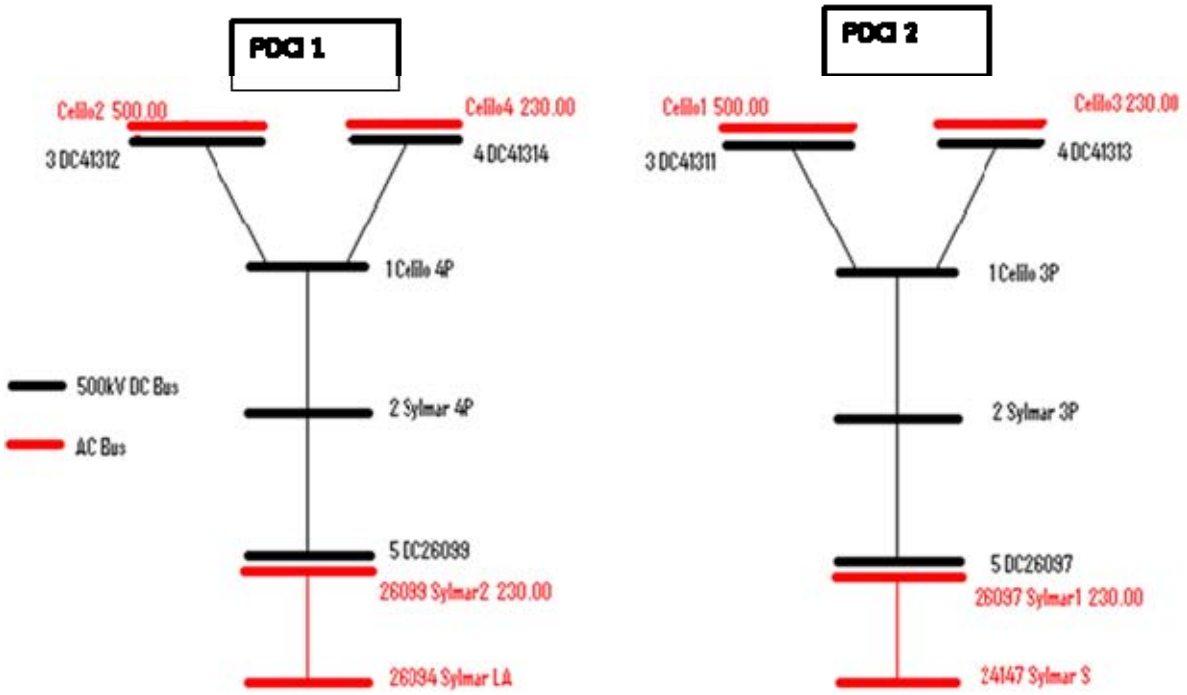
Integrating the Two Networks: The two networks described above – the detailed CA model obtained from the full Loop model and the 67-bus model obtained from the 127-bus equivalent model after correcting the flows, were integrated. The boundary buses and the 6 CA-equivalent generators were removed and replaced by the 4000+ detailed California model described in section II. Thus, the major interties were accounted for. For representing the other smaller interties, 11 small equivalent generators were introduced, with their P_{gen} and Q_{gen} being equal to the power carried by these interties in the full loop model. In order to remove any influence these fake generators may have on the dynamic response of the model, these generators are netted during the dynamic simulation. When generators are netted, they are represented as constant PQ-loads during the dynamic simulations, effectively curtailing their dynamic response. Thus, the new WECC model consists of a 4000+ bus network representing California in detail and a 67-bus 30-machine equivalent network representing the rest of the WECC, connected by 7 major tie lines and 11 equivalent generators representing smaller interties.

Modeling HVDC Lines: So far, the HVDC lines in our network have been replaced by constant PQ loads at Celilo & Sylmar (representing the Pacific DC Intertie) and at Inter-Mountain & Adelanto (representing the Inter-Mountain-Adelanto HVDC line) to reduce the complexity of the problem. With a working load flow for the new model at hand, it is easier to model the HVDC lines now.

Inter-Mountain – Adelanto HVDC Line: The Inter-Mountain – Adelanto HVDC Line is represented in PSLF by "epcdc" model dynamically. The "epcdc" model is used to represent a simple 2 terminal DC transmission. The parameters for the dynamic and load flow model are taken from the full loop model.

Pacific DC Intertie (PDCI): The Pacific DC Intertie originates at Celilo in the North in the BPA and terminates at Sylmar in the South in the LADWP area. The PDCI is represented in the Full Loop network by the multi-terminal DC transmission model "dcmt". The operation and control of the PDCI is carried out by a special user-written EPCL program, "pdci_ns3.p". The Celilo HVDC station is located in the equivalent network and the PDCI is represented by a single constant-PQ load at Celilo 230kV bus. In order to make use of the PDCI control program for an accurate representation of the HVDC line, the network around Celilo bus has to be modified. Figure5. 4.10 represents the configuration of the PDCI in the Full Loop Model.

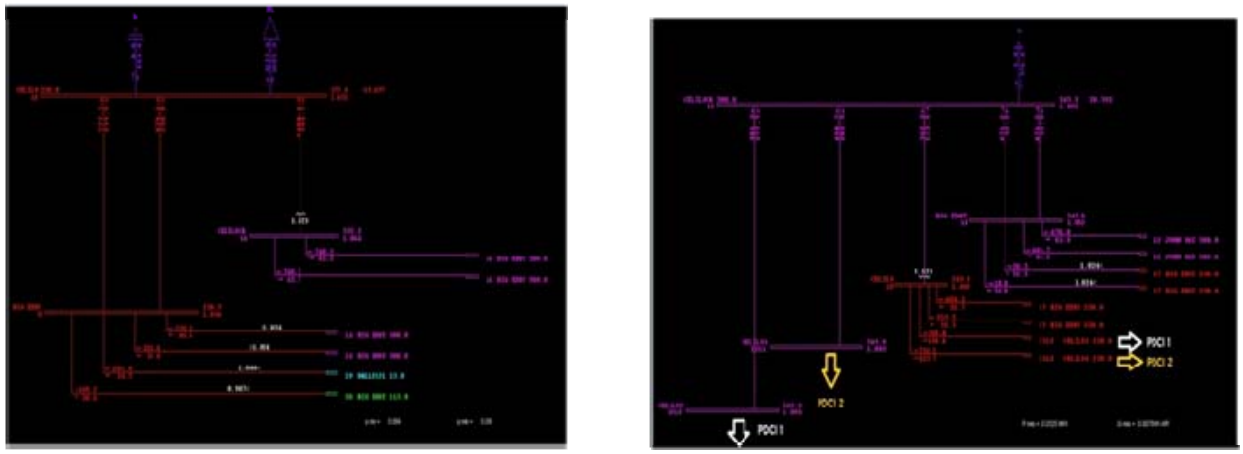
Figure 5.4.10 PDCI as represented in Full Loop Model



To obtain the same configuration as shown above, Celilo 230 kV bus (Number 18 earlier) and CeliloCA 500 kV bus (Number 16 earlier) in the equivalent network were bifurcated into 1313

Celilo3 230kV & 1314 Celilo4 230kV and 1311 Celilo1 500kV & 1312 Celilo2 500kV buses respectively. The PDCI was modeled in the load flow and dynamic data using these new buses. The parameters of the transmission lines connecting the new Celilo buses to the existing Celilo buses are set to the very minimum. Thus during load flow, these buses are jumpered (jumpered buses are considered as a single bus). This eliminates any change in the power flow solution due to the introduction of these new buses at Celilo.

Figure 5.4.11 Modifications to Celilo buses



Model Verification: The verification of this new model with the existing ones were carried out in two stages as described below.

Load Flow: Load flow was performed on the new model and the power flows along various paths and interties were verified against the corresponding flows in the full loop model. A comparison of intertie flows is presented in Table 5.4.3. As shown in Table 5.4.3, the inflows from the rest of WECC into California very closely match that of the full loop model. The reactive power mismatches are not significant enough to be a cause of concern. Power flows along important paths inside California were also verified. In addition to the major flows, the flows along the HVDC lines were also compared to ensure the accuracy of modeling of the HVDC lines, as shown below. Table 5.4.4 lists the differences observed in the AC power at each of the converters, between the full loop model and the new model.

Table 5.4.3: Comparison of Inter-tie flows

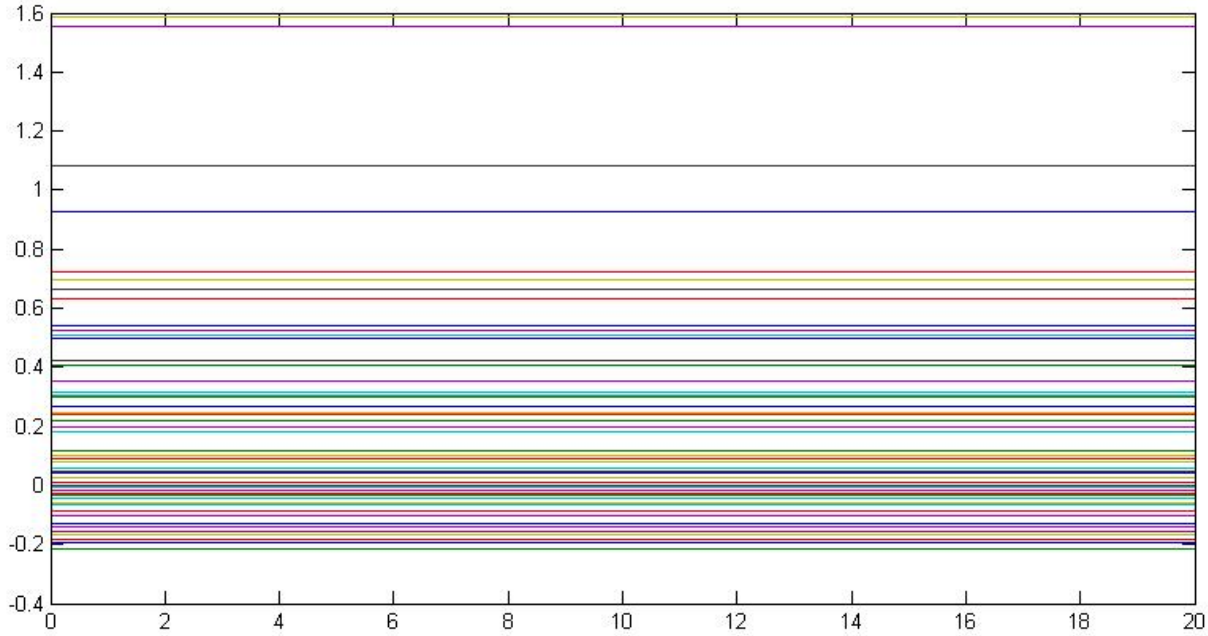
Major Inter-ties	Full WECC		New WECC	
	P	Q	P	Q
Malin – RoundMt 1	967	-17	990	-96
Malin – RoundMt 1	978	-148	999	-96
Malin – Olinda	1194	-295	1202	-190
Moenkopi – Eldordo	1098	-29	1077	-299
PaloVerde – Devers	1162	17.6	1192	117
Navajo – Crystal	1165	-31.5	1209	-128
Hassyamp – N. Gila	985.4	166	987	48.7

Table 5.4.4: Comparison of HVDC flows at Converters

				Difference	
FKV	**TO**	**TNAME**	**TKV**	**PAC**	**QAC**
345	1	INT MT1R	206	-0.2	-34.7
500	2	ADELAN1I	202	-6	-212.7
500	7	dc41311	500	0	-24.7
230	8	dc41313	500	0	-54.8
230	9	dc26097	500	0	5
500	11	dc41312	500	0	-25.1
230	12	dc41314	500	0	-55.9
230	13	dc26099	500	0	4.6

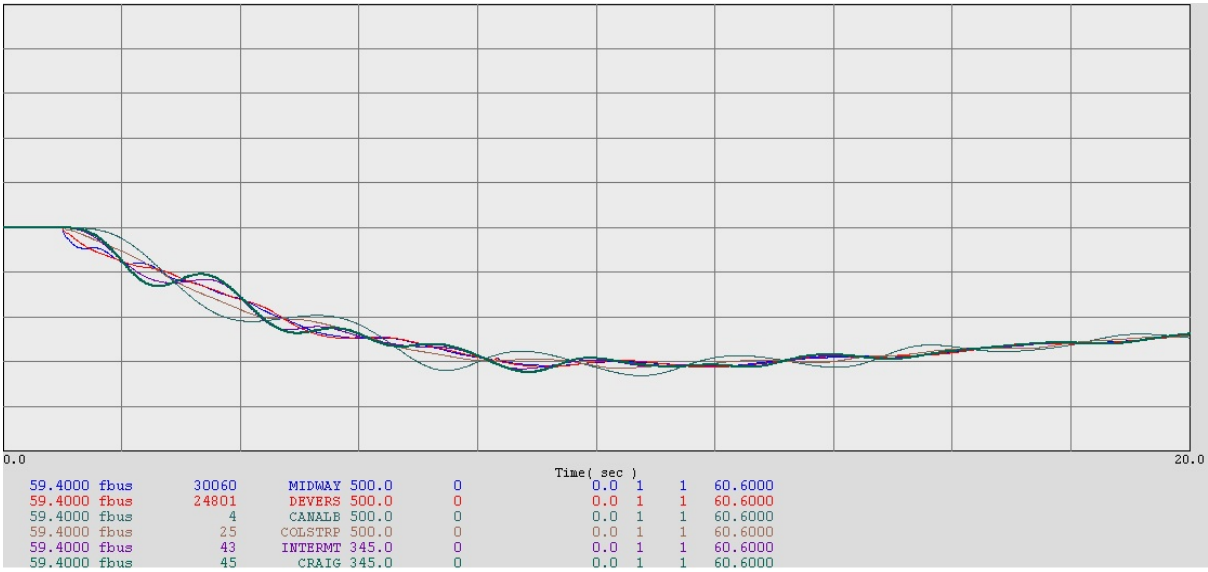
Dynamics: Dynamic simulations were also performed to verify the response of the new model. In order to check the accuracy of the initial conditions, a dynamic simulation was run for 20 seconds without any disturbances and the bus angles over the period of simulation were recorded and plotted in Figure 5.4.12.

Figure 5.4.12: Bus angles at High Voltage buses



Flat Voltage angle profile at all the buses throughout the simulation indicates that the model has a very good starting point for the dynamic simulation. Such a profile is necessary for any further dynamic analyses. The recorded frequency also stayed constant at 60 Hz, indicating a good steady state response and good initial conditions for the dynamic models. The dynamic response of the model for a few contingencies was also recorded. One such contingency is the loss of Diablo 1 generator (Pgen = 1180 MW), shown in Figure 5.4.13. The dynamic responses of the model for different contingencies were found to be similar to the responses of the full loop model proving that the modeling had been correctly.

Figure 5.4.13: Bus Angles after tripping Diablo I at t = 1 second



5.4.3 Application of Control to New Model

As the proposed technique was found to give encouraging results on the 127-bus model, it was now applied to the new model of the WECC System - whose creation is described in details in the previous section. In this new system, California is represented in detail by a 4000+ bus system whereas the "rest of WECC" is represented by a 67-bus equivalent network extracted from the 127-bus model. Since the "rest of WECC" was similar to what it was in the 127-bus model, the control for that portion of the big system remained the same. The only change needed was to find real measurements for the California region in the big system corresponding to the equivalent measurements obtained in the 127-bus system, as shown in Table 5.4.5.

Table 5.4.5: Selection of Measurements in the California region for the New Model

Machines in the 127-Bus Equivalent	Machines in the New Model
Mohav1CC (1680 MW)	MNTV-ST (1072 MW)
Miraloma (1690 MW)	San Onofr (2150 MW)
Litehipe (3195 MW)	AlamT G (2490.7 MW)
Tevatr2 (3467 MW)	Dukmoss (2858.3 MW)
Round Mt. (1057 MW)	Hyatt (700 MW)

Figures 5.4.14-5.4.20 compare the damping obtained in the absence and presence of the proposed control on the new model for the seven contingency cases outlined in the polytope. As the number of generators were too many in this system (more than one thousand), and as inter-area oscillations are system-wide phenomena, the real power flow across the seven tie-lines present in the system was used for comparison purposes. The plots on the left corresponded to those without control whereas the ones on the right represented those with control. The plots were obtained as a result of Prony Analysis done on the original waveforms. But from these figures, it was realized that a single case (out of the list of seven contingency cases) is not able to excite all five of the inter-area modes of oscillations that are present in this system. Therefore, we were in need of a new contingency case which would simultaneously excite all the inter-area modes of oscillations that are present in this system and thereby act as a suitable test to measure the robustness of the proposed control.

Figure 5.4.14: Comparison of damping w.r.t. Dominant Modes for Second Case

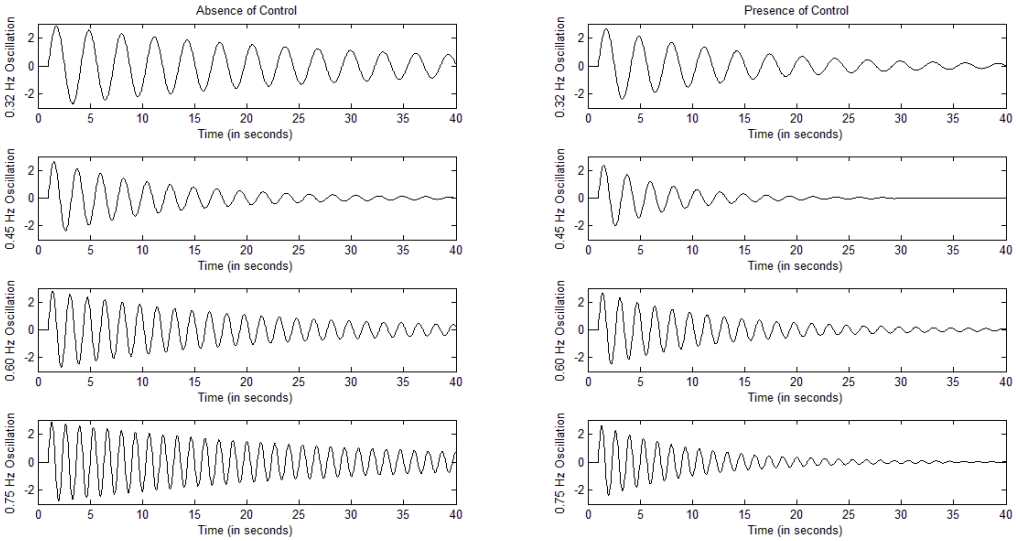


Figure 5.4.15: Comparison of damping w.r.t. Dominant Modes for Third Case

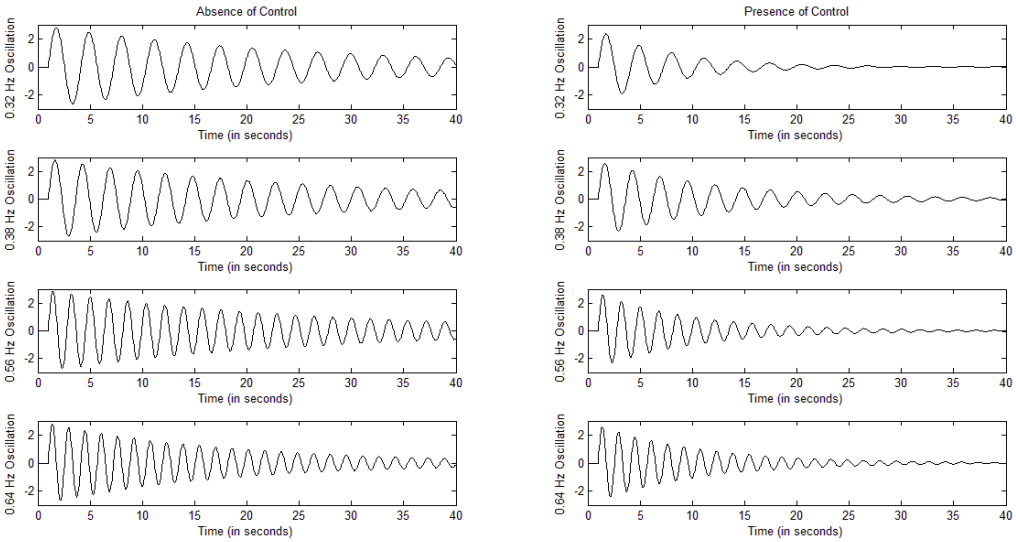


Figure 5.4.16: Comparison of damping w.r.t. Dominant Modes for Fourth Case

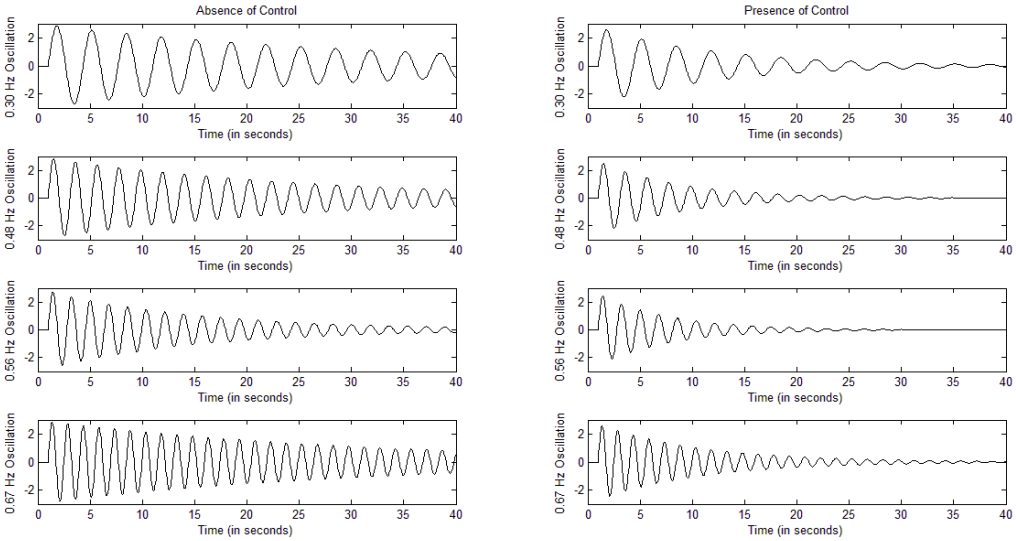


Figure 5. 4.17: Comparison of damping w.r.t. Dominant Modes for Fifth Case

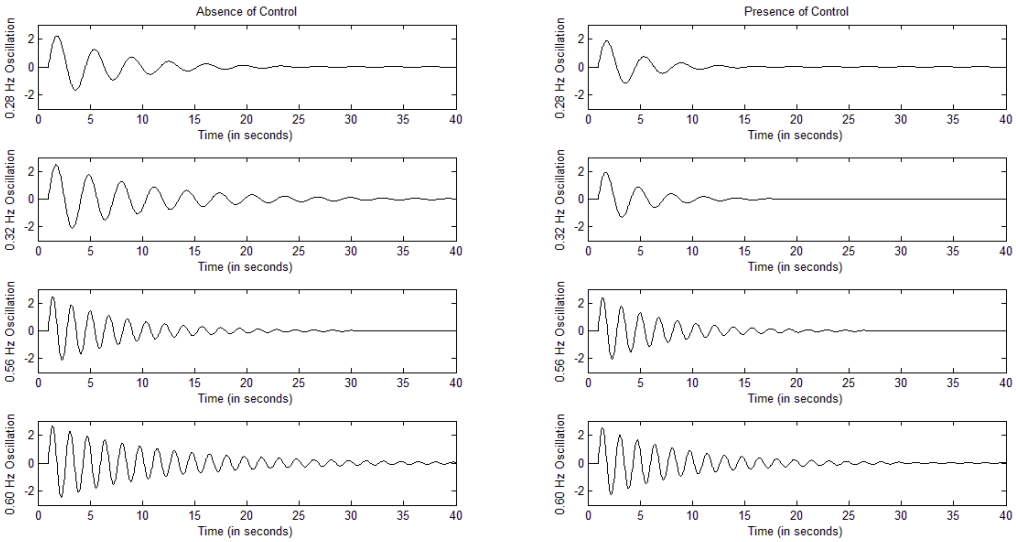


Figure 5.4.18: Comparison of damping w.r.t. Dominant Modes for Sixth Case

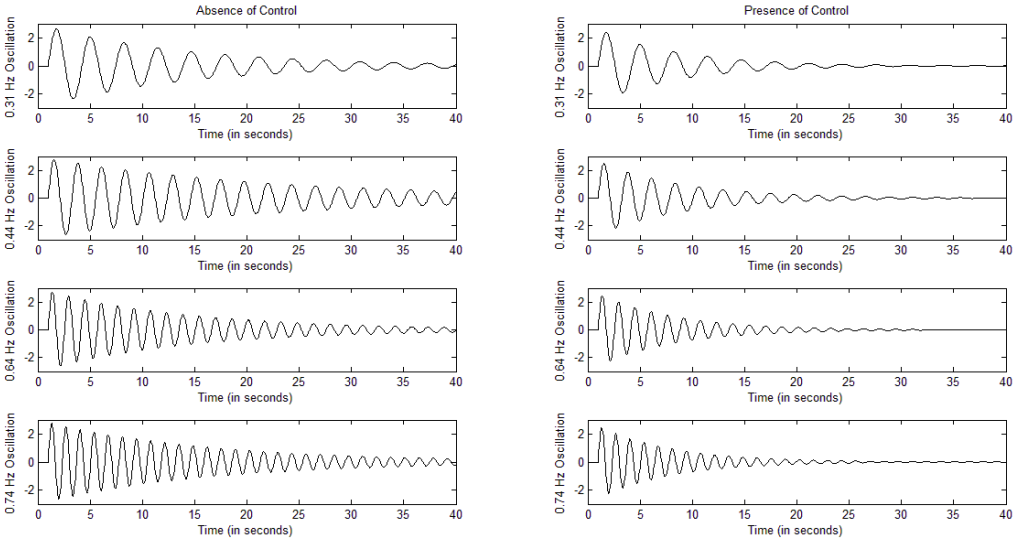


Figure 5.4.19: Comparison of damping w.r.t. Dominant Modes for Seventh Case

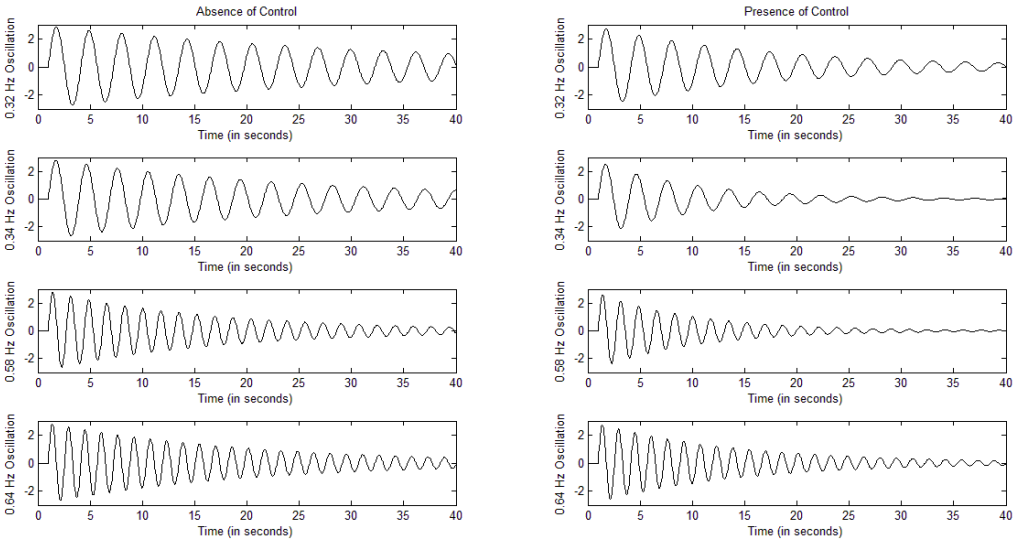
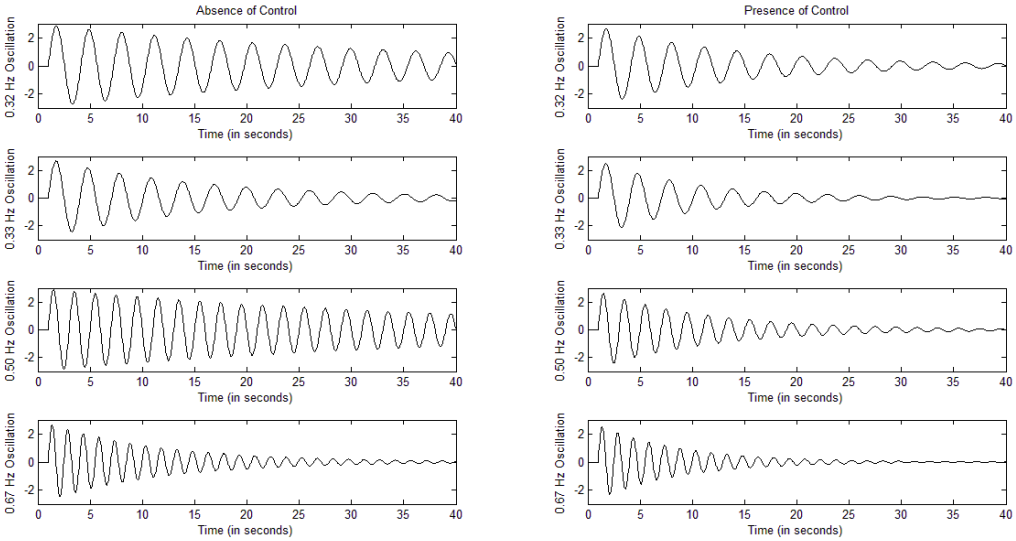


Figure 5.4.20: Comparison of damping w.r.t. Dominant Modes for Eighth Case



Based on analysis done previously on this system, a step change of 40% in the North-South HVDC Line extending from Celilo to Sylmar (Pacific DC Intertie), at time t = 1 second and lasting for 10 cycles was found to be a suitable contingency that would simultaneously excite all the inter-area modes of oscillations present in the new model. Figure 5.4.21 shows the oscillations taking place in the seven tie-lines corresponding to this contingency.

Figure 5.4.21: Oscillations in tie-lines due to a step input to the new model (absence of control)

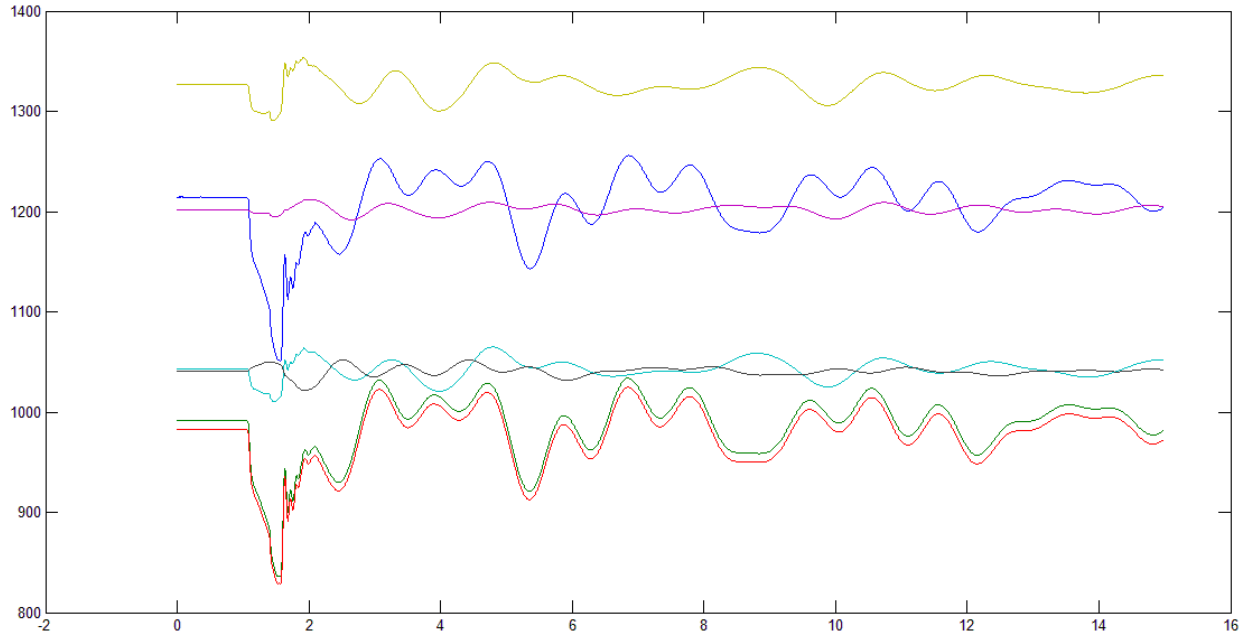


Figure 5.4.22 depicts the oscillations in the tie-lines when the control developed using the 127-bus equivalent model is applied to this big system. Figure 5.4.23 shows the control in action as it tries to damp the oscillations occurring in the system. In order to better examine the effect of the control on the inter-area modes, Prony Analysis was done on the uncontrolled and controlled waveforms. Table 5.4.6 summarizes the results obtained on performing Prony Analysis on the waveforms obtained on simulating this contingency. It confirms that the proposed control is able to increase the damping of the dominant inter-area modes observed in the respective tie-lines. Based on this observation, Table 5.4.7 is created to compare the improvement in damping corresponding to the dominant inter-area modes present in the system.

Figures 5.4.24-5.4.27 depict the four prominent inter-area modes of oscillations present in this system as identified by Prony Analysis. It is worthwhile to note here that the control logic developed on the basis of a small, equivalent system is able to improve the damping of all the inter-area modes of oscillations present in a much larger and complex system, that too for an untested contingency. This, if nothing else, clearly illustrates the huge advantage of using an LMI-based polytopic approach for the development of control for power system applications.

Figure 5.4.22: Oscillations in tie-lines due to a step input to the new model (presence of control)

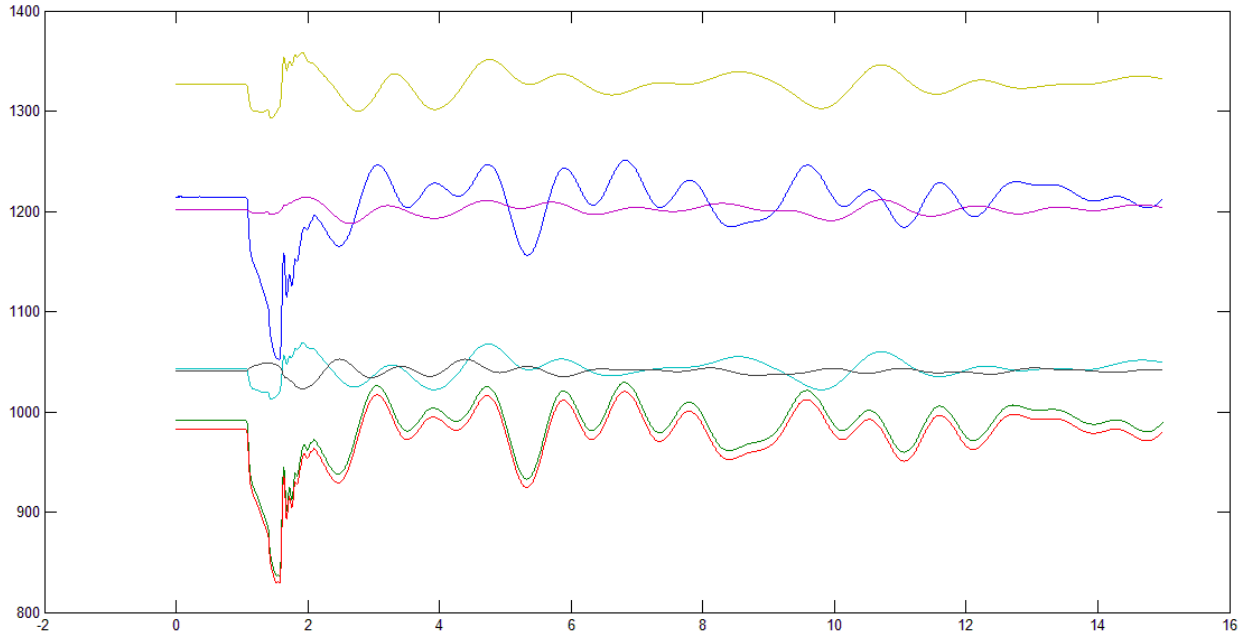


Figure 5.4.23: Change in the power flow across PDCI in response to the applied control

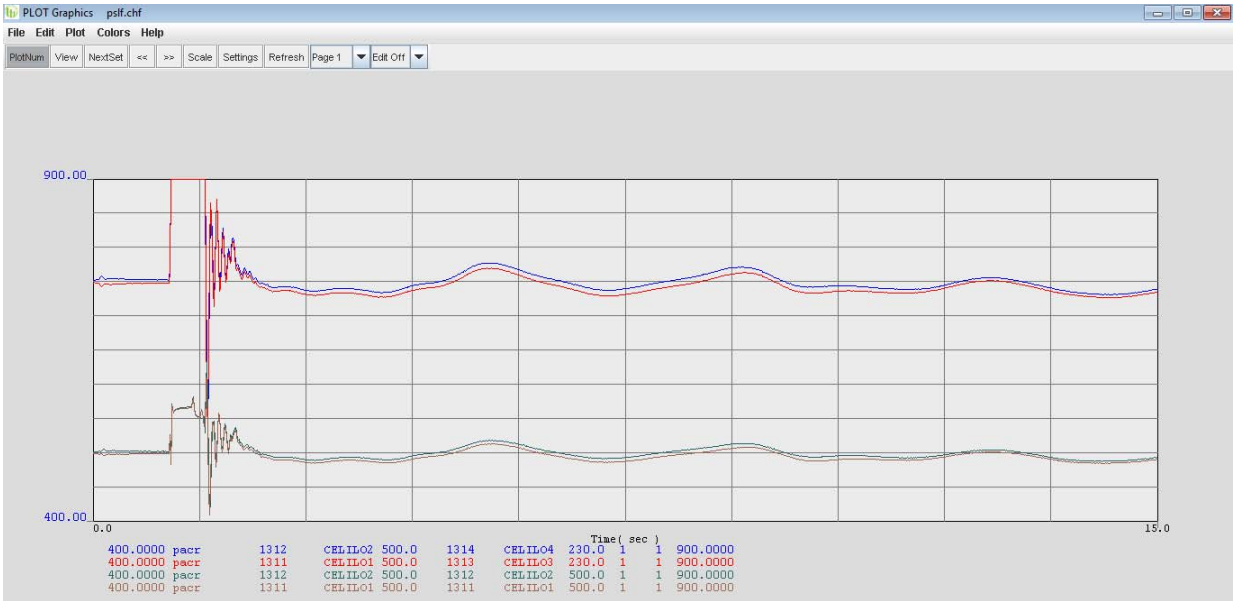


Table 5.4.6: Comparison of Damping with respect to Tie-lines

Major Tie-lines	Observed Modes (Hz)	Damping Ratio	
		Without Control	With Control
Malin – RoundMountain I	0.30	0.019	0.045
	0.63	0.113	0.137
Malin – RoundMountain II	0.30	0.019	0.052
	0.64	0.128	0.149
Malin – Olinda	0.30	0.025	0.040
	0.64	0.127	0.152
Moenkopi – Eldordo	0.48	0.098	0.149
	0.78	0.056	0.064
Navajo – Crystal	0.52	0.092	0.139
	0.78	0.049	0.050
PaloVerde - Devers	0.44	0.038	0.071
Hassyamp – N. Gila	0.40	0.045	0.088

Table 5.4.7: Comparison of Damping with respect to Dominant Modes

Dominant Modes (Hz)	Damping Ratio (approximate)	
	Without Control	**With Control**
0.30	0.021	0.046
0.42	0.041	0.079
0.50	0.095	0.144
0.64	0.122	0.146
0.78	0.053	0.057

Figure 5.4.24: Lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control)

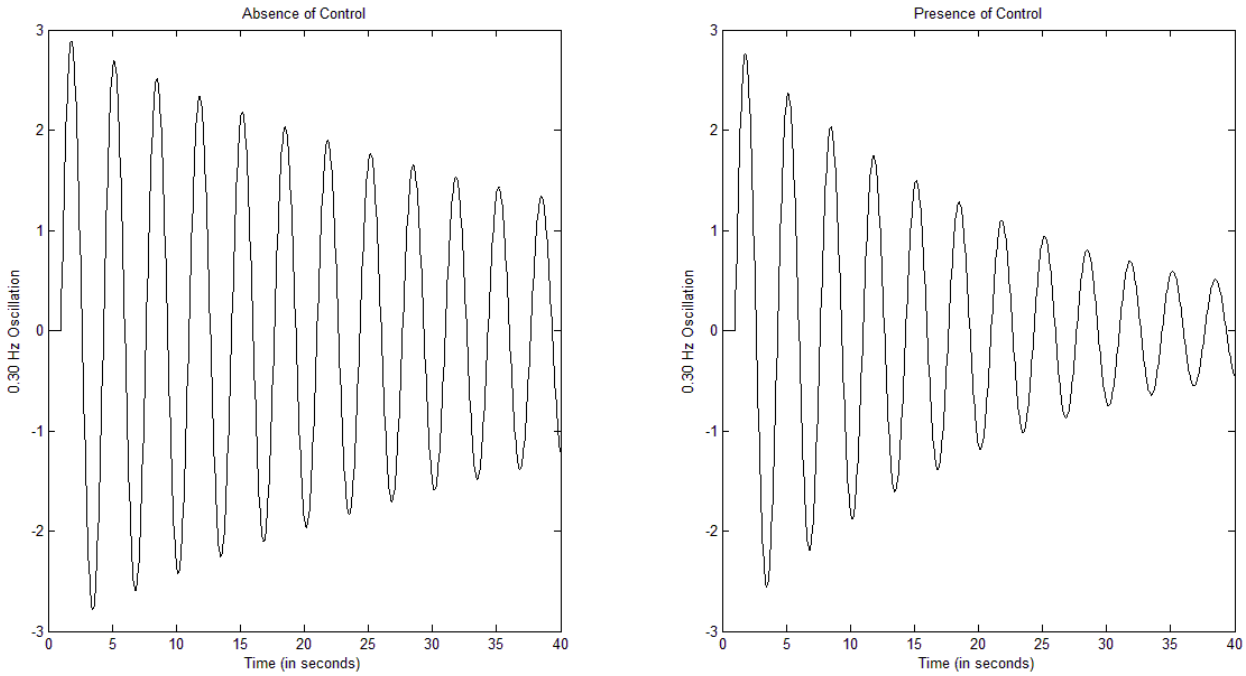


Figure 5.4.25: Second lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control)

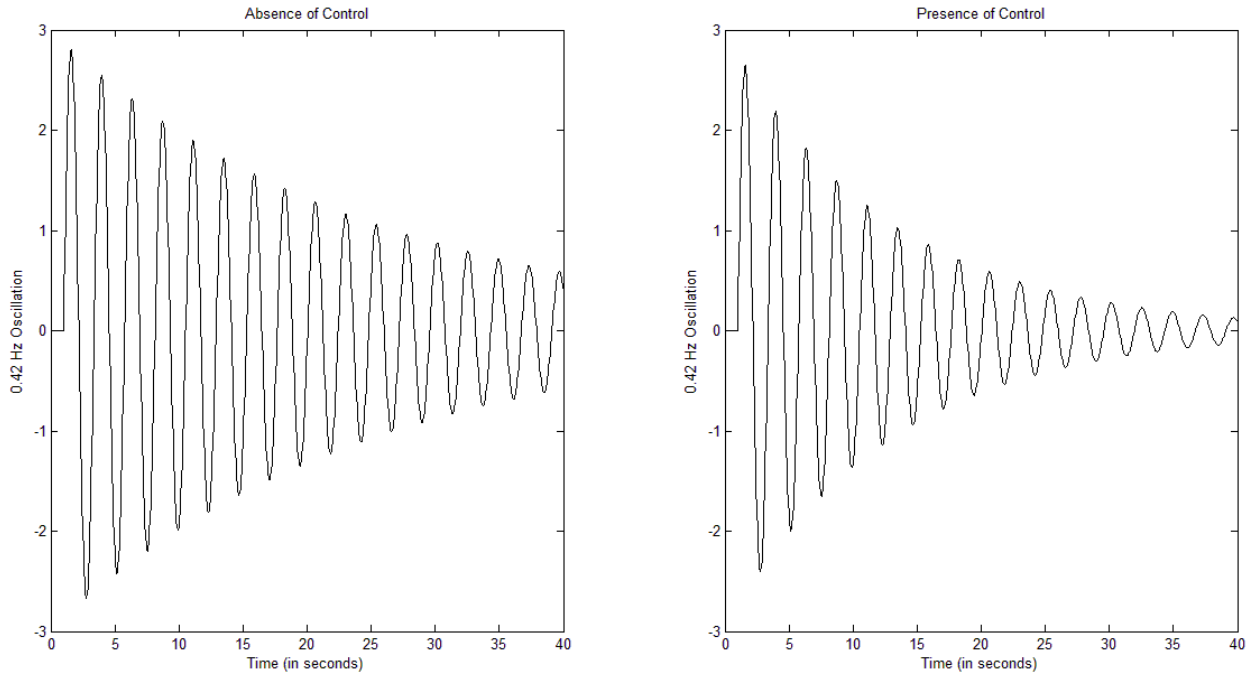


Figure 5.4.26: Third lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control)

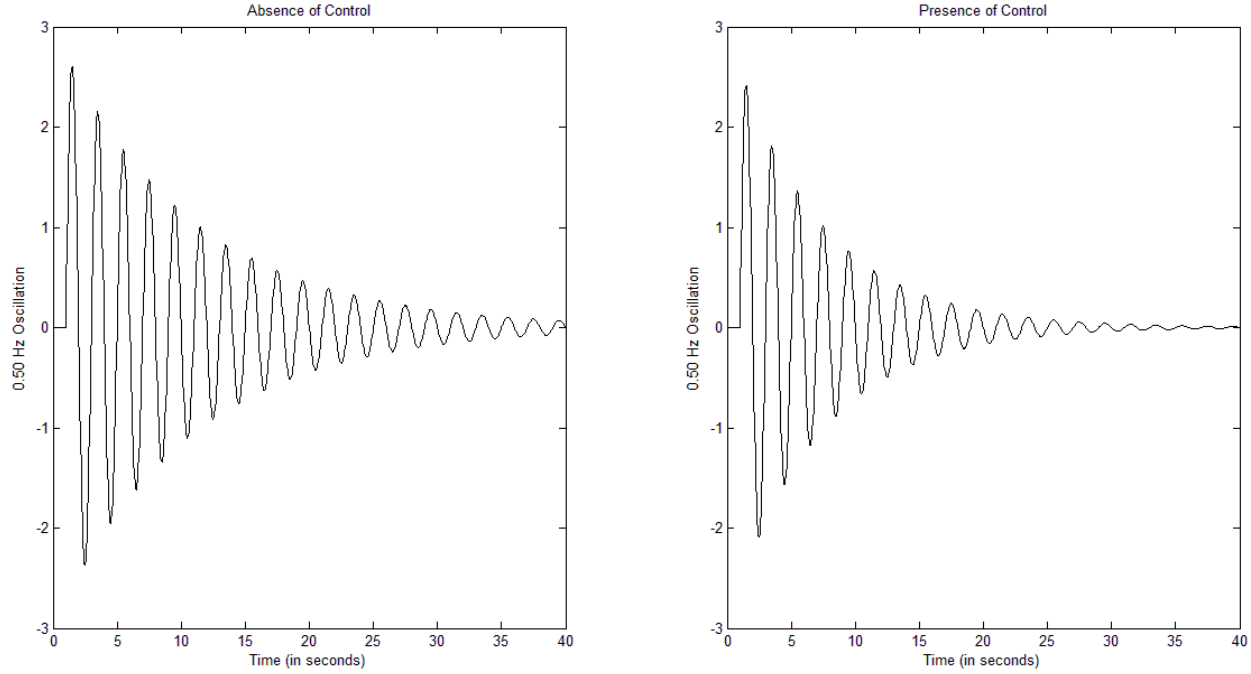
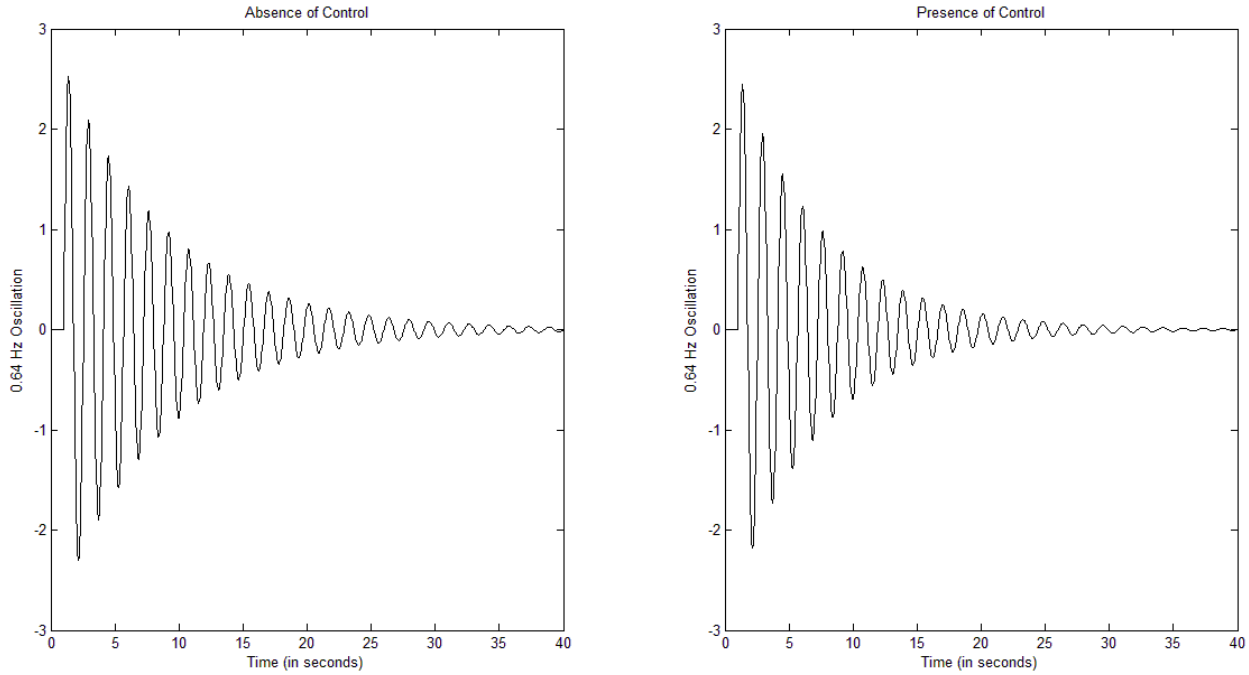


Figure 5.4.27: Fourth lowest inter-area mode of oscillation present in the New model (Left: In absence of Control; Right: In presence of control)



5.4.3.1 A Special Case

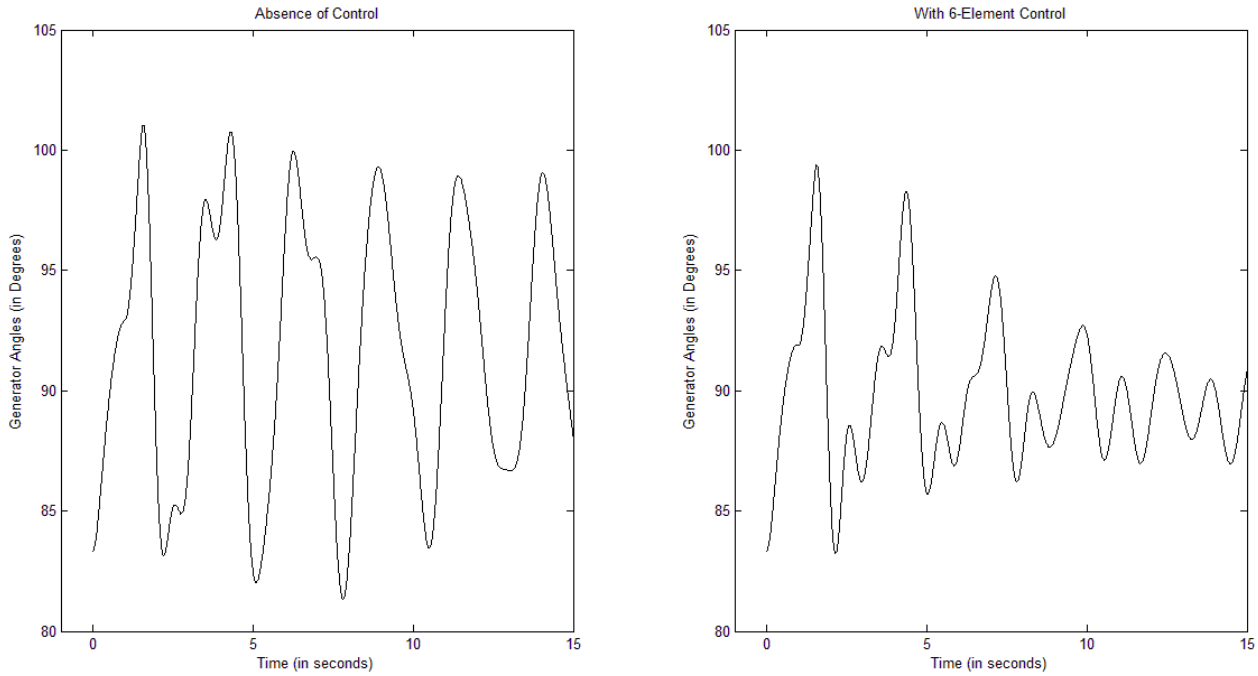
During all of our simulations, the assumption that was made was that the system was a stable one to start with. That is, all the vertices of the polytope had eigenvalues with negative real parts. This was done in accordance with our objective of improving the damping of the less damped inter-area mode of oscillations without making the other (local) modes unstable. But from a practical point of view, it is relevant to see the effect of the proposed control on an un-damped low frequency oscillation which would, if allowed to persist in the system, cause wide-spread havoc in it. In order to see this effect, the following simulations were performed to test the performance of the co-ordinated control developed in this study on un-damped oscillations.

Case 1: 127 Bus equivalent model of the WECC System

There are two ways in which one could visualize the effect of the proposed control methodology on an un-damped oscillation – one method is to create a control from a polytope, one of whose vertices would have an eigenvalue, corresponding to a low frequency inter-area mode, with positive real part. But, since this would imply creating a polytopic system from scratch and as there is no guarantee that the LMI control developed from an unstable system would be feasible, this method was not used in the present scheme of things. The second approach is to tweak around with the parameters of the system, based on which the control has been developed, to create a single unstable inter-area mode and then try to use the control to damp it. The reason for choosing a single inter-area mode is that if a large number of inter-area modes become simultaneously excited, there is a higher probability that the operating region would move out of the polytopic region and there would be no guarantee that the proposed control would work. In accordance with this second method, the reactance of the line between

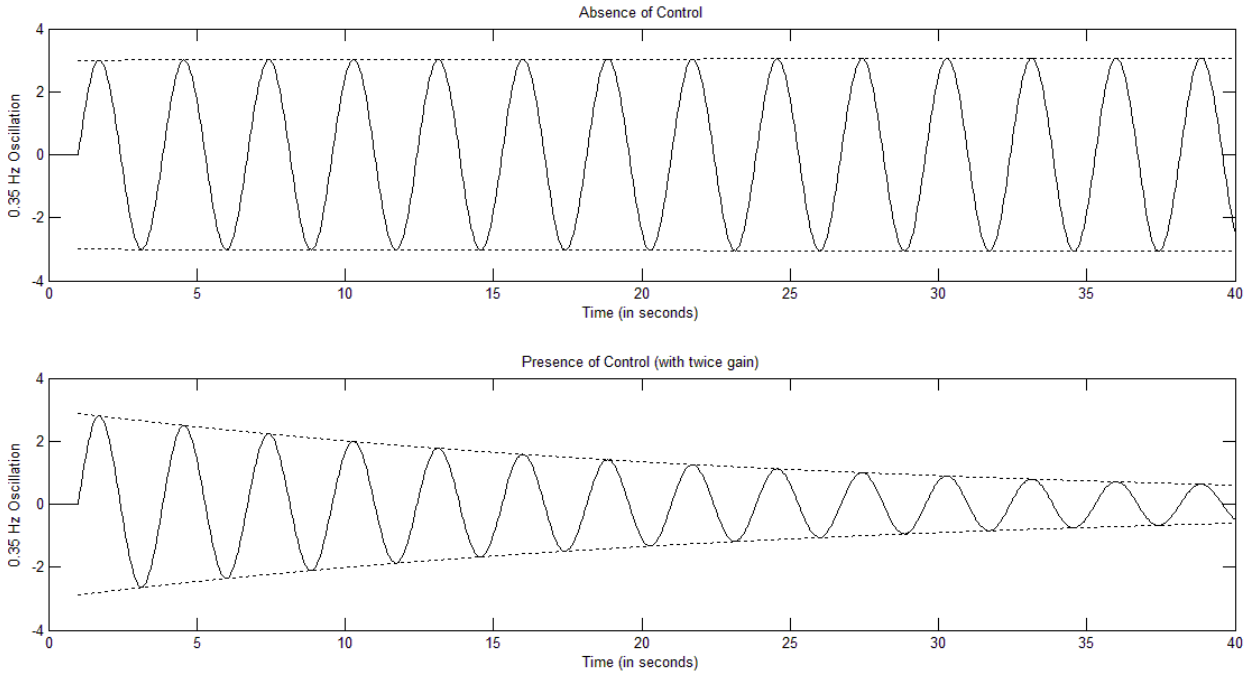
Bus 1 and Bus 2 was increased from 0.002 to 0.005. This change resulted in the system becoming less tightly connected than what it had been before and also made the 0.35 Hz oscillation more susceptible to contingencies. The step change that had been described previously (step change of 20% in the Celilo-Sylmar HVDC Line) was then applied on this system and the following waveforms were observed.

Figure5. 4.28: Sustained oscillations produced due to a negatively damped 0.35 Hz oscillation (Left: In absence of Control; Right: In presence of control)



The waveforms shown in Figure 5.4.28 above appear to have a superposition of higher harmonics; therefore to isolate the relevant mode of oscillation, Prony analysis was performed on the two waveforms. On doing so, the 0.35 Hz oscillation was indeed found to be the root cause behind the sustained oscillations and the effect of the proposed control on this un-damped oscillation also became prominent. The corresponding waveform is shown in Figure 5.4.29. By doing this analysis it was ascertained that the proposed control was robust enough to damp even un-damped or slightly damped oscillations as long as the operating condition lay within the polytopic region. In the next sub-section, a similar analysis is performed on the 4000+ bus model.

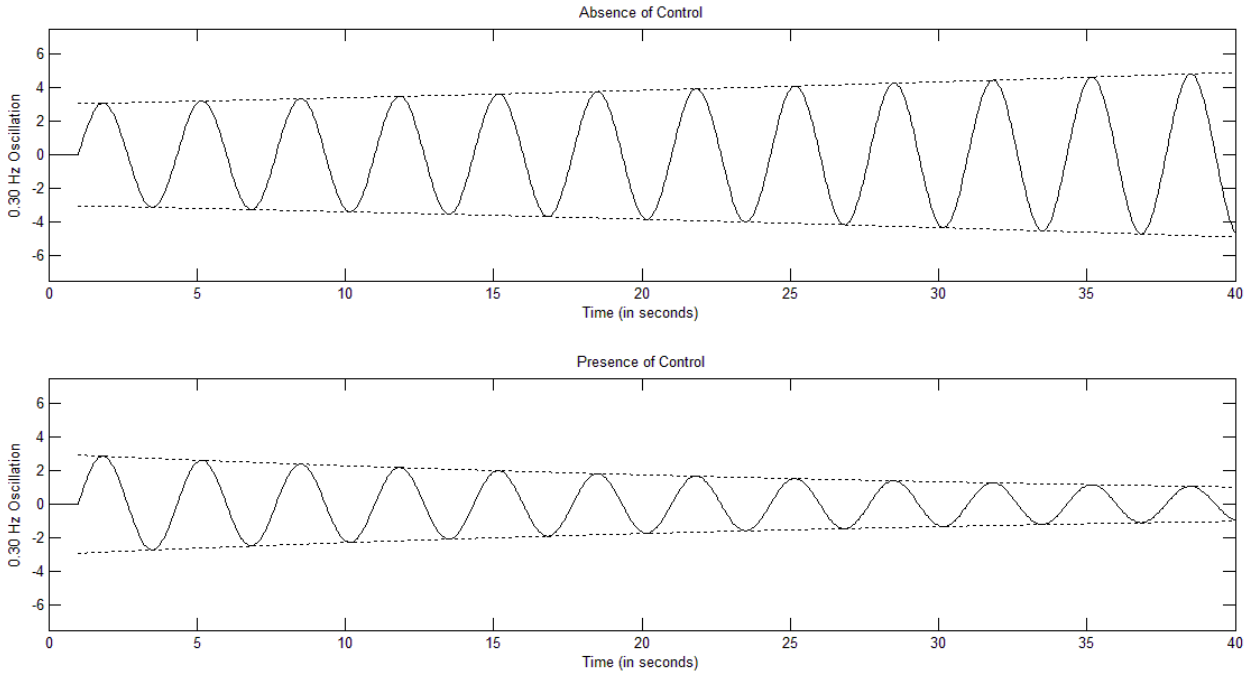
Figure 5.4.29: Performance of proposed control on sustained oscillations (29-machine system)



Case 2: 4000+ Bus model of the WECC System

In this system, it was realized that increasing the reactance of the line alone was not enough to excite the inter-area mode to the extent that we were interested in. If the reactance was increased by a small amount, the mode remained stable whereas if it was increased by a large amount, it caused transient stability problems. In order to overcome this dilemma, along with a slight increase in the reactance of the line, the duration of the step change was also increased from 0.16 seconds to 1.25 seconds. By doing this, we were able to create a negatively damped 0.3 Hz inter-area oscillation on which we could test the performance of the proposed control. On doing Prony analysis of the corresponding waveforms, Figure 5.4.30 was obtained. It clearly illustrates the ability of the proposed technique in damping unstable oscillations of low frequency.

Figure 5.4.30: Performance of proposed control on un-damped oscillations (New model)



5.4.4 Section Summary

This chapter describes how the control law that was formulated in the Matlab suite PST can be applied to other standard power system simulators. The procedure to be followed for transferring the control for each of the three controllers used is explained in great detail. An equivalent system, similar to the one in Matlab but more close to the real-world system is created in PSLF to test the effectiveness of the control. A step input was provided to excite all the inter-area modes present in the system. On applying the control, it was observed that the inter-area modes were considerably damped without the local modes getting negatively affected. Considering that the system used to come up with the control was not the same on which it was applied, the performance of the control was found to be exemplary.

The chapter then gives a detailed description of the new model for the California System which was created to illustrate the effect of the control in the real world. A contingency different from what it had been trained upon was used as a test case for the control on this new model. The results showed that even on an untested contingency, the proposed control was able to improve significantly the damping of all the inter-area modes of oscillations present in the system as well as damp un-damped oscillations (if present within the polytope); thereby proving further the robustness of the methodology developed herein. The inference drawn from the analysis is that, if the systems have good equivalence, then the proposed control technique developed in Matlab can be transferred to other power system simulators and even larger systems without significant loss in effectiveness.

5.5 Summary

In this project, we have presented an algorithm based on PMU measurements, Selective Modal Analysis (SMA) and Linear Matrix Inequalities (LMIs) to develop a robust damping controller capable of damping low frequency oscillations in general and the inter-area modes of oscillations in particular over a wide range of operating conditions. The advantage of the proposed technique is that it does not require frequent tuning/re-tuning of the controllers when the operating point undergoes small changes. Moreover, the design of the controller ensured that there is no negative interaction within the controls. Thus, we were successful in developing a robust co-ordinated form of control capable of damping low frequency inter-area oscillations over a wide variety of operating conditions.

The control that we have developed in the course of this project is the first of its kind, and therefore, further enhancements can be made. As an example of this, the proposed control had been able to provide more than 10% damping to all the inter-area modes present in the 127-bus model in the Matlab version whereas the damping percentage provided in the PSLF versions mainly ranged between 5 and 10. Although this difference was primarily because the two models were not identical, it also implied that there is room for improvement in the development of the control itself. Similarly, the effect of the control on damping un-damped or very slightly damped oscillations can also be looked into in more details.

In order to make the control more effective for future applications, the following areas can be considered good starting points –

a) Use of different cases to create the polytope,
b) Size of the Polytopic System,
c) Combination of Polytopes
d) Integrating PSSs into the control

These four topics are described in more details below.

Polytope composed of different cases: The eight cases that were the vertices of the polytope in this study were chosen so as to contain within them the relevant modes of oscillations that we wished to control. But they are not the only set of cases that will produce the desired result. A different choice of cases can be made to attain similar objective. Moreover, in future applications, one of the vertices can be made to contain an un-damped or very slightly damped inter-area mode of oscillation so that the control formed from such a polytope is guaranteed to damp un-stable oscillations. The control may not be feasible if the system is too unstable. This can be one area in which research can be done in the near future.

Size of Polytopic System: For this project, the polytopic system had a dimension of 8, i.e. the LMI control came out of an eight-dimensional polytope. The eight cases that had been used for the development of the polytope represented its eight vertices. The reason for choosing eight as

the size of the polytope was that the version of Matlab that was being used for the development of the control was unable to process polytopes larger than eight. Recently it has been found that the latest versions of Matlab can work on polytopic systems having dimensions greater than eight. This implies that we could have more diverse cases combined together to create the polytope, thereby making the control more robust. However, the issue with having a large number of diverse cases is that the chances of the control becoming infeasible are also greatly increased. Therefore, there is a need to come up with an optimum size of the polytopic formulation which can satisfy all of our requirements realistically. Research is currently being done to find this optimal size.

Combination of Polytopes: Before it was realized that the latest versions of Matlab could handle more than eight cases, the only way to increase the robustness of the control was to combine the gain matrices obtained from two or more eight-dimensional polytopes in an optimal manner. The logic to be used was that by combining m polytopes in an optimal fashion, one could handle $8 \times m$ cases at the same time. The control vector (u) would then look like,

$$u = -(\beta_1 K_1 + \beta_2 K_2 + \cdots + \beta_m K_m)x \tag{5.1}$$

Where,

$$\sum_{i=1}^{m} \beta_i = 1 \tag{5.2}$$

In the above equations, m denotes the number of polytopes being combined together and β_i represents the scalar multipliers denoting the percentage weight of the ith polytope in the overall control design. It is expected that the concept of maximum-likelihood criterion will be used for computing the values of $\beta_i s$.

The advantage of combining the polytopes is that if the $\beta_i s$ are properly selected, then a very high number of diverse cases can be combined together to develop the control without having to face the problem of the control becoming infeasible. Moreover, this technique can be combined with the previous one (increasing size of individual polytopes) to generate a much more robust control. The only issue that has to be addressed in this method is the proper selection of the $\beta_i s$. If they are not selected correctly, then the control obtained from one polytope might work against the control obtained from another polytope, thereby failing the very purpose for which the control was developed. Research is currently ongoing for the correct selection of $\beta_i s$.

Integrating PSSs into the control: For the development of control in this project, DC lines, FACTS devices (SVCs) and ESDs had been used as the controllers. However, PSSs are the traditional units used to provide damping to the different oscillations present in the system and so they can also be made a part of the integrated form of control that we have developed here. The primary reason for not including PSSs in the present control design was to alleviate the involved complexity associated with their inclusion in the iterations of SMA. This can be another topic on which research can be done in the near future.

Chapter 5 References

[1] D. N. Kosterev, W. Taylor, and W. A. Mittelstadt, "Model validation for the August 10, 1996 WSCC system outage," IEEE Trans. on Power Syst., Vol. 14, No. 3, pp. 967-979, Aug. 1999.

[2] P. Kundur, *Power System Stability and Control*, New York: McGraw-Hill, 1994.

[3] M. E. Aboul-Ela, A. A. Sallam, J. D. McCalley, and A. A. Fouad, "Damping controller design for power system oscillations using global signals", *IEEE Trans. Power Syst.*, Vol. 11, No. 2, pp. 767-773, May 1996.

[4] J. Ma, S. Garlapati, and J. Thorp, "Robust WAMS based control of inter area oscillations", *Electric Power Components and Systems*, Vol. 39, No. 9, pp. 850-862, May 2011.

[5] P. Gahinet, A. Nemirovski, A. J. Laub, and M. Chilali, *LMI Control Toolbox for use with MATLAB*, The Math Works, Inc., USA.

[6] G. C. Verghese, I. J. Perez-Arriaga, and F. C. Schweppe, "Selective modal analysis with applications to electric power systems, Part II: The Dynamic Stability Problem", *IEEE Trans. PAS*, Vol. 101, No. 9, pp. 3126-3134, Sept. 1982.

[7] F. L. Pagola, Rouco, and I. J. Perez-Arriaga, "Analysis and Control of Small-Signal Stability in Electric Power Systems by Selective Modal Analysis," *Eigenanalysis and Frequency Domain Methods for System Dynamic performance, IEEE publication 90TH0292-3-PWR*.

[8] G. Rogers, *Power System Oscillations*, Norwell, MA: Kluwer, 2000.

[9] Anamitra Pal, and James S. Thorp, "Co-ordinated control of inter-area oscillations using SMA and LMI," accepted for publication in *IEEE PES Conference on Innovative Smart Grid Technologies (ISGT 2012)*.

[10] Electric Power Research Institute, "DC Multi-Infeed Study," *EPRI, TR-TR-104586s, Projects 2675-04-05*, Final Report, Dec. 1994.

[11] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, "Energy Storage Systems for advanced power applications," *Proceedings of the IEEE*, Vol. 89, No. 12, pp. 1744-1756, 2001.

[12] Y. Zhang, and A. Bose, "Design of Wide-Area Damping Controls for Inter-area Oscillations", *IEEE Trans. Power Syst.*, Vol. 23, No. 3, pp.1136-1143. Aug. 2008.

[13] J. F. Hauer, C. J. Demeure, and L. L. Scharf, "Initial results in Prony Analysis of Power System response signals," *Power Systems, IEEE Transactions on*, Vol. 5, No. 1, pp. 80-89, 1990.

Chapter 6: Conclusions and Recommendations

The technical objective of this project was to use real-time synchronized phasor measurement data to provide improved protection system supervision in order to make it adaptive to prevailing system state. By using real-time wide area measurements, it is possible to determine optimum protection policies and settings for critically located relaying systems. This three year Research Development and Demonstration (RD&D) project aimed at slow speed protection functions in which the latency involved in remote phasor measurements is not an obstacle. It is recognized that primary protection of power system equipment requires high speed decision making that is incompatible with delays of even tens of milliseconds. Such protection is unlikely to be adaptive to remote inputs.

Four aspects of the protection system supervision and control were selected for research, because they address principal concerns regarding protection system responses, and are inter-related and complementary in their scope. Such measures are considered to be within the capabilities of technology available today, and when successfully applied can reduce the frequency and intensity of power system blackouts.

6.1 Techniques for Supervise Overreaching Zones

For this one year task the Virginia Tech Team with participation of the Technical Advisory Group selected areas on the California System that will benefit most from this research. There were two major tasks for this project, the development of the supervising scheme and the exhaustive testing of the schemes through simulations.

The method of line outage distribution factor was applied in this project and the lines with large LODF for one or multiple contingencies are considered the critical lines in the system. A technique is developed and presented in Chapter 2 to determine the LODF. This technique was applied to the Full California model for each of 3300 contingencies to form a 4474X4474 LODF matrix. The results are listed in Appendix A as percentage overload tables A.1 to A.6 for the 500kV, 230 kV, 287 kV 161 kV and 138 kV transmission lines. Lines with 30% or more overload were considered critical lines for this study and are highlighted in the tables of Appendix A.

No scenarios for zone 3 encroachment were found on the selected critical lines for a single contingency scenario of one single line outage. Multiple contingencies scenarios of a line outage combined with a generator outage were studied. Under normal operating conditions the multiple contingency scenarios resulted in no zone 3 encroachment on the identified critical lines. For the multiple contingency scenarios under severe conditions the system collapses before any zone 3 encroachment could be detected. These results lead us to conclude that zone 3 encroachment is not a problem in the system model used to perform the analysis. Although the results indicate that develop techniques for supervising overreaching zones do not apply to the present California model the develop techniques may be valuable in the future when the system load increases and a heavier demand is placed on the critical lines.

6.2 Adaptive Loss of Field

Impedance type- LOF relays are applied at the generator terminals to detect failure of the generator excitation in the form of DC Voltage or short circuit. Such Failure will collapse the internal generator voltage and result in reactive power flow into the generator far in excess of

generator rating. The LOF relay is designed to recognize this condition and trip the generator within one second of the failure. The LOF relay settings consists of two concentric circles; the inner circle is the impedance boundary criterion of actual steady state stability limit, which, if encroached, will lead to loss of synchronization of the generator and pole slipping and its eventual tripping. The outer circle is used to create an alarm for system operators if the apparent impedance seen by the relay will create operating condition which requires large adjustments.

As described in this report, the steady state stability limit circle is affected by the system operating conditions, which might result in mis-operation of the LOF relay. For this task, an approach was developed for creating coherent groups for generators and finding the LOF settings for the generator members of the group which allows on-line identifying system conditions based on PMU measurements. Thus the steady state stability limit circle can be adaptively fit for different operating conditions.

The application for this project is based on the behavior of the system impedance as seen from the generator terminals for various under-excited conditions or contingencies in the system. To implement and adaptive scheme, the required change of the relay characteristic was determined after creating possible contingencies, i.e. changing the operating condition that could possibility impact the equivalent impedance (Thévénin) of the power system, Xt. Since any topology change close to that terminal will change the value of Xt, the proposed technique trains the relay to adapt to these topology changes and create a LOF relay setting group for each generator or generator groups. Each members of LOF relay setting group will be representing the LOF settings for a specific operation conditions. After identifying the current operation condition, the relay will adapt to the system. The results and the relay settings determined from the developed technique are listed in Appendix B

6.3 Intelligent Load Shedding

Under-frequency load shedding performs well when the thresholds of frequencies and feeders assigned for tripping are allocated appropriately for credible contingencies. But the existing load shedding schemes do not operate unless there is an overall decay of system frequency. The objective of the Intelligent Load Shedding (ILS) algorithm is to detect a load shedding condition before an appreciable change in frequency occurs and use this determination to shed load effectively. In the event of a loss of supply, within the area of supervision, there will be an increased power flow on the boundary tie lines proportional to the amount of generation lost. The propose technique uses wide area measurement devices to monitors the tie lines for a marked increase in tie line flows that indicates the need for load shedding. The change in power flow is a rough indication of the amount of load to be shed. The location of the loads that can most effectively relieve the tie lines is determined by an off-line load sensitivity analysis.

The proposed technique uses Load Shift Factor to determine power flow changes in the tie lines. Load shift factors indicates how much the power flowing in a line changes due to a change in a load at a bus. PSLF simulations were used to compute the Load Shift Factors for each load within California with respect to each of the eight major tie lines. From these calculations, we can conclude that:

Any change in load anywhere within California, except San Diego Gas & Electric, is contributed by the California-Oregon Intertie (COI) comprising of the three Northern tie lines.

The loads located in Pacific Gas & Electric are best suited for relieving excess flow in the COI

The loads located in San Diego Gas & Electric are best suited for relieving excess flow in the Hassyampa - North Gila tie line

Based on the above conclusions, it was determined that in the proposed technique the California Oregon Intertie and the Hassyampa – North Gila would be monitored for detecting a loss of generation within California, while a sum total of excess flows along every tie line would be used to calculate the amount of load to be shed.

The following logic was implemented with simulation data for deciding the location of the load to be shed.

Excessive flow in Hassyampa – North Gila required load shedding of loads located within San Diego Gas & Electric

Excessive flow along the California Oregon Intertie require loads within Pacific Gas & Electric to be shed.

Chapter 4 provides some samples of this technique applied to specific scenarios.

6.4 Damping Low Frequency Oscillations

This task addresses the continuing problem of the control of low frequency inter-area oscillations. The premise of the work is that the traditional approach of individual controls (in most cases Power System Stabilizers) aimed at specific modes can be improved by coordinated control based on Wide Area Measurements (WAMs). Power System Stabilizers (PSSs) are the most commonly used devices for enhancing the damping of the inter-area modes of oscillations. However, power system instabilities can arise in certain circumstances due to negative damping effects of the PSS. The reason for this is that PSSs are tuned around a steady-state operating point. During severe disturbances, a PSS may actually cause the generator under its control to lose synchronism in an attempt to control its excitation. A new PSS using two signals, the first, to damp the local mode in the area and the second, global signal, using PMUs and Wide Area Measurements to damp inter-area modes has been proposed. An alternate approach that has been followed for damping low frequency oscillations has been the introduction of passive or active control elements including DC lines in addition to PSSs into the power system. Thus, the most effective approach would be to coordinate PSSs, FACTS devices, and DC lines using wide area measurements.

The direct application of modern robust control system design to a large power system is a daunting task. The approach taken for this application is to use control system design tools on a small power system model and through a sequence of operations described in Chapter 5 apply the control to a large (4000+ bus) simulation model of the California System. The design technique uses Linear Matrix Inequalities (LMIs) to find a control law which places the closed loop eigenvalues in a specified region of the complex plane while balancing two performance

indices measuring H_2 and H_∞ performance. Further robustness is provided by considering a polytopic description of the contingencies to be considered in the control system design. It is common to test PSS designs with tie line outages, load changes, etc. For this task each such case is a vertex of a polytope. The size of the problem with a large number of vertexes and a large number of system states can be overwhelming. Since the goal is damping the low frequency inter-area modes a model reduction technique, Selective Modal Analysis, aimed at preserving eigenvalue was considered appropriate for this task. For this task a technique to use SMA to systematically reduce the system to the smallest possible size was developed.

The reduced system consists of 29 machines, 127 buses and 215 lines. It has two HVDC lines and an SVC at Adelanto. It is a network that was developed in the 1990s for EPRI for analyzing low frequency interaction phenomena between DC links and the electro-mechanical stability cases. The California portion of the model is represented by a 12 machine, 60-bus network whereas the "rest of WECC" is depicted by a 17 machine, 67-bus network. Eight cases are presented in chapter 5 that include outages and flow changes of key lines as well as load changes. The modification of SMA allowed the reduction to 42 retained states. With six controls, two DC lines, one SVC, and Energy Storage Devices at three buses, the LMI polytopic system in Matlab converged in a little less than 26 minutes. A single control law placed all eigenvalues in a region with more than 7.5% damping.

The preceding simulations were performed in Matlab, but the model of the actual system was in PSLF. The control developed for the 127-bus equivalent system in PSLF was then applied to the new model of the California System that was created in PSLF. PSLF does not compute eigenvalues so responses on the tie-lines to disturbances were obtained and subjected to Prony analysis to determine the damping with and without control. In general, the damping of the inter-area modes showed significant increase.

The control developed in the course of this project is the first of its kind, and therefore, further enhancements can be made. For example, the effect of the control on un-damped or sustained oscillations can be looked into in more details. The advantage of the proposed technique is that it does not require frequent tuning/re-tuning of the controllers when the operating point undergoes small changes. Moreover, the design of the controller ensures that there is no negative interaction within the controls. Thus, we were successful in developing a robust coordinated form of control capable of damping low frequency inter-area oscillations over a wide variety of operating conditions.

6.5 Future Work

This projected was a proof of concept of four adaptive protection enhancements aimed to improve the reliability of the California electric grid. These enhancements had three things in common: the use of wide area measurement, the lack of very stringent communication requirements, and a fail safe mode that reverts to existing practices and procedures.

The smart grid funding provided by the recovery act of 2009 has accelerated the deployment of wide area measurement devices increasing the short time feasibility of the proposed protection schemes. The lack of a stringent time requirement on the data communication for these schemes makes them feasible with existing communication networks or requires relatively minor

enhancements to existing communication networks. The fail safe mode of these protection enhancements makes more acceptable to the protection engineers who are not asked to change their protection schemes but to build on what they have to develop an adaptive and more reliable protection system.

The next logical step on the development of these protection schemes is a laboratory test at the utilities using on-line data from the California system. These tests will reveal more details on limitations of available commercial equipment and the required communication enhancements and limitations, at the same time that the developed concepts are proved with real system date. Meaningful tests will require the cooperation and coordination of all California utilities and may help to determine other possible limitations due to non-technical requirements in the availability and sharing of the required wide area data and information among the California utilities.

Appendix A

Table A.1 Line Overload Results for 500 kV lines

Line Out						Line Monitored							
line no	from Bus	KV rate	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	Percent overload
7	25703	500	24042	500	972.4894	429	24155	230	24401	230	564.5799	489.06	15.44185
7	25703	500	24042	500	972.4894	659	24837	115	24819	115	213.7559	181.47	17.79325
8	27507	500	25703	500	717.9485	429	24155	230	24401	230	564.8338	489.06	15.49376
8	27507	500	25703	500	717.9485	659	24837	115	24819	115	213.7363	181.47	17.78248
9	27507	500	26123	500	1035.762	429	24155	230	24401	230	564.6121	489.06	15.44844
9	27507	500	26123	500	1035.762	659	24837	115	24819	115	213.7854	181.47	17.80953
10	25702	500	24801	500	1587.183	429	24155	230	24401	230	563.7526	489.06	15.27269
10	25702	500	24801	500	1587.183	659	24837	115	24819	115	213.3539	181.47	17.57174
11	22994	500	25702	500	1151.181	429	24155	230	24401	230	564.7605	489.06	15.47878
11	22994	500	25702	500	1151.181	659	24837	115	24819	115	213.7909	181.47	17.81254
12	22994	500	22536	500	1159.165	429	24155	230	24401	230	566.1351	489.06	15.75985
12	22994	500	22536	500	1159.165	659	24837	115	24819	115	210.9099	181.47	16.22494
21	27508	500	26044	500	952.8093	429	24155	230	24401	230	564.6366	489.06	15.45345
21	27508	500	26044	500	952.8093	659	24837	115	24819	115	213.7679	181.47	17.79985
174	22360	500	22468	500	1267.212	429	24155	230	24401	230	565.7872	489.06	15.68871
174	22360	500	22468	500	1267.212	659	24837	115	24819	115	219.4475	181.47	20.92968
174	22360	500	22468	500	1267.212	###	21026	161	21025	230	-330.4	222.75	48.32772
174	22360	500	22468	500	1267.212	###	21026	161	21027	92	203.9095	123.75	64.77538
230	22536	500	22360	500	951.1443	429	24155	230	24401	230	565.9116	489.06	15.71415
230	22536	500	22360	500	951.1443	659	24837	115	24819	115	211.3993	181.47	16.49463
353	24042	500	24086	500	672.8163	429	24155	230	24401	230	564.5274	489.06	15.43111
353	24042	500	24086	500	672.8163	659	24837	115	24819	115	214.1331	181.47	18.0011
354	24042	500	26048	500	-110.975	429	24155	230	24401	230	564.8751	489.06	15.50221

354	24042	500	26048	500	-110.975	659	24837	115	24819	115	213.713	181.47	17.76962
379	24086	500	24092	500	4732.185	659	24837	115	24819	115	203.2635	181.47	12.01129
379	24086	500	24092	500	4732.185	735	26061	230	26086	230	1027.111	908.82	13.01586
379	24086	500	24092	500	4732.185	429	24155	230	24401	230	568.9913	489.06	16.34386
380	24086	500	24097	500	-397.816	429	24155	230	24401	230	564.6984	489.06	15.46608
380	24086	500	24097	500	-397.816	659	24837	115	24819	115	213.9199	181.47	17.88361
381	24086	500	24156	500	-1075.16	429	24155	230	24401	230	568.2815	489.06	16.19873
381	24086	500	24156	500	-1075.16	659	24837	115	24819	115	212.1196	181.47	16.89157
382	24086	500	26105	500	-1383.96	429	24155	230	24401	230	563.8128	489.06	15.28499
382	24086	500	26105	500	-1383.96	659	24837	115	24819	115	212.9377	181.47	17.34238
392	24092	500	24138	500	1705.447	429	24155	230	24401	230	566.3682	489.06	15.80751
392	24092	500	24138	500	1705.447	659	24837	115	24819	115	210.4513	181.47	15.97221
395	24097	500	24042	500	-471.618	429	24155	230	24401	230	564.6618	489.06	15.4586
395	24097	500	24042	500	-471.618	659	24837	115	24819	115	213.9655	181.47	17.90875
418	24138	500	24151	500	250.8848	429	24155	230	24401	230	565.1415	489.06	15.55668
418	24138	500	24151	500	250.8848	659	24837	115	24819	115	213.1921	181.47	17.48259
423	24151	500	28040	500	-790.51	429	24155	230	24401	230	562.7856	489.06	15.07495
423	24151	500	28040	500	-790.51	659	24837	115	24819	115	212.3856	181.47	17.03812
625	24801	500	24151	500	526.1246	429	24155	230	24401	230	564.4565	489.06	15.41661
625	24801	500	24151	500	526.1246	659	24837	115	24819	115	214.7582	181.47	18.34557
714	26003	500	26079	500	825.1207	429	24155	230	24401	230	565.3132	489.06	15.5918
714	26003	500	26079	500	825.1207	659	24837	115	24819	115	214.709	181.47	18.31845
714	26003	500	26079	500	825.1207	737	26061	230	26103	230	1295.306	980.1	32.16065
715	26003	500	26105	500	980.7172	429	24155	230	24401	230	564.7038	489.06	15.46719
715	26003	500	26105	500	980.7172	659	24837	115	24819	115	213.0567	181.47	17.40795
716	26003	500	26115	500	473.8979	429	24155	230	24401	230	564.9006	489.06	15.50742
716	26003	500	26115	500	473.8979	659	24837	115	24819	115	214.2994	181.47	18.09275
724	26044	500	26003	500	540.376	429	24155	230	24401	230	564.7088	489.06	15.46821
724	26044	500	26003	500	540.376	659	24837	115	24819	115	214.1646	181.47	18.01849
725	26044	500	26048	500	411.4281	429	24155	230	24401	230	564.9147	489.06	15.51031

725	26044	500	26048	500	411.4281	659	24837	115	24819	115	213.493	181.47	17.64838
728	26048	500	26105	500	1083.915	429	24155	230	24401	230	564.4083	489.06	15.40677
728	26048	500	26105	500	1083.915	659	24837	115	24819	115	214.8496	181.47	18.39595
778	26105	500	26062	500	411.5582	429	24155	230	24401	230	564.9065	489.06	15.50864
778	26105	500	26062	500	411.5582	659	24837	115	24819	115	214.2221	181.47	18.05014
779	26123	500	26048	500	766.1809	429	24155	230	24401	230	564.6037	489.06	15.4467
779	26123	500	26048	500	766.1809	659	24837	115	24819	115	213.6907	181.47	17.75733
811	30005	500	30015	500	2790.059	429	24155	230	24401	230	564.0148	489.06	15.3263
811	30005	500	30015	500	2790.059	659	24837	115	24819	115	213.6783	181.47	17.75052
811	30005	500	30015	500	2790.059	814	30020	500	30035	500	3413.819	2564.1	33.13907
811	30005	500	30015	500	2790.059	###	30010	500	30020	500	2600.7	2286.9	13.72163
812	30015	500	30030	500	1552.162	429	24155	230	24401	230	564.7039	489.06	15.46721
812	30015	500	30030	500	1552.162	659	24837	115	24819	115	213.6609	181.47	17.74091
813	30015	500	30040	500	1121.142	812	30015	500	30030	500	2353.881	2124.4	10.80001
813	30015	500	30040	500	1121.142	429	24155	230	24401	230	564.7433	489.06	15.47526
813	30015	500	30040	500	1121.142	659	24837	115	24819	115	213.6577	181.47	17.73917
814	30020	500	30035	500	1427.552	429	24155	230	24401	230	564.2182	489.06	15.3679
814	30020	500	30035	500	1427.552	659	24837	115	24819	115	213.5376	181.47	17.67294
815	30030	500	30040	500	850.4684	429	24155	230	24401	230	564.7345	489.06	15.47345
815	30030	500	30040	500	850.4684	659	24837	115	24819	115	213.6496	181.47	17.7347
816	30035	500	30040	500	365.0468	429	24155	230	24401	230	564.687	489.06	15.46374
816	30035	500	30040	500	365.0468	659	24837	115	24819	115	213.6131	181.47	17.71455
817	30035	500	30050	500	47.00316	429	24155	230	24401	230	564.8407	489.06	15.49518
817	30035	500	30050	500	47.00316	659	24837	115	24819	115	213.66	181.47	17.74039
818	30040	500	30042	500	436.5461	429	24155	230	24401	230	564.6659	489.06	15.45943
818	30040	500	30042	500	436.5461	659	24837	115	24819	115	213.6199	181.47	17.71829
819	30040	500	30050	500	21.3375	429	24155	230	24401	230	564.8719	489.06	15.50155
819	30040	500	30050	500	21.3375	659	24837	115	24819	115	213.668	181.47	17.74483
820	30042	500	30045	500	-941.968	429	24155	230	24401	230	565.6626	489.06	15.66322
820	30042	500	30045	500	-941.968	659	24837	115	24819	115	213.8671	181.47	17.85456

821	30045	500	30050	500	379.8695	429	24155	230	24401	230	564.531	489.06	15.43186
821	30045	500	30050	500	379.8695	659	24837	115	24819	115	213.5805	181.47	17.69659
822	30050	500	30055	500	-47.4022	429	24155	230	24401	230	564.9675	489.06	15.5211
822	30050	500	30055	500	-47.4022	659	24837	115	24819	115	213.6924	181.47	17.75828
823	30050	500	30060	500	166.8083	429	24155	230	24401	230	564.6757	489.06	15.46144
823	30050	500	30060	500	166.8083	659	24837	115	24819	115	213.6175	181.47	17.71697
824	30055	500	30057	500	-702.442	429	24155	230	24401	230	565.1578	489.06	15.56001
824	30055	500	30057	500	-702.442	659	24837	115	24819	115	213.7411	181.47	17.78511
825	30055	500	30060	500	454.5465	429	24155	230	24401	230	564.3771	489.06	15.40039
825	30055	500	30060	500	454.5465	659	24837	115	24819	115	213.5401	181.47	17.67434
826	30057	500	30060	500	1569.604	429	24155	230	24401	230	563.988	489.06	15.32083
826	30057	500	30060	500	1569.604	659	24837	115	24819	115	213.4355	181.47	17.61668
827	30060	500	24156	500	3513.503		27507	500	26123	500	1883.2	1035.8	81.81116
3279	30001	500	30005	500	2602.189	###	30010	500	30020	500	3660.983	2286.9	60.08495
3280	30010	500	30020	500	1421.371	429	24155	230	24401	230	565.2728	489.06	15.58352
3280	30010	500	30020	500	1421.371	659	24837	115	24819	115	213.8696	181.47	17.85592
3281	30010	500	30001	500	619.7866	429	24155	230	24401	230	564.8442	489.06	15.49588
3281	30010	500	30001	500	619.7866	659	24837	115	24819	115	213.6624	181.47	17.74173
3286	99999	500	30001	500	1982.538	429	24155	230	24401	230	564.9311	489.06	15.51366
3286	99999	500	30001	500	1982.538	659	24837	115	24819	115	213.7424	181.47	17.78583
3287	99999	500	30010	500	2041.157	429	24155	230	24401	230	564.9656	489.06	15.52072
3287	99999	500	30010	500	2041.157	659	24837	115	24819	115	213.7564	181.47	17.79354
3288	99998	500	27508	500	952.8093	429	24155	230	24401	230	564.6366	489.06	15.45345
3288	99998	500	27508	500	952.8093	659	24837	115	24819	115	213.7679	181.47	17.79985
3289	99998	500	27507	500	1753.709	429	24155	230	24401	230	564.6776	489.06	15.46182
3289	99998	500	27507	500	1753.709	659	24837	115	24819	115	214.0356	181.47	17.94741
3290	99998	500	25703	500	258.0713	429	24155	230	24401	230	564.885	489.06	15.50422
3290	99998	500	25703	500	258.0713	659	24837	115	24819	115	213.6859	181.47	17.75469
3291	99998	500	25702	500	436.1236	429	24155	230	24401	230	564.9166	489.06	15.5107
3291	99998	500	25702	500	436.1236	659	24837	115	24819	115	213.6381	181.47	17.72836

3292	99998	500	99999	500	-97.837	429	24155	230	24401	230	564.793	489.06	15.48543
3292	99998	500	99999	500	-97.837	659	24837	115	24819	115	213.5276	181.47	17.66743
3293	99998	500	22994	500	2310.344	429	24155	230	24401	230	565.3632	489.06	15.60202
3293	99998	500	22994	500	2310.344	659	24837	115	24819	115	212.889	181.47	17.31556

Table A.2 Line Overload Results for 230 kV lines

Line Out					Line Monitored							
line no	from Bus	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	percent overload
3	27513	27514	230	-124.291	429	24155	230	24401	230	564.8954	489.06	15.50637
13	27513	27514	230	-124.291	659	24837	115	24819	115	213.674	181.467	17.7481
14	27513	26046	230	-179.311	429	24155	230	24401	230	564.8954	489.06	15.50637
14	27513	26046	230	-179.311	659	24837	115	24819	115	213.674	181.467	17.7481
15	25705	24041	230	73.8776	429	24155	230	24401	230	564.906	489.06	15.50853
15	25705	24041	230	73.8776	659	24837	115	24819	115	213.6094	181.467	17.71252
16	25701	24041	230	71.41602	429	24155	230	24401	230	564.8949	489.06	15.50625
16	25701	24041	230	71.41602	659	24837	115	24819	115	213.76	181.467	17.79552
17	25701	26046	230	127.7124	429	24155	230	24401	230	564.8857	489.06	15.50438
17	25701	26046	230	127.7124	659	24837	115	24819	115	213.8611	181.467	17.85125
20	27509	26046	230	34.493	429	24155	230	24401	230	564.8135	489.06	15.48962
20	27509	26046	230	34.493	659	24837	115	24819	115	213.5768	181.467	17.69459
22	25704	25402	230	93.86507	429	24155	230	24401	230	564.8845	489.06	15.50413
22	25704	25402	230	93.86507	659	24837	115	24819	115	213.5755	181.467	17.69387
34	21007	21076	230	191.7812	429	24155	230	24401	230	564.8879	489.06	15.50483
34	21007	21076	230	191.7812	659	24837	115	24819	115	210.2952	181.467	15.88617
35	21007	24804	230	34.25886	429	24155	230	24401	230	564.8988	489.06	15.50705
35	21007	24804	230	34.25886	659	24837	115	24819	115	214.109	181.467	17.98785
61	21076	24806	230	129.945	429	24155	230	24401	230	564.8924	489.06	15.50574
61	21076	24806	230	129.945	659	24837	115	24819	115	210.5417	181.467	16.022
137	22227	22232	230	-3.38415	429	24155	230	24401	230	564.895	489.06	15.50628
137	22227	22232	230	-3.38415	659	24837	115	24819	115	213.6737	181.467	17.74794
138	22227	22716	230	-21.3748	429	24155	230	24401	230	564.9004	489.06	15.50739
138	22227	22716	230	-21.3748	659	24837	115	24819	115	213.6773	181.467	17.74995

153	22260	22844	230	-18.3532	429	24155	230	24401	230	564.9077	489.06	15.50887
153	22260	22844	230	-18.3532	659	24837	115	24819	115	213.6815	181.467	17.75228
154	22261	22227	230	-24.7475	429	24155	230	24401	230	564.9038	489.06	15.50808
154	22261	22227	230	-24.7475	659	24837	115	24819	115	213.6796	181.467	17.75124
155	22261	22260	230	371.3051	429	24155	230	24401	230	564.8005	489.06	15.48695
155	22261	22260	230	371.3051	659	24837	115	24819	115	213.7382	181.467	17.78353
156	22261	22832	230	132.6518	429	24155	230	24401	230	564.985	489.06	15.52469
156	22261	22832	230	132.6518	659	24837	115	24819	115	213.692	181.467	17.75807
173	22356	21025	230	128.6379	429	24155	230	24401	230	565.039	489.06	15.53572
173	22356	21025	230	128.6379	659	24837	115	24819	115	210.7586	181.467	16.14154
210	22464	22504	230	316.9938	429	24155	230	24401	230	564.9136	489.06	15.51008
210	22464	22504	230	316.9938	659	24837	115	24819	115	213.8382	181.467	17.83862
241	22596	22464	230	-318.325	429	24155	230	24401	230	564.9294	489.06	15.51331
241	22596	22464	230	-318.325	659	24837	115	24819	115	213.8528	181.467	17.84666
242	22596	22504	230	-38.7246	429	24155	230	24401	230	564.9041	489.06	15.50813
242	22596	22504	230	-38.7246	659	24837	115	24819	115	213.6823	181.467	17.7527
263	22652	22232	230	-321.135	429	24155	230	24401	230	565.233	489.06	15.57539
263	22652	22232	230	-321.135	659	24837	115	24819	115	213.8942	181.467	17.86947
264	22652	22596	230	-73.8415	429	24155	230	24401	230	564.9177	489.06	15.51092
264	22652	22596	230	-73.8415	659	24837	115	24819	115	213.7192	181.467	17.77302
282	22716	22232	230	16.70925	429	24155	230	24401	230	564.8992	489.06	15.50714
282	22716	22232	230	16.70925	659	24837	115	24819	115	213.6765	181.467	17.7495
283	22716	22504	230	215.7893	429	24155	230	24401	230	565.0799	489.06	15.54408
283	22716	22504	230	215.7893	659	24837	115	24819	115	213.7551	181.467	17.79281
284	22716	24131	230	-513.887	429	24155	230	24401	230	566.0811	489.06	15.7488
284	22716	24131	230	-513.887	659	24837	115	24819	115	214.3726	181.467	18.1331
284	22716	24131	230	-513.887	3403	22836	69	22840	138	-29.2695	24.75	18.26048
306	22832	22464	230	-310.435	429	24155	230	24401	230	564.9231	489.06	15.51203
306	22832	22464	230	-310.435	659	24837	115	24819	115	213.9531	181.467	17.90193
312	22844	24131	230	-411.021	429	24155	230	24401	230	565.1766	489.06	15.56386

312	22844	24131	230	-411.021	659	24837	115	24819	115	214.013	181.467	17.93496
312	22844	24131	230	-411.021	170	22348	69	22368	69	39.88885	31.977	24.74232
312	22844	24131	230	-411.021	184	22400	69	22348	69	40.42932	31.977	26.4325
312	22844	24131	230	-411.021	3403	22836	69	22840	138	33.31241	24.75	34.59559
312	22844	24131	230	-411.021	296	22808	69	22400	69	43.13468	31.977	34.89284
312	22844	24131	230	-411.021	238	22588	69	22808	69	44.71876	31.977	39.84665
327	24006	24016	230	291.3335	429	24155	230	24401	230	565.009	489.06	15.52958
327	24006	24016	230	291.3335	659	24837	115	24819	115	213.5716	181.467	17.69172
328	24006	24021	230	608.6662	429	24155	230	24401	230	564.6583	489.06	15.45787
328	24006	24021	230	608.6662	659	24837	115	24819	115	213.8877	181.467	17.8659
329	24008	24016	230	213.2086	429	24155	230	24401	230	565.0695	489.06	15.54196
329	24008	24016	230	213.2086	659	24837	115	24819	115	213.4844	181.467	17.64363
330	24008	24084	230	486.8728	429	24155	230	24401	230	564.673	489.06	15.46089
330	24008	24084	230	486.8728	659	24837	115	24819	115	214.0741	181.467	17.96859
331	24015	24065	230	400.0001	659	24837	115	24819	115	213.674	181.467	17.7481
331	24015	24065	230	400.0001	429	24155	230	24401	230	580.4672	489.06	18.69039
332	24016	24044	230	250.179	429	24155	230	24401	230	564.7127	489.06	15.46899
332	24016	24044	230	250.179	659	24837	115	24819	115	213.8438	181.467	17.84171
333	24016	24154	230	-174.036	429	24155	230	24401	230	564.8421	489.06	15.49545
333	24016	24154	230	-174.036	659	24837	115	24819	115	213.7414	181.467	17.78526
334	24016	25201	230	-201.443	429	24155	230	24401	230	564.8128	489.06	15.48948
334	24016	25201	230	-201.443	659	24837	115	24819	115	213.775	181.467	17.8038
336	24019	25701	230	-197.915	659	24837	115	24819	115	205.1542	181.467	13.05316
336	24019	25701	230	-197.915	429	24155	230	24401	230	565.1947	489.06	15.56756
337	24019	25402	230	13.69392	429	24155	230	24401	230	564.922	489.06	15.5118
337	24019	25402	230	13.69392	659	24837	115	24819	115	213.8244	181.467	17.83101
338	24021	24091	230	-151.513	429	24155	230	24401	230	564.2953	489.06	15.38366
338	24021	24091	230	-151.513	659	24837	115	24819	115	213.581	181.467	17.69688
339	24021	24100	230	65.52997	429	24155	230	24401	230	565.0248	489.06	15.53281
339	24021	24100	230	65.52997	659	24837	115	24819	115	213.5311	181.467	17.66939

340	24025	24093	230	-357.398	429	24155	230	24401	230	564.7362	489.06	15.4738
340	24025	24093	230	-357.398	659	24837	115	24819	115	214.0721	181.467	17.96753
341	24025	24137	230	-48.4695	429	24155	230	24401	230	564.9725	489.06	15.52212
341	24025	24137	230	-48.4695	659	24837	115	24819	115	213.4818	181.467	17.64219
342	24025	25656	230	-237.81	429	24155	230	24401	230	564.7862	489.06	15.48403
342	24025	25656	230	-237.81	659	24837	115	24819	115	214.2699	181.467	18.07649
343	24029	24021	230	-207.659	429	24155	230	24401	230	563.9133	489.06	15.30554
343	24029	24021	230	-207.659	659	24837	115	24819	115	213.8339	181.467	17.83624
344	24029	24044	230	-172.931	429	24155	230	24401	230	564.395	489.06	15.40404
344	24029	24044	230	-172.931	659	24837	115	24819	115	213.7565	181.467	17.7936
345	24029	24076	230	33.27528	429	24155	230	24401	230	564.5739	489.06	15.44062
345	24029	24076	230	33.27528	659	24837	115	24819	115	213.705	181.467	17.7652
347	24036	24091	230	382.4936	429	24155	230	24401	230	565.5829	489.06	15.64694
347	24036	24091	230	382.4936	659	24837	115	24819	115	212.9854	181.467	17.36864
348	24036	24114	230	-144.888	429	24155	230	24401	230	564.9385	489.06	15.51516
348	24036	24114	230	-144.888	659	24837	115	24819	115	213.5748	181.467	17.69348
349	24036	24147	230	-429.361	429	24155	230	24401	230	565.366	489.06	15.60258
349	24036	24147	230	-429.361	659	24837	115	24819	115	213.1273	181.467	17.44689
350	24040	24074	230	-52.7992	429	24155	230	24401	230	564.8886	489.06	15.50498
350	24040	24074	230	-52.7992	659	24837	115	24819	115	213.6831	181.467	17.75313
351	24040	24082	230	265.4469	429	24155	230	24401	230	564.9033	489.06	15.50798
351	24040	24082	230	265.4469	659	24837	115	24819	115	213.6892	181.467	17.75652
352	24040	24198	230	-255.387	429	24155	230	24401	230	564.9041	489.06	15.50813
352	24040	24198	230	-255.387	659	24837	115	24819	115	213.6727	181.467	17.74741
355	24044	24069	230	-399.391	429	24155	230	24401	230	564.8954	489.06	15.50637
355	24044	24069	230	-399.391	659	24837	115	24819	115	213.674	181.467	17.7481
356	24044	24072	230	257.03	429	24155	230	24401	230	565.0599	489.06	15.54
356	24044	24072	230	257.03	659	24837	115	24819	115	213.6924	181.467	17.75827
357	24044	24134	230	30.88532	429	24155	230	24401	230	564.9148	489.06	15.51033
357	24044	24134	230	30.88532	659	24837	115	24819	115	213.6741	181.467	17.7482

358	24044	24369	230	-399.393	429	24155	230	24401	230	562.4876	489.06	15.01403
358	24044	24369	230	-399.393	659	24837	115	24819	115	212.8289	181.467	17.28245
359	24049	24040	230	290.3719	429	24155	230	24401	230	564.8982	489.06	15.50693
359	24049	24040	230	290.3719	659	24837	115	24819	115	213.6736	181.467	17.74788
360	24049	24198	230	309.6273	429	24155	230	24401	230	564.8925	489.06	15.50577
360	24049	24198	230	309.6273	659	24837	115	24819	115	213.6744	181.467	17.74833
362	24056	24112	230	312.2734	429	24155	230	24401	230	564.8488	489.06	15.49684
362	24056	24112	230	312.2734	659	24837	115	24819	115	214.0447	181.467	17.95242
363	24056	24132	230	-94.1014	429	24155	230	24401	230	564.8494	489.06	15.49696
363	24056	24132	230	-94.1014	659	24837	115	24819	115	213.967	181.467	17.90958
364	24056	24901	230	104.0691	429	24155	230	24401	230	564.9238	489.06	15.51217
364	24056	24901	230	104.0691	659	24837	115	24819	115	213.5027	181.467	17.65374
365	24056	25656	230	-336.298	429	24155	230	24401	230	565.0152	489.06	15.53085
365	24056	25656	230	-336.298	659	24837	115	24819	115	213.0471	181.467	17.40265
366	24061	24065	230	91.48275	429	24155	230	24401	230	564.8174	489.06	15.4904
366	24061	24065	230	91.48275	659	24837	115	24819	115	213.6773	181.467	17.74993
367	24061	24077	230	-6.48346	429	24155	230	24401	230	564.8899	489.06	15.50524
367	24061	24077	230	-6.48346	659	24837	115	24819	115	213.6742	181.467	17.74823
368	24065	24029	230	161.8028	429	24155	230	24401	230	564.6564	489.06	15.45748
368	24065	24029	230	161.8028	659	24837	115	24819	115	213.6314	181.467	17.72467
370	24072	24134	230	-143.491	429	24155	230	24401	230	564.8058	489.06	15.48804
370	24072	24134	230	-143.491	659	24837	115	24819	115	213.6803	181.467	17.7516
371	24074	24065	230	-94.3263	429	24155	230	24401	230	564.7522	489.06	15.47707
371	24074	24065	230	-94.3263	659	24837	115	24819	115	213.6979	181.467	17.76131
372	24074	24076	230	64.8065	429	24155	230	24401	230	564.383	489.06	15.40159
372	24074	24076	230	64.8065	659	24837	115	24819	115	213.692	181.467	17.75804
373	24074	24125	230	-811.448	429	24155	230	24401	230	561.3795	489.06	14.78744
373	24074	24125	230	-811.448	659	24837	115	24819	115	213.927	181.467	17.88755
374	24076	24126	230	-298.603	429	24155	230	24401	230	572.0446	489.06	16.96818
374	24076	24126	230	-298.603	659	24837	115	24819	115	213.578	181.467	17.69523

375	24077	24084	230	-6.48331	429	24155	230	24401	230	564.8899	489.06	15.50524
375	24077	24084	230	-6.48331	659	24837	115	24819	115	213.6742	181.467	17.74823
376	24082	24074	230	-195.1	429	24155	230	24401	230	564.8962	489.06	15.50652
376	24082	24074	230	-195.1	659	24837	115	24819	115	213.6859	181.467	17.75467
377	24084	24065	230	54.5039	429	24155	230	24401	230	564.8249	489.06	15.49193
377	24084	24065	230	54.5039	659	24837	115	24819	115	213.6769	181.467	17.74975
378	24084	24091	230	-58.1073	429	24155	230	24401	230	564.6452	489.06	15.45521
378	24084	24091	230	-58.1073	659	24837	115	24819	115	213.6734	181.467	17.74782
384	24087	24115	230	-227.066	659	24837	115	24819	115	213.6298	181.467	17.72375
384	24087	24115	230	-227.066	429	24155	230	24401	230	630.4275	489.06	28.90596
385	24087	24141	230	134.0544	429	24155	230	24401	230	547.6231	489.06	11.97462
385	24087	24141	230	134.0544	659	24837	115	24819	115	213.7029	181.467	17.76407
386	24087	24153	230	441.1649	659	24837	115	24819	115	213.802	181.467	17.81865
387	24087	24401	230	227.8367	659	24837	115	24819	115	213.5065	181.467	17.65581
387	24087	24401	230	227.8367	429	24155	230	24401	230	720.3328	489.06	47.28925
388	24091	24125	230	25.76798	429	24155	230	24401	230	564.7751	489.06	15.48176
388	24091	24125	230	25.76798	659	24837	115	24819	115	213.6786	181.467	17.75065
389	24091	24126	230	-121.955	429	24155	230	24401	230	570.3139	489.06	16.61431
389	24091	24126	230	-121.955	659	24837	115	24819	115	213.5465	181.467	17.67788
390	24091	24158	230	268.0641	429	24155	230	24401	230	564.4398	489.06	15.4132
390	24091	24158	230	268.0641	659	24837	115	24819	115	212.8788	181.467	17.30993
391	24091	24401	230	-73.6495	659	24837	115	24819	115	213.5841	181.467	17.69858
393	24093	24158	230	304.8033	429	24155	230	24401	230	564.8626	489.06	15.49965
393	24093	24158	230	304.8033	659	24837	115	24819	115	214.6486	181.467	18.2852
394	24093	24901	230	206.6657	429	24155	230	24401	230	565.0358	489.06	15.53507
394	24093	24901	230	206.6657	659	24837	115	24819	115	212.8274	181.467	17.28158
397	24100	24158	230	51.13859	429	24155	230	24401	230	564.9733	489.06	15.52229
397	24100	24158	230	51.13859	659	24837	115	24819	115	213.7264	181.467	17.77698
398	24114	24099	230	-476.315	659	24837	115	24819	115	213.6924	181.467	17.75828
398	24114	24099	230	-476.315	429	24155	230	24401	230	582.3316	489.06	19.0716

399	24114	24115	230	-3.56783	429	24155	230	24401	230	564.4894	489.06	15.42335
399	24114	24115	230	-3.56783	659	24837	115	24819	115	213.6742	181.467	17.74822
400	24114	24128	230	14.40809	429	24155	230	24401	230	564.505	489.06	15.42653
400	24114	24128	230	14.40809	659	24837	115	24819	115	213.6731	181.467	17.74761
401	24114	24147	230	-231.99	429	24155	230	24401	230	563.8083	489.06	15.28407
401	24114	24147	230	-231.99	659	24837	115	24819	115	213.5464	181.467	17.6778
402	24114	24155	230	-30.7758	429	24155	230	24401	230	570.1704	489.06	16.58496
402	24114	24155	230	-30.7758	659	24837	115	24819	115	213.6951	181.467	17.75976
403	24114	24200	230	590.6755	429	24155	230	24401	230	566.405	489.06	15.81503
403	24114	24200	230	590.6755	659	24837	115	24819	115	213.7622	181.467	17.79672
404	24114	24217	230	-34.5974	429	24155	230	24401	230	560.9189	489.06	14.69328
404	24114	24217	230	-34.5974	659	24837	115	24819	115	213.6761	181.467	17.74928
405	24114	24403	230	25.31828	429	24155	230	24401	230	567.6578	489.06	16.0712
405	24114	24403	230	25.31828	659	24837	115	24819	115	213.6729	181.467	17.74754
406	24115	24217	230	-39.1922	429	24155	230	24401	230	569.4001	489.06	16.42745
406	24115	24217	230	-39.1922	659	24837	115	24819	115	213.6715	181.467	17.74677
409	24125	24084	230	3.233031	429	24155	230	24401	230	564.9013	489.06	15.50756
409	24125	24084	230	3.233031	659	24837	115	24819	115	213.6732	181.467	17.74768
410	24126	24155	230	-552.8	659	24837	115	24819	115	213.3047	181.467	17.5446
410	24126	24155	230	-552.8	429	24155	230	24401	230	650.2693	489.06	32.9631
411	24128	24058	230	275.7748	429	24155	230	24401	230	571.1231	489.06	16.77977
411	24128	24058	230	275.7748	659	24837	115	24819	115	213.7309	181.467	17.77948
413	24128	24099	230	-283.851	429	24155	230	24401	230	552.4355	489.06	12.95864
413	24128	24099	230	-283.851	659	24837	115	24819	115	213.6358	181.467	17.72709
414	24131	24134	230	788.3931	429	24155	230	24401	230	563.0969	489.06	15.13862
414	24131	24134	230	788.3931	659	24837	115	24819	115	214.0004	181.467	17.92801
415	24131	24137	230	129.466	429	24155	230	24401	230	564.7774	489.06	15.48224
415	24131	24137	230	129.466	659	24837	115	24819	115	213.6047	181.467	17.70993
416	24132	24804	230	-44.7148	429	24155	230	24401	230	564.8571	489.06	15.49853
416	24132	24804	230	-44.7148	659	24837	115	24819	115	215.0215	181.467	18.4907

417	24137	24154	230	958.9157	429	24155	230	24401	230	564.6732	489.06	15.46093
417	24137	24154	230	958.9157	659	24837	115	24819	115	214.022	181.467	17.9399
419	24141	24303	230	-42.4209	429	24155	230	24401	230	567.2744	489.06	15.99279
419	24141	24303	230	-42.4209	659	24837	115	24819	115	213.6704	181.467	17.74616
420	24141	24304	230	-40.5302	429	24155	230	24401	230	567.0005	489.06	15.93681
420	24141	24304	230	-40.5302	659	24837	115	24819	115	213.6707	181.467	17.74633
425	24155	24091	230	556.2762	659	24837	115	24819	115	212.9767	181.467	17.36387
425	24155	24091	230	556.2762	429	24155	230	24401	230	658.8489	489.06	34.7174
426	24155	24126	230	567.9244	659	24837	115	24819	115	213.2914	181.467	17.53731
426	24155	24126	230	567.9244	429	24155	230	24401	230	653.004	489.06	33.52227
427	24155	24128	230	22.21579	429	24155	230	24401	230	567.8764	489.06	16.1159
427	24155	24128	230	22.21579	659	24837	115	24819	115	213.6869	181.467	17.75524
429	24155	24401	230	564.8954	462	24404	66	24452	66	77.12489	68.508	12.57794
429	24155	24401	230	564.8954	429	24155	230	24401	230	564.8954	489.06	15.50637
429	24155	24401	230	564.8954	659	24837	115	24819	115	213.7336	181.467	17.78096
430	24155	25616	230	92.94602	531	24463	66	24474	66	75.8653	67.914	11.7079
430	24155	25616	230	92.94602	429	24155	230	24401	230	570.9565	489.06	16.74569
430	24155	25616	230	92.94602	659	24837	115	24819	115	213.7941	181.467	17.81434
432	24218	24217	230	74.00002	429	24155	230	24401	230	564.0929	489.06	15.34226
432	24218	24217	230	74.00002	659	24837	115	24819	115	213.675	181.467	17.74867
433	24219	24041	230	-36.6584	429	24155	230	24401	230	564.9245	489.06	15.51232
433	24219	24041	230	-36.6584	659	24837	115	24819	115	213.7142	181.467	17.7703
434	24219	24085	230	73.05814	429	24155	230	24401	230	565.0367	489.06	15.53525
434	24219	24085	230	73.05814	659	24837	115	24819	115	213.8778	181.467	17.86046
435	24219	24627	230	-36.3997	429	24155	230	24401	230	564.9243	489.06	15.51226
435	24219	24627	230	-36.3997	659	24837	115	24819	115	213.7139	181.467	17.77013
437	24301	24235	230	189.6934	429	24155	230	24401	230	555.4252	489.06	13.56996
437	24301	24235	230	189.6934	659	24837	115	24819	115	213.6876	181.467	17.7556
438	24301	24302	230	-99.7413	429	24155	230	24401	230	559.916	489.06	14.4882
438	24301	24302	230	-99.7413	659	24837	115	24819	115	213.6811	181.467	17.75204

440	24302	24303	230	2.804737	429	24155	230	24401	230	564.9054	489.06	15.50841
440	24302	24303	230	2.804737	659	24837	115	24819	115	213.6739	181.467	17.74809
441	24302	24305	230	-22.7216	429	24155	230	24401	230	564.8277	489.06	15.49252
441	24302	24305	230	-22.7216	659	24837	115	24819	115	213.674	181.467	17.74815
442	24303	24235	230	227.6717	429	24155	230	24401	230	551.7576	489.06	12.82003
442	24303	24235	230	227.6717	659	24837	115	24819	115	213.6928	181.467	17.75849
443	24304	24303	230	4.913011	429	24155	230	24401	230	564.6403	489.06	15.45419
443	24304	24303	230	4.913011	659	24837	115	24819	115	213.6743	181.467	17.74832
444	24305	24303	230	8.27187	429	24155	230	24401	230	564.9201	489.06	15.51141
444	24305	24303	230	8.27187	659	24837	115	24819	115	213.6739	181.467	17.74808
459	24403	24115	230	-68.4135	429	24155	230	24401	230	557.9025	489.06	14.0765
459	24403	24115	230	-68.4135	659	24837	115	24819	115	213.6803	181.467	17.75162
546	24601	24085	230	448.4082	548	24602	115	24608	115	268.3836	238.59	12.48734
546	24601	24085	230	448.4082	429	24155	230	24401	230	564.028	489.06	15.32901
546	24601	24085	230	448.4082	659	24837	115	24819	115	212.8117	181.467	17.27297
546	24601	24085	230	448.4082	553	24602	115	24621	115	101.5714	81.873	24.05974
546	24601	24085	230	448.4082	3572	24601	230	24602	115	777.3092	561.33	38.47634
575	24627	24041	230	-37.6242	429	24155	230	24401	230	564.9253	489.06	15.51248
575	24627	24041	230	-37.6242	659	24837	115	24819	115	213.7153	181.467	17.77089
596	24729	26136	230	158.0603	590	24723	115	24728	115	-109.6	78.903	38.90474
596	24729	26136	230	158.0603	429	24155	230	24401	230	564.5018	489.06	15.42588
596	24729	26136	230	158.0603	659	24837	115	24819	115	213.7479	181.467	17.78886
596	24729	26136	230	158.0603	3590	24728	115	24730	115	-90.0205	55.44	62.37464
621	24779	24736	230	80.00008	429	24155	230	24401	230	564.8979	489.06	15.50687
621	24779	24736	230	80.00008	659	24837	115	24819	115	213.6648	181.467	17.74308
622	24780	24736	230	80.00008	429	24155	230	24401	230	564.8967	489.06	15.50663
622	24780	24736	230	80.00008	659	24837	115	24819	115	213.6687	181.467	17.74523
623	24781	24706	230	74.99957	429	24155	230	24401	230	564.9007	489.06	15.50745
623	24781	24706	230	74.99957	659	24837	115	24819	115	213.6705	181.467	17.74617
626	24804	24132	230	44.39901	429	24155	230	24401	230	564.855	489.06	15.4981

626	24804	24132	230	44.39901	659	24837	115	24819	115	215.0397	181.467	18.50073
627	24804	24806	230	172.9911	659	24837	115	24819	115	206.458	181.467	13.77163
627	24804	24806	230	172.9911	429	24155	230	24401	230	564.8639	489.06	15.49991
628	24804	24901	230	106.5194	429	24155	230	24401	230	564.7793	489.06	15.48262
628	24804	24901	230	106.5194	659	24837	115	24819	115	216.9821	181.467	19.57111
662	24901	24132	230	-450.73	429	24155	230	24401	230	564.6689	489.06	15.46004
662	24901	24132	230	-450.73	659	24837	115	24819	115	215.1339	181.467	18.55262
663	24901	24804	230	-104.352	429	24155	230	24401	230	564.7822	489.06	15.48321
663	24901	24804	230	-104.352	659	24837	115	24819	115	216.9019	181.467	19.52689
675	25001	24076	230	222.8322	429	24155	230	24401	230	563.2299	489.06	15.1658
675	25001	24076	230	222.8322	659	24837	115	24819	115	213.3206	181.467	17.5534
676	25201	24137	230	-572.613	429	24155	230	24401	230	564.7862	489.06	15.48402
676	25201	24137	230	-572.613	659	24837	115	24819	115	213.8325	181.467	17.83547
677	25201	24154	230	-118.6	429	24155	230	24401	230	564.8875	489.06	15.50475
677	25201	24154	230	-118.6	659	24837	115	24819	115	213.6845	181.467	17.75391
678	25401	25405	230	-151.326	659	24837	115	24819	115	207.1604	181.467	14.15872
678	25401	25405	230	-151.326	429	24155	230	24401	230	565.1242	489.06	15.55314
679	25405	24019	230	-178.478	659	24837	115	24819	115	205.9917	181.467	13.51469
679	25405	24019	230	-178.478	429	24155	230	24401	230	565.1652	489.06	15.56154
680	25406	24806	230	72.66156	429	24155	230	24401	230	564.9823	489.06	15.52413
680	25406	24806	230	72.66156	659	24837	115	24819	115	210.6456	181.467	16.07929
681	25406	25401	230	-147.062	659	24837	115	24819	115	207.5448	181.467	14.37056
681	25406	25401	230	-147.062	429	24155	230	24401	230	565.0713	489.06	15.54232
709	25654	24025	230	-8.39319	429	24155	230	24401	230	564.893	489.06	15.50587
709	25654	24025	230	-8.39319	659	24837	115	24819	115	213.7047	181.467	17.76506
710	25654	24131	230	-303.624	429	24155	230	24401	230	564.9696	489.06	15.52154
710	25654	24131	230	-303.624	659	24837	115	24819	115	212.6722	181.467	17.19609
711	25656	24100	230	356.9388	429	24155	230	24401	230	564.5698	489.06	15.43978
711	25656	24100	230	356.9388	659	24837	115	24819	115	215.1691	181.467	18.57202
712	25656	24112	230	323.0906	429	24155	230	24401	230	564.9383	489.06	15.51512

712	25656	24112	230	323.0906	659	24837	115	24819	115	213.5266	181.467	17.66691
713	25656	24901	230	240.41	429	24155	230	24401	230	565.0011	489.06	15.52796
713	25656	24901	230	240.41	659	24837	115	24819	115	213.0572	181.467	17.40821
717	26010	26052	230	255.1627	429	24155	230	24401	230	564.2096	489.06	15.36614
717	26010	26052	230	255.1627	659	24837	115	24819	115	213.0704	181.467	17.41553
718	26010	26086	230	281.6512	429	24155	230	24401	230	564.0899	489.06	15.34165
718	26010	26086	230	281.6512	659	24837	115	24819	115	213.0063	181.467	17.38019
719	26010	26094	230	246.4058	429	24155	230	24401	230	563.8785	489.06	15.29843
719	26010	26094	230	246.4058	659	24837	115	24819	115	213.1087	181.467	17.43663
720	26013	26081	230	446.7515	429	24155	230	24401	230	565.3229	489.06	15.59378
720	26013	26081	230	446.7515	659	24837	115	24819	115	213.5554	181.467	17.68279
723	26025	26081	230	128.7002	429	24155	230	24401	230	564.8587	489.06	15.49886
723	26025	26081	230	128.7002	659	24837	115	24819	115	213.6755	181.467	17.74895
726	26046	27514	230	160.2906	429	24155	230	24401	230	564.8954	489.06	15.50637
726	26046	27514	230	160.2906	659	24837	115	24819	115	213.674	181.467	17.7481
727	26046	25705	230	-200.055	429	24155	230	24401	230	564.8669	489.06	15.50053
727	26046	25705	230	-200.055	659	24837	115	24819	115	213.8488	181.467	17.84444
730	26052	26086	230	303.0757	429	24155	230	24401	230	564.1293	489.06	15.34972
730	26052	26086	230	303.0757	659	24837	115	24819	115	212.964	181.467	17.35686
735	26061	26086	230	591.325	429	24155	230	24401	230	565.3422	489.06	15.59773
735	26061	26086	230	591.325	659	24837	115	24819	115	214.2583	181.467	18.07013
736	26061	26094	230	-1283.07	429	24155	230	24401	230	566.6966	489.06	15.87466
736	26061	26094	230	-1283.07	659	24837	115	24819	115	213.1803	181.467	17.47609
736	26061	26094	230	-1283.07	770	26094	230	26086	230	1055.651	700.92	50.6093
737	26061	26103	230	846.9623	734	26061	230	26013	230	1007.549	908.82	10.86339
737	26061	26103	230	846.9623	429	24155	230	24401	230	565.5048	489.06	15.63097
737	26061	26103	230	846.9623	659	24837	115	24819	115	213.3365	181.467	17.56215
738	26063	26025	230	-213.279	429	24155	230	24401	230	564.876	489.06	15.5024
738	26063	26025	230	-213.279	659	24837	115	24819	115	213.6715	181.467	17.74675
739	26063	26080	230	49.75904	429	24155	230	24401	230	564.898	489.06	15.5069

739	26063	26080	230	49.75904	659	24837	115	24819	115	213.6707	181.467	17.74633
740	26066	26087	230	137.7979	429	24155	230	24401	230	564.8259	489.06	15.49215
740	26066	26087	230	137.7979	659	24837	115	24819	115	213.7198	181.467	17.77338
741	26068	26025	230	-184.247	429	24155	230	24401	230	564.8702	489.06	15.5012
741	26068	26025	230	-184.247	659	24837	115	24819	115	213.6736	181.467	17.74792
742	26068	26063	230	184.0716	429	24155	230	24401	230	564.9345	489.06	15.51435
742	26068	26063	230	184.0716	659	24837	115	24819	115	213.6662	181.467	17.74383
743	26068	26081	230	-215.334	429	24155	230	24401	230	564.9751	489.06	15.52265
743	26068	26081	230	-215.334	659	24837	115	24819	115	213.6666	181.467	17.74407
758	26078	26081	230	71.37959	429	24155	230	24401	230	564.9057	489.06	15.50847
758	26078	26081	230	71.37959	659	24837	115	24819	115	213.6851	181.467	17.75426
759	26080	26025	230	-243.795	429	24155	230	24401	230	564.8758	489.06	15.50234
759	26080	26025	230	-243.795	659	24837	115	24819	115	213.6661	181.467	17.74377
760	26080	26072	230	247.9119	429	24155	230	24401	230	565.0647	489.06	15.54098
760	26080	26072	230	247.9119	659	24837	115	24819	115	213.5589	181.467	17.68472
761	26080	26081	230	-166.973	429	24155	230	24401	230	564.9421	489.06	15.51591
761	26080	26081	230	-166.973	659	24837	115	24819	115	213.665	181.467	17.74314
762	26082	26078	230	-210.385	429	24155	230	24401	230	564.9469	489.06	15.51688
762	26082	26078	230	-210.385	659	24837	115	24819	115	213.6936	181.467	17.75891
766	26086	26093	230	1037.477	744	26069	138	26014	138	207.7204	180.576	15.03211
766	26086	26093	230	1037.477	745	26069	138	26015	138	207.7204	180.576	15.03211
766	26086	26093	230	1037.477	429	24155	230	24401	230	566.7875	489.06	15.89325
766	26086	26093	230	1037.477	659	24837	115	24819	115	213.1767	181.467	17.47406
766	26086	26093	230	1037.477	763	26083	138	26085	138	-228.985	189.09	21.09834
766	26086	26093	230	1037.477	764	26084	138	26085	138	-228.985	189.09	21.09834
766	26086	26093	230	1037.477	721	26014	138	26076	138	193.0133	157.41	22.61822
766	26086	26093	230	1037.477	722	26015	138	26076	138	193.0133	157.41	22.61822
767	26087	26093	230	-258.165	429	24155	230	24401	230	565.0755	489.06	15.54319
767	26087	26093	230	-258.165	659	24837	115	24819	115	213.6039	181.467	17.70949
770	26094	26086	230	334.1131	429	24155	230	24401	230	565.0007	489.06	15.52788

770	26094	26086	230	334.1131	659	24837	115	24819	115	213.8295	181.467	17.83384
777	26103	26078	230	581.4537	429	24155	230	24401	230	565.2431	489.06	15.57746
777	26103	26078	230	581.4537	659	24837	115	24819	115	213.432	181.467	17.61477
780	26129	26130	230	36.97931	3590	24728	115	24730	115	62.50736	55.44	12.74776
780	26129	26130	230	36.97931	429	24155	230	24401	230	564.8343	489.06	15.49386
780	26129	26130	230	36.97931	659	24837	115	24819	115	213.6665	181.467	17.74399
781	26130	26131	230	73.95136	429	24155	230	24401	230	564.7701	489.06	15.48074
781	26130	26131	230	73.95136	659	24837	115	24819	115	213.6586	181.467	17.73962
781	26130	26131	230	73.95136	3590	24728	115	24730	115	77.11633	55.44	39.09872
782	26131	24729	230	109.85	429	24155	230	24401	230	564.7048	489.06	15.46739
782	26131	24729	230	109.85	590	24723	115	24728	115	91.95367	78.903	16.54015
782	26131	24729	230	109.85	659	24837	115	24819	115	213.6504	181.467	17.73511
782	26131	24729	230	109.85	3590	24728	115	24730	115	91.81314	55.44	65.60812
783	26132	26061	230	150.3692	429	24155	230	24401	230	564.521	489.06	15.4298
783	26132	26061	230	150.3692	659	24837	115	24819	115	213.7443	181.467	17.78688
783	26132	26061	230	150.3692	3590	24728	115	24730	115	109.1	55.44	96.78932
784	26136	26132	230	154.8303	590	24723	115	24728	115	109.1	78.903	38.27105
784	26136	26132	230	154.8303	429	24155	230	24401	230	564.5098	489.06	15.42752
784	26136	26132	230	154.8303	659	24837	115	24819	115	213.7464	181.467	17.78803
784	26136	26132	230	154.8303	3590	24728	115	24730	115	109.6	55.44	97.6912
784	26136	26132	230	154.8303		24723	115	24728	115	-109.7	71.18	54.11632
785	26182	26078	230	-202.15	429	24155	230	24401	230	564.9438	489.06	15.51626
785	26182	26078	230	-202.15	659	24837	115	24819	115	213.6924	181.467	17.75827
828	30105	30111	230	109.5466	429	24155	230	24401	230	564.9529	489.06	15.51811
828	30105	30111	230	109.5466	659	24837	115	24819	115	213.6917	181.467	17.75787
829	30105	30245	230	-262.219	429	24155	230	24401	230	564.9098	489.06	15.5093
829	30105	30245	230	-262.219	659	24837	115	24819	115	213.6785	181.467	17.75061
830	30105	30450	230	130.4379	429	24155	230	24401	230	564.971	489.06	15.52183
830	30105	30450	230	130.4379	659	24837	115	24819	115	213.6972	181.467	17.76093
831	30106	30105	230	7.603877	429	24155	230	24401	230	564.8968	489.06	15.50664

831	30106	30105	230	7.603877	659	24837	115	24819	115	213.6743	181.467	17.74832
832	30106	30108	230	-99.4616	429	24155	230	24401	230	564.8962	489.06	15.50652
832	30106	30108	230	-99.4616	659	24837	115	24819	115	213.6742	181.467	17.74826
833	30106	30110	230	146.152	429	24155	230	24401	230	564.9812	489.06	15.52391
833	30106	30110	230	146.152	659	24837	115	24819	115	213.7003	181.467	17.76261
834	30106	30460	230	83.27531	429	24155	230	24401	230	564.9364	489.06	15.51474
834	30106	30460	230	83.27531	659	24837	115	24819	115	213.6866	181.467	17.75509
835	30106	37545	230	-113.088	429	24155	230	24401	230	564.9481	489.06	15.51714
835	30106	37545	230	-113.088	659	24837	115	24819	115	213.69	181.467	17.75692
836	30108	30185	230	-75.8484	429	24155	230	24401	230	564.8962	489.06	15.50653
836	30108	30185	230	-75.8484	659	24837	115	24819	115	213.6742	181.467	17.74825
837	30110	30460	230	46.78706	429	24155	230	24401	230	564.9155	489.06	15.51048
837	30110	30460	230	46.78706	659	24837	115	24819	115	213.6802	181.467	17.75157
838	30111	30460	230	70.87138	429	24155	230	24401	230	564.928	489.06	15.51303
838	30111	30460	230	70.87138	659	24837	115	24819	115	213.6841	181.467	17.75369
839	30185	30190	230	-11.5483	429	24155	230	24401	230	564.8958	489.06	15.50644
839	30185	30190	230	-11.5483	659	24837	115	24819	115	213.6741	181.467	17.74816
840	30186	30185	230	12.43524	429	24155	230	24401	230	564.8951	489.06	15.50629
840	30186	30185	230	12.43524	659	24837	115	24819	115	213.674	181.467	17.7481
841	30190	30195	230	-0.65479	429	24155	230	24401	230	564.8955	489.06	15.50637
841	30190	30195	230	-0.65479	659	24837	115	24819	115	213.674	181.467	17.74811
842	30195	30245	230	51.85881	429	24155	230	24401	230	564.8934	489.06	15.50596
842	30195	30245	230	51.85881	659	24837	115	24819	115	213.6733	181.467	17.74777
844	30205	30209	230	164.166	429	24155	230	24401	230	564.8877	489.06	15.50479
844	30205	30209	230	164.166	659	24837	115	24819	115	213.6635	181.467	17.74235
846	30210	30232	230	138.2571	429	24155	230	24401	230	564.7773	489.06	15.48222
846	30210	30232	230	138.2571	659	24837	115	24819	115	213.6365	181.467	17.72746
849	30222	30245	230	172.8822	429	24155	230	24401	230	564.8954	489.06	15.50637
849	30222	30245	230	172.8822	659	24837	115	24819	115	213.6621	181.467	17.74155
850	30223	30245	230	140.0643	429	24155	230	24401	230	564.7758	489.06	15.4819

850	30223	30245	230	140.0643	659	24837	115	24819	115	213.636	181.467	17.72719
853	30232	30223	230	140.4396	429	24155	230	24401	230	564.7755	489.06	15.48183
853	30232	30223	230	140.4396	659	24837	115	24819	115	213.6359	181.467	17.72714
855	30250	30261	230	168.9428	1609	32280	115	32212	115	79.84779	71.28	12.0199
855	30250	30261	230	168.9428	3136	38138	69	38139	69	33.30107	29.7	12.12482
858	30265	30272	230	51.07517	429	24155	230	24401	230	564.8875	489.06	15.50475
858	30265	30272	230	51.07517	659	24837	115	24819	115	213.6711	181.467	17.74653
860	30270	30272	230	50.72482	429	24155	230	24401	230	564.8946	489.06	15.5062
860	30270	30272	230	50.72482	659	24837	115	24819	115	213.6741	181.467	17.74817
864	30280	30330	230	257.8543		31786	14	30268	230	49	13.86	
865	30300	30303	230	-311.276	429	24155	230	24401	230	564.8957	489.06	15.50641
865	30300	30303	230	-311.276	659	24837	115	24819	115	213.674	181.467	17.74814
866	30300	30325	230	240.9969	429	24155	230	24401	230	564.9209	489.06	15.51158
866	30300	30325	230	240.9969	659	24837	115	24819	115	213.6818	181.467	17.75241
866	30300	30325	230	240.9969	867	30300	230	30330	230	426.6249	325.71	30.98306
867	30300	30330	230	260.9267	429	24155	230	24401	230	564.8981	489.06	15.50691
867	30300	30330	230	260.9267	659	24837	115	24819	115	213.675	181.467	17.7487
867	30300	30330	230	260.9267	866	30300	230	30325	230	413.8761	325.71	27.06889
868	30302	30300	230	195.2971	429	24155	230	24401	230	564.896	489.06	15.50648
868	30302	30300	230	195.2971	659	24837	115	24819	115	213.6741	181.467	17.7482
869	30302	30303	230	-116.271	429	24155	230	24401	230	564.8952	489.06	15.50632
869	30302	30303	230	-116.271	659	24837	115	24819	115	213.6739	181.467	17.74806
872	30325	30327	230	115.4283	429	24155	230	24401	230	564.9004	489.06	15.50739
872	30325	30327	230	115.4283	659	24837	115	24819	115	213.6755	181.467	17.74897
872	30325	30327	230	115.4283	1409	31658	60	32308	60	29.67551	24.948	18.94947
872	30325	30327	230	115.4283	1408	31656	60	31658	60	35.99018	28.71	25.35766
873	30327	30330	230	170.8636	867	30300	230	30330	230	359.8039	325.71	10.46755
873	30327	30330	230	170.8636	429	24155	230	24401	230	564.8867	489.06	15.50459
873	30327	30330	230	170.8636	659	24837	115	24819	115	213.6715	181.467	17.74674
873	30327	30330	230	170.8636	1621	32308	60	32313	60	51.35281	42.57	20.63146

874	30330	30335	230	229.3412	429	24155	230	24401	230	564.8845	489.06	15.50414
874	30330	30335	230	229.3412	659	24837	115	24819	115	213.6708	181.467	17.74636
875	30330	30337	230	173.0806	429	24155	230	24401	230	564.8827	489.06	15.50377
875	30330	30337	230	173.0806	659	24837	115	24819	115	213.6703	181.467	17.74606
876	30330	30348	230	205.3665	429	24155	230	24401	230	564.8941	489.06	15.50609
876	30330	30348	230	205.3665	659	24837	115	24819	115	213.6735	181.467	17.74788
877	30330	30482	230	112.784	429	24155	230	24401	230	564.8847	489.06	15.50418
877	30330	30482	230	112.784	659	24837	115	24819	115	213.6708	181.467	17.74637
878	30335	30337	230	81.21685	429	24155	230	24401	230	564.8864	489.06	15.50452
878	30335	30337	230	81.21685	659	24837	115	24819	115	213.6713	181.467	17.74664
880	30337	30622	230	4.108068	429	24155	230	24401	230	564.8945	489.06	15.50618
880	30337	30622	230	4.108068	659	24837	115	24819	115	213.6737	181.467	17.74795
881	30337	37012	230	131.9569	429	24155	230	24401	230	564.8943	489.06	15.50614
881	30337	37012	230	131.9569	659	24837	115	24819	115	213.6733	181.467	17.74776
882	30337	38000	230	2.055457	429	24155	230	24401	230	564.895	489.06	15.50627
882	30337	38000	230	2.055457	659	24837	115	24819	115	213.6738	181.467	17.74802
884	30348	30500	230	25.8024	429	24155	230	24401	230	564.8908	489.06	15.50541
884	30348	30500	230	25.8024	659	24837	115	24819	115	213.6726	181.467	17.74734
885	30391	30393	230	-84.7919	429	24155	230	24401	230	564.8944	489.06	15.50615
885	30391	30393	230	-84.7919	659	24837	115	24819	115	213.6739	181.467	17.74807
886	30391	30399	230	-179.16	3790	31166	4.16	31118	60	6.837959	5.94	15.11716
886	30391	30399	230	-179.16	429	24155	230	24401	230	564.8945	489.06	15.50617
886	30391	30399	230	-179.16	659	24837	115	24819	115	213.6692	181.467	17.74547
887	30391	30430	230	263.9566	3787	31152	13.8	31153	2.4	-9.08867	7.92	14.75597
887	30391	30430	230	263.9566	429	24155	230	24401	230	564.8528	489.06	15.49764
887	30391	30430	230	263.9566	659	24837	115	24819	115	213.6678	181.467	17.74473
887	30391	30430	230	263.9566	1272	31379	60	38050	60	38.79572	30.69	26.41161
887	30391	30430	230	263.9566	1207	31249	115	31250	115	128.9119	87.12	47.97048
887	30391	30430	230	263.9566	1395	31636	60	31638	60	-17.4632	10.395	67.99616
887	30391	30430	230	263.9566	3798	31315	12.47	31314	60	-13.7121	6.534	109.8572

887	30391	30430	230	263.9566	3799	31317	12.47	31316	60	19.30804	3.465	457.2307
888	30392	30405	230	-207.806	429	24155	230	24401	230	564.8958	489.06	15.50645
888	30392	30405	230	-207.806	659	24837	115	24819	115	213.674	181.467	17.74811
889	30393	30394	230	-30.959	429	24155	230	24401	230	564.8954	489.06	15.50636
889	30393	30394	230	-30.959	659	24837	115	24819	115	213.6745	181.467	17.7484
890	30393	30396	230	-53.8694	429	24155	230	24401	230	564.8947	489.06	15.50621
890	30393	30396	230	-53.8694	659	24837	115	24819	115	213.674	181.467	17.7481
891	30395	30392	230	55.96075	429	24155	230	24401	230	564.8953	489.06	15.50634
891	30395	30392	230	55.96075	659	24837	115	24819	115	213.6739	181.467	17.7481
893	30397	30398	230	-69.7689	429	24155	230	24401	230	564.8942	489.06	15.50612
893	30397	30398	230	-69.7689	659	24837	115	24819	115	213.6749	181.467	17.74864
898	30400	30402	230	-24.0965	429	24155	230	24401	230	564.895	489.06	15.50628
898	30400	30402	230	-24.0965	659	24837	115	24819	115	213.6739	181.467	17.74809
899	30400	30403	230	-63.9325	429	24155	230	24401	230	564.8937	489.06	15.506
899	30400	30403	230	-63.9325	659	24837	115	24819	115	213.6744	181.467	17.74837
901	30406	30407	230	-123.3	429	24155	230	24401	230	564.896	489.06	15.50649
901	30406	30407	230	-123.3	659	24837	115	24819	115	213.6741	181.467	17.74817
902	30406	30410	230	-51.9593	429	24155	230	24401	230	564.8958	489.06	15.50644
902	30406	30410	230	-51.9593	659	24837	115	24819	115	213.6732	181.467	17.74766
903	30407	30408	230	-64.2016	429	24155	230	24401	230	564.8959	489.06	15.50647
903	30407	30408	230	-64.2016	659	24837	115	24819	115	213.6743	181.467	17.74829
904	30407	30409	230	-59.1729	429	24155	230	24401	230	564.8972	489.06	15.50673
904	30407	30409	230	-59.1729	659	24837	115	24819	115	213.6742	181.467	17.74823
906	30426	30427	230	51.87488	429	24155	230	24401	230	564.8859	489.06	15.50441
906	30426	30427	230	51.87488	659	24837	115	24819	115	213.6706	181.467	17.74623
907	30427	30430	230	87.84837	429	24155	230	24401	230	564.8792	489.06	15.50305
907	30427	30430	230	87.84837	659	24837	115	24819	115	213.6682	181.467	17.74493
908	30430	30445	230	24.87631	429	24155	230	24401	230	564.8944	489.06	15.50616
908	30430	30445	230	24.87631	659	24837	115	24819	115	213.6736	181.467	17.74793
909	30432	30430	230	37.83348	429	24155	230	24401	230	564.9009	489.06	15.50748

909	30432	30430	230	37.83348	659	24837	115	24819	115	213.6756	181.467	17.74899
910	30435	30432	230	37.85587	429	24155	230	24401	230	564.9009	489.06	15.50748
910	30435	30432	230	37.85587	659	24837	115	24819	115	213.6756	181.467	17.74899
911	30435	30440	230	-33.2021	429	24155	230	24401	230	564.9022	489.06	15.50774
911	30435	30440	230	-33.2021	659	24837	115	24819	115	213.676	181.467	17.74922
912	30435	30445	230	154.3287	429	24155	230	24401	230	564.9105	489.06	15.50945
912	30435	30445	230	154.3287	659	24837	115	24819	115	213.6785	181.467	17.75061
913	30435	30460	230	-80.2606	429	24155	230	24401	230	564.9138	489.06	15.51012
913	30435	30460	230	-80.2606	659	24837	115	24819	115	213.6795	181.467	17.75115
914	30435	30540	230	1.292365	429	24155	230	24401	230	564.8955	489.06	15.50638
914	30435	30540	230	1.292365	659	24837	115	24819	115	213.674	181.467	17.74811
915	30437	30438	230	-237.779	429	24155	230	24401	230	564.8437	489.06	15.49579
915	30437	30438	230	-237.779	659	24837	115	24819	115	213.6562	181.467	17.73834
916	30437	30445	230	109.319	429	24155	230	24401	230	564.8976	489.06	15.5068
916	30437	30445	230	109.319	659	24837	115	24819	115	213.6745	181.467	17.74838
917	30437	30540	230	128.4578	429	24155	230	24401	230	564.8928	489.06	15.50584
917	30437	30540	230	128.4578	659	24837	115	24819	115	213.6733	181.467	17.74775
918	30440	30460	230	-114.393	429	24155	230	24401	230	564.9234	489.06	15.51209
918	30440	30460	230	-114.393	659	24837	115	24819	115	213.6824	181.467	17.75275
919	30450	30460	230	14.81125	429	24155	230	24401	230	564.8993	489.06	15.50715
919	30450	30460	230	14.81125	659	24837	115	24819	115	213.6752	181.467	17.74877
920	30460	30465	230	155.5634	429	24155	230	24401	230	564.9158	489.06	15.51053
920	30460	30465	230	155.5634	659	24837	115	24819	115	213.6802	181.467	17.75157
921	30460	30467	230	144.8649	429	24155	230	24401	230	564.9119	489.06	15.50974
921	30460	30467	230	144.8649	659	24837	115	24819	115	213.6791	181.467	17.75094
922	30460	30472	230	102.417	429	24155	230	24401	230	564.8983	489.06	15.50696
922	30460	30472	230	102.417	659	24837	115	24819	115	213.6749	181.467	17.74864
923	30460	30478	230	-27.808	429	24155	230	24401	230	564.8955	489.06	15.50638
923	30460	30478	230	-27.808	659	24837	115	24819	115	213.6739	181.467	17.74808
924	30465	30550	230	61.01754	429	24155	230	24401	230	564.8993	489.06	15.50716

924	30465	30550	230	61.01754	659	24837	115	24819	115	213.6752	181.467	17.7488
925	30467	30550	230	117.0285	429	24155	230	24401	230	564.9069	489.06	15.50871
925	30467	30550	230	117.0285	659	24837	115	24819	115	213.6776	181.467	17.75009
926	30472	30479	230	-33.271	429	24155	230	24401	230	564.896	489.06	15.50649
926	30472	30479	230	-33.271	659	24837	115	24819	115	213.6741	181.467	17.74816
927	30475	30529	230	0.000425	429	24155	230	24401	230	564.8954	489.06	15.50637
927	30475	30529	230	0.000425	659	24837	115	24819	115	213.6739	181.467	17.7481
928	30476	30479	230	149.9914	429	24155	230	24401	230	564.8358	489.06	15.49417
928	30476	30479	230	149.9914	659	24837	115	24819	115	213.6547	181.467	17.73752
930	30478	30479	230	110.5903	429	24155	230	24401	230	564.8952	489.06	15.50631
930	30478	30479	230	110.5903	659	24837	115	24819	115	213.6741	181.467	17.74817
931	30479	30480	230	-40.0029	429	24155	230	24401	230	564.8954	489.06	15.50637
931	30479	30480	230	-40.0029	659	24837	115	24819	115	213.6746	181.467	17.74848
932	30479	30523	230	239.5978	429	24155	230	24401	230	564.8954	489.06	15.50636
932	30479	30523	230	239.5978	659	24837	115	24819	115	213.6742	181.467	17.74822
933	30479	30529	230	-107.997	429	24155	230	24401	230	564.8524	489.06	15.49758
933	30479	30529	230	-107.997	659	24837	115	24819	115	213.6601	181.467	17.74047
933	30479	30529	230	-107.997	3913	32171	34.5	30475	230	-107.997	39.6	172.7201
934	30482	30500	230	-67.2173	429	24155	230	24401	230	564.9092	489.06	15.50919
934	30482	30500	230	-67.2173	659	24837	115	24819	115	213.6781	181.467	17.75037
935	30485	30487	230	1.208573	429	24155	230	24401	230	564.8954	489.06	15.50636
935	30485	30487	230	1.208573	659	24837	115	24819	115	213.6739	181.467	17.7481
936	30485	30490	230	87.70317	429	24155	230	24401	230	564.8966	489.06	15.50661
936	30485	30490	230	87.70317	659	24837	115	24819	115	213.6743	181.467	17.74829
937	30487	30500	230	73.8059	429	24155	230	24401	230	564.8931	489.06	15.5059
937	30487	30500	230	73.8059	659	24837	115	24819	115	213.6733	181.467	17.74773
938	30489	30624	230	-162.558	429	24155	230	24401	230	564.9322	489.06	15.51387
938	30489	30624	230	-162.558	659	24837	115	24819	115	213.6846	181.467	17.754
939	30490	30500	230	-1.34571	429	24155	230	24401	230	564.8955	489.06	15.50639
939	30490	30500	230	-1.34571	659	24837	115	24819	115	213.674	181.467	17.74812

940	30495	30496	230	121.5976	429	24155	230	24401	230	564.8837	489.06	15.50396
940	30495	30496	230	121.5976	659	24837	115	24819	115	213.6705	181.467	17.74619
941	30496	30497	230	76.70369	429	24155	230	24401	230	564.8864	489.06	15.50451
941	30496	30497	230	76.70369	659	24837	115	24819	115	213.6713	181.467	17.74663
942	30497	30498	230	25.95634	429	24155	230	24401	230	564.8917	489.06	15.50561
942	30497	30498	230	25.95634	659	24837	115	24819	115	213.6729	181.467	17.7475
943	30498	30499	230	-67.1865	429	24155	230	24401	230	564.9012	489.06	15.50755
943	30498	30499	230	-67.1865	659	24837	115	24819	115	213.6756	181.467	17.74903
944	30499	30489	230	-162.422	429	24155	230	24401	230	564.9321	489.06	15.51387
944	30499	30489	230	-162.422	659	24837	115	24819	115	213.6846	181.467	17.75399
946	30500	30505	230	10.06796	429	24155	230	24401	230	564.893	489.06	15.50588
946	30500	30505	230	10.06796	659	24837	115	24819	115	213.6732	181.467	17.74771
947	30500	30624	230	-117.291	429	24155	230	24401	230	564.9316	489.06	15.51375
947	30500	30624	230	-117.291	659	24837	115	24819	115	213.6844	181.467	17.75389
948	30500	38206	230	-138.115	429	24155	230	24401	230	564.8761	489.06	15.50241
948	30500	38206	230	-138.115	659	24837	115	24819	115	213.6681	181.467	17.74485
949	30500	38208	230	-10.8221	429	24155	230	24401	230	564.8949	489.06	15.50625
949	30500	38208	230	-10.8221	659	24837	115	24819	115	213.6738	181.467	17.748
950	30505	30624	230	-192.655	429	24155	230	24401	230	564.9614	489.06	15.51986
950	30505	30624	230	-192.655	659	24837	115	24819	115	213.6932	181.467	17.75868
951	30515	30800	230	-8.41521	429	24155	230	24401	230	564.8938	489.06	15.50603
951	30515	30800	230	-8.41521	659	24837	115	24819	115	213.6734	181.467	17.74782
953	30523	30525	230	77.0688	429	24155	230	24401	230	564.8925	489.06	15.50576
953	30523	30525	230	77.0688	659	24837	115	24819	115	213.6732	181.467	17.74766
954	30525	30479	230	-234.172	429	24155	230	24401	230	564.8939	489.06	15.50605
954	30525	30479	230	-234.172	659	24837	115	24819	115	213.6737	181.467	17.74798
955	30525	30543	230	167.1059	429	24155	230	24401	230	564.9171	489.06	15.5108
955	30525	30543	230	167.1059	659	24837	115	24819	115	213.6803	181.467	17.75161
956	30525	30544	230	154.8206	429	24155	230	24401	230	564.9149	489.06	15.51035
956	30525	30544	230	154.8206	659	24837	115	24819	115	213.6797	181.467	17.75125

957	30525	30565	230	117.9696	429	24155	230	24401	230	564.8633	489.06	15.49979
957	30525	30565	230	117.9696	659	24837	115	24819	115	213.6647	181.467	17.74299
958	30525	30567	230	201.3675	429	24155	230	24401	230	564.9264	489.06	15.5127
958	30525	30567	230	201.3675	659	24837	115	24819	115	213.6832	181.467	17.7532
959	30525	30575	230	50.95905	429	24155	230	24401	230	564.8782	489.06	15.50283
959	30525	30575	230	50.95905	659	24837	115	24819	115	213.669	181.467	17.74536
960	30525	30585	230	266.8189	429	24155	230	24401	230	564.9374	489.06	15.51494
960	30525	30585	230	266.8189	659	24837	115	24819	115	213.6865	181.467	17.75501
961	30526	30527	230	71.09831	429	24155	230	24401	230	564.8911	489.06	15.50548
961	30526	30527	230	71.09831	659	24837	115	24819	115	213.6727	181.467	17.7474
962	30526	30528	230	-868.171	429	24155	230	24401	230	564.6587	489.06	15.45796
962	30526	30528	230	-868.171	659	24837	115	24819	115	213.5956	181.467	17.70492
963	30526	30555	230	282.4976	429	24155	230	24401	230	564.9008	489.06	15.50745
963	30526	30555	230	282.4976	659	24837	115	24819	115	213.6753	181.467	17.74883
964	30526	30561	230	321.5084	429	24155	230	24401	230	564.8986	489.06	15.50702
964	30526	30561	230	321.5084	659	24837	115	24819	115	213.6749	181.467	17.74862
965	30527	30535	230	237.7301	429	24155	230	24401	230	564.9211	489.06	15.5116
965	30527	30535	230	237.7301	659	24837	115	24819	115	213.6814	181.467	17.7522
966	30527	30536	230	188.5819	429	24155	230	24401	230	564.9116	489.06	15.50966
966	30527	30536	230	188.5819	659	24837	115	24819	115	213.6786	181.467	17.75067
967	30527	30595	230	79.6088	429	24155	230	24401	230	564.875	489.06	15.50218
967	30527	30595	230	79.6088	659	24837	115	24819	115	213.668	181.467	17.7448
968	30527	30600	230	80.01554	429	24155	230	24401	230	564.8748	489.06	15.50215
968	30527	30600	230	80.01554	659	24837	115	24819	115	213.6679	181.467	17.74478
969	30530	30537	230	180.4789	429	24155	230	24401	230	564.9171	489.06	15.51079
969	30530	30537	230	180.4789	659	24837	115	24819	115	213.6805	181.467	17.75169
970	30535	30540	230	154.7805	429	24155	230	24401	230	564.9055	489.06	15.50843
970	30535	30540	230	154.7805	659	24837	115	24819	115	213.6768	181.467	17.7497
971	30536	30540	230	178.917	429	24155	230	24401	230	564.9103	489.06	15.50941
971	30536	30540	230	178.917	659	24837	115	24819	115	213.6783	181.467	17.75047

972	30537	35224	230	164.5435	429	24155	230	24401	230	564.9135	489.06	15.51006
972	30537	35224	230	164.5435	659	24837	115	24819	115	213.6794	181.467	17.75111
973	30543	30545	230	60.02741	429	24155	230	24401	230	564.9155	489.06	15.51047
973	30543	30545	230	60.02741	659	24837	115	24819	115	213.6805	181.467	17.75171
974	30543	30550	230	105.9076	429	24155	230	24401	230	564.907	489.06	15.50873
974	30543	30550	230	105.9076	659	24837	115	24819	115	213.6774	181.467	17.74998
975	30544	30550	230	153.818	429	24155	230	24401	230	564.9148	489.06	15.51033
975	30544	30550	230	153.818	659	24837	115	24819	115	213.6796	181.467	17.75123
976	30550	30554	230	183.1903	429	24155	230	24401	230	564.8996	489.06	15.50722
976	30550	30554	230	183.1903	659	24837	115	24819	115	213.6754	181.467	17.74887
977	30550	30555	230	5.776421	429	24155	230	24401	230	564.8961	489.06	15.5065
977	30550	30555	230	5.776421	659	24837	115	24819	115	213.6741	181.467	17.74821
978	30554	30556	230	3.873836	429	24155	230	24401	230	564.8966	489.06	15.50661
978	30554	30556	230	3.873836	659	24837	115	24819	115	213.6743	181.467	17.74831
979	30554	30631	230	115.0418	429	24155	230	24401	230	564.8945	489.06	15.50617
979	30554	30631	230	115.0418	659	24837	115	24819	115	213.6738	181.467	17.74801
980	30560	30527	230	-288.524	429	24155	230	24401	230	564.9185	489.06	15.51108
980	30560	30527	230	-288.524	659	24837	115	24819	115	213.6808	181.467	17.7519
981	30560	30700	230	130.6633	429	24155	230	24401	230	564.889	489.06	15.50505
981	30560	30700	230	130.6633	659	24837	115	24819	115	213.6721	181.467	17.74706
982	30561	30562	230	199.319	429	24155	230	24401	230	564.8842	489.06	15.50408
982	30561	30562	230	199.319	659	24837	115	24819	115	213.6707	181.467	17.7463
983	30562	30563	230	31.87547	429	24155	230	24401	230	564.9043	489.06	15.50819
983	30562	30563	230	31.87547	659	24837	115	24819	115	213.6769	181.467	17.74972
984	30562	30631	230	167.1073	429	24155	230	24401	230	564.883	489.06	15.50383
984	30562	30631	230	167.1073	659	24837	115	24819	115	213.6703	181.467	17.74611
985	30565	30569	230	4.774772	429	24155	230	24401	230	564.8939	489.06	15.50605
985	30565	30569	230	4.774772	659	24837	115	24819	115	213.6735	181.467	17.74785
986	30567	30590	230	200.8266	429	24155	230	24401	230	564.9219	489.06	15.51179
986	30567	30590	230	200.8266	659	24837	115	24819	115	213.6819	181.467	17.75248

987	30569	30570	230	-8.00041	429	24155	230	24401	230	564.8981	489.06	15.50691
987	30569	30570	230	-8.00041	659	24837	115	24819	115	213.6747	181.467	17.74852
989	30570	30625	230	0.457402	429	24155	230	24401	230	564.8953	489.06	15.50634
989	30570	30625	230	0.457402	659	24837	115	24819	115	213.6739	181.467	17.74808
990	30575	38610	230	50.8667	429	24155	230	24401	230	564.8782	489.06	15.50284
990	30575	38610	230	50.8667	659	24837	115	24819	115	213.669	181.467	17.74536
991	30580	30625	230	24.84964	429	24155	230	24401	230	564.887	489.06	15.50465
991	30580	30625	230	24.84964	659	24837	115	24819	115	213.6715	181.467	17.74676
992	30585	30630	230	135.3811	429	24155	230	24401	230	564.9031	489.06	15.50793
992	30585	30630	230	135.3811	659	24837	115	24819	115	213.6763	181.467	17.74941
993	30590	30530	230	199.1088	429	24155	230	24401	230	564.9216	489.06	15.51173
993	30590	30530	230	199.1088	659	24837	115	24819	115	213.6818	181.467	17.75243
994	30595	30640	230	80.99177	429	24155	230	24401	230	564.8746	489.06	15.5021
994	30595	30640	230	80.99177	659	24837	115	24819	115	213.6679	181.467	17.74474
995	30600	30640	230	79.76745	429	24155	230	24401	230	564.8749	489.06	15.50217
995	30600	30640	230	79.76745	659	24837	115	24819	115	213.6679	181.467	17.74479
996	30622	30495	230	121.789	429	24155	230	24401	230	564.8837	489.06	15.50396
996	30622	30495	230	121.789	659	24837	115	24819	115	213.6705	181.467	17.74619
997	30622	30624	230	-111.773	429	24155	230	24401	230	564.921	489.06	15.5116
997	30622	30624	230	-111.773	659	24837	115	24819	115	213.6814	181.467	17.75222
998	30624	30625	230	-453.703	429	24155	230	24401	230	565.1062	489.06	15.54946
998	30624	30625	230	-453.703	659	24837	115	24819	115	213.7356	181.467	17.78209
999	30624	30630	230	288.425	429	24155	230	24401	230	564.9683	489.06	15.52127
999	30624	30630	230	288.425	659	24837	115	24819	115	213.6953	181.467	17.75986
1000	30624	30670	230	65.8803	429	24155	230	24401	230	564.8868	489.06	15.5046
1000	30624	30670	230	65.8803	659	24837	115	24819	115	213.6715	181.467	17.74674
1001	30624	30703	230	334.0102	429	24155	230	24401	230	564.9975	489.06	15.52723
1001	30624	30703	230	334.0102	659	24837	115	24819	115	213.7039	181.467	17.7646
1002	30625	30640	230	-93.8655	429	24155	230	24401	230	564.8523	489.06	15.49754
1002	30625	30640	230	-93.8655	659	24837	115	24819	115	213.6613	181.467	17.74115

1003	30630	30631	230	-360.751	429	24155	230	24401	230	564.8937	489.06	15.506
1003	30630	30631	230	-360.751	659	24837	115	24819	115	213.6734	181.467	17.7478
1004	30630	30703	230	468.7394	429	24155	230	24401	230	564.9581	489.06	15.51918
1004	30630	30703	230	468.7394	659	24837	115	24819	115	213.6926	181.467	17.75836
1009	30670	30765	230	-218.164	429	24155	230	24401	230	564.8373	489.06	15.49448
1009	30670	30765	230	-218.164	659	24837	115	24819	115	213.6555	181.467	17.73793
1010	30670	38257	230	142.5627	429	24155	230	24401	230	564.943	489.06	15.51609
1010	30670	38257	230	142.5627	659	24837	115	24819	115	213.6877	181.467	17.75566
1011	30695	30685	230	112.8998	429	24155	230	24401	230	564.9146	489.06	15.51028
1011	30695	30685	230	112.8998	659	24837	115	24819	115	213.6807	181.467	17.75179
1012	30695	30690	230	112.9014	429	24155	230	24401	230	564.9146	489.06	15.51028
1012	30695	30690	230	112.9014	659	24837	115	24819	115	213.6807	181.467	17.75179
1013	30696	30695	230	201.4308	429	24155	230	24401	230	564.9061	489.06	15.50854
1013	30696	30695	230	201.4308	659	24837	115	24819	115	213.6769	181.467	17.74972
1014	30700	30527	230	-261.292	429	24155	230	24401	230	564.909	489.06	15.50913
1014	30700	30527	230	-261.292	659	24837	115	24819	115	213.678	181.467	17.75034
1015	30700	30695	230	203.3608	429	24155	230	24401	230	564.931	489.06	15.51363
1015	30700	30695	230	203.3608	659	24837	115	24819	115	213.6845	181.467	17.75394
1016	30703	30700	230	418.0829	1926	33310	115	33321	115	-104.853	90.882	15.37246
1016	30703	30700	230	418.0829	429	24155	230	24401	230	564.9698	489.06	15.52158
1016	30703	30700	230	418.0829	659	24837	115	24819	115	213.6959	181.467	17.76022
1017	30705	30710	230	191.9535	429	24155	230	24401	230	564.904	489.06	15.50813
1017	30705	30710	230	191.9535	659	24837	115	24819	115	213.6764	181.467	17.74947
1018	30705	30712	230	177.2235	429	24155	230	24401	230	564.9026	489.06	15.50783
1018	30705	30712	230	177.2235	659	24837	115	24819	115	213.676	181.467	17.74924
1019	30705	30720	230	-141.529	429	24155	230	24401	230	564.898	489.06	15.50689
1019	30705	30720	230	-141.529	659	24837	115	24819	115	213.6747	181.467	17.74849
1020	30705	30730	230	-202.67	429	24155	230	24401	230	564.9021	489.06	15.50773
1020	30705	30730	230	-202.67	659	24837	115	24819	115	213.6758	181.467	17.74915
1021	30710	30711	230	58.0327	429	24155	230	24401	230	564.9066	489.06	15.50865

1021	30710	30711	230	58.0327	659	24837	115	24819	115	213.6778	181.467	17.75021
1022	30710	30715	230	132.9318	429	24155	230	24401	230	564.899	489.06	15.5071
1022	30710	30715	230	132.9318	659	24837	115	24819	115	213.675	181.467	17.74867
1023	30712	30715	230	176.3936	429	24155	230	24401	230	564.9026	489.06	15.50782
1023	30712	30715	230	176.3936	659	24837	115	24819	115	213.676	181.467	17.74924
1024	30713	30714	230	202.111	429	24155	230	24401	230	564.9074	489.06	15.50881
1024	30713	30714	230	202.111	659	24837	115	24819	115	213.6774	181.467	17.75001
1025	30714	30716	230	202.111	429	24155	230	24401	230	564.9074	489.06	15.50881
1025	30714	30716	230	202.111	659	24837	115	24819	115	213.6774	181.467	17.75001
1026	30715	30713	230	202.2918	429	24155	230	24401	230	564.9074	489.06	15.50881
1026	30715	30713	230	202.2918	659	24837	115	24819	115	213.6774	181.467	17.75002
1027	30716	30717	230	201.9967	429	24155	230	24401	230	564.9074	489.06	15.50881
1027	30716	30717	230	201.9967	659	24837	115	24819	115	213.6774	181.467	17.75001
1028	30717	30696	230	201.7305	429	24155	230	24401	230	564.9074	489.06	15.5088
1028	30717	30696	230	201.7305	659	24837	115	24819	115	213.6774	181.467	17.75001
1029	30720	30733	230	-255.498	429	24155	230	24401	230	564.9076	489.06	15.50885
1029	30720	30733	230	-255.498	659	24837	115	24819	115	213.6774	181.467	17.75003
1030	30731	38901	230	181.4827	429	24155	230	24401	230	564.933	489.06	15.51405
1030	30731	38901	230	181.4827	659	24837	115	24819	115	213.685	181.467	17.75421
1031	30733	30735	230	-302.144	429	24155	230	24401	230	564.9135	489.06	15.51005
1031	30733	30735	230	-302.144	659	24837	115	24819	115	213.6791	181.467	17.75096
1032	30735	30705	230	295.7218	429	24155	230	24401	230	564.9098	489.06	15.50931
1032	30735	30705	230	295.7218	659	24837	115	24819	115	213.6781	181.467	17.75038
1033	30735	30730	230	346.2451	429	24155	230	24401	230	564.9191	489.06	15.51121
1033	30735	30730	230	346.2451	659	24837	115	24819	115	213.6808	181.467	17.75187
1034	30735	30731	230	302.3052	429	24155	230	24401	230	564.876	489.06	15.50239
1034	30735	30731	230	302.3052	659	24837	115	24819	115	213.6678	181.467	17.74469
1035	30735	30741	230	-254.675	429	24155	230	24401	230	564.8831	489.06	15.50384
1035	30735	30741	230	-254.675	659	24837	115	24819	115	213.6704	181.467	17.74614
1036	30735	30750	230	-230.777	429	24155	230	24401	230	564.9034	489.06	15.508

1036	30735	30750	230	-230.777	659	24837	115	24819	115	213.6759	181.467	17.7492
1037	30735	30755	230	-231.174	429	24155	230	24401	230	564.9035	489.06	15.50802
1037	30735	30755	230	-231.174	659	24837	115	24819	115	213.676	181.467	17.74921
1038	30741	30705	230	303.718	429	24155	230	24401	230	564.9102	489.06	15.50939
1038	30741	30705	230	303.718	659	24837	115	24819	115	213.6782	181.467	17.75044
1039	30750	30755	230	-33.4623	429	24155	230	24401	230	564.8955	489.06	15.50637
1039	30750	30755	230	-33.4623	659	24837	115	24819	115	213.674	181.467	17.7481
1040	30750	30790	230	88.10375	429	24155	230	24401	230	564.8889	489.06	15.50503
1040	30750	30790	230	88.10375	659	24837	115	24819	115	213.6721	181.467	17.74711
1041	30751	30750	230	64.96378	429	24155	230	24401	230	564.8957	489.06	15.50642
1041	30751	30750	230	64.96378	659	24837	115	24819	115	213.674	181.467	17.74814
1042	30751	30755	230	31.48738	429	24155	230	24401	230	564.8955	489.06	15.50639
1042	30751	30755	230	31.48738	659	24837	115	24819	115	213.674	181.467	17.74812
1043	30755	30760	230	-14.3183	429	24155	230	24401	230	564.8953	489.06	15.50635
1043	30755	30760	230	-14.3183	659	24837	115	24819	115	213.6739	181.467	17.74808
1044	30760	30790	230	86.42844	429	24155	230	24401	230	564.8858	489.06	15.50439
1044	30760	30790	230	86.42844	659	24837	115	24819	115	213.6712	181.467	17.7466
1045	30765	30790	230	0.760644	429	24155	230	24401	230	564.8957	489.06	15.50641
1045	30765	30790	230	0.760644	659	24837	115	24819	115	213.674	181.467	17.74814
1046	30765	38615	230	60.92098	429	24155	230	24401	230	564.907	489.06	15.50874
1046	30765	38615	230	60.92098	659	24837	115	24819	115	213.6774	181.467	17.74999
1048	30780	30755	230	514.8135	429	24155	230	24401	230	564.7597	489.06	15.47861
1048	30780	30755	230	514.8135	659	24837	115	24819	115	213.63	181.467	17.72389
1049	30787	30750	230	514.8112	429	24155	230	24401	230	564.7598	489.06	15.47863
1049	30787	30750	230	514.8112	659	24837	115	24819	115	213.63	181.467	17.7239
1050	30790	30825	230	98.28193	429	24155	230	24401	230	564.9243	489.06	15.51228
1050	30790	30825	230	98.28193	659	24837	115	24819	115	213.6823	181.467	17.75268
1051	30790	30873	230	58.77656	429	24155	230	24401	230	564.9083	489.06	15.50901
1051	30790	30873	230	58.77656	659	24837	115	24819	115	213.6777	181.467	17.75019
1052	30790	30900	230	-101.423	429	24155	230	24401	230	564.8897	489.06	15.50519

1052	30790	30900	230	-101.423	659	24837	115	24819	115	213.6718	181.467	17.74694
1053	30795	30805	230	-62.8447	429	24155	230	24401	230	564.8931	489.06	15.5059
1053	30795	30805	230	-62.8447	659	24837	115	24819	115	213.6732	181.467	17.74768
1054	30796	30800	230	54.9067	429	24155	230	24401	230	564.8928	489.06	15.50582
1054	30796	30800	230	54.9067	659	24837	115	24819	115	213.6731	181.467	17.74763
1056	30800	30795	230	-33.777	429	24155	230	24401	230	564.8936	489.06	15.50599
1056	30800	30795	230	-33.777	659	24837	115	24819	115	213.6734	181.467	17.74778
1057	30805	30810	230	-194.166	429	24155	230	24401	230	564.9048	489.06	15.50828
1057	30805	30810	230	-194.166	659	24837	115	24819	115	213.6765	181.467	17.74949
1059	30810	30835	230	473.143	429	24155	230	24401	230	564.9011	489.06	15.50752
1059	30810	30835	230	473.143	659	24837	115	24819	115	213.6757	181.467	17.74908
1059	30810	30835	230	473.143	1068	30845	230	30850	230	482.2255	292.644	64.78231
1059	30810	30835	230	473.143	1060	30810	230	30845	230	527.168	292.644	80.13968
1060	30810	30845	230	145.0074	429	24155	230	24401	230	564.898	489.06	15.50688
1060	30810	30845	230	145.0074	659	24837	115	24819	115	213.6747	181.467	17.7485
1061	30810	30879	230	-111.393	429	24155	230	24401	230	564.9178	489.06	15.51094
1061	30810	30879	230	-111.393	659	24837	115	24819	115	213.68	181.467	17.75146
1062	30825	30830	230	79.61569	429	24155	230	24401	230	564.9178	489.06	15.51094
1062	30825	30830	230	79.61569	659	24837	115	24819	115	213.6804	181.467	17.75164
1063	30830	30835	230	5.050848	429	24155	230	24401	230	564.8966	489.06	15.5066
1063	30830	30835	230	5.050848	659	24837	115	24819	115	213.6743	181.467	17.74828
1064	30835	30840	230	132.6042	429	24155	230	24401	230	564.8978	489.06	15.50685
1064	30835	30840	230	132.6042	659	24837	115	24819	115	213.6746	181.467	17.74847
1065	30840	30841	230	62.36017	429	24155	230	24401	230	564.9035	489.06	15.50802
1065	30840	30841	230	62.36017	659	24837	115	24819	115	213.6768	181.467	17.74969
1066	30840	30850	230	70.01292	429	24155	230	24401	230	564.8961	489.06	15.50651
1066	30840	30850	230	70.01292	659	24837	115	24819	115	213.6741	181.467	17.74821
1067	30845	30846	230	44.64405	429	24155	230	24401	230	564.901	489.06	15.50751
1067	30845	30846	230	44.64405	659	24837	115	24819	115	213.676	181.467	17.74921
1068	30845	30850	230	100.1122	429	24155	230	24401	230	564.8966	489.06	15.50661

1068	30845	30850	230	100.1122	659	24837	115	24819	115	213.6743	181.467	17.74828
1073	30873	30875	230	67.68382	429	24155	230	24401	230	564.9103	489.06	15.5094
1073	30873	30875	230	67.68382	659	24837	115	24819	115	213.6783	181.467	17.75051
1074	30875	30880	230	-104.136	429	24155	230	24401	230	564.9162	489.06	15.51061
1074	30875	30880	230	-104.136	659	24837	115	24819	115	213.6797	181.467	17.75129
1075	30879	30881	230	12.70902	429	24155	230	24401	230	564.9002	489.06	15.50734
1075	30879	30881	230	12.70902	659	24837	115	24819	115	213.6753	181.467	17.74886
1076	30879	30900	230	-125.104	429	24155	230	24401	230	564.9364	489.06	15.51475
1076	30879	30900	230	-125.104	659	24837	115	24819	115	213.6855	181.467	17.75445
1077	30880	30900	230	-104.936	429	24155	230	24401	230	564.9164	489.06	15.51064
1077	30880	30900	230	-104.936	659	24837	115	24819	115	213.6798	181.467	17.75132
1078	30900	30905	230	-35.578	429	24155	230	24401	230	564.8913	489.06	15.50552
1078	30900	30905	230	-35.578	659	24837	115	24819	115	213.6727	181.467	17.74743
1079	30900	30915	230	-69.3268	429	24155	230	24401	230	564.8892	489.06	15.50509
1079	30900	30915	230	-69.3268	659	24837	115	24819	115	213.6721	181.467	17.74707
1080	30900	30935	230	-3.56907	429	24155	230	24401	230	564.8954	489.06	15.50636
1080	30900	30935	230	-3.56907	659	24837	115	24819	115	213.6739	181.467	17.74809
1081	30900	30970	230	-57.0308	429	24155	230	24401	230	564.8971	489.06	15.50671
1081	30900	30970	230	-57.0308	659	24837	115	24819	115	213.6743	181.467	17.74827
1082	30905	30915	230	-179.039	429	24155	230	24401	230	564.8972	489.06	15.50673
1082	30905	30915	230	-179.039	659	24837	115	24819	115	213.6742	181.467	17.74826
1083	30915	30925	230	87.59582	429	24155	230	24401	230	564.8997	489.06	15.50724
1083	30915	30925	230	87.59582	659	24837	115	24819	115	213.6752	181.467	17.74877
1084	30915	30930	230	144.3157	429	24155	230	24401	230	564.9057	489.06	15.50847
1084	30915	30930	230	144.3157	659	24837	115	24819	115	213.6769	181.467	17.74971
1085	30915	30970	230	25.98456	429	24155	230	24401	230	564.8907	489.06	15.50539
1085	30915	30970	230	25.98456	659	24837	115	24819	115	213.6727	181.467	17.74739
1086	30925	30930	230	87.38245	429	24155	230	24401	230	564.8997	489.06	15.50724
1086	30925	30930	230	87.38245	659	24837	115	24819	115	213.6752	181.467	17.74877
1087	30935	30970	230	-78.8864	429	24155	230	24401	230	564.8996	489.06	15.50723

1087	30935	30970	230	-78.8864	659	24837	115	24819	115	213.6749	181.467	17.74864
1088	30940	30942	230	-89.23	429	24155	230	24401	230	564.9222	489.06	15.51184
1088	30940	30942	230	-89.23	659	24837	115	24819	115	213.682	181.467	17.75256
1089	30941	30943	230	-43.5438	429	24155	230	24401	230	564.9081	489.06	15.50895
1089	30941	30943	230	-43.5438	659	24837	115	24819	115	213.6778	181.467	17.75021
1090	30945	30942	230	-12.8672	429	24155	230	24401	230	564.8958	489.06	15.50644
1090	30945	30942	230	-12.8672	659	24837	115	24819	115	213.674	181.467	17.74815
1091	30945	30943	230	-60.3557	429	24155	230	24401	230	564.8974	489.06	15.50677
1091	30945	30943	230	-60.3557	659	24837	115	24819	115	213.6745	181.467	17.7484
1092	30945	30944	230	-52.8875	429	24155	230	24401	230	564.8971	489.06	15.5067
1092	30945	30944	230	-52.8875	659	24837	115	24819	115	213.6744	181.467	17.74836
1094	30948	30970	230	571.9001	429	24155	230	24401	230	564.7179	489.06	15.47007
1094	30948	30970	230	571.9001	659	24837	115	24819	115	213.6204	181.467	17.71858
1095	30950	30942	230	-46.9381	429	24155	230	24401	230	564.9091	489.06	15.50915
1095	30950	30942	230	-46.9381	659	24837	115	24819	115	213.6781	181.467	17.75038
1096	30951	30944	230	-41.076	429	24155	230	24401	230	564.9075	489.06	15.50883
1096	30951	30944	230	-41.076	659	24837	115	24819	115	213.6776	181.467	17.75011
1097	30970	30942	230	149.8732	429	24155	230	24401	230	564.9027	489.06	15.50786
1097	30970	30942	230	149.8732	659	24837	115	24819	115	213.676	181.467	17.74922
1098	30970	30943	230	104.2273	429	24155	230	24401	230	564.8997	489.06	15.50724
1098	30970	30943	230	104.2273	659	24837	115	24819	115	213.6751	181.467	17.74876
1099	30970	30944	230	94.23254	429	24155	230	24401	230	564.8992	489.06	15.50713
1099	30970	30944	230	94.23254	659	24837	115	24819	115	213.675	181.467	17.74868
1101	30970	30973	230	-213.284	429	24155	230	24401	230	564.8293	489.06	15.49284
1101	30970	30973	230	-213.284	659	24837	115	24819	115	213.654	181.467	17.7371
2686	35219	30630	230	93.97266	429	24155	230	24401	230	564.9014	489.06	15.50759
2686	35219	30630	230	93.97266	659	24837	115	24819	115	213.6758	181.467	17.74912
2687	35219	35224	230	-136.262	429	24155	230	24401	230	564.9079	489.06	15.50892
2687	35219	35224	230	-136.262	659	24837	115	24819	115	213.6777	181.467	17.75019
3002	36893	38900	230	181.4229	429	24155	230	24401	230	564.933	489.06	15.51405

3002	36893	38900	230	181.4229	659	24837	115	24819	115	213.685	181.467	17.75421
3011	37001	37012	230	178.0658	429	24155	230	24401	230	564.8983	489.06	15.50695
3011	37001	37012	230	178.0658	659	24837	115	24819	115	213.6748	181.467	17.74857
3012	37001	37017	230	-120.727	429	24155	230	24401	230	564.8957	489.06	15.50643
3012	37001	37017	230	-120.727	659	24837	115	24819	115	213.674	181.467	17.74815
3013	37001	37018	230	42.46035	429	24155	230	24401	230	564.8952	489.06	15.50632
3013	37001	37018	230	42.46035	659	24837	115	24819	115	213.6739	181.467	17.74806
3014	37002	37009	230	91.11387	429	24155	230	24401	230	564.8926	489.06	15.50578
3014	37002	37009	230	91.11387	659	24837	115	24819	115	213.6731	181.467	17.74761
3015	37002	37014	230	33.69957	429	24155	230	24401	230	564.8965	489.06	15.50659
3015	37002	37014	230	33.69957	659	24837	115	24819	115	213.6743	181.467	17.74828
3016	37003	37010	230	-170.63	429	24155	230	24401	230	564.9124	489.06	15.50984
3016	37003	37010	230	-170.63	659	24837	115	24819	115	213.6789	181.467	17.75084
3017	37003	37013	230	-12.2598	429	24155	230	24401	230	564.8946	489.06	15.50619
3017	37003	37013	230	-12.2598	659	24837	115	24819	115	213.6737	181.467	17.74796
3018	37004	37009	230	-0.19496	429	24155	230	24401	230	564.8955	489.06	15.50637
3018	37004	37009	230	-0.19496	659	24837	115	24819	115	213.674	181.467	17.7481
3019	37004	37016	230	-339.854	429	24155	230	24401	230	564.9084	489.06	15.50902
3019	37004	37016	230	-339.854	659	24837	115	24819	115	213.6776	181.467	17.7501
3020	37005	37008	230	122.1647	429	24155	230	24401	230	564.9056	489.06	15.50844
3020	37005	37008	230	122.1647	659	24837	115	24819	115	213.677	181.467	17.74976
3021	37005	37013	230	81.79762	429	24155	230	24401	230	564.8996	489.06	15.50723
3021	37005	37013	230	81.79762	659	24837	115	24819	115	213.6752	181.467	17.7488
3022	37005	37021	230	191.9627	429	24155	230	24401	230	564.8984	489.06	15.50698
3022	37005	37021	230	191.9627	659	24837	115	24819	115	213.6749	181.467	17.74864
3023	37005	37546	230	-654.034	3016	37003	230	37010	230	-338.763	299.772	13.00701
3023	37005	37546	230	-654.034	429	24155	230	24401	230	564.9548	489.06	15.5185
3023	37005	37546	230	-654.034	659	24837	115	24819	115	213.6919	181.467	17.75798
3023	37005	37546	230	-654.034	3036	37021	230	37010	230	-376.539	299.673	25.64988
3024	37008	37013	230	5.884098	429	24155	230	24401	230	564.8956	489.06	15.50639

3024	37008	37013	230	5.884098	659	24837	115	24819	115	213.674	181.467	17.74812
3025	37009	37016	230	-205.21	429	24155	230	24401	230	564.8967	489.06	15.50663
3025	37009	37016	230	-205.21	659	24837	115	24819	115	213.6742	181.467	17.74824
3026	37011	37017	230	-12.13	429	24155	230	24401	230	564.8954	489.06	15.50636
3026	37011	37017	230	-12.13	659	24837	115	24819	115	213.6739	181.467	17.7481
3027	37011	37018	230	111.9663	429	24155	230	24401	230	564.8952	489.06	15.50631
3027	37011	37018	230	111.9663	659	24837	115	24819	115	213.6739	181.467	17.74806
3028	37012	37013	230	69.79105	429	24155	230	24401	230	564.8897	489.06	15.5052
3028	37012	37013	230	69.79105	659	24837	115	24819	115	213.6722	181.467	17.74715
3029	37013	37018	230	-197.491	429	24155	230	24401	230	564.8895	489.06	15.50516
3029	37013	37018	230	-197.491	659	24837	115	24819	115	213.6721	181.467	17.7471
3030	37014	37012	230	15.94458	429	24155	230	24401	230	564.8951	489.06	15.50629
3030	37014	37012	230	15.94458	659	24837	115	24819	115	213.6738	181.467	17.74804
3031	37014	37016	230	-308.674	429	24155	230	24401	230	564.9058	489.06	15.50848
3031	37014	37016	230	-308.674	659	24837	115	24819	115	213.6768	181.467	17.74967
3032	37015	37009	230	129.4327	429	24155	230	24401	230	564.916	489.06	15.51057
3032	37015	37009	230	129.4327	659	24837	115	24819	115	213.6801	181.467	17.7515
3033	37015	37010	230	32.76111	429	24155	230	24401	230	564.8902	489.06	15.5053
3033	37015	37010	230	32.76111	659	24837	115	24819	115	213.6724	181.467	17.74724
3034	37016	30500	230	-359.419	429	24155	230	24401	230	564.9443	489.06	15.51637
3034	37016	30500	230	-359.419	659	24837	115	24819	115	213.6876	181.467	17.75563
3035	37018	37009	230	133.4949	429	24155	230	24401	230	564.898	489.06	15.50689
3035	37018	37009	230	133.4949	659	24837	115	24819	115	213.6747	181.467	17.74854
3036	37021	37010	230	6.687836	429	24155	230	24401	230	564.8954	489.06	15.50636
3036	37021	37010	230	6.687836	659	24837	115	24819	115	213.6739	181.467	17.74809
3038	37023	37016	230	164.7545	429	24155	230	24401	230	564.8967	489.06	15.50663
3038	37023	37016	230	164.7545	659	24837	115	24819	115	213.6729	181.467	17.7475
3039	37024	37016	230	169.7312	429	24155	230	24401	230	564.9139	489.06	15.51015
3041	37026	37016	230	-0.00264	659	24837	115	24819	115	213.6739	181.467	17.7481
3065	37520	37546	230	766.1932	429	24155	230	24401	230	565.4999	489.06	15.62996

3065	37520	37546	230	766.1932	659	24837	115	24819	115	213.8594	181.467	17.85028
3067	37544	37545	230	25.82042	429	24155	230	24401	230	564.894	489.06	15.50608
3067	37544	37545	230	25.82042	659	24837	115	24819	115	213.6735	181.467	17.74787
3068	37545	30245	230	-128.492	429	24155	230	24401	230	564.8975	489.06	15.50679
3068	37545	30245	230	-128.492	659	24837	115	24819	115	213.6746	181.467	17.74846
3069	37545	37567	230	184.5161	429	24155	230	24401	230	565.0172	489.06	15.53126
3069	37545	37567	230	184.5161	659	24837	115	24819	115	213.7112	181.467	17.76865
3072	37546	37010	230	202.7325	429	24155	230	24401	230	564.8968	489.06	15.50664
3072	37546	37010	230	202.7325	659	24837	115	24819	115	213.6745	181.467	17.74843
3074	37558	37520	230	146.7404	429	24155	230	24401	230	564.9793	489.06	15.52351
3074	37558	37520	230	146.7404	659	24837	115	24819	115	213.6997	181.467	17.76229
3075	37558	37544	230	95.75591	429	24155	230	24401	230	564.8965	489.06	15.50658
3075	37558	37544	230	95.75591	659	24837	115	24819	115	213.6743	181.467	17.74827
3078	37563	30800	230	104.1882	429	24155	230	24401	230	564.9073	489.06	15.5088
3078	37563	30800	230	104.1882	659	24837	115	24819	115	213.6776	181.467	17.75012
3079	37565	37520	230	152.535	429	24155	230	24401	230	564.9987	489.06	15.52748
3079	37565	37520	230	152.535	659	24837	115	24819	115	213.7055	181.467	17.7655
3080	37565	37545	230	-92.4648	429	24155	230	24401	230	564.8472	489.06	15.4965
3080	37565	37545	230	-92.4648	659	24837	115	24819	115	213.6594	181.467	17.74006
3081	37565	37558	230	-101.328	429	24155	230	24401	230	564.8741	489.06	15.502
3081	37565	37558	230	-101.328	659	24837	115	24819	115	213.6675	181.467	17.74457
3082	37567	37546	230	51.09757	429	24155	230	24401	230	564.896	489.06	15.50648
3082	37567	37546	230	51.09757	659	24837	115	24819	115	213.6741	181.467	17.74821
3084	37568	37546	230	53.85283	429	24155	230	24401	230	564.8952	489.06	15.50632
3084	37568	37546	230	53.85283	659	24837	115	24819	115	213.6739	181.467	17.74807
3085	37568	37567	230	-39.857	429	24155	230	24401	230	564.8966	489.06	15.50659
3085	37568	37567	230	-39.857	659	24837	115	24819	115	213.6743	181.467	17.74829
3086	37569	37558	230	-25.1962	429	24155	230	24401	230	564.8969	489.06	15.50667
3086	37569	37558	230	-25.1962	659	24837	115	24819	115	213.6744	181.467	17.74833
3092	37580	37569	230	-0.127	429	24155	230	24401	230	564.8954	489.06	15.50637

3092	37580	37569	230	-0.127	659	24837	115	24819	115	213.674	181.467	17.7481
3094	37585	30625	230	33.99318	429	24155	230	24401	230	564.9273	489.06	15.51287
3094	37585	30625	230	33.99318	659	24837	115	24819	115	213.6832	181.467	17.7532
3095	37585	30670	230	295.9575	429	24155	230	24401	230	565.0816	489.06	15.54444
3095	37585	30670	230	295.9575	659	24837	115	24819	115	213.7286	181.467	17.77819
3096	37585	37010	230	435.6522	429	24155	230	24401	230	565.271	489.06	15.58315
3096	37585	37010	230	435.6522	659	24837	115	24819	115	213.7829	181.467	17.80813
3097	37585	37560	230	86.24833	429	24155	230	24401	230	564.9244	489.06	15.51229
3097	37585	37560	230	86.24833	659	24837	115	24819	115	213.6823	181.467	17.75273
3122	38000	30622	230	50.20048	429	24155	230	24401	230	564.8839	489.06	15.504
3122	38000	30622	230	50.20048	659	24837	115	24819	115	213.6706	181.467	17.74624
3146	38204	30670	230	-185.918	429	24155	230	24401	230	564.9293	489.06	15.51329
3146	38204	30670	230	-185.918	659	24837	115	24819	115	213.6837	181.467	17.75347
3147	38204	38202	230	96.7108	429	24155	230	24401	230	564.911	489.06	15.50955
3147	38204	38202	230	96.7108	659	24837	115	24819	115	213.6784	181.467	17.75056
3148	38204	38210	230	96.30235	429	24155	230	24401	230	564.9108	489.06	15.5095
3148	38204	38210	230	96.30235	659	24837	115	24819	115	213.6783	181.467	17.75052
3149	38204	38400	230	-7.09566	429	24155	230	24401	230	564.8954	489.06	15.50636
3149	38204	38400	230	-7.09566	659	24837	115	24819	115	213.6739	181.467	17.7481
3150	38206	37563	230	-162.87	429	24155	230	24401	230	564.8769	489.06	15.50257
3150	38206	37563	230	-162.87	659	24837	115	24819	115	213.6682	181.467	17.74495
3151	38208	30515	230	-38.2853	429	24155	230	24401	230	564.894	489.06	15.50607
3151	38208	30515	230	-38.2853	659	24837	115	24819	115	213.6735	181.467	17.74785
3212	38400	30670	230	-169.481	429	24155	230	24401	230	564.9257	489.06	15.51255
3212	38400	30670	230	-169.481	659	24837	115	24819	115	213.6827	181.467	17.7529
3258	38600	30970	230	-145.838	429	24155	230	24401	230	564.9003	489.06	15.50736
3258	38600	30970	230	-145.838	659	24837	115	24819	115	213.6753	181.467	17.74885
3259	38600	38601	230	19.00205	429	24155	230	24401	230	564.8957	489.06	15.50642
3259	38600	38601	230	19.00205	659	24837	115	24819	115	213.6743	181.467	17.74828
3260	38600	38640	230	126.8367	429	24155	230	24401	230	564.8997	489.06	15.50724

3260	38600	38640	230	126.8367	659	24837	115	24819	115	213.6751	181.467	17.74876
3261	38605	30970	230	-168.661	429	24155	230	24401	230	564.9011	489.06	15.50752
3261	38605	30970	230	-168.661	659	24837	115	24819	115	213.6755	181.467	17.74897
3263	38605	38645	230	129.6531	429	24155	230	24401	230	564.8998	489.06	15.50725
3263	38605	38645	230	129.6531	659	24837	115	24819	115	213.6752	181.467	17.74877
3264	38610	30580	230	24.85605	429	24155	230	24401	230	564.887	489.06	15.50464
3264	38610	30580	230	24.85605	659	24837	115	24819	115	213.6715	181.467	17.74676
3265	38615	30790	230	-33.2035	429	24155	230	24401	230	564.8891	489.06	15.50508
3265	38615	30790	230	-33.2035	659	24837	115	24819	115	213.6721	181.467	17.74707
3271	38640	38650	230	118.4017	429	24155	230	24401	230	564.8994	489.06	15.50718
3271	38640	38650	230	118.4017	659	24837	115	24819	115	213.6751	181.467	17.74871
3272	38645	38646	230	45.01461	429	24155	230	24401	230	564.8955	489.06	15.50638
3272	38645	38646	230	45.01461	659	24837	115	24819	115	213.6739	181.467	17.7481
3273	38645	38655	230	83.8622	429	24155	230	24401	230	564.8982	489.06	15.50694
3273	38645	38655	230	83.8622	659	24837	115	24819	115	213.6747	181.467	17.74853
3274	38650	30994	230	87.32394	429	24155	230	24401	230	564.8984	489.06	15.50697
3274	38650	30994	230	87.32394	659	24837	115	24819	115	213.6748	181.467	17.74855
3276	38655	30994	230	-15.2258	429	24155	230	24401	230	564.8949	489.06	15.50626
3276	38655	30994	230	-15.2258	659	24837	115	24819	115	213.6738	181.467	17.74802
3277	38655	38656	230	99.0515	429	24155	230	24401	230	564.8939	489.06	15.50605
3277	38655	38656	230	99.0515	659	24837	115	24819	115	213.6739	181.467	17.74807
3278	38901	36893	230	181.4829	429	24155	230	24401	230	564.933	489.06	15.51405
3278	38901	36893	230	181.4829	659	24837	115	24819	115	213.685	181.467	17.75421
3294	25701	26051	287	103.6974	429	24155	230	24401	230	564.8671	489.06	15.50058
3294	25701	26051	287	103.6974	659	24837	115	24819	115	213.9757	181.467	17.9144
3300	21008	21007	230	-156.666	429	24155	230	24401	230	564.8954	489.06	15.50636
3300	21008	21007	230	-156.666	659	24837	115	24819	115	216.0405	181.467	19.05224
3308	21026	21025	230	-127.879	429	24155	230	24401	230	565.0381	489.06	15.53554
3308	21026	21025	230	-127.879	659	24837	115	24819	115	210.7758	181.467	16.15102
3323	21045	21046	92	-317.758	659	24837	115	24819	115	202.1647	181.467	11.40575

3323	21045	21046	92	-317.758	429	24155	230	24401	230	564.5845	489.06	15.4428
3337	21076	21077	92	61.06321	429	24155	230	24401	230	564.892	489.06	15.50567
3337	21076	21077	92	61.06321	659	24837	115	24819	115	214.5982	181.467	18.2574
3355	22256	22260	230	-388.988	201	22442	69	22708	69	-109.906	96.525	13.86246
3355	22256	22260	230	-388.988	429	24155	230	24401	230	565.1374	489.06	15.55583
3355	22256	22260	230	-388.988	659	24837	115	24819	115	214.0447	181.467	17.95244
3360	22356	22360	500	322.3459	429	24155	230	24401	230	564.5358	489.06	15.43283
3360	22356	22360	500	322.3459	659	24837	115	24819	115	220.9794	181.467	21.7739
3360	22356	22360	500	322.3459	173	22356	230	21025	230	450.9838	347.49	29.78324
3360	22356	22360	500	322.3459	3308	21026	161	21025	230	-450.225	222.75	102.1211
3360	22356	22360	500	322.3459	3309	21026	161	21027	92	256.6754	123.75	107.4145
3374	22456	22464	230	-314.304	123	22172	69	22556	69	109.5779	96.525	13.52283
3374	22456	22464	230	-314.304	429	24155	230	24401	230	565.0698	489.06	15.54201
3374	22456	22464	230	-314.304	3394	22768	69	22772	138	-160.83	138.6	16.039
3374	22456	22464	230	-314.304	659	24837	115	24819	115	214.06	181.467	17.96081
3375	22464	22460	138	176.5132	429	24155	230	24401	230	564.9725	489.06	15.52212
3375	22464	22460	138	176.5132	659	24837	115	24819	115	213.8454	181.467	17.84257
3376	22464	22468	500	-610.041	429	24155	230	24401	230	564.9741	489.06	15.52244
3376	22464	22468	500	-610.041	659	24837	115	24819	115	214.0874	181.467	17.97593
3377	22464	22472	500	-644.761	429	24155	230	24401	230	564.9822	489.06	15.52412
3377	22464	22472	500	-644.761	659	24837	115	24819	115	214.1319	181.467	18.00047
3382	22504	22496	69	165.6005	429	24155	230	24401	230	564.9674	489.06	15.52107
3382	22504	22496	69	165.6005	659	24837	115	24819	115	213.7855	181.467	17.8096
3383	22504	22500	138	324.8171	429	24155	230	24401	230	565.0525	489.06	15.53847
3383	22504	22500	138	324.8171	659	24837	115	24819	115	213.8962	181.467	17.87055
3385	22592	22596	230	-282.621	429	24155	230	24401	230	565.0411	489.06	15.53614
3385	22592	22596	230	-282.621	659	24837	115	24819	115	213.9214	181.467	17.88445
3389	22652	22644	69	296.2972	3387	22644	69	22648	138	-310.433	277.2	11.98876
3389	22652	22644	69	296.2972	429	24155	230	24401	230	565.2663	489.06	15.58221
3389	22652	22644	69	296.2972	659	24837	115	24819	115	214.0599	181.467	17.96079

3390	22652	22648	138	98.67902	429	24155	230	24401	230	564.9924	489.06	15.5262
3390	22652	22648	138	98.67902	659	24837	115	24819	115	213.7772	181.467	17.80502
3392	22708	22716	230	-259.591	429	24155	230	24401	230	565.0732	489.06	15.54272
3392	22708	22716	230	-259.591	151	22256	69	22724	69	113.1564	96.525	17.23016
3392	22708	22716	230	-259.591	659	24837	115	24819	115	213.8969	181.467	17.87099
3392	22708	22716	230	-259.591	3393	22712	138	22708	69	170.1256	138.6	22.74576
3392	22708	22716	230	-259.591	3403	22836	69	22840	138	-36.1483	24.75	46.05365
3400	22832	22828	69	290.8426	429	24155	230	24401	230	565.0465	489.06	15.53725
3400	22832	22828	69	290.8426	659	24837	115	24819	115	213.945	181.467	17.89745
3401	22832	22831	138	151.8332	429	24155	230	24401	230	564.9893	489.06	15.52556
3401	22832	22831	138	151.8332	659	24837	115	24819	115	213.8095	181.467	17.8228
3410	22982	22984	230	170	429	24155	230	24401	230	564.8954	489.06	15.50637
3410	22982	22984	230	170	659	24837	115	24819	115	213.674	181.467	17.7481
3411	22983	22984	230	170	429	24155	230	24401	230	564.8954	489.06	15.50637
3411	22983	22984	230	170	659	24837	115	24819	115	213.674	181.467	17.7481
3421	24008	24007	66	188.5359	429	24155	230	24401	230	565.5197	489.06	15.63402
3421	24008	24007	66	188.5359	659	24837	115	24819	115	214.0194	181.467	17.93848
3428	24016	24201	66	628.0088	429	24155	230	24401	230	566.9294	489.06	15.92225
3428	24016	24201	66	628.0088	659	24837	115	24819	115	215.066	181.467	18.51523
3429	24019	24202	66	2.000003	429	24155	230	24401	230	564.8995	489.06	15.5072
3429	24019	24202	66	2.000003	659	24837	115	24819	115	213.6971	181.467	17.76084
3430	24021	24203	66	482.749	429	24155	230	24401	230	566.5216	489.06	15.83887
3430	24021	24203	66	482.749	659	24837	115	24819	115	214.6187	181.467	18.26872
3433	24025	24024	66	635.2509	429	24155	230	24401	230	566.2442	489.06	15.78216
3433	24025	24024	66	635.2509	659	24837	115	24819	115	216.7205	181.467	19.42693
3434	24029	24028	66	508.7909	429	24155	230	24401	230	567.3942	489.06	16.01729
3434	24029	24028	66	508.7909	659	24837	115	24819	115	214.5463	181.467	18.22882
3435	24036	24205	66	191.755	429	24155	230	24401	230	565.3157	489.06	15.5923
3435	24036	24205	66	191.755	659	24837	115	24819	115	213.8076	181.467	17.82173
3436	24040	24039	66	332.8499	429	24155	230	24401	230	566.5609	489.06	15.84692

3436	24040	24039	66	332.8499	659	24837	115	24819	115	214.1499	181.467	18.01037
3437	24041	24043	115	-9.96943	429	24155	230	24401	230	564.8754	489.06	15.50227
3437	24041	24043	115	-9.96943	659	24837	115	24819	115	213.6491	181.467	17.73443
3438	24042	24041	230	-80.2348	429	24155	230	24401	230	564.8833	489.06	15.50389
3438	24042	24041	230	-80.2348	659	24837	115	24819	115	213.7819	181.467	17.80761
3439	24044	24197	66	586.8205	429	24155	230	24401	230	566.9199	489.06	15.92032
3439	24044	24197	66	586.8205	659	24837	115	24819	115	214.845	181.467	18.39343
3447	24056	24031	66	70.12965	429	24155	230	24401	230	565.0244	489.06	15.53274
3447	24056	24031	66	70.12965	659	24837	115	24819	115	214.1029	181.467	17.98447
3452	24056	24055	66	543.9276	429	24155	230	24401	230	565.908	489.06	15.7134
3452	24056	24055	66	543.9276	659	24837	115	24819	115	217.115	181.467	19.64435
3453	24058	24057	66	272.34	429	24155	230	24401	230	571.0456	489.06	16.76391
3453	24058	24057	66	272.34	659	24837	115	24819	115	213.7302	181.467	17.77909
3454	24059	24206	66	122.345	429	24155	230	24401	230	565.6916	489.06	15.66917
3454	24059	24206	66	122.345	659	24837	115	24819	115	213.7572	181.467	17.794
3464	24065	24064	66	289.4461	429	24155	230	24401	230	566.1168	489.06	15.7561
3464	24065	24064	66	289.4461	659	24837	115	24819	115	214.1325	181.467	18.00079
3468	24072	24207	66	400.2719	429	24155	230	24401	230	566.2171	489.06	15.7766
3468	24072	24207	66	400.2719	659	24837	115	24819	115	214.4598	181.467	18.18113
3470	24074	24073	66	592.48	429	24155	230	24401	230	567.8776	489.06	16.11614
3470	24074	24073	66	592.48	659	24837	115	24819	115	214.5428	181.467	18.22691
3472	24076	24075	66	618.4831	429	24155	230	24401	230	570.6425	489.06	16.68149
3472	24076	24075	66	618.4831	659	24837	115	24819	115	214.4865	181.467	18.19588
3476	24082	24208	66	459.8339	429	24155	230	24401	230	567.2176	489.06	15.98118
3476	24082	24208	66	459.8339	659	24837	115	24819	115	214.3366	181.467	18.11324
3478	24084	24083	66	484.6243	429	24155	230	24401	230	566.5722	489.06	15.84923
3478	24084	24083	66	484.6243	659	24837	115	24819	115	214.4587	181.467	18.18057
3482	24091	24209	66	617.973	429	24155	230	24401	230	565.5669	489.06	15.64367
3482	24091	24209	66	617.973	659	24837	115	24819	115	214.6623	181.467	18.29274
3483	24092	24093	230	1508.53	659	24837	115	24819	115	208.2486	181.467	14.7584

3483	24092	24093	230	1508.53	429	24155	230	24401	230	566.1542	489.06	15.76375
3484	24092	25656	230	1495.472	659	24837	115	24819	115	207.3554	181.467	14.26617
3484	24092	25656	230	1495.472	429	24155	230	24401	230	566.2627	489.06	15.78593
3485	24093	24210	66	639.0879	429	24155	230	24401	230	566.2132	489.06	15.77582
3485	24093	24210	66	639.0879	659	24837	115	24819	115	216.8508	181.467	19.49875
3489	24099	24098	66	728.386	429	24155	230	24401	230	571.6267	489.06	16.88274
3489	24099	24098	66	728.386	659	24837	115	24819	115	213.796	181.467	17.81537
3490	24100	24211	66	368.454	429	24155	230	24401	230	565.7061	489.06	15.67212
3490	24100	24211	66	368.454	659	24837	115	24819	115	214.8117	181.467	18.37505
3497	24112	24111	66	631.9881	429	24155	230	24401	230	566.1031	489.06	15.75331
3497	24112	24111	66	631.9881	659	24837	115	24819	115	217.4684	181.467	19.83908
3502	24126	24213	66	689.0882	659	24837	115	24819	115	214.4562	181.467	18.17915
3502	24126	24213	66	689.0882	429	24155	230	24401	230	579.6108	489.06	18.51527
3506	24128	24127	66	443.2997	429	24155	230	24401	230	575.392	489.06	17.65264
3506	24128	24127	66	443.2997	659	24837	115	24819	115	213.7656	181.467	17.79862
3509	24132	24214	66	596.0039	429	24155	230	24401	230	565.8197	489.06	15.69536
3509	24132	24214	66	596.0039	659	24837	115	24819	115	218.6657	181.467	20.49886
3510	24134	24133	66	670.4339	429	24155	230	24401	230	566.9752	489.06	15.93162
3510	24134	24133	66	670.4339	659	24837	115	24819	115	215.0327	181.467	18.49688
3516	24138	24137	230	1451.832	429	24155	230	24401	230	564.6615	489.06	15.45853
3516	24138	24137	230	1451.832	659	24837	115	24819	115	212.0457	181.467	16.85081
3517	24141	24215	66	215.524	659	24837	115	24819	115	213.7169	181.467	17.77178
3518	24142	24143	13.8	-70	429	24155	230	24401	230	564.8954	489.06	15.50637
3518	24142	24143	13.8	-70	659	24837	115	24819	115	213.674	181.467	17.7481
3519	24142	24144	13.8	-70	429	24155	230	24401	230	575.8882	489.06	17.7541
3519	24142	24144	13.8	-70	659	24837	115	24819	115	213.735	181.467	17.78173
3527	24153	24152	66	74.86602	429	24155	230	24401	230	558.3617	489.06	14.17039
3527	24153	24152	66	74.86602	659	24837	115	24819	115	213.6839	181.467	17.75359
3528	24154	24216	66	665.131	429	24155	230	24401	230	566.9228	489.06	15.9209
3528	24154	24216	66	665.131	659	24837	115	24819	115	215.3127	181.467	18.65116

3529	24156	24155	230	2394.01	659	24837	115	24819	115	214.4194	181.467	18.1589
3531	24158	24157	66	620.6989	429	24155	230	24401	230	566.1158	489.06	15.7559
3531	24158	24157	66	620.6989	659	24837	115	24819	115	215.4951	181.467	18.75166
3532	24198	24199	66	54.0001	429	24155	230	24401	230	565.1623	489.06	15.56093
3532	24198	24199	66	54.0001	659	24837	115	24819	115	213.7496	181.467	17.7898
3535	24200	24135	66	590.218	429	24155	230	24401	230	566.4038	489.06	15.81479
3535	24200	24135	66	590.218	659	24837	115	24819	115	213.7621	181.467	17.79669
3541	24235	24212	66	749.8818	659	24837	115	24819	115	213.7402	181.467	17.78463
3564	24404	24403	230	-93.6147	429	24155	230	24401	230	562.322	489.06	14.98017
3564	24404	24403	230	-93.6147	659	24837	115	24819	115	213.6924	181.467	17.75827
3572	24601	24602	115	328.901	554	24602	115	24702	115	-243.323	214.929	13.21078
3572	24601	24602	115	328.901	559	24614	115	24702	115	-247.776	214.929	15.28251
3572	24601	24602	115	328.901	429	24155	230	24401	230	565.5317	489.06	15.63646
3572	24601	24602	115	328.901	659	24837	115	24819	115	214.3064	181.467	18.09661
3573	24627	24628	66	1	429	24155	230	24401	230	564.8976	489.06	15.5068
3573	24627	24628	66	1	659	24837	115	24819	115	213.6766	181.467	17.74959
3577	24707	24705	13.8	-12	429	24155	230	24401	230	564.8954	489.06	15.50637
3577	24707	24705	13.8	-12	659	24837	115	24819	115	213.674	181.467	17.7481
3580	24717	24718	13.8	-50	429	24155	230	24401	230	564.8954	489.06	15.50637
3580	24717	24718	13.8	-50	659	24837	115	24819	115	213.674	181.467	17.7481
3582	24717	24720	13.8	-60	429	24155	230	24401	230	564.8954	489.06	15.50637
3582	24717	24720	13.8	-60	659	24837	115	24819	115	213.674	181.467	17.7481
3591	24729	24730	115	-48.4132	429	24155	230	24401	230	564.79	489.06	15.48481
3591	24729	24730	115	-48.4132	659	24837	115	24819	115	213.701	181.467	17.76301
3607	24760	24724	115	48.97911	429	24155	230	24401	230	564.835	489.06	15.49401
3607	24760	24724	115	48.97911	659	24837	115	24819	115	213.6573	181.467	17.73894
3618	24801	24804	230	1009.836	429	24155	230	24401	230	566.5912	489.06	15.8531
3619	24805	24804	230	-569.518	429	24155	230	24401	230	565.4163	489.06	15.61288
3620	24806	24807	115	193.6203	429	24155	230	24401	230	565.0115	489.06	15.53011
3620	24806	24807	115	193.6203	659	24837	115	24819	115	223.8295	181.467	23.34444

3621	24806	24837	115	180.1628	429	24155	230	24401	230	564.9977	489.06	15.52728
3625	24901	24902	66	917.8689	429	24155	230	24401	230	566.4657	489.06	15.82745
3625	24901	24902	66	917.8689	659	24837	115	24819	115	220.4923	181.467	21.50547
3626	24901	24903	115	292.2936	429	24155	230	24401	230	565.3896	489.06	15.60741
3626	24901	24903	115	292.2936	659	24837	115	24819	115	215.8046	181.467	18.92224
3636	25001	25002	33	250	429	24155	230	24401	230	566.7702	489.06	15.88971
3636	25001	25002	33	250	659	24837	115	24819	115	213.9024	181.467	17.87398
3637	25201	25202	66	539.608	429	24155	230	24401	230	566.5512	489.06	15.84493
3637	25201	25202	66	539.608	659	24837	115	24819	115	214.969	181.467	18.46175
3639	25401	24035	161	-72.8363	429	24155	230	24401	230	564.8642	489.06	15.49997
3639	25401	24035	161	-72.8363	659	24837	115	24819	115	212.9687	181.467	17.35947
3640	25401	24204	66	2.000005	429	24155	230	24401	230	564.8983	489.06	15.50695
3640	25401	24204	66	2.000005	659	24837	115	24819	115	213.7311	181.467	17.77958
3672	25654	25655	66	312.017	429	24155	230	24401	230	565.5962	489.06	15.64966
3672	25654	25655	66	312.017	659	24837	115	24819	115	214.7018	181.467	18.31453
3677	26013	27361	69	56.764	429	24155	230	24401	230	564.912	489.06	15.50976
3677	26013	27361	69	56.764	659	24837	115	24819	115	213.675	181.467	17.74869
3678	26013	27362	69	56.764	429	24155	230	24401	230	564.912	489.06	15.50976
3678	26013	27362	69	56.764	659	24837	115	24819	115	213.675	181.467	17.74869
3679	26013	27363	69	56.764	429	24155	230	24401	230	564.912	489.06	15.50976
3679	26013	27363	69	56.764	659	24837	115	24819	115	213.675	181.467	17.74869
3682	26025	26026	18	-88.9073	429	24155	230	24401	230	564.7027	489.06	15.46696
3682	26025	26026	18	-88.9073	659	24837	115	24819	115	213.6605	181.467	17.7407
3683	26025	26030	18	-192	429	24155	230	24401	230	564.4792	489.06	15.42125
3683	26025	26030	18	-192	659	24837	115	24819	115	213.645	181.467	17.73212
3684	26025	26151	18	-194.554	429	24155	230	24401	230	564.4649	489.06	15.41833
3684	26025	26151	18	-194.554	659	24837	115	24819	115	213.6441	181.467	17.73167
3685	26025	26152	18	-148.787	429	24155	230	24401	230	564.5659	489.06	15.43898
3685	26025	26152	18	-148.787	659	24837	115	24819	115	213.6511	181.467	17.73551
3686	26025	26153	18	-148.787	429	24155	230	24401	230	564.5659	489.06	15.43898

3686	26025	26153	18	-148.787	659	24837	115	24819	115	213.6511	181.467	17.73551
3687	26048	26046	230	-20.9204	429	24155	230	24401	230	564.8754	489.06	15.50226
3687	26048	26046	230	-20.9204	659	24837	115	24819	115	213.8755	181.467	17.85916
3688	26052	26053	115	-25.8337	429	24155	230	24401	230	564.8783	489.06	15.50287
3688	26052	26053	115	-25.8337	659	24837	115	24819	115	213.6859	181.467	17.75466
3689	26052	26054	115	-23.474	429	24155	230	24401	230	564.8799	489.06	15.50319
3689	26052	26054	115	-23.474	659	24837	115	24819	115	213.6847	181.467	17.75405
3692	26062	26061	230	409.9862	429	24155	230	24401	230	564.9065	489.06	15.50863
3692	26062	26061	230	409.9862	659	24837	115	24819	115	214.22	181.467	18.04899
3694	26066	26065	138	96.75076	429	24155	230	24401	230	564.9423	489.06	15.51594
3694	26066	26065	138	96.75076	659	24837	115	24819	115	213.6416	181.467	17.73029
3695	26066	26067	24	-234.548	429	24155	230	24401	230	564.3885	489.06	15.40271
3695	26066	26067	24	-234.548	659	24837	115	24819	115	213.7356	181.467	17.78209
3698	26072	26069	138	-28.9932	429	24155	230	24401	230	564.8874	489.06	15.50472
3698	26072	26069	138	-28.9932	659	24837	115	24819	115	213.6889	181.467	17.75636
3699	26078	26077	138	103.2464	429	24155	230	24401	230	564.9145	489.06	15.51027
3699	26078	26077	138	103.2464	659	24837	115	24819	115	213.6814	181.467	17.75222
3700	26078	27248	69	79.08342	429	24155	230	24401	230	564.9678	489.06	15.52116
3700	26078	27248	69	79.08342	659	24837	115	24819	115	213.6898	181.467	17.75682
3701	26079	26078	230	819.6883	429	24155	230	24401	230	565.3105	489.06	15.59123
3701	26079	26078	230	819.6883	659	24837	115	24819	115	214.7021	181.467	18.3147
3701	26079	26078	230	819.6883	737	26061	230	26103	230	1292.355	980.1	31.85947
3702	26082	26085	138	210.3845	429	24155	230	24401	230	564.9469	489.06	15.51688
3702	26082	26085	138	210.3845	659	24837	115	24819	115	213.6936	181.467	17.75891
3703	26087	26088	138	395.7715	429	24155	230	24401	230	565.0495	489.06	15.53787
3703	26087	26088	138	395.7715	659	24837	115	24819	115	213.6621	181.467	17.74155
3703	26087	26088	138	395.7715	3705	26093	230	26092	138	367.4691	287.1	27.9934
3703	26087	26088	138	395.7715	768	26088	138	26092	138	366.5702	284.13	29.01495
3705	26093	26092	138	151.2098	429	24155	230	24401	230	564.9626	489.06	15.5201
3705	26093	26092	138	151.2098	659	24837	115	24819	115	213.6539	181.467	17.73706

3706	26094	24147	230	-45.4751	429	24155	230	24401	230	565.0101	489.06	15.52981
3706	26094	24147	230	-45.4751	659	24837	115	24819	115	213.732	181.467	17.78006
3707	26103	26102	138	261.2681	429	24155	230	24401	230	565.5706	489.06	15.64441
3707	26103	26102	138	261.2681	659	24837	115	24819	115	213.7006	181.467	17.7628
3709	26115	26061	230	472.3227	429	24155	230	24401	230	564.9006	489.06	15.50742
3709	26115	26061	230	472.3227	659	24837	115	24819	115	214.2973	181.467	18.0916
3712	26129	26032	11.5	-36.9798	3590	24728	115	24730	115	62.50756	55.44	12.74812
3712	26129	26032	11.5	-36.9798	429	24155	230	24401	230	564.8343	489.06	15.49386
3712	26129	26032	11.5	-36.9798	659	24837	115	24819	115	213.6665	181.467	17.74399
3713	26130	26033	11.5	-36.9796	3590	24728	115	24730	115	62.50755	55.44	12.7481
3713	26130	26033	11.5	-36.9796	429	24155	230	24401	230	564.8343	489.06	15.49386
3713	26130	26033	11.5	-36.9796	659	24837	115	24819	115	213.6665	181.467	17.74399
3714	26131	26034	11.5	-35.9801	3590	24728	115	24730	115	62.13577	55.44	12.0775
3714	26131	26034	11.5	-35.9801	429	24155	230	24401	230	564.8359	489.06	15.49418
3714	26131	26034	11.5	-35.9801	659	24837	115	24819	115	213.6667	181.467	17.7441
3715	26182	26085	138	202.1496	429	24155	230	24401	230	564.9438	489.06	15.51626
3715	26182	26085	138	202.1496	659	24837	115	24819	115	213.6924	181.467	17.75827
3738	30000	30527	230	454.9637	429	24155	230	24401	230	564.7707	489.06	15.48087
3738	30000	30527	230	454.9637	659	24837	115	24819	115	213.6327	181.467	17.72536
3739	30035	37585	230	1000.026	429	24155	230	24401	230	567.167	489.06	15.97084
3739	30035	37585	230	1000.026	659	24837	115	24819	115	214.3336	181.467	18.11162
3740	30110	31722	60	97.20083	429	24155	230	24401	230	564.9638	489.06	15.52034
3740	30110	31722	60	97.20083	659	24837	115	24819	115	213.6957	181.467	17.76008
3741	30195	31802	11.5	-52.5162	429	24155	230	24401	230	564.851	489.06	15.49728
3741	30195	31802	11.5	-52.5162	659	24837	115	24819	115	213.6598	181.467	17.74033
3742	30245	30005	500	219.7796	429	24155	230	24401	230	564.7736	489.06	15.48146
3742	30245	30005	500	219.7796	659	24837	115	24819	115	213.6358	181.467	17.72705
3743	30250	30255	230	-58.627	429	24155	230	24401	230	564.8781	489.06	15.50282
3743	30250	30255	230	-58.627	1310	31482	115	31516	115	-75.0565	64.35	16.63792
3743	30250	30255	230	-58.627	1331	31516	115	31512	115	-75.1536	64.35	16.78886

3743	30250	30255	230	-58.627	659	24837	115	24819	115	213.6686	181.467	17.74515
3745	30300	30301	230	45.32289	429	24155	230	24401	230	564.9099	489.06	15.50933
3745	30300	30301	230	45.32289	659	24837	115	24819	115	213.6784	181.467	17.75053
3746	30302	30015	500	-79.0377	429	24155	230	24401	230	565.0071	489.06	15.5292
3746	30302	30015	500	-79.0377	659	24837	115	24819	115	213.7078	181.467	17.76673
3747	30325	30324	230	16.19237	429	24155	230	24401	230	564.8973	489.06	15.50676
3747	30325	30324	230	16.19237	659	24837	115	24819	115	213.6745	181.467	17.74842
3749	30450	30451	230	56.56614	429	24155	230	24401	230	564.9251	489.06	15.51242
3749	30450	30451	230	56.56614	659	24837	115	24819	115	213.6835	181.467	17.75335
3750	30460	30030	500	-682.053	429	24155	230	24401	230	565.6614	489.06	15.66299
3750	30460	30030	500	-682.053	659	24837	115	24819	115	213.8982	181.467	17.87165
3751	30464	30465	230	-52.37	429	24155	230	24401	230	564.9136	489.06	15.51008
3751	30464	30465	230	-52.37	659	24837	115	24819	115	213.6799	181.467	17.75137
3752	30485	30486	230	-88.9117	429	24155	230	24401	230	564.8743	489.06	15.50205
3752	30485	30486	230	-88.9117	659	24837	115	24819	115	213.6668	181.467	17.74417
3753	30487	33812	13.8	-72.5975	429	24155	230	24401	230	564.8779	489.06	15.50278
3753	30487	33812	13.8	-72.5975	659	24837	115	24819	115	213.668	181.467	17.74484
3754	30496	33803	21	44.81416	429	24155	230	24401	230	564.9124	489.06	15.50983
3754	30496	33803	21	44.81416	659	24837	115	24819	115	213.6794	181.467	17.75109
3755	30497	33801	21	50.72202	429	24155	230	24401	230	564.9148	489.06	15.51032
3755	30497	33801	21	50.72202	659	24837	115	24819	115	213.6801	181.467	17.75151
3756	30500	30501	230	51.24241	429	24155	230	24401	230	564.8966	489.06	15.50661
3756	30500	30501	230	51.24241	659	24837	115	24819	115	213.6743	181.467	17.74829
3762	30550	30551	230	52.26956	429	24155	230	24401	230	564.9053	489.06	15.50839
3762	30550	30551	230	52.26956	659	24837	115	24819	115	213.6769	181.467	17.74971
3763	30550	30552	230	51.41319	429	24155	230	24401	230	564.9051	489.06	15.50835
3763	30550	30552	230	51.41319	659	24837	115	24819	115	213.6768	181.467	17.74968
3764	30624	30040	500	-823.747	429	24155	230	24401	230	565.7307	489.06	15.67716
3764	30624	30040	500	-823.747	659	24837	115	24819	115	213.916	181.467	17.88146
3765	30625	30040	500	-589.084	429	24155	230	24401	230	565.3831	489.06	15.60609

3765	30625	30040	500	-589.084	659	24837	115	24819	115	213.815	181.467	17.82585
3766	30640	30040	500	-442.405	429	24155	230	24401	230	565.3587	489.06	15.6011
3766	30640	30040	500	-442.405	659	24837	115	24819	115	213.8081	181.467	17.82205
3767	30735	30042	500	-1375.43	429	24155	230	24401	230	567.0679	489.06	15.95057
3767	30735	30042	500	-1375.43	659	24837	115	24819	115	214.2955	181.467	18.09063
3768	30751	30045	500	-96.4555	429	24155	230	24401	230	565.0597	489.06	15.53996
3768	30751	30045	500	-96.4555	659	24837	115	24819	115	213.7203	181.467	17.77364
3769	30760	36075	60	-100.781	429	24155	230	24401	230	564.8661	489.06	15.50037
3769	30760	36075	60	-100.781	659	24837	115	24819	115	213.6646	181.467	17.74294
3770	30765	30050	500	-327.144	429	24155	230	24401	230	565.4964	489.06	15.62925
3770	30765	30050	500	-327.144	659	24837	115	24819	115	213.8397	181.467	17.83946
3771	30790	34158	115	83.86755	429	24155	230	24401	230	564.9134	489.06	15.51004
3771	30790	34158	115	83.86755	659	24837	115	24819	115	213.6791	181.467	17.75095
3772	30835	34412	115	345.0143	429	24155	230	24401	230	564.9809	489.06	15.52383
3772	30835	34412	115	345.0143	659	24837	115	24819	115	213.6996	181.467	17.76223
3774	30875	34370	115	464.277	2390	34418	115	34428	115	-173.143	156.42	10.69122
3774	30875	34370	115	464.277	2396	34429	115	34428	115	180.7308	162.36	11.31484
3774	30875	34370	115	464.277	429	24155	230	24401	230	565.1001	489.06	15.54822
3774	30875	34370	115	464.277	659	24837	115	24819	115	213.7339	181.467	17.78111
3775	30881	34430	115	7.331315	429	24155	230	24401	230	564.8974	489.06	15.50676
3775	30881	34430	115	7.331315	659	24837	115	24819	115	213.6745	181.467	17.74841
3776	30900	30055	500	-200.023	429	24155	230	24401	230	565.3932	489.06	15.60815
3776	30900	30055	500	-200.023	659	24837	115	24819	115	213.8105	181.467	17.82335
3777	30900	30901	230	32.83414	429	24155	230	24401	230	564.9017	489.06	15.50764
3777	30900	30901	230	32.83414	659	24837	115	24819	115	213.6757	181.467	17.74907
3779	30970	30060	500	1335.829	1081	30900	230	30970	230	-323.028	292.644	10.38244
3779	30970	30060	500	1335.829	3674	26010	230	26005	18	-328.098	287.1	14.2799
3779	30970	30060	500	1335.829	3675	26010	230	26006	18	-328.098	287.1	14.2799
3779	30970	30060	500	1335.829	3676	26010	230	26007	18	-328.098	287.1	14.2799
3779	30970	30060	500	1335.829	429	24155	230	24401	230	560.7443	489.06	14.65757

3779	30970	30060	500	1335.829	659	24837	115	24819	115	212.5375	181.467	17.12185
3792	31236	30430	230	-309.715	429	24155	230	24401	230	565.0007	489.06	15.52789
3792	31236	30430	230	-309.715	659	24837	115	24819	115	213.7063	181.467	17.76591
3793	31255	30435	230	-191.519	429	24155	230	24401	230	564.9495	489.06	15.51741
3793	31255	30435	230	-191.519	659	24837	115	24819	115	213.6902	181.467	17.75704
3805	31392	30435	230	-58.6939	429	24155	230	24401	230	564.9098	489.06	15.50931
3805	31392	30435	230	-58.6939	659	24837	115	24819	115	213.6788	181.467	17.7508
3816	31421	30426	230	52.5	429	24155	230	24401	230	564.8857	489.06	15.50438
3816	31421	30426	230	52.5	659	24837	115	24819	115	213.6705	181.467	17.74621
3828	31464	30105	230	11.03697	429	24155	230	24401	230	564.8948	489.06	15.50625
3828	31464	30105	230	11.03697	659	24837	115	24819	115	213.6738	181.467	17.74801
3829	31464	30106	230	24.57354	429	24155	230	24401	230	564.8923	489.06	15.50574
3829	31464	30106	230	24.57354	659	24837	115	24819	115	213.673	181.467	17.7476
3833	31482	30325	230	-108.093	429	24155	230	24401	230	564.9107	489.06	15.50949
3833	31482	30325	230	-108.093	659	24837	115	24819	115	213.6786	181.467	17.75064
3834	31486	30255	230	59.01241	429	24155	230	24401	230	564.8928	489.06	15.50583
3834	31486	30255	230	59.01241	659	24837	115	24819	115	213.6731	181.467	17.74766
3834	31486	30255	230	59.01241	1316	31488	115	31512	115	96.38213	79.2	21.6946
3834	31486	30255	230	59.01241	1310	31482	115	31516	115	95.24579	64.35	48.01211
3834	31486	30255	230	59.01241	1331	31516	115	31512	115	95.34292	64.35	48.16305
3836	31504	30300	230	-124.478	429	24155	230	24401	230	564.9171	489.06	15.5108
3836	31504	30300	230	-124.478	659	24837	115	24819	115	213.6804	181.467	17.75166
3837	31504	30303	230	-127.64	429	24155	230	24401	230	564.9367	489.06	15.51481
3837	31504	30303	230	-127.64	659	24837	115	24819	115	213.6865	181.467	17.75504
3842	31604	30105	230	-40.677	429	24155	230	24401	230	564.9162	489.06	15.51062
3842	31604	30105	230	-40.677	659	24837	115	24819	115	213.6802	181.467	17.75153
3842	31604	30105	230	-40.677	1355	31581	60	31578	60	34.47861	28.71	20.09268
3842	31604	30105	230	-40.677	1352	31580	60	31581	60	38.27472	28.71	33.31493
3846	31656	30324	230	-16.1841	429	24155	230	24401	230	564.8973	489.06	15.50676
3846	31656	30324	230	-16.1841	659	24837	115	24819	115	213.6745	181.467	17.74842

3847	31690	30255	230	-0.17669	429	24155	230	24401	230	564.8955	489.06	15.50637
3847	31690	30255	230	-0.17669	659	24837	115	24819	115	213.674	181.467	17.74811
3849	31718	30301	230	-45.2733	429	24155	230	24401	230	564.9099	489.06	15.50933
3849	31718	30301	230	-45.2733	659	24837	115	24819	115	213.6784	181.467	17.75053
3864	31798	30108	230	24.98	429	24155	230	24401	230	564.8745	489.06	15.50208
3864	31798	30108	230	24.98	659	24837	115	24819	115	213.6673	181.467	17.74444
3866	31804	30210	230	68.86699	429	24155	230	24401	230	564.8366	489.06	15.49434
3866	31804	30210	230	68.86699	659	24837	115	24819	115	213.6553	181.467	17.73782
3871	31818	30185	230	52.32581	429	24155	230	24401	230	564.8511	489.06	15.49731
3871	31818	30185	230	52.32581	659	24837	115	24819	115	213.6599	181.467	17.74036
3872	31820	30265	230	51.39199	429	24155	230	24401	230	564.8875	489.06	15.50474
3872	31820	30265	230	51.39199	659	24837	115	24819	115	213.6711	181.467	17.74652
3885	31874	30190	230	10.9	429	24155	230	24401	230	564.8862	489.06	15.50448
3885	31874	30190	230	10.9	659	24837	115	24819	115	213.671	181.467	17.74649
3897	31950	30450	230	-55.9334	429	24155	230	24401	230	564.9308	489.06	15.5136
3897	31950	30450	230	-55.9334	659	24837	115	24819	115	213.6847	181.467	17.75404
3898	31951	30451	230	-6.66601	429	24155	230	24401	230	564.8985	489.06	15.507
3898	31951	30451	230	-6.66601	659	24837	115	24819	115	213.675	181.467	17.74865
3899	31984	30348	230	-176.426	429	24155	230	24401	230	564.9481	489.06	15.51713
3899	31984	30348	230	-176.426	659	24837	115	24819	115	213.6896	181.467	17.75675
3899	31984	30348	230	-176.426	1476	31990	115	31992	115	-151.904	123.75	22.75051
3899	31984	30348	230	-176.426	1569	32214	115	31986	115	107.125	87.12	22.96261
3899	31984	30348	230	-176.426	1460	31962	115	31992	115	152.4969	123.75	23.22981
3900	31998	30460	230	-246.327	429	24155	230	24401	230	564.9082	489.06	15.50899
3900	31998	30460	230	-246.327	659	24837	115	24819	115	213.6776	181.467	17.75013
3900	31998	30460	230	-246.327	1488	31999	115	31998	115	317.5459	236.61	34.20644
3901	31999	30460	230	-38.171	429	24155	230	24401	230	564.9019	489.06	15.50769
3901	31999	30460	230	-38.171	659	24837	115	24819	115	213.6758	181.467	17.74914
3903	32056	30451	230	-49.7438	429	24155	230	24401	230	564.9212	489.06	15.51164
3903	32056	30451	230	-49.7438	659	24837	115	24819	115	213.6823	181.467	17.75268

3913	32171	30475	230	0	429	24155	230	24401	230	564.8954	489.06	15.50637
3913	32171	30475	230	0	659	24837	115	24819	115	213.674	181.467	17.7481
3918	32177	30476	230	149.999	429	24155	230	24401	230	564.8358	489.06	15.49417
3918	32177	30476	230	149.999	659	24837	115	24819	115	213.6547	181.467	17.73752
3920	32214	30330	230	-105.112	429	24155	230	24401	230	564.9229	489.06	15.51198
3920	32214	30330	230	-105.112	659	24837	115	24819	115	213.6822	181.467	17.75263
3920	32214	30330	230	-105.112	1469	31978	115	31984	115	-107.688	87.12	23.6085
3934	32386	30346	230	15.83656	429	24155	230	24401	230	564.8934	489.06	15.50595
3934	32386	30346	230	15.83656	659	24837	115	24819	115	213.6736	181.467	17.74792
3936	32412	30335	230	-146.113	429	24155	230	24401	230	564.9249	489.06	15.51239
3936	32412	30335	230	-146.113	659	24837	115	24819	115	213.6841	181.467	17.75371
3964	32568	30445	230	-287.52	429	24155	230	24401	230	564.9676	489.06	15.52113
3964	32568	30445	230	-287.52	659	24837	115	24819	115	213.6984	181.467	17.76158
3965	32654	30440	230	-81.1265	429	24155	230	24401	230	564.9208	489.06	15.51155
3965	32654	30440	230	-81.1265	659	24837	115	24819	115	213.6823	181.467	17.75273
3977	32950	30526	230	-192.698	429	24155	230	24401	230	564.9466	489.06	15.51684
3977	32950	30526	230	-192.698	659	24837	115	24819	115	213.6892	181.467	17.7565
3987	33000	30523	230	-23.6707	429	24155	230	24401	230	564.905	489.06	15.50833
3987	33000	30523	230	-23.6707	659	24837	115	24819	115	213.677	181.467	17.74979
3988	33010	30540	230	-462.488	429	24155	230	24401	230	565.0062	489.06	15.52901
3988	33010	30540	230	-462.488	659	24837	115	24819	115	213.707	181.467	17.76633
3989	33020	30550	230	-143.567	429	24155	230	24401	230	564.9165	489.06	15.51067
3989	33020	30550	230	-143.567	659	24837	115	24819	115	213.6802	181.467	17.75153
3990	33020	30551	230	-52.0279	429	24155	230	24401	230	564.9053	489.06	15.50838
3990	33020	30551	230	-52.0279	659	24837	115	24819	115	213.6769	181.467	17.74971
3991	33020	30552	230	-51.182	429	24155	230	24401	230	564.9051	489.06	15.50834
3991	33020	30552	230	-51.182	659	24837	115	24819	115	213.6768	181.467	17.74967
3994	33105	30527	230	314.48	429	24155	230	24401	230	564.8095	489.06	15.48879
3994	33105	30527	230	314.48	659	24837	115	24819	115	213.6455	181.467	17.73242
3995	33106	30527	230	314.48	429	24155	230	24401	230	564.8095	489.06	15.48879

3995	33106	30527	230	314.48	659	24837	115	24819	115	213.6455	181.467	17.73242
3998	33116	30525	230	325	429	24155	230	24401	230	564.7647	489.06	15.47963
3998	33116	30525	230	325	659	24837	115	24819	115	213.632	181.467	17.725
3999	33117	30525	230	325	429	24155	230	24401	230	564.7647	489.06	15.47963
3999	33117	30525	230	325	659	24837	115	24819	115	213.632	181.467	17.725
4008	33151	30535	230	30.94013	1891	33150	12.47	33151	12.5	-125.73	113.85	10.43467
4008	33151	30535	230	30.94013	429	24155	230	24401	230	564.8878	489.06	15.50481
4008	33151	30535	230	30.94013	659	24837	115	24819	115	213.6714	181.467	17.74669
4012	33208	30695	230	-177.373	429	24155	230	24401	230	564.9216	489.06	15.51171
4012	33208	30695	230	-177.373	659	24837	115	24819	115	213.6817	181.467	17.75235
4028	33310	30700	230	-604.576	429	24155	230	24401	230	565.0257	489.06	15.533
4028	33310	30700	230	-604.576	659	24837	115	24819	115	213.7127	181.467	17.76947
4028	33310	30700	230	-604.576	1981	33378	60	33380	60	69.20548	55.341	25.05282
4028	33310	30700	230	-604.576	1926	33310	115	33321	115	215.4852	90.882	137.1044
4030	33315	30703	230	-190.589	429	24155	230	24401	230	564.9367	489.06	15.51481
4030	33315	30703	230	-190.589	659	24837	115	24819	115	213.6862	181.467	17.75484
4031	33321	30703	230	-188.311	429	24155	230	24401	230	564.9166	489.06	15.5107
4031	33321	30703	230	-188.311	659	24837	115	24819	115	213.6802	181.467	17.75153
4037	33380	30715	230	-106.311	429	24155	230	24401	230	564.9115	489.06	15.50964
4037	33380	30715	230	-106.311	659	24837	115	24819	115	213.6786	181.467	17.75068
4042	33540	30625	230	-287.074	429	24155	230	24401	230	565.0159	489.06	15.531
4042	33540	30625	230	-287.074	659	24837	115	24819	115	213.7094	181.467	17.76761
4042	33540	30625	230	-287.074	4359	37560	230	37649	115	215.2924	178.2	20.81506
4043	33562	30500	230	-50.5368	429	24155	230	24401	230	564.8966	489.06	15.50661
4043	33562	30500	230	-50.5368	659	24837	115	24819	115	213.6743	181.467	17.74829
4044	33562	30501	230	-51.1074	429	24155	230	24401	230	564.8966	489.06	15.50661
4044	33562	30501	230	-51.1074	659	24837	115	24819	115	213.6743	181.467	17.74829
4045	33584	30486	230	35.55808	429	24155	230	24401	230	564.887	489.06	15.50464
4045	33584	30486	230	35.55808	659	24837	115	24819	115	213.6711	181.467	17.74653
4047	33610	30490	230	-88.0283	429	24155	230	24401	230	564.9179	489.06	15.51097

4047	33610	30490	230	-88.0283	659	24837	115	24819	115	213.6815	181.467	17.75225
4049	33650	30505	230	-117.937	429	24155	230	24401	230	564.9018	489.06	15.50767
4049	33650	30505	230	-117.937	659	24837	115	24819	115	213.6758	181.467	17.74911
4050	33662	30505	230	-23.0214	429	24155	230	24401	230	564.8963	489.06	15.50654
4050	33662	30505	230	-23.0214	659	24837	115	24819	115	213.6742	181.467	17.74823
4051	33704	30498	230	-92.8791	429	24155	230	24401	230	564.8984	489.06	15.50698
4051	33704	30498	230	-92.8791	659	24837	115	24819	115	213.6748	181.467	17.74857
4052	33704	30499	230	-94.9446	429	24155	230	24401	230	564.899	489.06	15.5071
4052	33704	30499	230	-94.9446	659	24837	115	24819	115	213.675	181.467	17.74867
4053	33724	30482	230	-177.276	429	24155	230	24401	230	564.9384	489.06	15.51516
4053	33724	30482	230	-177.276	659	24837	115	24819	115	213.6885	181.467	17.75609
4067	33822	30486	230	53.49999	429	24155	230	24401	230	564.883	489.06	15.50382
4067	33822	30486	230	53.49999	659	24837	115	24819	115	213.6697	181.467	17.74578
4070	33836	30570	230	4.159998	429	24155	230	24401	230	564.8929	489.06	15.50585
4070	33836	30570	230	4.159998	659	24837	115	24819	115	213.6732	181.467	17.74767
4071	33838	30590	230	-0.5	429	24155	230	24401	230	564.8956	489.06	15.50641
4071	33838	30590	230	-0.5	659	24837	115	24819	115	213.674	181.467	17.74813
4072	33840	30595	230	1.680003	429	24155	230	24401	230	564.8947	489.06	15.50622
4072	33840	30595	230	1.680003	659	24837	115	24819	115	213.6737	181.467	17.74797
4085	34134	30800	230	-90.7969	429	24155	230	24401	230	564.8998	489.06	15.50727
4085	34134	30800	230	-90.7969	659	24837	115	24819	115	213.6752	181.467	17.74882
4086	34136	30800	230	-90.9246	429	24155	230	24401	230	564.8998	489.06	15.50726
4086	34136	30800	230	-90.9246	659	24837	115	24819	115	213.6752	181.467	17.74881
4109	34378	30901	230	-32.6292	429	24155	230	24401	230	564.9016	489.06	15.50764
4109	34378	30901	230	-32.6292	659	24837	115	24819	115	213.6757	181.467	17.74906
4115	34474	30873	230	9.195882	429	24155	230	24401	230	564.8946	489.06	15.5062
4115	34474	30873	230	9.195882	659	24837	115	24819	115	213.6737	181.467	17.74797
4116	34480	30830	230	-74.1729	429	24155	230	24401	230	564.9077	489.06	15.50888
4116	34480	30830	230	-74.1729	659	24837	115	24819	115	213.6781	181.467	17.75041
4121	34540	30881	230	-0.02738	429	24155	230	24401	230	564.8955	489.06	15.50637

4121	34540	30881	230	-0.02738	659	24837	115	24819	115	213.674	181.467	17.7481
4126	34582	30935	230	-75.0745	429	24155	230	24401	230	564.9182	489.06	15.51103
4126	34582	30935	230	-75.0745	659	24837	115	24819	115	213.6809	181.467	17.75195
4152	34752	30945	230	-106.158	429	24155	230	24401	230	564.9336	489.06	15.51417
4152	34752	30945	230	-106.158	659	24837	115	24819	115	213.6849	181.467	17.75413
4155	34774	30970	230	-121.083	429	24155	230	24401	230	564.9401	489.06	15.51551
4155	34774	30970	230	-121.083	659	24837	115	24819	115	213.6867	181.467	17.75513
4161	34874	30994	230	-71.7532	429	24155	230	24401	230	564.9184	489.06	15.51107
4161	34874	30994	230	-71.7532	659	24837	115	24819	115	213.6809	181.467	17.75192
4196	35076	30948	230	173.3	429	24155	230	24401	230	564.8419	489.06	15.49542
4196	35076	30948	230	173.3	659	24837	115	24819	115	213.6578	181.467	17.73919
4197	35077	30948	230	173.3	429	24155	230	24401	230	564.8419	489.06	15.49542
4197	35077	30948	230	173.3	659	24837	115	24819	115	213.6578	181.467	17.73919
4199	35105	30560	230	-157.543	429	24155	230	24401	230	564.9259	489.06	15.51261
4199	35105	30560	230	-157.543	659	24837	115	24819	115	213.683	181.467	17.75309
4200	35120	30630	230	-201.709	429	24155	230	24401	230	564.9364	489.06	15.51473
4200	35120	30630	230	-201.709	659	24837	115	24819	115	213.686	181.467	17.75477
4202	35121	30630	230	-204.571	429	24155	230	24401	230	564.9406	489.06	15.5156
4202	35121	30630	230	-204.571	659	24837	115	24819	115	213.6873	181.467	17.75547
4203	35122	30631	230	-248.754	429	24155	230	24401	230	564.9467	489.06	15.51685
4203	35122	30631	230	-248.754	659	24837	115	24819	115	213.6891	181.467	17.75645
4204	35209	30555	230	-35.0568	429	24155	230	24401	230	564.8965	489.06	15.50658
4204	35209	30555	230	-35.0568	659	24837	115	24819	115	213.6743	181.467	17.74827
4206	35220	30585	230	-36.2865	429	24155	230	24401	230	564.9035	489.06	15.50801
4206	35220	30585	230	-36.2865	659	24837	115	24819	115	213.6763	181.467	17.74941
4209	35356	30705	230	-509.308	429	24155	230	24401	230	564.9825	489.06	15.52418
4209	35356	30705	230	-509.308	659	24837	115	24819	115	213.6995	181.467	17.76218
4209	35356	30705	230	-509.308	4210	35455	60	30705	230	-245.028	133.056	84.15405
4210	35455	30705	230	-62.1267	429	24155	230	24401	230	564.9061	489.06	15.50854
4210	35455	30705	230	-62.1267	659	24837	115	24819	115	213.6771	181.467	17.74982

4212	35642	30735	230	-425.425	429	24155	230	24401	230	564.9755	489.06	15.52274
4212	35642	30735	230	-425.425	659	24837	115	24819	115	213.6973	181.467	17.76098
4213	35643	30735	230	-416.261	429	24155	230	24401	230	564.9827	489.06	15.52421
4213	35643	30735	230	-416.261	659	24837	115	24819	115	213.6994	181.467	17.76215
4218	35658	30731	230	-196.879	429	24155	230	24401	230	564.9473	489.06	15.51697
4218	35658	30731	230	-196.879	659	24837	115	24819	115	213.6892	181.467	17.75651
4232	35921	30750	230	-206.179	429	24155	230	24401	230	564.9107	489.06	15.5095
4232	35921	30750	230	-206.179	659	24837	115	24819	115	213.6784	181.467	17.75054
4233	35921	30755	230	-207.107	429	24155	230	24401	230	564.9041	489.06	15.50814
4233	35921	30755	230	-207.107	659	24837	115	24819	115	213.6765	181.467	17.74948
4234	35922	30750	230	-80.1813	429	24155	230	24401	230	564.8992	489.06	15.50713
4234	35922	30750	230	-80.1813	659	24837	115	24819	115	213.675	181.467	17.74869
4235	35922	30755	230	-80.7265	429	24155	230	24401	230	564.8992	489.06	15.50714
4235	35922	30755	230	-80.7265	659	24837	115	24819	115	213.675	181.467	17.7487
4250	36221	30780	230	163.41	429	24155	230	24401	230	564.8525	489.06	15.49759
4250	36221	30780	230	163.41	659	24837	115	24819	115	213.6601	181.467	17.74044
4251	36222	30780	230	163.41	429	24155	230	24401	230	564.8525	489.06	15.49759
4251	36222	30780	230	163.41	659	24837	115	24819	115	213.6601	181.467	17.74044
4253	36224	30787	230	163.41	429	24155	230	24401	230	564.8526	489.06	15.4976
4253	36224	30787	230	163.41	659	24837	115	24819	115	213.6601	181.467	17.74045
4254	36225	30787	230	163.41	429	24155	230	24401	230	564.8526	489.06	15.4976
4254	36225	30787	230	163.41	659	24837	115	24819	115	213.6601	181.467	17.74045
4256	36252	30915	230	-135.262	429	24155	230	24401	230	564.9187	489.06	15.51112
4256	36252	30915	230	-135.262	659	24837	115	24819	115	213.6806	181.467	17.75176
4259	36310	30905	230	-63.7351	429	24155	230	24401	230	564.9068	489.06	15.50869
4259	36310	30905	230	-63.7351	659	24837	115	24819	115	213.6772	181.467	17.74989
4266	36409	30915	230	323	429	24155	230	24401	230	564.8229	489.06	15.49153
4266	36409	30915	230	323	659	24837	115	24819	115	213.6512	181.467	17.73554
4267	36410	30915	230	323	429	24155	230	24401	230	564.8229	489.06	15.49153
4267	36410	30915	230	323	659	24837	115	24819	115	213.6512	181.467	17.73554

4290	36964	30515	230	-83.4915	429	24155	230	24401	230	564.8803	489.06	15.50327
4290	36964	30515	230	-83.4915	659	24837	115	24819	115	213.6694	181.467	17.74558
4296	37005	37052	115	66.82719	429	24155	230	24401	230	564.9022	489.06	15.50776
4296	37005	37052	115	66.82719	659	24837	115	24819	115	213.676	181.467	17.74922
4297	37009	37053	115	199.9676	429	24155	230	24401	230	564.906	489.06	15.50853
4297	37009	37053	115	199.9676	659	24837	115	24819	115	213.6769	181.467	17.74972
4297	37009	37053	115	199.9676	4298	37010	230	37054	115	241.9618	198	22.20293
4298	37010	37054	115	112.5788	429	24155	230	24401	230	564.9098	489.06	15.50929
4298	37010	37054	115	112.5788	659	24837	115	24819	115	213.6782	181.467	17.75042
4310	37101	37003	230	-182.414	429	24155	230	24401	230	564.9436	489.06	15.51622
4310	37101	37003	230	-182.414	659	24837	115	24819	115	213.6903	181.467	17.75714
4311	37102	37004	230	-156.961	429	24155	230	24401	230	564.9294	489.06	15.51331
4311	37102	37004	230	-156.961	659	24837	115	24819	115	213.6857	181.467	17.7546
4312	37103	37005	230	-190.898	429	24155	230	24401	230	564.9519	489.06	15.51792
4312	37103	37005	230	-190.898	659	24837	115	24819	115	213.6929	181.467	17.75857
4313	37105	37008	230	-115.607	429	24155	230	24401	230	564.9275	489.06	15.51293
4313	37105	37008	230	-115.607	659	24837	115	24819	115	213.6848	181.467	17.75408
4314	37106	37009	230	-184.535	429	24155	230	24401	230	564.9372	489.06	15.5149
4314	37106	37009	230	-184.535	659	24837	115	24819	115	213.6884	181.467	17.75606
4315	37107	37009	230	-171.809	429	24155	230	24401	230	564.9343	489.06	15.51432
4315	37107	37009	230	-171.809	659	24837	115	24819	115	213.6874	181.467	17.75551
4316	37108	37010	230	-191.959	429	24155	230	24401	230	564.952	489.06	15.51793
4316	37108	37010	230	-191.959	659	24837	115	24819	115	213.6929	181.467	17.75854
4317	37109	37010	230	-189.838	429	24155	230	24401	230	564.9508	489.06	15.51768
4317	37109	37010	230	-189.838	659	24837	115	24819	115	213.6925	181.467	17.75834
4319	37111	37012	230	-158.021	429	24155	230	24401	230	564.932	489.06	15.51383
4319	37111	37012	230	-158.021	659	24837	115	24819	115	213.6866	181.467	17.75505
4322	37114	37013	230	-169.687	429	24155	230	24401	230	564.9387	489.06	15.51522
4322	37114	37013	230	-169.687	659	24837	115	24819	115	213.6887	181.467	17.75625
4323	37115	37013	230	-171.809	429	24155	230	24401	230	564.9396	489.06	15.51539

4323	37115	37013	230	-171.809	659	24837	115	24819	115	213.689	181.467	17.7564
4324	37116	37014	230	-193.019	429	24155	230	24401	230	564.9375	489.06	15.51497
4324	37116	37014	230	-193.019	659	24837	115	24819	115	213.6886	181.467	17.75616
4325	37117	37014	230	-132.751	429	24155	230	24401	230	564.9246	489.06	15.51233
4325	37117	37014	230	-132.751	659	24837	115	24819	115	213.6841	181.467	17.75369
4327	37121	37004	230	-182.414	429	24155	230	24401	230	564.9352	489.06	15.51449
4327	37121	37004	230	-182.414	659	24837	115	24819	115	213.6878	181.467	17.75571
4328	37122	37012	230	-95.4492	429	24155	230	24401	230	564.9168	489.06	15.51073
4328	37122	37012	230	-95.4492	659	24837	115	24819	115	213.6814	181.467	17.75218
4329	37123	37021	230	-184.535	429	24155	230	24401	230	564.9495	489.06	15.51741
4329	37123	37021	230	-184.535	659	24837	115	24819	115	213.6921	181.467	17.75811
4349	37524	37521	18	-159.739	429	24155	230	24401	230	564.8954	489.06	15.50637
4349	37524	37521	18	-159.739	659	24837	115	24819	115	213.674	181.467	17.7481
4350	37524	37522	18	-159.739	429	24155	230	24401	230	564.8954	489.06	15.50637
4350	37524	37522	18	-159.739	659	24837	115	24819	115	213.674	181.467	17.7481
4351	37524	37523	18	-159.739	429	24155	230	24401	230	564.8954	489.06	15.50637
4351	37524	37523	18	-159.739	659	24837	115	24819	115	213.674	181.467	17.7481
4352	37544	37901	115	69.69027	429	24155	230	24401	230	564.9057	489.06	15.50847
4352	37544	37901	115	69.69027	659	24837	115	24819	115	213.677	181.467	17.74976
4357	37555	37553	13.8	-146.583	429	24155	230	24401	230	564.8954	489.06	15.50637
4357	37555	37553	13.8	-146.583	659	24837	115	24819	115	213.674	181.467	17.7481
4358	37558	37505	115	62.8729	429	24155	230	24401	230	564.9013	489.06	15.50757
4358	37558	37505	115	62.8729	659	24837	115	24819	115	213.6757	181.467	17.74904
4359	37560	37649	115	86.06094	429	24155	230	24401	230	564.9243	489.06	15.51228
4359	37560	37649	115	86.06094	659	24837	115	24819	115	213.6823	181.467	17.75272
4360	37563	37561	13.8	-118.693	429	24155	230	24401	230	564.8954	489.06	15.50637
4360	37563	37561	13.8	-118.693	659	24837	115	24819	115	213.674	181.467	17.7481
4361	37563	37562	13.8	-149.593	429	24155	230	24401	230	564.8954	489.06	15.50637
4361	37563	37562	13.8	-149.593	659	24837	115	24819	115	213.674	181.467	17.7481
4362	37565	30020	500	41.25803	429	24155	230	24401	230	564.8409	489.06	15.49522

4362	37565	30020	500	41.25803	659	24837	115	24819	115	213.6574	181.467	17.739
4363	37567	37572	60	117.3807	429	24155	230	24401	230	564.9073	489.06	15.5088
4363	37567	37572	60	117.3807	659	24837	115	24819	115	213.6775	181.467	17.75003
4363	37567	37572	60	117.3807	4364	37567	230	37573	60	232.9032	148.5	56.83718
4364	37567	37573	60	122.6468	429	24155	230	24401	230	564.9084	489.06	15.50902
4364	37567	37573	60	122.6468	659	24837	115	24819	115	213.6778	181.467	17.75021
4364	37567	37573	60	122.6468	4363	37567	230	37572	60	232.1762	148.5	56.3476
4365	37568	37574	60	-13.9957	429	24155	230	24401	230	564.8913	489.06	15.50552
4365	37568	37574	60	-13.9957	659	24837	115	24819	115	213.6726	181.467	17.74733
4366	37569	37570	115	25.06919	429	24155	230	24401	230	564.8969	489.06	15.50666
4366	37569	37570	115	25.06919	659	24837	115	24819	115	213.6744	181.467	17.74833
4368	37585	37582	69	147.6613	429	24155	230	24401	230	565.0217	489.06	15.53218
4368	37585	37582	69	147.6613	659	24837	115	24819	115	213.7123	181.467	17.76923
4410	38250	38202	230	-96.6639	429	24155	230	24401	230	564.911	489.06	15.50954
4410	38250	38202	230	-96.6639	659	24837	115	24819	115	213.6784	181.467	17.75056
4411	38250	38210	230	-96.2556	429	24155	230	24401	230	564.9107	489.06	15.5095
4411	38250	38210	230	-96.2556	659	24837	115	24819	115	213.6783	181.467	17.75052
4414	38256	38257	230	-142.408	429	24155	230	24401	230	564.9429	489.06	15.51608
4414	38256	38257	230	-142.408	659	24837	115	24819	115	213.6876	181.467	17.75565
4428	38410	30670	230	-78.9502	429	24155	230	24401	230	564.9153	489.06	15.51043
4428	38410	30670	230	-78.9502	659	24837	115	24819	115	213.6797	181.467	17.75125
4429	38436	38400	230	-5.95907	429	24155	230	24401	230	564.8961	489.06	15.50651
4429	38436	38400	230	-5.95907	659	24837	115	24819	115	213.6741	181.467	17.74821
4437	38480	38400	230	-156.244	429	24155	230	24401	230	564.9772	489.06	15.52308
4437	38480	38400	230	-156.244	659	24837	115	24819	115	213.6979	181.467	17.76131
4467	38900	36851	115	181.3954	429	24155	230	24401	230	564.933	489.06	15.51405
4467	38900	36851	115	181.3954	659	24837	115	24819	115	213.685	181.467	17.7542

Table A.3 Line Overload Results for 287 kV lines

Line Out					Line Monitored							
line no	from Bus	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	percent overload
729	26051	26104	287	103.6587	429	24155	230	24401	230	564.8671	489.06	15.50058
729	26051	26104	287	103.6587	659	24837	115	24819	115	213.9756	181.467	17.91434
747	26070	26104	287	-176.399	429	24155	230	24401	230	564.9908	489.06	15.52586
747	26070	26104	287	-176.399	659	24837	115	24819	115	213.8413	181.467	17.84031
748	26071	26104	287	-176.399	429	24155	230	24401	230	564.9908	489.06	15.52586
748	26071	26104	287	-176.399	659	24837	115	24819	115	213.8413	181.467	17.84031
3294	25701	26051	287	103.6974	429	24155	230	24401	230	564.8671	489.06	15.50058
3294	25701	26051	287	103.6974	659	24837	115	24819	115	213.9757	181.467	17.9144
3696	26070	26069	138	176.3993	429	24155	230	24401	230	564.9908	489.06	15.52586
3696	26070	26069	138	176.3993	659	24837	115	24819	115	213.8413	181.467	17.84031
3697	26071	26069	138	176.3993	429	24155	230	24401	230	564.9908	489.06	15.52586
3697	26071	26069	138	176.3993	659	24837	115	24819	115	213.8413	181.467	17.84031
3708	26105	26104	287	258.4321	429	24155	230	24401	230	565.0826	489.06	15.54463
3708	26105	26104	287	258.4321	659	24837	115	24819	115	213.7287	181.467	17.7783

Table A.4 Line Overload Results for 161 kV lines

Line Out					Line Monitored							
line no	from Bus	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	percent overload
18	21085	21047	161	106.6777	659	24837	115	24819	115	214.4846	181.467	18.1948
19	21085	24017	161	130.9305	18	21085	161	21047	161	237.6082	163.35	45.45956
19	21085	24017	161	130.9305	429	24155	230	24401	230	564.8627	489.06	15.49967
19	21085	24017	161	130.9305	659	24837	115	24819	115	212.679	181.467	17.19984
23	21084	21059	161	37.90238	429	24155	230	24401	230	564.8515	489.06	15.49738
23	21084	21059	161	37.90238	659	24837	115	24819	115	213.0699	181.467	17.41522
24	21003	21006	161	-37.1758	429	24155	230	24401	230	564.895	489.06	15.50627
24	21003	21006	161	-37.1758	659	24837	115	24819	115	213.7615	181.467	17.79633
25	21003	21026	161	-45.8122	429	24155	230	24401	230	564.9031	489.06	15.50794
25	21003	21026	161	-45.8122	659	24837	115	24819	115	212.7648	181.467	17.24712
32	21006	21047	161	-58.6758	429	24155	230	24401	230	564.8997	489.06	15.50723
32	21006	21047	161	-58.6758	659	24837	115	24819	115	212.7731	181.467	17.2517
43	21026	21047	161	-3.43934	429	24155	230	24401	230	564.8949	489.06	15.50625
43	21026	21047	161	-3.43934	659	24837	115	24819	115	213.7185	181.467	17.77266
44	21026	21059	161	-34.4893	429	24155	230	24401	230	564.8872	489.06	15.50468
44	21026	21059	161	-34.4893	659	24837	115	24819	115	213.6308	181.467	17.72433
59	21059	21072	161	-33.605	429	24155	230	24401	230	564.8967	489.06	15.50663
59	21059	21072	161	-33.605	659	24837	115	24819	115	213.6061	181.467	17.71071
335	24017	24035	161	76.00645	429	24155	230	24401	230	564.8628	489.06	15.49969
335	24017	24035	161	76.00645	659	24837	115	24819	115	212.938	181.467	17.34256
3295	21004	21003	161	-82.988	429	24155	230	24401	230	564.9025	489.06	15.50781
3295	21004	21003	161	-82.988	659	24837	115	24819	115	213.0644	181.467	17.41218
3299	21008	21006	161	-21.3448	429	24155	230	24401	230	564.8971	489.06	15.50671
3299	21008	21006	161	-21.3448	659	24837	115	24819	115	213.4572	181.467	17.62863

3308	21026	21025	230	-127.879	429	24155	230	24401	230	565.0381	489.06	15.53554
3308	21026	21025	230	-127.879	659	24837	115	24819	115	210.7758	181.467	16.15102
3309	21026	21027	92	118.5366	429	24155	230	24401	230	564.9685	489.06	15.5213
3309	21026	21027	92	118.5366	659	24837	115	24819	115	213.9571	181.467	17.90415
3324	21048	21047	161	-37.3644	429	24155	230	24401	230	564.904	489.06	15.50811
3324	21048	21047	161	-37.3644	659	24837	115	24819	115	213.7527	181.467	17.7915
3333	21059	21061	92	36.28542	429	24155	230	24401	230	564.9037	489.06	15.50806
3333	21059	21061	92	36.28542	659	24837	115	24819	115	213.7133	181.467	17.76976
3333	21059	21061	92	36.28542	3309	21026	161	21027	92	144.0317	123.75	16.38921
3639	25401	24035	161	-72.8363	429	24155	230	24401	230	564.8642	489.06	15.49997
3639	25401	24035	161	-72.8363	659	24837	115	24819	115	212.9687	181.467	17.35947

Table A.5 Line Overload Results for 138 kV lines

Line Out					Line Monitored							
line no	from Bus	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	percent overload
84	22048	22052	138	-40.3665	429	24155	230	24401	230	564.891	489.06	15.50546
84	22048	22052	138	-40.3665	659	24837	115	24819	115	213.6707	181.467	17.74633
85	22048	22436	138	58.24067	429	24155	230	24401	230	564.8854	489.06	15.50432
85	22048	22436	138	58.24067	659	24837	115	24819	115	213.6637	181.467	17.74246
86	22052	22648	138	87.22781	429	24155	230	24401	230	564.9319	489.06	15.51382
86	22052	22648	138	87.22781	659	24837	115	24819	115	213.6976	181.467	17.76113
104	22100	22108	138	-107.13	429	24155	230	24401	230	564.8579	489.06	15.49869
104	22100	22108	138	-107.13	659	24837	115	24819	115	213.6515	181.467	17.73573
106	22100	22760	138	63.60196	429	24155	230	24401	230	564.9029	489.06	15.5079
106	22100	22760	138	63.60196	659	24837	115	24819	115	213.6784	181.467	17.75058
107	22112	22396	138	53.51807	429	24155	230	24401	230	564.8959	489.06	15.50646
107	22112	22396	138	53.51807	659	24837	115	24819	115	213.6781	181.467	17.75041
108	22112	22656	138	-100.691	429	24155	230	24401	230	564.8921	489.06	15.50569
108	22112	22656	138	-100.691	659	24837	115	24819	115	213.6818	181.467	17.7524
109	22112	22860	138	4.554631	429	24155	230	24401	230	564.8954	489.06	15.50636
109	22112	22860	138	4.554631	659	24837	115	24819	115	213.674	181.467	17.74812
110	22116	22734	138	128.1678	429	24155	230	24401	230	565.0091	489.06	15.52961
110	22116	22734	138	128.1678	659	24837	115	24819	115	213.7884	181.467	17.81117
111	22120	22116	138	-6.93174	429	24155	230	24401	230	564.8949	489.06	15.50625
111	22120	22116	138	-6.93174	659	24837	115	24819	115	213.674	181.467	17.74815
112	22124	22436	138	-48.2229	429	24155	230	24401	230	564.8861	489.06	15.50445
112	22124	22436	138	-48.2229	659	24837	115	24819	115	213.6554	181.467	17.73787
127	22192	22300	138	20.43276	429	24155	230	24401	230	564.888	489.06	15.50484
127	22192	22300	138	20.43276	659	24837	115	24819	115	213.667	181.467	17.74428
128	22192	22648	138	-20.4328	429	24155	230	24401	230	564.888	489.06	15.50484

128	22192	22648	138	-20.4328	659	24837	115	24819	115	213.667	181.467	17.74428
139	22228	22052	138	127.9078	429	24155	230	24401	230	564.8984	489.06	15.50698
139	22228	22052	138	127.9078	659	24837	115	24819	115	213.6749	181.467	17.74862
140	22228	22108	138	159.2354	429	24155	230	24401	230	564.8389	489.06	15.4948
140	22228	22108	138	159.2354	659	24837	115	24819	115	213.6442	181.467	17.73168
140	22228	22108	138	159.2354	289	22760	138	22436	138	-131.48	110.979	18.4731
141	22228	22580	138	134.7896	429	24155	230	24401	230	564.9545	489.06	15.51844
141	22228	22580	138	134.7896	659	24837	115	24819	115	213.711	181.467	17.76854
162	22300	22500	138	-25.5898	429	24155	230	24401	230	564.9047	489.06	15.50825
162	22300	22500	138	-25.5898	659	24837	115	24819	115	213.6832	181.467	17.75322
190	22412	22734	138	-68.1209	429	24155	230	24401	230	564.9561	489.06	15.51876
190	22412	22734	138	-68.1209	659	24837	115	24819	115	213.7323	181.467	17.78023
191	22412	22772	138	-113.988	429	24155	230	24401	230	564.9747	489.06	15.52258
191	22412	22772	138	-113.988	659	24837	115	24819	115	213.736	181.467	17.78232
196	22424	22772	138	-89.1588	429	24155	230	24401	230	564.8855	489.06	15.50434
196	22424	22772	138	-89.1588	659	24837	115	24819	115	213.671	181.467	17.74648
197	22428	22772	138	-156.585	3394	22768	69	22772	138	-153.193	138.6	10.52902
197	22428	22772	138	-156.585	429	24155	230	24401	230	564.8719	489.06	15.50155
197	22428	22772	138	-156.585	659	24837	115	24819	115	213.6678	181.467	17.74471
198	22432	22860	138	29.4821	429	24155	230	24401	230	564.8955	489.06	15.50637
198	22432	22860	138	29.4821	659	24837	115	24819	115	213.6741	181.467	17.74818
221	22500	22120	138	27.60103	429	24155	230	24401	230	564.8976	489.06	15.5068
221	22500	22120	138	27.60103	659	24837	115	24819	115	213.6742	181.467	17.74824
222	22500	22865	138	-66.8868	429	24155	230	24401	230	564.8884	489.06	15.50493
222	22500	22865	138	-66.8868	659	24837	115	24819	115	213.6619	181.467	17.74148
235	22580	22648	138	81.32947	429	24155	230	24401	230	564.9317	489.06	15.51379
235	22580	22648	138	81.32947	659	24837	115	24819	115	213.6938	181.467	17.75902
269	22672	22460	138	-175.644	429	24155	230	24401	230	564.9721	489.06	15.52204
269	22672	22460	138	-175.644	659	24837	115	24819	115	213.8445	181.467	17.84211
285	22720	22396	138	45.00282	429	24155	230	24401	230	564.8942	489.06	15.50612

285	22720	22396	138	45.00282	659	24837	115	24819	115	213.6767	181.467	17.74964
289	22760	22436	138	-9.79396	429	24155	230	24401	230	564.8942	489.06	15.50612
289	22760	22436	138	-9.79396	659	24837	115	24819	115	213.6736	181.467	17.7479
304	22831	22116	138	135.9268	429	24155	230	24401	230	564.9763	489.06	15.52291
304	22831	22116	138	135.9268	659	24837	115	24819	115	213.7705	181.467	17.80133
305	22831	22124	138	15.83059	429	24155	230	24401	230	564.8983	489.06	15.50696
305	22831	22124	138	15.83059	659	24837	115	24819	115	213.681	181.467	17.752
308	22840	22432	138	87.1934	429	24155	230	24401	230	564.8916	489.06	15.50559
308	22840	22432	138	87.1934	659	24837	115	24819	115	213.6817	181.467	17.75236
309	22840	22656	138	140.5798	429	24155	230	24401	230	564.8894	489.06	15.50513
309	22840	22656	138	140.5798	659	24837	115	24819	115	213.6886	181.467	17.75617
310	22840	22720	138	77.72987	429	24155	230	24401	230	564.8929	489.06	15.50584
310	22840	22720	138	77.72987	659	24837	115	24819	115	213.6823	181.467	17.75273
311	22840	22860	138	76.61192	429	24155	230	24401	230	564.8929	489.06	15.50585
311	22840	22860	138	76.61192	659	24837	115	24819	115	213.6791	181.467	17.75096
313	22852	22772	138	52.97746	429	24155	230	24401	230	564.9259	489.06	15.51259
313	22852	22772	138	52.97746	659	24837	115	24819	115	213.7071	181.467	17.76638
316	22865	22772	138	-87.1053	429	24155	230	24401	230	564.8863	489.06	15.50451
316	22865	22772	138	-87.1053	659	24837	115	24819	115	213.6596	181.467	17.74021
721	26014	26076	138	65.67351	429	24155	230	24401	230	564.9089	489.06	15.50912
721	26014	26076	138	65.67351	659	24837	115	24819	115	213.7031	181.467	17.76418
722	26015	26076	138	65.67351	429	24155	230	24401	230	564.9089	489.06	15.50912
722	26015	26076	138	65.67351	659	24837	115	24819	115	213.7031	181.467	17.76418
744	26069	26014	138	102.3115	429	24155	230	24401	230	564.9167	489.06	15.51071
744	26069	26014	138	102.3115	659	24837	115	24819	115	213.6893	181.467	17.75654
745	26069	26015	138	102.3115	429	24155	230	24401	230	564.9167	489.06	15.51071
745	26069	26015	138	102.3115	659	24837	115	24819	115	213.6893	181.467	17.75654
746	26069	26073	138	118.8058	429	24155	230	24401	230	564.9359	489.06	15.51464
746	26069	26073	138	118.8058	659	24837	115	24819	115	213.6828	181.467	17.75299
749	26073	26091	138	132.5838	429	24155	230	24401	230	565.1779	489.06	15.56413

749	26073	26091	138	132.5838	659	24837	115	24819	115	213.7067	181.467	17.76617
750	26073	26095	138	-13.0113	429	24155	230	24401	230	564.8962	489.06	15.50652
750	26073	26095	138	-13.0113	659	24837	115	24819	115	213.6739	181.467	17.74805
751	26073	26096	138	-13.0113	429	24155	230	24401	230	564.8962	489.06	15.50652
751	26073	26096	138	-13.0113	659	24837	115	24819	115	213.6739	181.467	17.74805
752	26075	26019	138	-149.458	429	24155	230	24401	230	564.6112	489.06	15.44824
752	26075	26019	138	-149.458	659	24837	115	24819	115	213.6409	181.467	17.72991
753	26075	26073	138	-11.6927	429	24155	230	24401	230	564.9202	489.06	15.51142
753	26075	26073	138	-11.6927	659	24837	115	24819	115	213.6768	181.467	17.74968
754	26076	26083	138	-75.5349	429	24155	230	24401	230	564.928	489.06	15.51303
754	26076	26083	138	-75.5349	659	24837	115	24819	115	213.697	181.467	17.76081
755	26076	26084	138	-75.5349	429	24155	230	24401	230	564.928	489.06	15.51303
755	26076	26084	138	-75.5349	659	24837	115	24819	115	213.697	181.467	17.76081
756	26076	26088	138	-180.552	429	24155	230	24401	230	564.9281	489.06	15.51305
756	26076	26088	138	-180.552	659	24837	115	24819	115	213.6238	181.467	17.72049
757	26076	26089	138	78.86767	429	24155	230	24401	230	564.8988	489.06	15.50705
757	26076	26089	138	78.86767	659	24837	115	24819	115	213.7023	181.467	17.76374
763	26083	26085	138	-75.5977	429	24155	230	24401	230	564.9281	489.06	15.51304
763	26083	26085	138	-75.5977	659	24837	115	24819	115	213.697	181.467	17.76082
764	26084	26085	138	-75.5977	429	24155	230	24401	230	564.9281	489.06	15.51304
764	26084	26085	138	-75.5977	659	24837	115	24819	115	213.697	181.467	17.76082
765	26085	26077	138	-102.981	429	24155	230	24401	230	564.9145	489.06	15.51026
765	26085	26077	138	-102.981	659	24837	115	24819	115	213.6814	181.467	17.75221
768	26088	26092	138	-150.311	429	24155	230	24401	230	564.9622	489.06	15.52002
768	26088	26092	138	-150.311	659	24837	115	24819	115	213.654	181.467	17.73712
769	26089	26065	138	-112.441	429	24155	230	24401	230	564.9387	489.06	15.51522
769	26089	26065	138	-112.441	659	24837	115	24819	115	213.6364	181.467	17.72741
771	26095	26014	138	-36.3235	429	24155	230	24401	230	564.9002	489.06	15.50734
771	26095	26014	138	-36.3235	659	24837	115	24819	115	213.6737	181.467	17.74796
772	26095	26016	138	23.308	429	24155	230	24401	230	564.8959	489.06	15.50647

772	26095	26016	138	23.308	659	24837	115	24819	115	213.674	181.467	17.74813
773	26096	26015	138	-36.3235	429	24155	230	24401	230	564.9002	489.06	15.50734
773	26096	26015	138	-36.3235	659	24837	115	24819	115	213.6737	181.467	17.74796
774	26096	26016	138	23.308	429	24155	230	24401	230	564.8959	489.06	15.50647
774	26096	26016	138	23.308	659	24837	115	24819	115	213.674	181.467	17.74813
3370	22412	22408	69	93.02271	429	24155	230	24401	230	564.9085	489.06	15.50904
3370	22412	22408	69	93.02271	659	24837	115	24819	115	213.6906	181.467	17.75729
3371	22420	22424	138	-88.9036	429	24155	230	24401	230	564.8856	489.06	15.50435
3371	22420	22424	138	-88.9036	659	24837	115	24819	115	213.671	181.467	17.74649
3372	22428	22420	69	156.5856	3394	22768	69	22772	138	-153.193	138.6	10.52907
3372	22428	22420	69	156.5856	429	24155	230	24401	230	564.8719	489.06	15.50155
3372	22428	22420	69	156.5856	659	24837	115	24819	115	213.6678	181.467	17.74471
3375	22464	22460	138	176.5132	429	24155	230	24401	230	564.9725	489.06	15.52212
3375	22464	22460	138	176.5132	659	24837	115	24819	115	213.8454	181.467	17.84257
3381	22500	22496	69	338.1749	429	24155	230	24401	230	564.9131	489.06	15.50998
3381	22500	22496	69	338.1749	302	22828	69	22216	69	78.14103	67.518	15.73363
3381	22500	22496	69	338.1749	659	24837	115	24819	115	213.7385	181.467	17.78367
3381	22500	22496	69	338.1749	3382	22504	230	22496	69	264.9917	221.76	19.4948
3383	22504	22500	138	324.8171	429	24155	230	24401	230	565.0525	489.06	15.53847
3383	22504	22500	138	324.8171	659	24837	115	24819	115	213.8962	181.467	17.87055
3387	22644	22648	138	-160.634	429	24155	230	24401	230	565.0701	489.06	15.54209
3387	22644	22648	138	-160.634	659	24837	115	24819	115	213.8382	181.467	17.83862
3388	22648	22644	69	85.17173	429	24155	230	24401	230	564.9341	489.06	15.51428
3388	22648	22644	69	85.17173	659	24837	115	24819	115	213.7138	181.467	17.77004
3390	22652	22648	138	98.67902	429	24155	230	24401	230	564.9924	489.06	15.5262
3390	22652	22648	138	98.67902	659	24837	115	24819	115	213.7772	181.467	17.80502
3394	22768	22772	138	-97.0208	429	24155	230	24401	230	564.8853	489.06	15.50429
3394	22768	22772	138	-97.0208	659	24837	115	24819	115	213.6748	181.467	17.74857
3401	22832	22831	138	151.8332	429	24155	230	24401	230	564.9893	489.06	15.52556
3401	22832	22831	138	151.8332	659	24837	115	24819	115	213.8095	181.467	17.8228

3402	22834	22840	138	-1.20E-05	429	24155	230	24401	230	564.8954	489.06	15.50637
3402	22834	22840	138	-1.20E-05	659	24837	115	24819	115	213.674	181.467	17.7481
3403	22836	22840	138	-10.2319	429	24155	230	24401	230	564.9036	489.06	15.50803
3403	22836	22840	138	-10.2319	659	24837	115	24819	115	213.6787	181.467	17.7507
3680	26019	26110	13.8	-74.7629	429	24155	230	24401	230	564.7564	489.06	15.47793
3680	26019	26110	13.8	-74.7629	659	24837	115	24819	115	213.6578	181.467	17.7392
3681	26019	26111	13.8	-74.7629	429	24155	230	24401	230	564.7564	489.06	15.47793
3681	26019	26111	13.8	-74.7629	659	24837	115	24819	115	213.6578	181.467	17.7392
3693	26065	26112	18	-41.9969	429	24155	230	24401	230	564.8105	489.06	15.48901
3693	26065	26112	18	-41.9969	659	24837	115	24819	115	213.682	181.467	17.75251
3694	26066	26065	138	96.75076	429	24155	230	24401	230	564.9423	489.06	15.51594
3694	26066	26065	138	96.75076	659	24837	115	24819	115	213.6416	181.467	17.73029
3696	26070	26069	138	176.3993	429	24155	230	24401	230	564.9908	489.06	15.52586
3696	26070	26069	138	176.3993	659	24837	115	24819	115	213.8413	181.467	17.84031
3697	26071	26069	138	176.3993	429	24155	230	24401	230	564.9908	489.06	15.52586
3697	26071	26069	138	176.3993	659	24837	115	24819	115	213.8413	181.467	17.84031
3698	26072	26069	138	-28.9932	429	24155	230	24401	230	564.8874	489.06	15.50472
3698	26072	26069	138	-28.9932	659	24837	115	24819	115	213.6889	181.467	17.75636
3699	26078	26077	138	103.2464	429	24155	230	24401	230	564.9145	489.06	15.51027
3699	26078	26077	138	103.2464	659	24837	115	24819	115	213.6814	181.467	17.75222
3702	26082	26085	138	210.3845	429	24155	230	24401	230	564.9469	489.06	15.51688
3702	26082	26085	138	210.3845	659	24837	115	24819	115	213.6936	181.467	17.75891
3703	26087	26088	138	395.7715	429	24155	230	24401	230	565.0495	489.06	15.53787
3703	26087	26088	138	395.7715	659	24837	115	24819	115	213.6621	181.467	17.74155
3703	26087	26088	138	395.7715	3705	26093	230	26092	138	367.4691	287.1	27.9934
3703	26087	26088	138	395.7715	768	26088	138	26092	138	-366.57	284.13	29.01495
3704	26091	26023	13.8	-59.673	429	24155	230	24401	230	564.7763	489.06	15.48201
3704	26091	26023	13.8	-59.673	659	24837	115	24819	115	213.6601	181.467	17.74048

3705	26093	26092	138	151.2098	429	24155	230	24401	230	564.9626	489.06	15.5201
3705	26093	26092	138	151.2098	659	24837	115	24819	115	213.6539	181.467	17.73706
3707	26103	26102	138	261.2681	429	24155	230	24401	230	565.5706	489.06	15.64441
3707	26103	26102	138	261.2681	659	24837	115	24819	115	213.7006	181.467	17.7628
3715	26182	26085	138	202.1496	429	24155	230	24401	230	564.9438	489.06	15.51626
3715	26182	26085	138	202.1496	659	24837	115	24819	115	213.6924	181.467	17.75827
4468	22433	22432	138	49.1	429	24155	230	24401	230	564.7701	489.06	15.48075
4468	22433	22432	138	49.1	659	24837	115	24819	115	213.5883	181.467	17.70089

Table A.6 Line Overload Results for 115 kV lines

Line Out					Line Monitored							
line no	from Bus	To Bus	KV rate	Pre-Con flow	line no	from Bus	KV rate	To Bus	KV rate	Post-con Flow	Rating	percent overload
2	35120	38432	115	-7.6557	659	24837	115	24819	115	213.6744	181.467	17.74835
2	35120	38432	115	-7.6557	429	24155	230	24401	230	564.8969	489.06	15.50667
3	38426	38422	115	32.87974	659	24837	115	24819	115	213.6743	181.467	17.7483
3	38426	38422	115	32.87974	429	24155	230	24401	230	564.8967	489.06	15.50662
4	38422	38421	115	-23.3577	659	24837	115	24819	115	213.6741	181.467	17.7482
4	38422	38421	115	-23.3577	429	24155	230	24401	230	564.8961	489.06	15.5065
5	38426	38421	115	36.19849	659	24837	115	24819	115	213.6744	181.467	17.74834
5	38426	38421	115	36.19849	429	24155	230	24401	230	564.897	489.06	15.50668
6	38410	38434	115	52.05773	659	24837	115	24819	115	213.6765	181.467	17.74949
6	38410	38434	115	52.05773	429	24155	230	24401	230	564.9042	489.06	15.50817
431	24160	25423	115	22.54657	659	24837	115	24819	115	213.6674	181.467	17.7445
431	24160	25423	115	22.54657	429	24155	230	24401	230	564.8825	489.06	15.50373
547	24602	24606	115	70.42065	553	24602	115	24621	115	115.0081	81.873	40.47129
547	24602	24606	115	70.42065	659	24837	115	24819	115	213.6849	181.467	17.75415
547	24602	24606	115	70.42065	429	24155	230	24401	230	564.906	489.06	15.50852
548	24602	24608	115	203.3969	567	24619	115	24603	115	238.653	119.295	100.0528
548	24602	24608	115	203.3969	551	24602	115	24619	115	136.1092	81.873	66.24428
548	24602	24608	115	203.3969	565	24618	115	24603	115	-175.773	119.295	47.34351
548	24602	24608	115	203.3969	553	24602	115	24621	115	119.3619	81.873	45.78909
548	24602	24608	115	203.3969	552	24602	115	24620	115	113.7956	81.873	38.99038
548	24602	24608	115	203.3969	570	24620	115	24605	115	154.8112	119.295	29.77175
548	24602	24608	115	203.3969	659	24837	115	24819	115	213.7347	181.467	17.78156
548	24602	24608	115	203.3969	429	24155	230	24401	230	564.9584	489.06	15.51923
549	24602	24614	115	-131.606	659	24837	115	24819	115	213.694	181.467	17.75914

549	24602	24614	115	-131.606	429	24155	230	24401	230	564.9372	489.06	15.51491
550	24602	24615	115	32.46804	659	24837	115	24819	115	213.704	181.467	17.76463
550	24602	24615	115	32.46804	429	24155	230	24401	230	564.9095	489.06	15.50925
551	24602	24619	115	59.64396	659	24837	115	24819	115	213.6787	181.467	17.7507
551	24602	24619	115	59.64396	429	24155	230	24401	230	564.9003	489.06	15.50736
551	24602	24619	115	59.64396	553	24602	115	24621	115	91.36162	81.873	11.58944
552	24602	24620	115	61.73237	553	24602	115	24621	115	104.6461	81.873	27.81521
552	24602	24620	115	61.73237	659	24837	115	24819	115	213.6778	181.467	17.75025
552	24602	24620	115	61.73237	429	24155	230	24401	230	564.8993	489.06	15.50715
553	24602	24621	115	75.4868	659	24837	115	24819	115	213.6792	181.467	17.75101
553	24602	24621	115	75.4868	429	24155	230	24401	230	564.9007	489.06	15.50744
553	24602	24621	115	75.4868	552	24602	115	24620	115	94.014	81.873	14.82906
554	24602	24702	115	-157.031	659	24837	115	24819	115	213.7092	181.467	17.76752
554	24602	24702	115	-157.031	559	24614	115	24702	115	-252.915	214.929	17.67365
554	24602	24702	115	-157.031	429	24155	230	24401	230	564.9589	489.06	15.51935
556	24608	24618	115	55.47579	659	24837	115	24819	115	213.6778	181.467	17.75025
556	24608	24618	115	55.47579	429	24155	230	24401	230	564.8996	489.06	15.50721
557	24609	24608	115	-10.0008	659	24837	115	24819	115	213.6824	181.467	17.75273
557	24609	24608	115	-10.0008	429	24155	230	24401	230	564.899	489.06	15.50709
558	24614	24607	115	30.09778	659	24837	115	24819	115	213.7021	181.467	17.76364
558	24614	24607	115	30.09778	429	24155	230	24401	230	564.9095	489.06	15.50925
559	24614	24702	115	-162.678	659	24837	115	24819	115	213.7132	181.467	17.76976
559	24614	24702	115	-162.678	554	24602	115	24702	115	-250.054	214.929	16.3424
559	24614	24702	115	-162.678	429	24155	230	24401	230	564.964	489.06	15.52039
560	24615	24612	115	15.0072	659	24837	115	24819	115	213.6873	181.467	17.75544
560	24615	24612	115	15.0072	429	24155	230	24401	230	564.9015	489.06	15.50761
561	24615	24616	115	17.16583	659	24837	115	24819	115	213.6893	181.467	17.75654
561	24615	24616	115	17.16583	429	24155	230	24401	230	564.9025	489.06	15.5078
562	24616	24610	115	17.03629	659	24837	115	24819	115	213.6891	181.467	17.75648
562	24616	24610	115	17.03629	429	24155	230	24401	230	564.9024	489.06	15.50779

563	24617	24611	115	3.000921	659	24837	115	24819	115	213.6764	181.467	17.74944
563	24617	24611	115	3.000921	429	24155	230	24401	230	564.8964	489.06	15.50657
565	24618	24603	115	15.9324	659	24837	115	24819	115	213.6747	181.467	17.74852
565	24618	24603	115	15.9324	429	24155	230	24401	230	564.8959	489.06	15.50646
567	24619	24603	115	52.7999	659	24837	115	24819	115	213.6777	181.467	17.75019
567	24619	24603	115	52.7999	429	24155	230	24401	230	564.9	489.06	15.50729
568	24619	24605	115	5.475011	659	24837	115	24819	115	213.674	181.467	17.74814
568	24619	24605	115	5.475011	429	24155	230	24401	230	564.8955	489.06	15.50638
569	24620	24604	115	12.96005	659	24837	115	24819	115	213.6742	181.467	17.74821
569	24620	24604	115	12.96005	429	24155	230	24401	230	564.8956	489.06	15.5064
570	24620	24605	115	47.65461	659	24837	115	24819	115	213.6765	181.467	17.7495
570	24620	24605	115	47.65461	429	24155	230	24401	230	564.8982	489.06	15.50693
571	24621	24604	115	25.86939	659	24837	115	24819	115	213.6746	181.467	17.74846
571	24621	24604	115	25.86939	429	24155	230	24401	230	564.8961	489.06	15.5065
572	24621	24606	115	48.4726	659	24837	115	24819	115	213.6789	181.467	17.75082
572	24621	24606	115	48.4726	429	24155	230	24401	230	564.9007	489.06	15.50744
573	24622	24613	115	-30.9999	659	24837	115	24819	115	213.7009	181.467	17.76297
573	24622	24613	115	-30.9999	429	24155	230	24401	230	564.9064	489.06	15.50861
574	24623	24613	115	-23.622	659	24837	115	24819	115	213.694	181.467	17.75916
574	24623	24613	115	-23.622	429	24155	230	24401	230	564.9034	489.06	15.508
578	24702	24716	115	-33.5345	659	24837	115	24819	115	213.6713	181.467	17.74665
578	24702	24716	115	-33.5345	429	24155	230	24401	230	564.8943	489.06	15.50614
580	24702	24759	115	-18.5571	659	24837	115	24819	115	213.6717	181.467	17.74688
580	24702	24759	115	-18.5571	429	24155	230	24401	230	564.8939	489.06	15.50606
581	24702	24767	115	10.02564	659	24837	115	24819	115	213.6841	181.467	17.75371
581	24702	24767	115	10.02564	429	24155	230	24401	230	564.9019	489.06	15.50769
584	24716	24765	115	42.40453	659	24837	115	24819	115	213.679	181.467	17.7509
584	24716	24765	115	42.40453	429	24155	230	24401	230	564.9028	489.06	15.50787
585	24716	24771	115	-3.06364	659	24837	115	24819	115	213.6709	181.467	17.74643
585	24716	24771	115	-3.06364	429	24155	230	24401	230	564.8935	489.06	15.50597

586	24716	24773	115	24.14819	659	24837	115	24819	115	213.6981	181.467	17.7614
586	24716	24773	115	24.14819	429	24155	230	24401	230	564.9112	489.06	15.5096
587	24716	24774	115	27.43389	659	24837	115	24819	115	213.6431	181.467	17.73109
587	24716	24774	115	27.43389	429	24155	230	24401	230	564.8647	489.06	15.50007
590	24723	24728	115	48.5537	659	24837	115	24819	115	213.7011	181.467	17.76305
590	24723	24728	115	48.5537	429	24155	230	24401	230	564.7897	489.06	15.48474
591	24723	24731	115	9.780098	659	24837	115	24819	115	213.6651	181.467	17.74321
591	24723	24731	115	9.780098	429	24155	230	24401	230	564.9057	489.06	15.50847
592	24724	24723	115	48.9809	659	24837	115	24819	115	213.6573	181.467	17.73894
592	24724	24723	115	48.9809	429	24155	230	24401	230	564.835	489.06	15.494
593	24725	24723	115	-1.39223	659	24837	115	24819	115	213.674	181.467	17.74814
593	24725	24723	115	-1.39223	429	24155	230	24401	230	564.8957	489.06	15.50642
594	24725	24775	115	-25.4442	659	24837	115	24819	115	213.6663	181.467	17.74386
594	24725	24775	115	-25.4442	429	24155	230	24401	230	564.8675	489.06	15.50066
595	24727	24702	115	25.58728	659	24837	115	24819	115	213.6459	181.467	17.73266
595	24727	24702	115	25.58728	429	24155	230	24401	230	564.8774	489.06	15.50268
597	24731	24702	115	75.34272	659	24837	115	24819	115	213.6357	181.467	17.72705
597	24731	24702	115	75.34272	429	24155	230	24401	230	564.8893	489.06	15.50511
598	24731	24762	115	-60.6167	599	24731	115	24763	115	-111.153	81.873	35.76271
598	24731	24762	115	-60.6167	659	24837	115	24819	115	213.6672	181.467	17.74437
598	24731	24762	115	-60.6167	429	24155	230	24401	230	564.8892	489.06	15.50509
599	24731	24763	115	-57.5184	659	24837	115	24819	115	213.6678	181.467	17.74472
599	24731	24763	115	-57.5184	429	24155	230	24401	230	564.8898	489.06	15.50521
601	24739	24762	115	53.49955	659	24837	115	24819	115	213.674	181.467	17.7481
601	24739	24762	115	53.49955	429	24155	230	24401	230	564.8954	489.06	15.50637
602	24739	24763	115	51.50048	659	24837	115	24819	115	213.6739	181.467	17.7481
602	24739	24763	115	51.50048	429	24155	230	24401	230	564.8954	489.06	15.50637
605	24759	24765	115	-71.756	659	24837	115	24819	115	213.6825	181.467	17.75284
605	24759	24765	115	-71.756	429	24155	230	24401	230	564.9079	489.06	15.50891
607	24761	24702	115	59.87404	659	24837	115	24819	115	213.6507	181.467	17.7353

607	24761	24702	115	59.87404	429	24155	230	24401	230	564.8921	489.06	15.50569
608	24761	24731	115	-69.0963	659	24837	115	24819	115	213.6532	181.467	17.73668
608	24761	24731	115	-69.0963	429	24155	230	24401	230	564.8963	489.06	15.50654
609	24762	24749	115	-12.163	659	24837	115	24819	115	213.6738	181.467	17.748
609	24762	24749	115	-12.163	429	24155	230	24401	230	564.8953	489.06	15.50633
610	24763	24749	115	-10.8221	659	24837	115	24819	115	213.6738	181.467	17.74802
610	24763	24749	115	-10.8221	429	24155	230	24401	230	564.8953	489.06	15.50634
611	24764	24723	115	-1.87224	659	24837	115	24819	115	213.6741	181.467	17.74818
611	24764	24723	115	-1.87224	429	24155	230	24401	230	564.896	489.06	15.50648
612	24764	24725	115	0.702234	659	24837	115	24819	115	213.674	181.467	17.74812
612	24764	24725	115	0.702234	429	24155	230	24401	230	564.8956	489.06	15.5064
613	24766	24043	115	10.19589	659	24837	115	24819	115	213.6486	181.467	17.73412
613	24766	24043	115	10.19589	429	24155	230	24401	230	564.8749	489.06	15.50217
614	24766	24778	115	-10.1959	659	24837	115	24819	115	213.6486	181.467	17.73412
614	24766	24778	115	-10.1959	429	24155	230	24401	230	564.8749	489.06	15.50217
615	24768	24761	115	-9.22592	659	24837	115	24819	115	213.682	181.467	17.75253
615	24768	24761	115	-9.22592	429	24155	230	24401	230	564.9012	489.06	15.50756
616	24769	24727	115	-57.2231	659	24837	115	24819	115	213.7336	181.467	17.78096
616	24769	24727	115	-57.2231	429	24155	230	24401	230	564.9335	489.06	15.51415
617	24769	24770	115	21.07702	659	24837	115	24819	115	213.6929	181.467	17.75855
617	24769	24770	115	21.07702	429	24155	230	24401	230	564.9072	489.06	15.50876
618	24776	24775	115	11.05997	659	24837	115	24819	115	213.6706	181.467	17.74626
618	24776	24775	115	11.05997	429	24155	230	24401	230	564.8833	489.06	15.50389
619	24777	24774	115	-24.572	659	24837	115	24819	115	213.6354	181.467	17.72687
619	24777	24774	115	-24.572	429	24155	230	24401	230	564.8611	489.06	15.49935
620	24777	24778	115	23.60195	659	24837	115	24819	115	213.6262	181.467	17.72179
620	24777	24778	115	23.60195	429	24155	230	24401	230	564.8561	489.06	15.49832
629	24805	24645	115	30.27504	659	24837	115	24819	115	215.0905	181.467	18.52869
629	24805	24645	115	30.27504	429	24155	230	24401	230	564.896	489.06	15.50647
630	24805	24808	115	54.31572	659	24837	115	24819	115	220.6642	181.467	21.60016

630	24805	24808	115	54.31572	429	24155	230	24401	230	564.9406	489.06	15.51561
631	24805	24813	115	73.9111	659	24837	115	24819	115	217.7912	181.467	20.01698
631	24805	24813	115	73.9111	429	24155	230	24401	230	564.897	489.06	15.50668
632	24805	24817	115	126.925	659	24837	115	24819	115	230.2446	181.467	26.87958
632	24805	24817	115	126.925	635	24805	115	25625	115	225.8612	181.17	24.66813
632	24805	24817	115	126.925	689	25625	115	25642	115	225.5513	181.467	24.29327
632	24805	24817	115	126.925	649	24818	115	25642	115	-223.379	181.17	23.29782
632	24805	24817	115	126.925	429	24155	230	24401	230	564.9106	489.06	15.50947
633	24805	25622	115	33.83223	429	24155	230	24401	230	564.8966	489.06	15.5066
634	24805	25623	115	64.93758	659	24837	115	24819	115	222.6685	181.467	22.7047
634	24805	25623	115	64.93758	429	24155	230	24401	230	564.9484	489.06	15.5172
636	24805	25644	115	36.73478	659	24837	115	24819	115	218.7131	181.467	20.52499
636	24805	25644	115	36.73478	429	24155	230	24401	230	564.9251	489.06	15.51244
637	24807	24821	115	193.6202	659	24837	115	24819	115	223.8295	181.467	23.34444
637	24807	24821	115	193.6202	429	24155	230	24401	230	565.0115	489.06	15.53011
640	24810	25624	115	-62.185	659	24837	115	24819	115	222.2873	181.467	22.4946
640	24810	25624	115	-62.185	429	24155	230	24401	230	564.9462	489.06	15.51674
641	24814	25641	115	-64.2689	659	24837	115	24819	115	222.4901	181.467	22.60637
641	24814	25641	115	-64.2689	429	24155	230	24401	230	564.9474	489.06	15.51699
642	24815	24645	115	-120.033	659	24837	115	24819	115	219.29	181.467	20.84292
642	24815	24645	115	-120.033	429	24155	230	24401	230	564.8975	489.06	15.50678
643	24815	24813	115	-73.7427	659	24837	115	24819	115	217.7818	181.467	20.01182
643	24815	24813	115	-73.7427	429	24155	230	24401	230	564.897	489.06	15.50668
644	24815	24816	115	113.0449	659	24837	115	24819	115	265.4939	181.467	46.30423
644	24815	24816	115	113.0449	429	24155	230	24401	230	564.9099	489.06	15.50933
651	24819	24823	115	88.25073	429	24155	230	24401	230	564.8962	489.06	15.50651
651	24819	24823	115	88.25073	659	24837	115	24819	115	207.6319	181.467	14.41855
652	24821	24816	115	51.31291	659	24837	115	24819	115	235.6662	181.467	29.86727
652	24821	24816	115	51.31291	429	24155	230	24401	230	564.8986	489.06	15.50701
657	24829	25622	115	-33.63	429	24155	230	24401	230	564.8966	489.06	15.5066

659	24837	24819	115	213.674	644	24815	115	24816	115	216.7636	181.368	19.5159
659	24837	24819	115	213.674	659	24837	115	24819	115	213.674	181.467	17.7481
659	24837	24819	115	213.674	429	24155	230	24401	230	564.9538	489.06	15.51831
660	24837	24829	115	-33.5112	429	24155	230	24401	230	564.8966	489.06	15.5066
661	24850	25628	115	0.010549	659	24837	115	24819	115	213.674	181.467	17.7481
661	24850	25628	115	0.010549	429	24155	230	24401	230	564.8954	489.06	15.50637
664	24904	24903	115	113.0313	667	24910	115	24903	115	217.1935	181.467	19.68758
664	24904	24903	115	113.0313	659	24837	115	24819	115	213.674	181.467	17.7481
664	24904	24903	115	113.0313	429	24155	230	24401	230	564.8954	489.06	15.50637
665	24909	24904	115	36.30941	659	24837	115	24819	115	213.674	181.467	17.7481
665	24909	24904	115	36.30941	429	24155	230	24401	230	564.8954	489.06	15.50637
666	24909	24910	115	-36.3094	659	24837	115	24819	115	213.674	181.467	17.7481
666	24909	24910	115	-36.3094	429	24155	230	24401	230	564.8954	489.06	15.50637
667	24910	24903	115	104.1622	659	24837	115	24819	115	213.674	181.467	17.7481
667	24910	24903	115	104.1622	429	24155	230	24401	230	564.8954	489.06	15.50637
668	24910	24904	115	77.71515	659	24837	115	24819	115	213.674	181.467	17.7481
668	24910	24904	115	77.71515	429	24155	230	24401	230	564.8954	489.06	15.50637
669	24910	24912	115	-95.4321	659	24837	115	24819	115	213.674	181.467	17.7481
669	24910	24912	115	-95.4321	429	24155	230	24401	230	564.8954	489.06	15.50637
670	24910	24917	115	-122.835	669	24910	115	24912	115	-218.267	163.35	33.6195
670	24910	24917	115	-122.835	659	24837	115	24819	115	213.674	181.467	17.7481
670	24910	24917	115	-122.835	429	24155	230	24401	230	564.8954	489.06	15.50637
672	24912	24917	115	-30.177	659	24837	115	24819	115	213.674	181.467	17.7481
672	24912	24917	115	-30.177	429	24155	230	24401	230	564.8954	489.06	15.50637
685	25601	24916	115	53.9999	659	24837	115	24819	115	213.6739	181.467	17.74807
685	25601	24916	115	53.9999	429	24155	230	24401	230	564.8965	489.06	15.50657
686	25602	24917	115	154	659	24837	115	24819	115	213.674	181.467	17.7481
686	25602	24917	115	154	429	24155	230	24401	230	565.0541	489.06	15.5388
688	25623	25624	115	64.89478	659	24837	115	24819	115	222.6626	181.467	22.70144
688	25623	25624	115	64.89478	429	24155	230	24401	230	564.9484	489.06	15.5172

691	25628	25629	115	0.005697	659	24837	115	24819	115	213.674	181.467	17.7481
691	25628	25629	115	0.005697	429	24155	230	24401	230	564.8954	489.06	15.50637
693	25632	25623	115	0	659	24837	115	24819	115	213.674	181.467	17.7481
693	25632	25623	115	0	429	24155	230	24401	230	564.8954	489.06	15.50637
694	25633	25622	115	0	659	24837	115	24819	115	213.674	181.467	17.7481
694	25633	25622	115	0	429	24155	230	24401	230	564.8954	489.06	15.50637
696	25634	28020	115	0	659	24837	115	24819	115	213.674	181.467	17.7481
696	25634	28020	115	0	429	24155	230	24401	230	564.8954	489.06	15.50637
698	25637	25629	115	-0.00655	659	24837	115	24819	115	213.674	181.467	17.7481
698	25637	25629	115	-0.00655	429	24155	230	24401	230	564.8954	489.06	15.50637
699	25639	25664	115	0.001684	659	24837	115	24819	115	213.674	181.467	17.7481
699	25639	25664	115	0.001684	429	24155	230	24401	230	564.8954	489.06	15.50637
700	25639	28260	115	0	659	24837	115	24819	115	213.674	181.467	17.7481
700	25639	28260	115	0	429	24155	230	24401	230	564.8954	489.06	15.50637
701	25640	25664	115	29.99835	659	24837	115	24819	115	213.674	181.467	17.7481
701	25640	25664	115	29.99835	429	24155	230	24401	230	564.8954	489.06	15.50637
702	25641	25644	115	-36.5433	659	24837	115	24819	115	218.6868	181.467	20.51051
702	25641	25644	115	-36.5433	429	24155	230	24401	230	564.925	489.06	15.51241
706	25646	25644	115	-7.70E-05	659	24837	115	24819	115	213.6739	181.467	17.7481
706	25646	25644	115	-7.70E-05	429	24155	230	24401	230	564.8954	489.06	15.50637
731	26053	26057	115	-25.8633	659	24837	115	24819	115	213.6859	181.467	17.75467
731	26053	26057	115	-25.8633	429	24155	230	24401	230	564.8783	489.06	15.50287
732	26054	26059	115	-23.4985	659	24837	115	24819	115	213.6848	181.467	17.75405
732	26054	26059	115	-23.4985	429	24155	230	24401	230	564.8799	489.06	15.50319
733	26057	26059	115	13.74256	659	24837	115	24819	115	213.6741	181.467	17.74817
733	26057	26059	115	13.74256	429	24155	230	24401	230	564.8953	489.06	15.50634
810	28060	24832	115	0	659	24837	115	24819	115	213.674	181.467	17.7481
810	28060	24832	115	0	429	24155	230	24401	230	564.8954	489.06	15.50637

1104	31000	31015	115	8.294347	659	24837	115	24819	115	213.6735	181.467	17.74786
1104	31000	31015	115	8.294347	429	24155	230	24401	230	564.894	489.06	15.50607
1105	31000	31452	115	8.87254	659	24837	115	24819	115	213.6729	181.467	17.74751
1105	31000	31452	115	8.87254	429	24155	230	24401	230	564.8919	489.06	15.50565
1106	31010	31015	115	-1.06561	659	24837	115	24819	115	213.6738	181.467	17.748
1106	31010	31015	115	-1.06561	429	24155	230	24401	230	564.8948	489.06	15.50624
1107	31011	31010	115	-0.79243	659	24837	115	24819	115	213.6738	181.467	17.74802
1107	31011	31010	115	-0.79243	429	24155	230	24401	230	564.895	489.06	15.50628
1166	31200	31202	115	19.60613	659	24837	115	24819	115	213.6744	181.467	17.74834
1166	31200	31202	115	19.60613	429	24155	230	24401	230	564.8968	489.06	15.50665
1167	31200	31217	115	-30.819	659	24837	115	24819	115	213.674	181.467	17.74815
1167	31200	31217	115	-30.819	429	24155	230	24401	230	564.8958	489.06	15.50644
1168	31202	31204	115	8.465962	659	24837	115	24819	115	213.6741	181.467	17.74818
1168	31202	31204	115	8.465962	429	24155	230	24401	230	564.8959	489.06	15.50646
1169	31204	31206	115	-43.4666	659	24837	115	24819	115	213.6742	181.467	17.74824
1169	31204	31206	115	-43.4666	429	24155	230	24401	230	564.8963	489.06	15.50653
1170	31204	38020	115	37.98821	659	24837	115	24819	115	213.6748	181.467	17.74859
1170	31204	38020	115	37.98821	429	24155	230	24401	230	564.897	489.06	15.50669
1171	31206	31208	115	-61.2113	659	24837	115	24819	115	213.6746	181.467	17.74848
1171	31206	31208	115	-61.2113	429	24155	230	24401	230	564.8977	489.06	15.50682
1172	31208	31210	115	-76.2224	659	24837	115	24819	115	213.6753	181.467	17.74884
1172	31208	31210	115	-76.2224	429	24155	230	24401	230	564.8998	489.06	15.50726
1174	31210	31214	115	-58.8422	659	24837	115	24819	115	213.675	181.467	17.74867
1174	31210	31214	115	-58.8422	429	24155	230	24401	230	564.8988	489.06	15.50705
1175	31214	31220	115	18.79729	659	24837	115	24819	115	213.6736	181.467	17.74792
1175	31214	31220	115	18.79729	429	24155	230	24401	230	564.8944	489.06	15.50615
1176	31215	31200	115	32.17426	659	24837	115	24819	115	213.6759	181.467	17.74919
1176	31215	31200	115	32.17426	429	24155	230	24401	230	564.9019	489.06	15.50769
1177	31215	31216	115	10.79279	659	24837	115	24819	115	213.6743	181.467	17.74831
1177	31215	31216	115	10.79279	429	24155	230	24401	230	564.8963	489.06	15.50655

1178	31217	31223	115	-31.2691	659	24837	115	24819	115	213.674	181.467	17.74816
1178	31217	31223	115	-31.2691	429	24155	230	24401	230	564.8958	489.06	15.50644
1179	31218	32549	115	37.41684	659	24837	115	24819	115	213.675	181.467	17.74869
1179	31218	32549	115	37.41684	429	24155	230	24401	230	564.8977	489.06	15.50683
1180	31219	31218	115	59.53615	659	24837	115	24819	115	213.674	181.467	17.74812
1180	31219	31218	115	59.53615	429	24155	230	24401	230	564.8955	489.06	15.50639
1181	31220	31219	115	59.71495	659	24837	115	24819	115	213.674	181.467	17.74812
1181	31220	31219	115	59.71495	429	24155	230	24401	230	564.8955	489.06	15.50639
1183	31220	31228	115	5.774786	659	24837	115	24819	115	213.6736	181.467	17.7479
1183	31220	31228	115	5.774786	429	24155	230	24401	230	564.8943	489.06	15.50613
1184	31220	31263	115	44.99886	659	24837	115	24819	115	213.6744	181.467	17.74837
1184	31220	31263	115	44.99886	429	24155	230	24401	230	564.8971	489.06	15.5067
1185	31223	31222	115	-31.4624	659	24837	115	24819	115	213.674	181.467	17.74816
1185	31223	31222	115	-31.4624	429	24155	230	24401	230	564.8958	489.06	15.50644
1186	31224	31215	115	43.54885	659	24837	115	24819	115	213.6771	181.467	17.74981
1186	31224	31215	115	43.54885	429	24155	230	24401	230	564.9056	489.06	15.50844
1187	31224	31950	115	-42.6688	659	24837	115	24819	115	213.677	181.467	17.74978
1187	31224	31950	115	-42.6688	429	24155	230	24401	230	564.9054	489.06	15.5084
1188	31225	31262	115	44.66973	659	24837	115	24819	115	213.6744	181.467	17.74837
1188	31225	31262	115	44.66973	429	24155	230	24401	230	564.8971	489.06	15.5067
1189	31227	31226	115	17.51994	659	24837	115	24819	115	213.6746	181.467	17.74845
1189	31227	31226	115	17.51994	429	24155	230	24401	230	564.8969	489.06	15.50667
1190	31227	31261	115	-12.5611	659	24837	115	24819	115	213.6749	181.467	17.74863
1190	31227	31261	115	-12.5611	429	24155	230	24401	230	564.8986	489.06	15.50701
1191	31228	31227	115	4.966803	659	24837	115	24819	115	213.6736	181.467	17.74793
1191	31228	31227	115	4.966803	429	24155	230	24401	230	564.8944	489.06	15.50616
1192	31228	31230	115	0.800424	659	24837	115	24819	115	213.674	181.467	17.74811
1192	31228	31230	115	0.800424	429	24155	230	24401	230	564.8955	489.06	15.50638
1193	31229	31222	115	44.36729	659	24837	115	24819	115	213.6744	181.467	17.74837
1193	31229	31222	115	44.36729	429	24155	230	24401	230	564.897	489.06	15.50669

1195	31236	31238	115	65.64697	659	24837	115	24819	115	213.6745	181.467	17.74843
1195	31236	31238	115	65.64697	429	24155	230	24401	230	564.8974	489.06	15.50677
1196	31236	31239	115	71.64735	659	24837	115	24819	115	213.6747	181.467	17.74849
1196	31236	31239	115	71.64735	429	24155	230	24401	230	564.8978	489.06	15.50684
1197	31236	31249	115	10.58018	659	24837	115	24819	115	213.6744	181.467	17.74832
1197	31236	31249	115	10.58018	429	24155	230	24401	230	564.8967	489.06	15.50663
1198	31236	31251	115	22.20939	659	24837	115	24819	115	213.6743	181.467	17.74829
1198	31236	31251	115	22.20939	429	24155	230	24401	230	564.8966	489.06	15.50661
1199	31238	31240	115	44.61062	659	24837	115	24819	115	213.6742	181.467	17.74826
1199	31238	31240	115	44.61062	429	24155	230	24401	230	564.8964	489.06	15.50657
1200	31239	31240	115	31.33717	659	24837	115	24819	115	213.6741	181.467	17.74818
1200	31239	31240	115	31.33717	429	24155	230	24401	230	564.8959	489.06	15.50647
1201	31240	31242	115	-7.81698	659	24837	115	24819	115	213.6739	181.467	17.74809
1201	31240	31242	115	-7.81698	429	24155	230	24401	230	564.8954	489.06	15.50636
1202	31242	31244	115	6.715823	659	24837	115	24819	115	213.6741	181.467	17.74819
1202	31242	31244	115	6.715823	429	24155	230	24401	230	564.8957	489.06	15.50643
1203	31242	31246	115	-14.5357	659	24837	115	24819	115	213.6739	181.467	17.7481
1203	31242	31246	115	-14.5357	429	24155	230	24401	230	564.8954	489.06	15.50637
1204	31246	31248	115	-56.4523	659	24837	115	24819	115	213.6749	181.467	17.7486
1204	31246	31248	115	-56.4523	429	24155	230	24401	230	564.8984	489.06	15.50698
1205	31248	31254	115	-63.028	659	24837	115	24819	115	213.6751	181.467	17.74875
1205	31248	31254	115	-63.028	429	24155	230	24401	230	564.8993	489.06	15.50716
1206	31249	31218	115	-21.9317	659	24837	115	24819	115	213.6734	181.467	17.74781
1206	31249	31218	115	-21.9317	429	24155	230	24401	230	564.8937	489.06	15.50602
1207	31249	31250	115	32.50838	659	24837	115	24819	115	213.6749	181.467	17.7486
1207	31249	31250	115	32.50838	429	24155	230	24401	230	564.8973	489.06	15.50675
1208	31251	32551	115	22.17378	659	24837	115	24819	115	213.6743	181.467	17.74829
1208	31251	32551	115	22.17378	429	24155	230	24401	230	564.8966	489.06	15.50661
1209	31253	31974	115	25.67482	659	24837	115	24819	115	213.6769	181.467	17.74975
1209	31253	31974	115	25.67482	429	24155	230	24401	230	564.9045	489.06	15.50823

1210	31254	31255	115	-84.1232	659	24837	115	24819	115	213.6762	181.467	17.74933
1210	31254	31255	115	-84.1232	429	24155	230	24401	230	564.9028	489.06	15.50787
1211	31255	31258	115	90.75528	659	24837	115	24819	115	213.6779	181.467	17.75026
1211	31255	31258	115	90.75528	429	24155	230	24401	230	564.9083	489.06	15.509
1212	31258	32564	115	52.42292	659	24837	115	24819	115	213.6753	181.467	17.74884
1212	31258	32564	115	52.42292	429	24155	230	24401	230	564.8999	489.06	15.50727
1213	31261	31950	115	-12.5697	659	24837	115	24819	115	213.6749	181.467	17.74863
1213	31261	31950	115	-12.5697	429	24155	230	24401	230	564.8986	489.06	15.50701
1214	31262	31229	115	44.4817	659	24837	115	24819	115	213.6744	181.467	17.74837
1214	31262	31229	115	44.4817	429	24155	230	24401	230	564.897	489.06	15.5067
1215	31263	31225	115	44.74225	659	24837	115	24819	115	213.6744	181.467	17.74837
1215	31263	31225	115	44.74225	429	24155	230	24401	230	564.8971	489.06	15.5067
1216	31264	32553	115	-3.75641	659	24837	115	24819	115	213.6739	181.467	17.74806
1216	31264	32553	115	-3.75641	429	24155	230	24401	230	564.8953	489.06	15.50634
1218	31265	32562	115	22.09142	659	24837	115	24819	115	213.6743	181.467	17.74829
1218	31265	32562	115	22.09142	429	24155	230	24401	230	564.8966	489.06	15.50661
1286	31407	31220	115	70.83992	659	24837	115	24819	115	213.6741	181.467	17.74819
1286	31407	31220	115	70.83992	429	24155	230	24401	230	564.8951	489.06	15.5063
1287	31450	31011	115	-0.78365	659	24837	115	24819	115	213.6738	181.467	17.74803
1287	31450	31011	115	-0.78365	429	24155	230	24401	230	564.895	489.06	15.50628
1288	31450	31464	115	0.38166	659	24837	115	24819	115	213.6739	181.467	17.74806
1288	31450	31464	115	0.38166	429	24155	230	24401	230	564.8952	489.06	15.50632
1289	31452	31461	115	-8.55625	659	24837	115	24819	115	213.675	181.467	17.7487
1289	31452	31461	115	-8.55625	429	24155	230	24401	230	564.899	489.06	15.5071
1290	31454	31462	115	-12.7233	659	24837	115	24819	115	213.6772	181.467	17.74988
1290	31454	31462	115	-12.7233	429	24155	230	24401	230	564.9056	489.06	15.50844
1292	31459	31469	115	7.04115	659	24837	115	24819	115	213.6735	181.467	17.74787
1292	31459	31469	115	7.04115	429	24155	230	24401	230	564.894	489.06	15.50608
1293	31461	31464	115	-8.62417	659	24837	115	24819	115	213.675	181.467	17.7487
1293	31461	31464	115	-8.62417	429	24155	230	24401	230	564.899	489.06	15.50711

1294	31463	31462	115	-28.3896	659	24837	115	24819	115	213.6667	181.467	17.74413
1294	31463	31462	115	-28.3896	429	24155	230	24401	230	564.8728	489.06	15.50174
1295	31464	31463	115	-81.1338	659	24837	115	24819	115	213.6533	181.467	17.73673
1295	31464	31463	115	-81.1338	429	24155	230	24401	230	564.8306	489.06	15.49312
1296	31464	31466	115	15.9328	659	24837	115	24819	115	213.6753	181.467	17.74887
1296	31464	31466	115	15.9328	429	24155	230	24401	230	564.9001	489.06	15.50732
1297	31466	31467	115	21.51973	659	24837	115	24819	115	213.6793	181.467	17.75106
1297	31466	31467	115	21.51973	429	24155	230	24401	230	564.9123	489.06	15.50981
1298	31466	31469	115	-5.70787	659	24837	115	24819	115	213.6736	181.467	17.74789
1298	31466	31469	115	-5.70787	429	24155	230	24401	230	564.8942	489.06	15.50611
1299	31468	31459	115	21.25115	659	24837	115	24819	115	213.673	181.467	17.74758
1299	31468	31459	115	21.25115	429	24155	230	24401	230	564.8923	489.06	15.50572
1303	31475	31476	115	-1.00412	659	24837	115	24819	115	213.674	181.467	17.74811
1303	31475	31476	115	-1.00412	429	24155	230	24401	230	564.8955	489.06	15.50638
1304	31476	31482	115	92.9968	1303	31475	115	31476	115	-94.0009	59.4	58.25071
1304	31476	31482	115	92.9968	659	24837	115	24819	115	213.6719	181.467	17.74697
1304	31476	31482	115	92.9968	429	24155	230	24401	230	564.8917	489.06	15.50561
1305	31478	31494	115	37.301	659	24837	115	24819	115	213.6745	181.467	17.74842
1305	31478	31494	115	37.301	429	24155	230	24401	230	564.8974	489.06	15.50676
1306	31478	31504	115	-37.3009	659	24837	115	24819	115	213.6745	181.467	17.74842
1306	31478	31504	115	-37.3009	429	24155	230	24401	230	564.8974	489.06	15.50676
1307	31480	31518	115	-52.8611	659	24837	115	24819	115	213.6755	181.467	17.74896
1307	31480	31518	115	-52.8611	429	24155	230	24401	230	564.8988	489.06	15.50706
1308	31482	31506	115	86.78743	1311	31482	115	32280	115	85.96393	71.28	20.60035
1308	31482	31506	115	86.78743	1609	32280	115	32212	115	84.14269	71.28	18.0453
1308	31482	31506	115	86.78743	659	24837	115	24819	115	213.6749	181.467	17.74865
1308	31482	31506	115	86.78743	429	24155	230	24401	230	564.8987	489.06	15.50703
1308	31482	31506	115	86.78743	1565	32208	115	32214	115	98.33884	87.12	12.87746
1309	31482	31508	115	40.57175	659	24837	115	24819	115	213.6742	181.467	17.74826
1309	31482	31508	115	40.57175	429	24155	230	24401	230	564.8964	489.06	15.50656

1310	31482	31516	115	-36.2334	659	24837	115	24819	115	213.6744	181.467	17.74837
1310	31482	31516	115	-36.2334	429	24155	230	24401	230	564.8971	489.06	15.5067
1310	31482	31516	115	-36.2334	3834	31486	115	30255	230	95.24579	83.16	14.53318
1311	31482	32280	115	55.73782	659	24837	115	24819	115	213.6733	181.467	17.74777
1311	31482	32280	115	55.73782	429	24155	230	24401	230	564.8934	489.06	15.50595
1311	31482	32280	115	55.73782	1308	31482	115	31506	115	107.8036	96.03	12.26031
1312	31484	31508	115	-13.5765	659	24837	115	24819	115	213.6743	181.467	17.74827
1312	31484	31508	115	-13.5765	429	24155	230	24401	230	564.896	489.06	15.50649
1313	31486	31488	115	20.72012	659	24837	115	24819	115	213.6742	181.467	17.74826
1313	31486	31488	115	20.72012	429	24155	230	24401	230	564.8964	489.06	15.50656
1315	31488	31492	115	-16.7257	659	24837	115	24819	115	213.6722	181.467	17.74713
1315	31488	31492	115	-16.7257	429	24155	230	24401	230	564.8966	489.06	15.50661
1316	31488	31512	115	37.36971	659	24837	115	24819	115	213.6745	181.467	17.74838
1316	31488	31512	115	37.36971	3834	31486	115	30255	230	96.38213	83.16	15.89962
1316	31488	31512	115	37.36971	429	24155	230	24401	230	564.8971	489.06	15.50671
1317	31496	31498	115	2.486441	659	24837	115	24819	115	213.674	181.467	17.7481
1317	31496	31498	115	2.486441	429	24155	230	24401	230	564.8955	489.06	15.50637
1318	31496	31503	115	-34.2992	659	24837	115	24819	115	213.6741	181.467	17.7482
1318	31496	31503	115	-34.2992	429	24155	230	24401	230	564.8961	489.06	15.5065
1319	31497	31498	115	67.78329	659	24837	115	24819	115	213.6746	181.467	17.74848
1319	31497	31498	115	67.78329	429	24155	230	24401	230	564.8977	489.06	15.50683
1320	31497	31499	115	-4.10325	659	24837	115	24819	115	213.674	181.467	17.7481
1320	31497	31499	115	-4.10325	429	24155	230	24401	230	564.8955	489.06	15.50637
1321	31499	31500	115	-21.4249	659	24837	115	24819	115	213.674	181.467	17.74813
1321	31499	31500	115	-21.4249	429	24155	230	24401	230	564.8956	489.06	15.5064
1323	31500	31504	115	-62.3282	659	24837	115	24819	115	213.6747	181.467	17.7485
1323	31500	31504	115	-62.3282	429	24155	230	24401	230	564.8979	489.06	15.50687
1324	31500	31514	115	8.609471	659	24837	115	24819	115	213.674	181.467	17.74812
1324	31500	31514	115	8.609471	429	24155	230	24401	230	564.8955	489.06	15.50639
1325	31501	31502	115	28.12908	659	24837	115	24819	115	213.6746	181.467	17.74846

1325	31501	31502	115	28.12908	429	24155	230	24401	230	564.8966	489.06	15.5066
1326	31501	31504	115	-87.0072	659	24837	115	24819	115	213.6754	181.467	17.74888
1326	31501	31504	115	-87.0072	429	24155	230	24401	230	564.9001	489.06	15.50733
1327	31503	31500	115	-34.4742	659	24837	115	24819	115	213.6741	181.467	17.7482
1327	31503	31500	115	-34.4742	429	24155	230	24401	230	564.8961	489.06	15.5065
1328	31504	31497	115	64.63553	659	24837	115	24819	115	213.6748	181.467	17.74857
1328	31504	31497	115	64.63553	429	24155	230	24401	230	564.8983	489.06	15.50695
1329	31508	32286	115	26.52798	659	24837	115	24819	115	213.6739	181.467	17.74808
1329	31508	32286	115	26.52798	429	24155	230	24401	230	564.8953	489.06	15.50634
1330	31514	31494	115	-36.7547	659	24837	115	24819	115	213.6745	181.467	17.74842
1330	31514	31494	115	-36.7547	429	24155	230	24401	230	564.8973	489.06	15.50676
1331	31516	31512	115	-36.3305	659	24837	115	24819	115	213.6744	181.467	17.74837
1331	31516	31512	115	-36.3305	429	24155	230	24401	230	564.8971	489.06	15.5067
1331	31516	31512	115	-36.3305	3834	31486	115	30255	230	95.34292	83.16	14.64998
1332	31518	31482	115	-52.8736	659	24837	115	24819	115	213.6755	181.467	17.74896
1332	31518	31482	115	-52.8736	429	24155	230	24401	230	564.8988	489.06	15.50706
1452	31952	31253	115	25.68949	659	24837	115	24819	115	213.6769	181.467	17.74975
1452	31952	31253	115	25.68949	429	24155	230	24401	230	564.9045	489.06	15.50823
1453	31952	31998	115	-40.6968	659	24837	115	24819	115	213.6788	181.467	17.75079
1453	31952	31998	115	-40.6968	429	24155	230	24401	230	564.9103	489.06	15.5094
1455	31953	31954	115	6.730522	659	24837	115	24819	115	213.6747	181.467	17.74854
1455	31953	31954	115	6.730522	429	24155	230	24401	230	564.8979	489.06	15.50686
1456	31958	32012	115	-15.0802	659	24837	115	24819	115	213.6757	181.467	17.74907
1456	31958	32012	115	-15.0802	429	24155	230	24401	230	564.9008	489.06	15.50746
1457	31960	31966	115	-72.1309	659	24837	115	24819	115	213.6752	181.467	17.74881
1457	31960	31966	115	-72.1309	429	24155	230	24401	230	564.8997	489.06	15.50725
1458	31960	31970	115	72.03062	659	24837	115	24819	115	213.6752	181.467	17.7488
1458	31960	31970	115	72.03062	429	24155	230	24401	230	564.8997	489.06	15.50725
1459	31962	31970	115	-34.5948	659	24837	115	24819	115	213.6738	181.467	17.74804
1459	31962	31970	115	-34.5948	429	24155	230	24401	230	564.8951	489.06	15.5063

1460	31962	31992	115	58.105	659	24837	115	24819	115	213.6737	181.467	17.74799
1460	31962	31992	115	58.105	1469	31978	115	31984	115	-101.186	87.12	16.14553
1460	31962	31992	115	58.105	429	24155	230	24401	230	564.8948	489.06	15.50623
1461	31963	31965	115	-8.1366	659	24837	115	24819	115	213.6741	181.467	17.74821
1461	31963	31965	115	-8.1366	429	24155	230	24401	230	564.8958	489.06	15.50645
1462	31964	31968	115	81.42504	659	24837	115	24819	115	213.6756	181.467	17.74903
1462	31964	31968	115	81.42504	429	24155	230	24401	230	564.9011	489.06	15.50753
1463	31965	31966	115	72.77644	659	24837	115	24819	115	213.6752	181.467	17.74881
1463	31965	31966	115	72.77644	429	24155	230	24401	230	564.8998	489.06	15.50726
1465	31968	31970	115	71.2905	659	24837	115	24819	115	213.6752	181.467	17.74878
1465	31968	31970	115	71.2905	429	24155	230	24401	230	564.8996	489.06	15.50721
1466	31968	31973	115	10.06475	659	24837	115	24819	115	213.6742	181.467	17.74824
1466	31968	31973	115	10.06475	429	24155	230	24401	230	564.8959	489.06	15.50647
1467	31973	31972	115	10.04332	659	24837	115	24819	115	213.6742	181.467	17.74823
1467	31973	31972	115	10.04332	429	24155	230	24401	230	564.8959	489.06	15.50647
1468	31976	31980	115	-2.6201	659	24837	115	24819	115	213.674	181.467	17.74814
1468	31976	31980	115	-2.6201	429	24155	230	24401	230	564.8956	489.06	15.5064
1469	31978	31984	115	-85.7326	659	24837	115	24819	115	213.6778	181.467	17.75023
1469	31978	31984	115	-85.7326	429	24155	230	24401	230	564.9085	489.06	15.50904
1470	31978	31986	115	54.22746	659	24837	115	24819	115	213.6759	181.467	17.74917
1470	31978	31986	115	54.22746	429	24155	230	24401	230	564.902	489.06	15.50771
1471	31978	31988	115	31.50465	659	24837	115	24819	115	213.6749	181.467	17.74863
1471	31978	31988	115	31.50465	429	24155	230	24401	230	564.8976	489.06	15.5068
1472	31980	31986	115	-29.2139	659	24837	115	24819	115	213.6744	181.467	17.74836
1472	31980	31986	115	-29.2139	429	24155	230	24401	230	564.897	489.06	15.50668
1473	31980	32003	115	26.59331	659	24837	115	24819	115	213.6744	181.467	17.74833
1473	31980	32003	115	26.59331	429	24155	230	24401	230	564.8968	489.06	15.50664
1474	31984	31993	115	57.69715	659	24837	115	24819	115	213.6761	181.467	17.74927
1474	31984	31993	115	57.69715	429	24155	230	24401	230	564.9026	489.06	15.50784
1475	31984	31994	115	31.74439	659	24837	115	24819	115	213.6754	181.467	17.74891

1475	31984	31994	115	31.74439	429	24155	230	24401	230	564.8993	489.06	15.50715
1476	31990	31992	115	-57.4797	659	24837	115	24819	115	213.6737	181.467	17.74799
1476	31990	31992	115	-57.4797	1469	31978	115	31984	115	-101.025	87.12	15.96026
1476	31990	31992	115	-57.4797	429	24155	230	24401	230	564.8948	489.06	15.50623
1477	31991	31989	115	1.749329	659	24837	115	24819	115	213.674	181.467	17.74813
1477	31991	31989	115	1.749329	429	24155	230	24401	230	564.8955	489.06	15.50639
1478	31993	31991	115	1.750319	659	24837	115	24819	115	213.674	181.467	17.74813
1478	31993	31991	115	1.750319	429	24155	230	24401	230	564.8955	489.06	15.50639
1479	31993	32001	115	54.68454	659	24837	115	24819	115	213.6759	181.467	17.74919
1479	31993	32001	115	54.68454	429	24155	230	24401	230	564.9021	489.06	15.50774
1480	31996	31995	115	2.391841	659	24837	115	24819	115	213.6742	181.467	17.74825
1480	31996	31995	115	2.391841	429	24155	230	24401	230	564.8962	489.06	15.50653
1481	31996	32006	115	-35.928	659	24837	115	24819	115	213.6782	181.467	17.75046
1481	31996	32006	115	-35.928	429	24155	230	24401	230	564.9085	489.06	15.50903
1482	31996	32020	115	33.53797	659	24837	115	24819	115	213.6779	181.467	17.75029
1482	31996	32020	115	33.53797	429	24155	230	24401	230	564.9075	489.06	15.50884
1483	31998	31953	115	6.731021	659	24837	115	24819	115	213.6747	181.467	17.74854
1483	31998	31953	115	6.731021	429	24155	230	24401	230	564.8979	489.06	15.50686
1484	31998	31997	115	22.47654	659	24837	115	24819	115	213.6744	181.467	17.74838
1484	31998	31997	115	22.47654	429	24155	230	24401	230	564.8971	489.06	15.50671
1485	31998	32004	115	91.48524	659	24837	115	24819	115	213.6852	181.467	17.75427
1485	31998	32004	115	91.48524	429	24155	230	24401	230	564.9296	489.06	15.51336
1486	31998	32006	115	62.67434	659	24837	115	24819	115	213.6815	181.467	17.75228
1486	31998	32006	115	62.67434	429	24155	230	24401	230	564.9185	489.06	15.51109
1487	31998	32011	115	12.56932	659	24837	115	24819	115	213.6742	181.467	17.74824
1487	31998	32011	115	12.56932	429	24155	230	24401	230	564.8963	489.06	15.50654
1488	31999	31998	115	76.64023	659	24837	115	24819	115	213.6777	181.467	17.75018
1488	31999	31998	115	76.64023	429	24155	230	24401	230	564.9084	489.06	15.50902
1489	32000	32006	115	-26.149	659	24837	115	24819	115	213.677	181.467	17.74981
1489	32000	32006	115	-26.149	429	24155	230	24401	230	564.9048	489.06	15.50829

1490	32001	31990	115	54.40273	659	24837	115	24819	115	213.6759	181.467	17.74919
1490	32001	31990	115	54.40273	429	24155	230	24401	230	564.9021	489.06	15.50773
1491	32002	32004	115	-75.9411	659	24837	115	24819	115	213.6832	181.467	17.75318
1491	32002	32004	115	-75.9411	429	24155	230	24401	230	564.9235	489.06	15.51211
1492	32003	31990	115	-6.55385	659	24837	115	24819	115	213.6739	181.467	17.74808
1492	32003	31990	115	-6.55385	429	24155	230	24401	230	564.8954	489.06	15.50635
1493	32003	32103	115	33.09607	659	24837	115	24819	115	213.6747	181.467	17.74853
1493	32003	32103	115	33.09607	429	24155	230	24401	230	564.8969	489.06	15.50667
1494	32004	32012	115	15.201	659	24837	115	24819	115	213.6757	181.467	17.74908
1494	32004	32012	115	15.201	429	24155	230	24401	230	564.9008	489.06	15.50747
1495	32008	31997	115	-12.2166	659	24837	115	24819	115	213.6742	181.467	17.74821
1495	32008	31997	115	-12.2166	429	24155	230	24401	230	564.8961	489.06	15.50651
1497	32011	32008	115	61.01344	659	24837	115	24819	115	213.6751	181.467	17.74875
1497	32011	32008	115	61.01344	429	24155	230	24401	230	564.8994	489.06	15.50719
1498	32018	32229	115	62.89043	659	24837	115	24819	115	213.6755	181.467	17.74898
1498	32018	32229	115	62.89043	429	24155	230	24401	230	564.9007	489.06	15.50745
1499	32018	32231	115	36.00626	659	24837	115	24819	115	213.6746	181.467	17.74847
1499	32018	32231	115	36.00626	429	24155	230	24401	230	564.8977	489.06	15.50682
1500	32018	32263	115	116.6292	659	24837	115	24819	115	213.6761	181.467	17.74927
1500	32018	32263	115	116.6292	429	24155	230	24401	230	564.8987	489.06	15.50703
1501	32018	32268	115	78.37402	1697	32482	115	32255	115	-97.8136	77.22	26.66875
1501	32018	32268	115	78.37402	659	24837	115	24819	115	213.6769	181.467	17.74972
1501	32018	32268	115	78.37402	429	24155	230	24401	230	564.905	489.06	15.50833
1502	32018	32275	115	33.55682	659	24837	115	24819	115	213.6747	181.467	17.74851
1502	32018	32275	115	33.55682	429	24155	230	24401	230	564.8979	489.06	15.50686
1503	32020	32010	115	33.38766	659	24837	115	24819	115	213.6779	181.467	17.75028
1503	32020	32010	115	33.38766	429	24155	230	24401	230	564.9075	489.06	15.50883
1549	32102	32103	115	-33.0667	659	24837	115	24819	115	213.6747	181.467	17.74853
1549	32102	32103	115	-33.0667	429	24155	230	24401	230	564.8969	489.06	15.50667
1559	32200	31506	115	-82.9761	1311	31482	115	32280	115	84.63651	71.28	18.7381

1559	32200	31506	115	-82.9761	659	24837	115	24819	115	213.6749	181.467	17.74863
1559	32200	31506	115	-82.9761	1609	32280	115	32212	115	82.81528	71.28	16.18305
1559	32200	31506	115	-82.9761	429	24155	230	24401	230	564.8985	489.06	15.507
1559	32200	31506	115	-82.9761	1565	32208	115	32214	115	97.25007	87.12	11.62772
1560	32200	32288	115	46.7982	659	24837	115	24819	115	213.6732	181.467	17.7477
1560	32200	32288	115	46.7982	429	24155	230	24401	230	564.8931	489.06	15.50588
1561	32206	32208	115	24.88155	659	24837	115	24819	115	213.6732	181.467	17.74766
1561	32206	32208	115	24.88155	429	24155	230	24401	230	564.8928	489.06	15.50583
1562	32206	32286	115	-26.1079	659	24837	115	24819	115	213.6739	181.467	17.74808
1562	32206	32286	115	-26.1079	429	24155	230	24401	230	564.8953	489.06	15.50634
1563	32206	32292	115	-48.3923	659	24837	115	24819	115	213.6729	181.467	17.74753
1563	32206	32292	115	-48.3923	429	24155	230	24401	230	564.8936	489.06	15.50599
1564	32208	32210	115	-48.6864	659	24837	115	24819	115	213.6729	181.467	17.74751
1564	32208	32210	115	-48.6864	429	24155	230	24401	230	564.8935	489.06	15.50596
1565	32208	32214	115	73.54667	659	24837	115	24819	115	213.6716	181.467	17.74678
1565	32208	32214	115	73.54667	1308	31482	115	31506	115	110.9343	96.03	15.52045
1565	32208	32214	115	73.54667	429	24155	230	24401	230	564.8875	489.06	15.50475
1566	32212	32214	115	29.21306	659	24837	115	24819	115	213.6733	181.467	17.74776
1566	32212	32214	115	29.21306	429	24155	230	24401	230	564.8934	489.06	15.50595
1567	32214	31964	115	82.58015	659	24837	115	24819	115	213.6757	181.467	17.74904
1567	32214	31964	115	82.58015	429	24155	230	24401	230	564.9012	489.06	15.50755
1568	32214	31965	115	82.06074	659	24837	115	24819	115	213.6756	181.467	17.74903
1568	32214	31965	115	82.06074	429	24155	230	24401	230	564.9011	489.06	15.50753
1569	32214	31986	115	49.63941	1469	31978	115	31984	115	-110.502	87.12	26.83876
1569	32214	31986	115	49.63941	659	24837	115	24819	115	213.6744	181.467	17.74833
1569	32214	31986	115	49.63941	429	24155	230	24401	230	564.8969	489.06	15.50666
1570	32214	32225	115	-7.73611	659	24837	115	24819	115	213.6736	181.467	17.74793
1570	32214	32225	115	-7.73611	429	24155	230	24401	230	564.8944	489.06	15.50616
1571	32214	32244	115	-0.39113	659	24837	115	24819	115	213.6739	181.467	17.74809
1571	32214	32244	115	-0.39113	429	24155	230	24401	230	564.8954	489.06	15.50636

1572	32218	32220	115	57.65489	659	24837	115	24819	115	213.6762	181.467	17.74935
1572	32218	32220	115	57.65489	429	24155	230	24401	230	564.9029	489.06	15.5079
1573	32218	32222	115	6.496686	659	24837	115	24819	115	213.6738	181.467	17.748
1573	32218	32222	115	6.496686	429	24155	230	24401	230	564.8948	489.06	15.50625
1574	32218	32244	115	37.03474	659	24837	115	24819	115	213.6731	181.467	17.74764
1574	32218	32244	115	37.03474	429	24155	230	24401	230	564.8927	489.06	15.50581
1575	32220	32224	115	79.21032	1574	32218	115	32244	115	75.55405	64.053	17.95553
1575	32220	32224	115	79.21032	659	24837	115	24819	115	213.6771	181.467	17.74982
1575	32220	32224	115	79.21032	429	24155	230	24401	230	564.9057	489.06	15.50847
1576	32224	32232	115	116.5742	1574	32218	115	32244	115	93.72381	64.053	46.32229
1576	32224	32232	115	116.5742	1577	32225	115	32222	115	-87.0435	64.35	35.26575
1576	32224	32232	115	116.5742	659	24837	115	24819	115	213.6785	181.467	17.75063
1576	32224	32232	115	116.5742	429	24155	230	24401	230	564.9106	489.06	15.50946
1577	32225	32222	115	-30.4919	659	24837	115	24819	115	213.6731	181.467	17.74763
1577	32225	32222	115	-30.4919	429	24155	230	24401	230	564.8926	489.06	15.50579
1578	32225	32227	115	22.70891	659	24837	115	24819	115	213.6743	181.467	17.74832
1578	32225	32227	115	22.70891	429	24155	230	24401	230	564.896	489.06	15.50649
1579	32226	32244	115	-35.947	659	24837	115	24819	115	213.6746	181.467	17.74847
1579	32226	32244	115	-35.947	429	24155	230	24401	230	564.8965	489.06	15.50658
1580	32228	32238	115	-47.9208	659	24837	115	24819	115	213.674	181.467	17.74814
1580	32228	32238	115	-47.9208	429	24155	230	24401	230	564.8957	489.06	15.50642
1581	32228	32239	115	-22.0535	659	24837	115	24819	115	213.6743	181.467	17.74828
1581	32228	32239	115	-22.0535	429	24155	230	24401	230	564.8965	489.06	15.50659
1582	32229	32230	115	47.48163	659	24837	115	24819	115	213.6742	181.467	17.74824
1582	32229	32230	115	47.48163	429	24155	230	24401	230	564.8948	489.06	15.50623
1583	32229	32233	115	15.05111	659	24837	115	24819	115	213.6741	181.467	17.74821
1583	32229	32233	115	15.05111	429	24155	230	24401	230	564.8961	489.06	15.5065
1584	32231	32235	115	35.88076	659	24837	115	24819	115	213.6746	181.467	17.74847
1584	32231	32235	115	35.88076	429	24155	230	24401	230	564.8976	489.06	15.50682
1585	32232	32238	115	83.75263	1574	32218	115	32244	115	75.96243	64.053	18.5931

1585	32232	32238	115	83.75263	659	24837	115	24819	115	213.6757	181.467	17.74908
1585	32232	32238	115	83.75263	429	24155	230	24401	230	564.9013	489.06	15.50757
1586	32233	32234	115	0.000637	659	24837	115	24819	115	213.674	181.467	17.7481
1586	32233	32234	115	0.000637	429	24155	230	24401	230	564.8954	489.06	15.50637
1587	32233	32236	115	15.04463	659	24837	115	24819	115	213.6741	181.467	17.74821
1587	32233	32236	115	15.04463	429	24155	230	24401	230	564.8961	489.06	15.5065
1588	32235	32239	115	35.85033	659	24837	115	24819	115	213.6746	181.467	17.74847
1588	32235	32239	115	35.85033	429	24155	230	24401	230	564.8976	489.06	15.50682
1589	32236	32228	115	15.04141	659	24837	115	24819	115	213.6741	181.467	17.74821
1589	32236	32228	115	15.04141	429	24155	230	24401	230	564.8961	489.06	15.5065
1590	32239	32237	115	13.77915	659	24837	115	24819	115	213.6739	181.467	17.74808
1590	32239	32237	115	13.77915	429	24155	230	24401	230	564.8949	489.06	15.50625
1592	32250	32481	115	19.04671	659	24837	115	24819	115	213.6741	181.467	17.74817
1592	32250	32481	115	19.04671	429	24155	230	24401	230	564.8958	489.06	15.50645
1593	32250	32482	115	-7.56729	659	24837	115	24819	115	213.674	181.467	17.74814
1593	32250	32482	115	-7.56729	429	24155	230	24401	230	564.8957	489.06	15.50642
1594	32254	32256	115	23.93161	659	24837	115	24819	115	213.6739	181.467	17.74808
1594	32254	32256	115	23.93161	429	24155	230	24401	230	564.8945	489.06	15.50618
1595	32255	32261	115	-33.2985	659	24837	115	24819	115	213.6747	181.467	17.7485
1595	32255	32261	115	-33.2985	429	24155	230	24401	230	564.8979	489.06	15.50686
1596	32257	32254	115	32.23776	659	24837	115	24819	115	213.6739	181.467	17.7481
1596	32257	32254	115	32.23776	429	24155	230	24401	230	564.8944	489.06	15.50615
1597	32257	32260	115	-7.80368	659	24837	115	24819	115	213.674	181.467	17.74814
1597	32257	32260	115	-7.80368	429	24155	230	24401	230	564.8957	489.06	15.50642
1598	32258	32259	115	-34.9795	659	24837	115	24819	115	213.674	181.467	17.74811
1598	32258	32259	115	-34.9795	429	24155	230	24401	230	564.8944	489.06	15.50615
1599	32259	32260	115	7.806338	659	24837	115	24819	115	213.674	181.467	17.74814
1599	32259	32260	115	7.806338	429	24155	230	24401	230	564.8957	489.06	15.50642
1600	32259	32268	115	-42.7953	659	24837	115	24819	115	213.675	181.467	17.74868
1600	32259	32268	115	-42.7953	429	24155	230	24401	230	564.8989	489.06	15.50707

1601	32261	32267	115	-33.3254	659	24837	115	24819	115	213.6747	181.467	17.7485
1601	32261	32267	115	-33.3254	429	24155	230	24401	230	564.8979	489.06	15.50686
1602	32262	32264	115	-33.3761	659	24837	115	24819	115	213.6747	181.467	17.7485
1602	32262	32264	115	-33.3761	429	24155	230	24401	230	564.8979	489.06	15.50686
1604	32267	32262	115	-33.3527	659	24837	115	24819	115	213.6747	181.467	17.7485
1604	32267	32262	115	-33.3527	429	24155	230	24401	230	564.8979	489.06	15.50686
1605	32268	32265	115	34.68217	659	24837	115	24819	115	213.674	181.467	17.74815
1605	32268	32265	115	34.68217	429	24155	230	24401	230	564.8946	489.06	15.5062
1607	32275	32264	115	33.50913	659	24837	115	24819	115	213.6747	181.467	17.74851
1607	32275	32264	115	33.50913	429	24155	230	24401	230	564.8979	489.06	15.50686
1608	32278	32252	115	21.33753	659	24837	115	24819	115	213.6739	181.467	17.7481
1608	32278	32252	115	21.33753	429	24155	230	24401	230	564.8947	489.06	15.50622
1609	32280	32212	115	53.91658	659	24837	115	24819	115	213.6734	181.467	17.74778
1609	32280	32212	115	53.91658	429	24155	230	24401	230	564.8935	489.06	15.50596
1609	32280	32212	115	53.91658	1308	31482	115	31506	115	107.1169	96.03	11.54522
1610	32288	32202	115	18.97442	659	24837	115	24819	115	213.6744	181.467	17.74833
1610	32288	32202	115	18.97442	429	24155	230	24401	230	564.8962	489.06	15.50652
1611	32290	32204	115	26.41937	659	24837	115	24819	115	213.6746	181.467	17.74846
1611	32290	32204	115	26.41937	429	24155	230	24401	230	564.8968	489.06	15.50664
1612	32290	32214	115	0.979861	659	24837	115	24819	115	213.6739	181.467	17.74808
1612	32290	32214	115	0.979861	429	24155	230	24401	230	564.8953	489.06	15.50634
1613	32290	32288	115	-27.4022	659	24837	115	24819	115	213.6733	181.467	17.74773
1613	32290	32288	115	-27.4022	429	24155	230	24401	230	564.8932	489.06	15.50592
1696	32481	32257	115	18.9818	659	24837	115	24819	115	213.6741	181.467	17.74816
1696	32481	32257	115	18.9818	429	24155	230	24401	230	564.8958	489.06	15.50645
1697	32482	32255	115	-33.1147	659	24837	115	24819	115	213.6747	181.467	17.7485
1697	32482	32255	115	-33.1147	429	24155	230	24401	230	564.8978	489.06	15.50686
1698	32482	32278	115	25.54084	659	24837	115	24819	115	213.674	181.467	17.7481
1698	32482	32278	115	25.54084	429	24155	230	24401	230	564.8946	489.06	15.5062
1699	32549	31264	115	-3.75573	659	24837	115	24819	115	213.6739	181.467	17.74806

1699	32549	31264	115	-3.75573	429	24155	230	24401	230	564.8953	489.06	15.50634
1700	32549	32550	115	40.93105	659	24837	115	24819	115	213.6751	181.467	17.74872
1700	32549	32550	115	40.93105	429	24155	230	24401	230	564.8978	489.06	15.50685
1701	32551	31265	115	22.09069	659	24837	115	24819	115	213.6743	181.467	17.74829
1701	32551	31265	115	22.09069	429	24155	230	24401	230	564.8966	489.06	15.50661
1702	32553	32554	115	5.518052	659	24837	115	24819	115	213.6741	181.467	17.74816
1702	32553	32554	115	5.518052	429	24155	230	24401	230	564.8956	489.06	15.50641
1705	32559	32560	115	-9.2968	659	24837	115	24819	115	213.674	181.467	17.7481
1705	32559	32560	115	-9.2968	429	24155	230	24401	230	564.8952	489.06	15.50632
1706	32562	32564	115	22.08063	659	24837	115	24819	115	213.6743	181.467	17.74829
1706	32562	32564	115	22.08063	429	24155	230	24401	230	564.8966	489.06	15.5066
1707	32568	32570	115	57.69063	659	24837	115	24819	115	213.6746	181.467	17.74844
1707	32568	32570	115	57.69063	429	24155	230	24401	230	564.8975	489.06	15.50679
1708	32568	32574	115	31.88417	659	24837	115	24819	115	213.6741	181.467	17.74821
1708	32568	32574	115	31.88417	429	24155	230	24401	230	564.8961	489.06	15.5065
1709	32568	32576	115	25.36693	659	24837	115	24819	115	213.6756	181.467	17.74899
1709	32568	32576	115	25.36693	429	24155	230	24401	230	564.9	489.06	15.5073
1710	32568	32578	115	38.77076	659	24837	115	24819	115	213.6765	181.467	17.74948
1710	32568	32578	115	38.77076	429	24155	230	24401	230	564.9025	489.06	15.50781
1711	32570	32574	115	27.50332	659	24837	115	24819	115	213.6741	181.467	17.74818
1711	32570	32574	115	27.50332	429	24155	230	24401	230	564.8959	489.06	15.50647
1713	32576	32588	115	25.15715	659	24837	115	24819	115	213.6756	181.467	17.74898
1713	32576	32588	115	25.15715	429	24155	230	24401	230	564.8999	489.06	15.50729
1714	32578	32586	115	38.28032	659	24837	115	24819	115	213.6764	181.467	17.74947
1714	32578	32586	115	38.28032	429	24155	230	24401	230	564.9024	489.06	15.5078
1716	32586	32590	115	37.991	659	24837	115	24819	115	213.6764	181.467	17.74945
1716	32586	32590	115	37.991	429	24155	230	24401	230	564.9024	489.06	15.50778
1717	32588	32593	115	25.03217	659	24837	115	24819	115	213.6755	181.467	17.74898
1717	32588	32593	115	25.03217	429	24155	230	24401	230	564.8999	489.06	15.50728
1718	32593	32595	115	2.40E-05	659	24837	115	24819	115	213.674	181.467	17.7481

1718	32593	32595	115	2.40E-05	429	24155	230	24401	230	564.8954	489.06	15.50637
1719	32593	32604	115	24.87838	659	24837	115	24819	115	213.6755	181.467	17.74897
1719	32593	32604	115	24.87838	429	24155	230	24401	230	564.8999	489.06	15.50728
1722	32600	32614	115	-0.23927	659	24837	115	24819	115	213.674	181.467	17.74811
1722	32600	32614	115	-0.23927	429	24155	230	24401	230	564.8955	489.06	15.50638
1723	32602	32620	115	-27.1659	659	24837	115	24819	115	213.6754	181.467	17.74887
1723	32602	32620	115	-27.1659	429	24155	230	24401	230	564.8993	489.06	15.50715
1724	32604	32612	115	24.75304	659	24837	115	24819	115	213.6755	181.467	17.74897
1724	32604	32612	115	24.75304	429	24155	230	24401	230	564.8999	489.06	15.50727
1725	32608	32616	115	0.000729	659	24837	115	24819	115	213.6739	181.467	17.7481
1725	32608	32616	115	0.000729	429	24155	230	24401	230	564.8954	489.06	15.50637
1726	32612	32610	115	4.250975	659	24837	115	24819	115	213.6742	181.467	17.74823
1726	32612	32610	115	4.250975	429	24155	230	24401	230	564.8961	489.06	15.50649
1727	32612	32614	115	20.46331	659	24837	115	24819	115	213.6752	181.467	17.74879
1727	32612	32614	115	20.46331	429	24155	230	24401	230	564.899	489.06	15.50709
1728	32614	32606	115	20.21341	659	24837	115	24819	115	213.6752	181.467	17.74878
1728	32614	32606	115	20.21341	429	24155	230	24401	230	564.8989	489.06	15.50707
1730	32620	32778	115	-27.1605	659	24837	115	24819	115	213.6754	181.467	17.74887
1730	32620	32778	115	-27.1605	429	24155	230	24401	230	564.8993	489.06	15.50715
1761	32740	33006	115	-2.63988	659	24837	115	24819	115	213.674	181.467	17.7481
1761	32740	33006	115	-2.63988	429	24155	230	24401	230	564.8955	489.06	15.50637
1762	32740	33008	115	-3.59034	659	24837	115	24819	115	213.674	181.467	17.7481
1762	32740	33008	115	-3.59034	429	24155	230	24401	230	564.8955	489.06	15.50637
1763	32748	32750	115	-0.19101	659	24837	115	24819	115	213.674	181.467	17.74811
1763	32748	32750	115	-0.19101	429	24155	230	24401	230	564.8955	489.06	15.50637
1764	32750	32774	115	-12.4911	659	24837	115	24819	115	213.6746	181.467	17.74844
1764	32750	32774	115	-12.4911	429	24155	230	24401	230	564.8971	489.06	15.50671
1765	32754	32778	115	19.02873	659	24837	115	24819	115	213.6738	181.467	17.74802
1765	32754	32778	115	19.02873	429	24155	230	24401	230	564.8949	489.06	15.50627
1766	32754	32802	115	22.11143	659	24837	115	24819	115	213.6738	181.467	17.74801

1766	32754	32802	115	22.11143	429	24155	230	24401	230	564.8949	489.06	15.50625
1767	32754	32804	115	14.94616	659	24837	115	24819	115	213.6738	181.467	17.74803
1767	32754	32804	115	14.94616	429	24155	230	24401	230	564.895	489.06	15.50628
1768	32754	32849	115	25.00624	659	24837	115	24819	115	213.6752	181.467	17.74879
1768	32754	32849	115	25.00624	429	24155	230	24401	230	564.8988	489.06	15.50706
1769	32756	32778	115	8.247909	659	24837	115	24819	115	213.6741	181.467	17.74816
1769	32756	32778	115	8.247909	429	24155	230	24401	230	564.8958	489.06	15.50644
1770	32756	33010	115	-11.4427	659	24837	115	24819	115	213.6742	181.467	17.74823
1770	32756	33010	115	-11.4427	429	24155	230	24401	230	564.8962	489.06	15.50653
1771	32760	32750	115	-12.3215	659	24837	115	24819	115	213.6746	181.467	17.74844
1771	32760	32750	115	-12.3215	429	24155	230	24401	230	564.8971	489.06	15.50671
1772	32762	32774	115	-13.132	659	24837	115	24819	115	213.6742	181.467	17.74826
1772	32762	32774	115	-13.132	429	24155	230	24401	230	564.8964	489.06	15.50657
1773	32765	33010	115	-45.3731	659	24837	115	24819	115	213.6744	181.467	17.74834
1773	32765	33010	115	-45.3731	429	24155	230	24401	230	564.8969	489.06	15.50667
1774	32766	32765	115	-45.3553	659	24837	115	24819	115	213.6744	181.467	17.74834
1774	32766	32765	115	-45.3553	429	24155	230	24401	230	564.8969	489.06	15.50667
1775	32766	33010	115	-45.1787	659	24837	115	24819	115	213.6744	181.467	17.74834
1775	32766	33010	115	-45.1787	429	24155	230	24401	230	564.8969	489.06	15.50667
1776	32767	33010	115	-23.4169	659	24837	115	24819	115	213.674	181.467	17.74814
1776	32767	33010	115	-23.4169	429	24155	230	24401	230	564.8957	489.06	15.50642
1777	32768	32767	115	-23.3878	659	24837	115	24819	115	213.674	181.467	17.74814
1777	32768	32767	115	-23.3878	429	24155	230	24401	230	564.8957	489.06	15.50642
1778	32768	33010	115	-23.3492	659	24837	115	24819	115	213.674	181.467	17.74814
1778	32768	33010	115	-23.3492	429	24155	230	24401	230	564.8957	489.06	15.50642
1779	32770	32740	115	-2.22373	659	24837	115	24819	115	213.6741	181.467	17.74817
1779	32770	32740	115	-2.22373	429	24155	230	24401	230	564.8958	489.06	15.50644
1780	32774	32808	115	-25.6425	659	24837	115	24819	115	213.6746	181.467	17.74847
1780	32774	32808	115	-25.6425	429	24155	230	24401	230	564.8977	489.06	15.50682
1781	32780	32782	115	160.6524	1784	32786	115	32790	115	-207.964	155.826	33.45923

1781	32780	32782	115	160.6524	659	24837	115	24819	115	213.6753	181.467	17.74883
1781	32780	32782	115	160.6524	429	24155	230	24401	230	564.8998	489.06	15.50727
1782	32782	32788	115	69.40105	659	24837	115	24819	115	213.6742	181.467	17.74823
1782	32782	32788	115	69.40105	429	24155	230	24401	230	564.8962	489.06	15.50653
1783	32786	32788	115	-24.3148	659	24837	115	24819	115	213.674	181.467	17.74811
1783	32786	32788	115	-24.3148	429	24155	230	24401	230	564.8955	489.06	15.50638
1784	32786	32790	115	-52.281	659	24837	115	24819	115	213.6743	181.467	17.74827
1784	32786	32790	115	-52.281	429	24155	230	24401	230	564.8965	489.06	15.50658
1785	32786	32793	115	9.110749	659	24837	115	24819	115	213.6745	181.467	17.74839
1785	32786	32793	115	9.110749	429	24155	230	24401	230	564.8969	489.06	15.50667
1786	32786	32904	115	-0.00049	659	24837	115	24819	115	213.6739	181.467	17.7481
1786	32786	32904	115	-0.00049	429	24155	230	24401	230	564.8954	489.06	15.50637
1787	32786	38026	115	36.67416	659	24837	115	24819	115	213.6761	181.467	17.74929
1787	32786	38026	115	36.67416	429	24155	230	24401	230	564.9015	489.06	15.50761
1788	32792	32798	115	9.069431	659	24837	115	24819	115	213.6744	181.467	17.74835
1788	32792	32798	115	9.069431	429	24155	230	24401	230	564.8967	489.06	15.50662
1789	32792	32814	115	-41.892	659	24837	115	24819	115	213.6744	181.467	17.74837
1789	32792	32814	115	-41.892	429	24155	230	24401	230	564.8971	489.06	15.5067
1790	32792	38024	115	26.53805	659	24837	115	24819	115	213.6753	181.467	17.74886
1790	32792	38024	115	26.53805	429	24155	230	24401	230	564.8992	489.06	15.50714
1791	32793	32794	115	1.370393	659	24837	115	24819	115	213.674	181.467	17.74814
1791	32793	32794	115	1.370393	429	24155	230	24401	230	564.8957	489.06	15.50641
1792	32798	32800	115	9.074783	659	24837	115	24819	115	213.6744	181.467	17.74835
1792	32798	32800	115	9.074783	429	24155	230	24401	230	564.8967	489.06	15.50662
1793	32802	32764	115	19.44835	659	24837	115	24819	115	213.675	181.467	17.74867
1793	32802	32764	115	19.44835	429	24155	230	24401	230	564.8983	489.06	15.50695
1794	32802	32766	115	2.578654	659	24837	115	24819	115	213.6739	181.467	17.74809
1794	32802	32766	115	2.578654	429	24155	230	24401	230	564.8954	489.06	15.50635
1795	32804	32766	115	14.90134	659	24837	115	24819	115	213.6738	181.467	17.74803
1795	32804	32766	115	14.90134	429	24155	230	24401	230	564.895	489.06	15.50628

1796	32806	32758	115	16.64771	659	24837	115	24819	115	213.6748	181.467	17.74856
1796	32806	32758	115	16.64771	429	24155	230	24401	230	564.8977	489.06	15.50683
1797	32806	32762	115	8.890811	659	24837	115	24819	115	213.6741	181.467	17.7482
1797	32806	32762	115	8.890811	429	24155	230	24401	230	564.8961	489.06	15.50649
1798	32806	33010	115	-25.5386	659	24837	115	24819	115	213.6746	181.467	17.74847
1798	32806	33010	115	-25.5386	429	24155	230	24401	230	564.8977	489.06	15.50682
1799	32808	33010	115	-25.6498	659	24837	115	24819	115	213.6746	181.467	17.74847
1799	32808	33010	115	-25.6498	429	24155	230	24401	230	564.8977	489.06	15.50682
1801	32814	32810	115	40.2887	659	24837	115	24819	115	213.6761	181.467	17.7493
1801	32814	32810	115	40.2887	429	24155	230	24401	230	564.9014	489.06	15.50759
1802	32814	35113	115	-82.2261	659	24837	115	24819	115	213.6758	181.467	17.7491
1802	32814	35113	115	-82.2261	429	24155	230	24401	230	564.9015	489.06	15.50761
1802	32814	35113	115	-82.2261	1849	33020	115	32792	115	141.2604	126.027	12.08738
1809	32911	32754	115	29.23654	659	24837	115	24819	115	213.6725	181.467	17.74731
1809	32911	32754	115	29.23654	429	24155	230	24401	230	564.8916	489.06	15.50557
1810	32950	32970	115	297.0182	659	24837	115	24819	115	213.6756	181.467	17.74902
1810	32950	32970	115	297.0182	429	24155	230	24401	230	564.9011	489.06	15.50752
1811	32950	32978	115	-431.688	659	24837	115	24819	115	213.6605	181.467	17.74068
1811	32950	32978	115	-431.688	429	24155	230	24401	230	564.8642	489.06	15.49998
1812	32950	32992	115	57.77661	659	24837	115	24819	115	213.6731	181.467	17.74762
1812	32950	32992	115	57.77661	429	24155	230	24401	230	564.8925	489.06	15.50578
1813	32950	32993	115	58.80255	659	24837	115	24819	115	213.6732	181.467	17.74767
1813	32950	32993	115	58.80255	429	24155	230	24401	230	564.8928	489.06	15.50584
1814	32950	33030	115	-33.9162	659	24837	115	24819	115	213.673	181.467	17.74755
1814	32950	33030	115	-33.9162	429	24155	230	24401	230	564.8932	489.06	15.50591
1815	32950	33032	115	127.3135	659	24837	115	24819	115	213.6743	181.467	17.74829
1815	32950	33032	115	127.3135	429	24155	230	24401	230	564.8966	489.06	15.5066
1816	32950	33033	115	117.3899	659	24837	115	24819	115	213.678	181.467	17.75034
1816	32950	33033	115	117.3899	429	24155	230	24401	230	564.9053	489.06	15.50838
1817	32951	33033	115	-117.021	659	24837	115	24819	115	213.678	181.467	17.75034

1817	32951	33033	115	-117.021	429	24155	230	24401	230	564.9053	489.06	15.50838
1818	32956	32954	115	44.29351	659	24837	115	24819	115	213.6728	181.467	17.74745
1818	32956	32954	115	44.29351	429	24155	230	24401	230	564.8929	489.06	15.50585
1819	32961	32960	115	-9.37878	659	24837	115	24819	115	213.6737	181.467	17.74797
1819	32961	32960	115	-9.37878	429	24155	230	24401	230	564.8949	489.06	15.50627
1820	32970	32971	115	96.13098	659	24837	115	24819	115	213.6744	181.467	17.74833
1820	32970	32971	115	96.13098	429	24155	230	24401	230	564.8968	489.06	15.50665
1821	32970	32974	115	110.1155	659	24837	115	24819	115	213.6739	181.467	17.74807
1821	32970	32974	115	110.1155	429	24155	230	24401	230	564.8953	489.06	15.50633
1822	32970	33032	115	-126.601	659	24837	115	24819	115	213.6743	181.467	17.74829
1822	32970	33032	115	-126.601	429	24155	230	24401	230	564.8966	489.06	15.5066
1823	32970	33035	115	108.0047	659	24837	115	24819	115	213.6739	181.467	17.74808
1823	32970	33035	115	108.0047	429	24155	230	24401	230	564.8954	489.06	15.50635
1824	32971	32972	115	-16.4736	659	24837	115	24819	115	213.6741	181.467	17.74817
1824	32971	32972	115	-16.4736	429	24155	230	24401	230	564.8959	489.06	15.50646
1825	32972	33035	115	-22.1219	659	24837	115	24819	115	213.6741	181.467	17.7482
1825	32972	33035	115	-22.1219	429	24155	230	24401	230	564.8961	489.06	15.50649
1826	32973	33035	115	-84.8425	659	24837	115	24819	115	213.6735	181.467	17.74784
1826	32973	33035	115	-84.8425	429	24155	230	24401	230	564.8939	489.06	15.50606
1827	32974	32973	115	-30.0528	659	24837	115	24819	115	213.6737	181.467	17.74795
1827	32974	32973	115	-30.0528	429	24155	230	24401	230	564.8945	489.06	15.50618
1828	32974	32976	115	37.20886	659	24837	115	24819	115	213.6717	181.467	17.74685
1828	32974	32976	115	37.20886	429	24155	230	24401	230	564.888	489.06	15.50484
1829	32990	33014	115	45.73805	659	24837	115	24819	115	213.6725	181.467	17.74733
1829	32990	33014	115	45.73805	429	24155	230	24401	230	564.8908	489.06	15.50541
1830	32990	33016	115	52.38275	659	24837	115	24819	115	213.6726	181.467	17.74738
1830	32990	33016	115	52.38275	429	24155	230	24401	230	564.8911	489.06	15.50548
1831	32991	32990	115	120.8238	659	24837	115	24819	115	213.6707	181.467	17.74631
1831	32991	32990	115	120.8238	429	24155	230	24401	230	564.8846	489.06	15.50415
1832	32991	33042	115	-46.0979	659	24837	115	24819	115	213.6732	181.467	17.7477

1832	32991	33042	115	-46.0979	429	24155	230	24401	230	564.893	489.06	15.50587
1833	32991	33043	115	-58.351	659	24837	115	24819	115	213.673	181.467	17.7476
1833	32991	33043	115	-58.351	429	24155	230	24401	230	564.8924	489.06	15.50574
1834	32994	33040	115	-4.66023	659	24837	115	24819	115	213.6741	181.467	17.74819
1834	32994	33040	115	-4.66023	429	24155	230	24401	230	564.8958	489.06	15.50645
1835	32996	32990	115	7.856823	659	24837	115	24819	115	213.6738	181.467	17.74804
1835	32996	32990	115	7.856823	429	24155	230	24401	230	564.8951	489.06	15.5063
1836	32997	32991	115	7.581879	659	24837	115	24819	115	213.6739	181.467	17.74805
1836	32997	32991	115	7.581879	429	24155	230	24401	230	564.8951	489.06	15.5063
1837	33000	33046	115	-13.7041	659	24837	115	24819	115	213.6724	181.467	17.74724
1837	33000	33046	115	-13.7041	429	24155	230	24401	230	564.8906	489.06	15.50539
1838	33000	33047	115	1.300757	659	24837	115	24819	115	213.6741	181.467	17.74818
1838	33000	33047	115	1.300757	429	24155	230	24401	230	564.8959	489.06	15.50646
1839	33006	33010	115	-88.9479	659	24837	115	24819	115	213.6741	181.467	17.74818
1839	33006	33010	115	-88.9479	429	24155	230	24401	230	564.896	489.06	15.50647
1840	33006	33012	115	86.29301	659	24837	115	24819	115	213.6741	181.467	17.74821
1840	33006	33012	115	86.29301	429	24155	230	24401	230	564.8961	489.06	15.5065
1841	33008	32780	115	54.59852	659	24837	115	24819	115	213.674	181.467	17.74815
1841	33008	32780	115	54.59852	429	24155	230	24401	230	564.8957	489.06	15.50643
1842	33008	33010	115	-58.2056	659	24837	115	24819	115	213.674	181.467	17.74815
1842	33008	33010	115	-58.2056	429	24155	230	24401	230	564.8957	489.06	15.50642
1843	33012	32780	115	78.35487	659	24837	115	24819	115	213.6741	181.467	17.74817
1843	33012	32780	115	78.35487	429	24155	230	24401	230	564.8959	489.06	15.50646
1844	33014	33010	115	28.90779	659	24837	115	24819	115	213.6729	181.467	17.74755
1844	33014	33010	115	28.90779	429	24155	230	24401	230	564.8921	489.06	15.50569
1845	33014	33011	115	16.73833	659	24837	115	24819	115	213.6746	181.467	17.74849
1845	33014	33011	115	16.73833	429	24155	230	24401	230	564.8972	489.06	15.50674
1846	33016	32754	115	52.26772	659	24837	115	24819	115	213.6727	181.467	17.74739
1846	33016	32754	115	52.26772	429	24155	230	24401	230	564.8911	489.06	15.50548
1847	33020	32780	115	44.6993	659	24837	115	24819	115	213.6742	181.467	17.74824

1847	33020	32780	115	44.6993	429	24155	230	24401	230	564.8963	489.06	15.50654
1848	33020	32790	115	98.12186	659	24837	115	24819	115	213.6748	181.467	17.74855
1848	33020	32790	115	98.12186	429	24155	230	24401	230	564.8982	489.06	15.50693
1849	33020	32792	115	65.20017	659	24837	115	24819	115	213.6751	181.467	17.74874
1849	33020	32792	115	65.20017	429	24155	230	24401	230	564.8994	489.06	15.50717
1850	33020	32976	115	-37.068	659	24837	115	24819	115	213.6717	181.467	17.74685
1850	33020	32976	115	-37.068	429	24155	230	24401	230	564.888	489.06	15.50485
1851	33020	33010	115	-123.959	659	24837	115	24819	115	213.6737	181.467	17.74797
1851	33020	33010	115	-123.959	429	24155	230	24401	230	564.8947	489.06	15.50621
1852	33020	35101	115	175.1477	1849	33020	115	32792	115	213.2421	126.027	69.20353
1852	33020	35101	115	175.1477	659	24837	115	24819	115	213.6814	181.467	17.7522
1852	33020	35101	115	175.1477	429	24155	230	24401	230	564.9202	489.06	15.51143
1853	33030	33036	115	-34.0028	659	24837	115	24819	115	213.6729	181.467	17.74755
1853	33030	33036	115	-34.0028	429	24155	230	24401	230	564.8932	489.06	15.5059
1856	33036	32954	115	-44.2723	659	24837	115	24819	115	213.6728	181.467	17.74745
1856	33036	32954	115	-44.2723	429	24155	230	24401	230	564.8929	489.06	15.50585
1857	33036	32961	115	10.22968	659	24837	115	24819	115	213.6742	181.467	17.74826
1857	33036	32961	115	10.22968	429	24155	230	24401	230	564.8961	489.06	15.5065
1859	33038	32957	115	19.61346	659	24837	115	24819	115	213.6745	181.467	17.7484
1859	33038	32957	115	19.61346	429	24155	230	24401	230	564.8966	489.06	15.50661
1860	33038	32961	115	-19.6163	659	24837	115	24819	115	213.6745	181.467	17.7484
1860	33038	32961	115	-19.6163	429	24155	230	24401	230	564.8966	489.06	15.50661
1861	33040	32993	115	-50.9255	659	24837	115	24819	115	213.6732	181.467	17.74768
1861	33040	32993	115	-50.9255	429	24155	230	24401	230	564.8929	489.06	15.50585
1862	33041	33043	115	1.389571	659	24837	115	24819	115	213.6739	181.467	17.74807
1862	33041	33043	115	1.389571	429	24155	230	24401	230	564.8953	489.06	15.50634
1863	33042	33040	115	-46.1957	659	24837	115	24819	115	213.6732	181.467	17.7477
1863	33042	33040	115	-46.1957	429	24155	230	24401	230	564.893	489.06	15.50587
1864	33043	32992	115	-57.1177	659	24837	115	24819	115	213.6731	181.467	17.74763
1864	33043	32992	115	-57.1177	429	24155	230	24401	230	564.8926	489.06	15.50578

1865	33044	33002	115	-16.1824	659	24837	115	24819	115	213.6721	181.467	17.74709
1865	33044	33002	115	-16.1824	429	24155	230	24401	230	564.8898	489.06	15.50522
1866	33045	33048	115	1.297889	659	24837	115	24819	115	213.6741	181.467	17.74818
1866	33045	33048	115	1.297889	429	24155	230	24401	230	564.8959	489.06	15.50646
1867	33046	33001	115	2.463685	659	24837	115	24819	115	213.6742	181.467	17.74825
1867	33046	33001	115	2.463685	429	24155	230	24401	230	564.8963	489.06	15.50654
1868	33046	33044	115	-16.1919	659	24837	115	24819	115	213.6721	181.467	17.74709
1868	33046	33044	115	-16.1919	429	24155	230	24401	230	564.8898	489.06	15.50522
1869	33047	33045	115	1.300942	659	24837	115	24819	115	213.6741	181.467	17.74818
1869	33047	33045	115	1.300942	429	24155	230	24401	230	564.8959	489.06	15.50646
1870	33048	33049	115	1.300882	659	24837	115	24819	115	213.6741	181.467	17.74818
1870	33048	33049	115	1.300882	429	24155	230	24401	230	564.8959	489.06	15.50646
1895	33200	33204	115	-68.3218	659	24837	115	24819	115	213.6753	181.467	17.74883
1895	33200	33204	115	-68.3218	429	24155	230	24401	230	564.8999	489.06	15.50728
1896	33201	33203	115	-1.00679	659	24837	115	24819	115	213.674	181.467	17.7481
1896	33201	33203	115	-1.00679	429	24155	230	24401	230	564.8954	489.06	15.50637
1897	33201	33204	115	-67.2572	659	24837	115	24819	115	213.674	181.467	17.74813
1897	33201	33204	115	-67.2572	429	24155	230	24401	230	564.8956	489.06	15.5064
1898	33203	33204	115	-71.287	659	24837	115	24819	115	213.674	181.467	17.74813
1898	33203	33204	115	-71.287	429	24155	230	24401	230	564.8956	489.06	15.5064
1899	33203	33205	115	-86.1398	659	24837	115	24819	115	213.6741	181.467	17.7482
1899	33203	33205	115	-86.1398	429	24155	230	24401	230	564.8961	489.06	15.50649
1900	33204	33205	115	1.766998	659	24837	115	24819	115	213.6739	181.467	17.7481
1900	33204	33205	115	1.766998	429	24155	230	24401	230	564.8954	489.06	15.50637
1901	33206	33204	115	49.6797	659	24837	115	24819	115	213.6741	181.467	17.74817
1901	33206	33204	115	49.6797	429	24155	230	24401	230	564.8958	489.06	15.50645
1902	33207	33204	115	45.39288	659	24837	115	24819	115	213.6741	181.467	17.74816
1902	33207	33204	115	45.39288	429	24155	230	24401	230	564.8958	489.06	15.50644
1903	33208	33202	115	71.29373	659	24837	115	24819	115	213.6755	181.467	17.74895
1903	33208	33202	115	71.29373	429	24155	230	24401	230	564.9007	489.06	15.50743

1904	33208	33205	115	132.642	659	24837	115	24819	115	213.6745	181.467	17.74839
1904	33208	33205	115	132.642	429	24155	230	24401	230	564.8972	489.06	15.50673
1905	33208	33206	115	54.48602	659	24837	115	24819	115	213.6741	181.467	17.74818
1905	33208	33206	115	54.48602	429	24155	230	24401	230	564.8959	489.06	15.50646
1906	33208	33207	115	52.11155	659	24837	115	24819	115	213.6741	181.467	17.74817
1906	33208	33207	115	52.11155	429	24155	230	24401	230	564.8959	489.06	15.50646
1907	33208	33300	115	31.76918	659	24837	115	24819	115	213.674	181.467	17.74814
1907	33208	33300	115	31.76918	429	24155	230	24401	230	564.8957	489.06	15.50642
1908	33208	33301	115	35.29035	659	24837	115	24819	115	213.674	181.467	17.74815
1908	33208	33301	115	35.29035	429	24155	230	24401	230	564.8957	489.06	15.50643
1909	33208	33303	115	5.681934	659	24837	115	24819	115	213.6739	181.467	17.74809
1909	33208	33303	115	5.681934	429	24155	230	24401	230	564.8954	489.06	15.50636
1910	33208	33307	115	-46.6523	659	24837	115	24819	115	213.6744	181.467	17.74833
1910	33208	33307	115	-46.6523	429	24155	230	24401	230	564.8968	489.06	15.50665
1911	33208	33310	115	-69.1132	659	24837	115	24819	115	213.6747	181.467	17.74854
1911	33208	33310	115	-69.1132	429	24155	230	24401	230	564.8981	489.06	15.50692
1912	33208	33322	115	-65.7611	659	24837	115	24819	115	213.6745	181.467	17.74843
1912	33208	33322	115	-65.7611	429	24155	230	24401	230	564.8975	489.06	15.50678
1914	33210	33204	115	0.000181	659	24837	115	24819	115	213.6739	181.467	17.7481
1914	33210	33204	115	0.000181	429	24155	230	24401	230	564.8954	489.06	15.50637
1915	33300	33301	115	-26.911	659	24837	115	24819	115	213.674	181.467	17.74813
1915	33300	33301	115	-26.911	429	24155	230	24401	230	564.8956	489.06	15.5064
1916	33301	33302	115	8.300552	659	24837	115	24819	115	213.6742	181.467	17.74824
1916	33301	33302	115	8.300552	429	24155	230	24401	230	564.896	489.06	15.50648
1917	33305	33208	115	65.68776	659	24837	115	24819	115	213.6747	181.467	17.7485
1917	33305	33208	115	65.68776	429	24155	230	24401	230	564.8979	489.06	15.50687
1918	33306	33310	115	-75.3463	659	24837	115	24819	115	213.675	181.467	17.74866
1918	33306	33310	115	-75.3463	429	24155	230	24401	230	564.8989	489.06	15.50707
1919	33307	33310	115	-107.255	659	24837	115	24819	115	213.6757	181.467	17.74904
1919	33307	33310	115	-107.255	429	24155	230	24401	230	564.9012	489.06	15.50754

1920	33308	33303	115	89.62943	659	24837	115	24819	115	213.6752	181.467	17.74879
1920	33308	33303	115	89.62943	429	24155	230	24401	230	564.8996	489.06	15.50723
1921	33309	33307	115	-7.99425	659	24837	115	24819	115	213.6742	181.467	17.74826
1921	33309	33307	115	-7.99425	429	24155	230	24401	230	564.8961	489.06	15.50651
1922	33310	33305	115	75.17116	659	24837	115	24819	115	213.6749	181.467	17.7486
1922	33310	33305	115	75.17116	429	24155	230	24401	230	564.8985	489.06	15.507
1923	33310	33308	115	110.9075	659	24837	115	24819	115	213.6758	181.467	17.7491
1923	33310	33308	115	110.9075	429	24155	230	24401	230	564.9015	489.06	15.50762
1924	33310	33311	115	79.42749	659	24837	115	24819	115	213.6773	181.467	17.74996
1924	33310	33311	115	79.42749	429	24155	230	24401	230	564.9043	489.06	15.50818
1925	33310	33312	115	22.82308	659	24837	115	24819	115	213.6737	181.467	17.74795
1925	33310	33312	115	22.82308	429	24155	230	24401	230	564.8945	489.06	15.50617
1926	33310	33321	115	-44.5489	659	24837	115	24819	115	213.675	181.467	17.7487
1926	33310	33321	115	-44.5489	429	24155	230	24401	230	564.8991	489.06	15.50712
1927	33310	33356	115	71.9736	659	24837	115	24819	115	213.6748	181.467	17.74858
1927	33310	33356	115	71.9736	429	24155	230	24401	230	564.8984	489.06	15.50697
1928	33312	33313	115	-32.037	659	24837	115	24819	115	213.6747	181.467	17.74849
1928	33312	33313	115	-32.037	429	24155	230	24401	230	564.8979	489.06	15.50686
1929	33313	33319	115	-44.3335	659	24837	115	24819	115	213.6744	181.467	17.74833
1929	33313	33319	115	-44.3335	429	24155	230	24401	230	564.8969	489.06	15.50666
1930	33314	33320	115	2.78614	659	24837	115	24819	115	213.6741	181.467	17.74818
1930	33314	33320	115	2.78614	429	24155	230	24401	230	564.8958	489.06	15.50645
1931	33315	33316	115	94.20683	659	24837	115	24819	115	213.6744	181.467	17.74837
1931	33315	33316	115	94.20683	429	24155	230	24401	230	564.8971	489.06	15.5067
1932	33315	33321	115	2.95431	659	24837	115	24819	115	213.674	181.467	17.74813
1932	33315	33321	115	2.95431	429	24155	230	24401	230	564.8956	489.06	15.50641
1933	33315	35350	115	-25.765	659	24837	115	24819	115	213.6735	181.467	17.74787
1933	33315	35350	115	-25.765	429	24155	230	24401	230	564.894	489.06	15.50608
1934	33315	35351	115	-25.686	659	24837	115	24819	115	213.6735	181.467	17.74787
1934	33315	35351	115	-25.686	429	24155	230	24401	230	564.894	489.06	15.50608

1935	33315	38028	115	144.8773	1931	33315	115	33316	115	226.8889	153.45	47.85851
1935	33315	38028	115	144.8773	1936	33316	115	38028	115	189.2534	153.45	23.33231
1935	33315	38028	115	144.8773	659	24837	115	24819	115	213.6751	181.467	17.74873
1935	33315	38028	115	144.8773	429	24155	230	24401	230	564.8993	489.06	15.50715
1936	33316	38028	115	47.75795	659	24837	115	24819	115	213.6741	181.467	17.74816
1936	33316	38028	115	47.75795	429	24155	230	24401	230	564.8958	489.06	15.50644
1937	33319	33314	115	7.806791	659	24837	115	24819	115	213.6744	181.467	17.74833
1937	33319	33314	115	7.806791	429	24155	230	24401	230	564.8966	489.06	15.5066
1938	33319	33321	115	-52.1555	659	24837	115	24819	115	213.6745	181.467	17.74839
1938	33319	33321	115	-52.1555	429	24155	230	24401	230	564.8972	489.06	15.50674
1939	33321	33313	115	43.182	659	24837	115	24819	115	213.6743	181.467	17.74831
1939	33321	33313	115	43.182	429	24155	230	24401	230	564.8968	489.06	15.50664
1940	33321	33317	115	50.70805	659	24837	115	24819	115	213.6747	181.467	17.74852
1940	33321	33317	115	50.70805	429	24155	230	24401	230	564.898	489.06	15.50689
1942	33322	33306	115	-37.9083	659	24837	115	24819	115	213.6743	181.467	17.74829
1942	33322	33306	115	-37.9083	429	24155	230	24401	230	564.8966	489.06	15.50661
1954	33356	33208	115	65.1529	659	24837	115	24819	115	213.6747	181.467	17.7485
1954	33356	33208	115	65.1529	429	24155	230	24401	230	564.8979	489.06	15.50687
1994	33500	33509	115	10.6602	659	24837	115	24819	115	213.6735	181.467	17.74784
1994	33500	33509	115	10.6602	429	24155	230	24401	230	564.8938	489.06	15.50604
1995	33501	33500	115	3.369044	659	24837	115	24819	115	213.674	181.467	17.74812
1995	33501	33500	115	3.369044	429	24155	230	24401	230	564.8955	489.06	15.50639
1996	33501	33502	115	19.406	659	24837	115	24819	115	213.6762	181.467	17.74932
1996	33501	33502	115	19.406	429	24155	230	24401	230	564.9023	489.06	15.50777
1997	33503	33936	115	12.87926	659	24837	115	24819	115	213.6741	181.467	17.74818
1997	33503	33936	115	12.87926	429	24155	230	24401	230	564.8959	489.06	15.50647
1998	33504	33503	115	12.92042	659	24837	115	24819	115	213.6741	181.467	17.74818
1998	33504	33503	115	12.92042	429	24155	230	24401	230	564.8959	489.06	15.50647
1999	33506	33501	115	22.95332	659	24837	115	24819	115	213.6744	181.467	17.74834
1999	33506	33501	115	22.95332	429	24155	230	24401	230	564.8969	489.06	15.50667

2000	33506	33504	115	12.93849	659	24837	115	24819	115	213.6741	181.467	17.74818
2000	33506	33504	115	12.93849	429	24155	230	24401	230	564.8959	489.06	15.50647
2001	33506	33948	115	18.44918	659	24837	115	24819	115	213.6731	181.467	17.74765
2001	33506	33948	115	18.44918	429	24155	230	24401	230	564.8927	489.06	15.5058
2002	33509	33510	115	12.14797	659	24837	115	24819	115	213.6756	181.467	17.74899
2002	33509	33510	115	12.14797	429	24155	230	24401	230	564.9005	489.06	15.5074
2003	33509	33514	115	-1.65406	659	24837	115	24819	115	213.674	181.467	17.74815
2003	33509	33514	115	-1.65406	429	24155	230	24401	230	564.8957	489.06	15.50643
2004	33511	33514	115	18.12539	659	24837	115	24819	115	213.6731	181.467	17.74765
2004	33511	33514	115	18.12539	429	24155	230	24401	230	564.8927	489.06	15.50581
2005	33514	33526	115	-58.5128	659	24837	115	24819	115	213.6755	181.467	17.74893
2005	33514	33526	115	-58.5128	429	24155	230	24401	230	564.9007	489.06	15.50743
2006	33514	33970	115	-35.5829	659	24837	115	24819	115	213.6754	181.467	17.74892
2006	33514	33970	115	-35.5829	429	24155	230	24401	230	564.9006	489.06	15.50743
2007	33516	33514	115	-15.124	659	24837	115	24819	115	213.6749	181.467	17.74865
2007	33516	33514	115	-15.124	429	24155	230	24401	230	564.8988	489.06	15.50705
2008	33516	33520	115	25.74876	659	24837	115	24819	115	213.6775	181.467	17.75007
2008	33516	33520	115	25.74876	429	24155	230	24401	230	564.9067	489.06	15.50866
2009	33518	33514	115	21.35913	659	24837	115	24819	115	213.6743	181.467	17.74831
2009	33518	33514	115	21.35913	429	24155	230	24401	230	564.8967	489.06	15.50663
2010	33518	33522	115	-59.9859	659	24837	115	24819	115	213.6754	181.467	17.7489
2010	33518	33522	115	-59.9859	429	24155	230	24401	230	564.9005	489.06	15.50739
2011	33522	33524	115	1.679287	659	24837	115	24819	115	213.6742	181.467	17.74824
2011	33522	33524	115	1.679287	429	24155	230	24401	230	564.8962	489.06	15.50653
2012	33522	33530	115	-61.6849	659	24837	115	24819	115	213.6755	181.467	17.74894
2012	33522	33530	115	-61.6849	429	24155	230	24401	230	564.9007	489.06	15.50744
2013	33526	33528	115	21.61716	659	24837	115	24819	115	213.6739	181.467	17.74808
2013	33526	33528	115	21.61716	429	24155	230	24401	230	564.8953	489.06	15.50634
2014	33528	33529	115	-61.5929	659	24837	115	24819	115	213.6759	181.467	17.74918
2014	33528	33529	115	-61.5929	429	24155	230	24401	230	564.9022	489.06	15.50775

2015	33528	33530	115	39.23553	659	24837	115	24819	115	213.6742	181.467	17.74824
2015	33528	33530	115	39.23553	429	24155	230	24401	230	564.8963	489.06	15.50655
2016	33529	33531	115	-104.546	659	24837	115	24819	115	213.6784	181.467	17.75053
2016	33529	33531	115	-104.546	429	24155	230	24401	230	564.9107	489.06	15.50949
2017	33530	33550	115	-22.749	659	24837	115	24819	115	213.6745	181.467	17.74838
2017	33530	33550	115	-22.749	429	24155	230	24401	230	564.8972	489.06	15.50672
2018	33531	33532	115	11.34356	659	24837	115	24819	115	213.6759	181.467	17.74915
2018	33531	33532	115	11.34356	429	24155	230	24401	230	564.9015	489.06	15.50762
2019	33533	33526	115	81.4465	2023	33540	115	33541	115	153.4781	124.443	23.33206
2019	33533	33526	115	81.4465	659	24837	115	24819	115	213.677	181.467	17.74978
2019	33533	33526	115	81.4465	429	24155	230	24401	230	564.906	489.06	15.50853
2020	33535	33533	115	81.64245	2023	33540	115	33541	115	153.5522	124.443	23.39156
2020	33535	33533	115	81.64245	659	24837	115	24819	115	213.677	181.467	17.74978
2020	33535	33533	115	81.64245	429	24155	230	24401	230	564.906	489.06	15.50853
2021	33537	33534	115	5.380465	659	24837	115	24819	115	213.6749	181.467	17.74861
2021	33537	33534	115	5.380465	429	24155	230	24401	230	564.8984	489.06	15.50697
2022	33537	33549	115	116.3215	659	24837	115	24819	115	213.6793	181.467	17.75103
2022	33537	33549	115	116.3215	429	24155	230	24401	230	564.9138	489.06	15.51013
2023	33540	33541	115	122.6973	659	24837	115	24819	115	213.6798	181.467	17.7513
2023	33540	33541	115	122.6973	429	24155	230	24401	230	564.9155	489.06	15.51047
2024	33540	33543	115	85.1117	2023	33540	115	33541	115	154.5788	124.443	24.21654
2024	33540	33543	115	85.1117	659	24837	115	24819	115	213.6773	181.467	17.74994
2024	33540	33543	115	85.1117	429	24155	230	24401	230	564.907	489.06	15.50873
2025	33540	33544	115	113.0372	659	24837	115	24819	115	213.6791	181.467	17.75094
2025	33540	33544	115	113.0372	429	24155	230	24401	230	564.9133	489.06	15.51001
2027	33540	33574	115	-8.82242	659	24837	115	24819	115	213.6745	181.467	17.7484
2027	33540	33574	115	-8.82242	429	24155	230	24401	230	564.8973	489.06	15.50674
2028	33540	33959	115	42.0404	659	24837	115	24819	115	213.6754	181.467	17.74892
2028	33540	33959	115	42.0404	429	24155	230	24401	230	564.9006	489.06	15.50743
2029	33540	33961	115	34.80539	659	24837	115	24819	115	213.6753	181.467	17.74885

2029	33540	33961	115	34.80539	429	24155	230	24401	230	564.9001	489.06	15.50733
2030	33541	33537	115	122.1505	659	24837	115	24819	115	213.6797	181.467	17.75129
2030	33541	33537	115	122.1505	429	24155	230	24401	230	564.9154	489.06	15.51045
2031	33542	33546	115	-107.68	659	24837	115	24819	115	213.6787	181.467	17.75074
2031	33542	33546	115	-107.68	429	24155	230	24401	230	564.912	489.06	15.50976
2032	33542	33548	115	104.0092	659	24837	115	24819	115	213.6785	181.467	17.75058
2032	33542	33548	115	104.0092	429	24155	230	24401	230	564.911	489.06	15.50956
2033	33543	33535	115	81.83897	2023	33540	115	33541	115	153.6264	124.443	23.45125
2033	33543	33535	115	81.83897	659	24837	115	24819	115	213.677	181.467	17.74979
2033	33543	33535	115	81.83897	429	24155	230	24401	230	564.9061	489.06	15.50854
2034	33543	33545	115	3.006658	659	24837	115	24819	115	213.6745	181.467	17.7484
2034	33543	33545	115	3.006658	429	24155	230	24401	230	564.8972	489.06	15.50672
2035	33544	33546	115	109.2305	659	24837	115	24819	115	213.6788	181.467	17.75078
2035	33544	33546	115	109.2305	429	24155	230	24401	230	564.9123	489.06	15.50981
2036	33545	33547	115	3.011615	659	24837	115	24819	115	213.6745	181.467	17.7484
2036	33545	33547	115	3.011615	429	24155	230	24401	230	564.8972	489.06	15.50672
2037	33548	33550	115	22.78559	659	24837	115	24819	115	213.6745	181.467	17.74838
2037	33548	33550	115	22.78559	429	24155	230	24401	230	564.8972	489.06	15.50672
2038	33549	33531	115	116.0571	659	24837	115	24819	115	213.6793	181.467	17.75103
2038	33549	33531	115	116.0571	429	24155	230	24401	230	564.9138	489.06	15.51012
2039	33552	33553	115	26.26224	659	24837	115	24819	115	213.6761	181.467	17.74927
2039	33552	33553	115	26.26224	429	24155	230	24401	230	564.9017	489.06	15.50765
2040	33552	33558	115	-26.2627	659	24837	115	24819	115	213.6761	181.467	17.74927
2040	33552	33558	115	-26.2627	429	24155	230	24401	230	564.9017	489.06	15.50765
2041	33556	33555	115	46.79488	659	24837	115	24819	115	213.6778	181.467	17.75021
2041	33556	33555	115	46.79488	429	24155	230	24401	230	564.9068	489.06	15.50869
2042	33556	33560	115	-3.99325	659	24837	115	24819	115	213.6743	181.467	17.74828
2042	33556	33560	115	-3.99325	429	24155	230	24401	230	564.8964	489.06	15.50657
2043	33556	33958	115	-42.8019	659	24837	115	24819	115	213.6708	181.467	17.74636
2043	33556	33958	115	-42.8019	429	24155	230	24401	230	564.8862	489.06	15.50448

2044	33558	33562	115	-25.9972	659	24837	115	24819	115	213.6742	181.467	17.74824
2044	33558	33562	115	-25.9972	429	24155	230	24401	230	564.8963	489.06	15.50654
2045	33558	33564	115	-0.32881	659	24837	115	24819	115	213.6739	181.467	17.7481
2045	33558	33564	115	-0.32881	429	24155	230	24401	230	564.8954	489.06	15.50637
2046	33560	33562	115	-3.99862	659	24837	115	24819	115	213.6743	181.467	17.74828
2046	33560	33562	115	-3.99862	429	24155	230	24401	230	564.8964	489.06	15.50657
2047	33561	33562	115	-16.6135	659	24837	115	24819	115	213.6741	181.467	17.74817
2047	33561	33562	115	-16.6135	429	24155	230	24401	230	564.8959	489.06	15.50646
2048	33561	33564	115	27.08021	659	24837	115	24819	115	213.6742	181.467	17.74822
2048	33561	33564	115	27.08021	429	24155	230	24401	230	564.8962	489.06	15.50652
2049	33562	33946	115	27.0453	659	24837	115	24819	115	213.674	181.467	17.74811
2049	33562	33946	115	27.0453	429	24155	230	24401	230	564.8955	489.06	15.50639
2050	33562	33950	115	27.83234	659	24837	115	24819	115	213.6738	181.467	17.74801
2050	33562	33950	115	27.83234	429	24155	230	24401	230	564.8949	489.06	15.50625
2052	33565	33566	115	-10.4757	659	24837	115	24819	115	213.674	181.467	17.74812
2052	33565	33566	115	-10.4757	429	24155	230	24401	230	564.897	489.06	15.50669
2056	33582	33584	115	36.06976	659	24837	115	24819	115	213.6711	181.467	17.74651
2056	33582	33584	115	36.06976	429	24155	230	24401	230	564.8869	489.06	15.50462
2172	33906	33910	115	1.605434	659	24837	115	24819	115	213.6738	181.467	17.74802
2172	33906	33910	115	1.605434	429	24155	230	24401	230	564.895	489.06	15.50628
2174	33910	33912	115	16.26121	659	24837	115	24819	115	213.6725	181.467	17.74732
2174	33910	33912	115	16.26121	429	24155	230	24401	230	564.8912	489.06	15.5055
2175	33912	33914	115	90.35562	659	24837	115	24819	115	213.6661	181.467	17.74376
2175	33912	33914	115	90.35562	429	24155	230	24401	230	564.8719	489.06	15.50155
2176	33914	33917	115	78.67896	659	24837	115	24819	115	213.6668	181.467	17.74414
2176	33914	33917	115	78.67896	429	24155	230	24401	230	564.8738	489.06	15.50194
2177	33916	33917	115	-78.605	659	24837	115	24819	115	213.6667	181.467	17.74411
2177	33916	33917	115	-78.605	429	24155	230	24401	230	564.8736	489.06	15.5019
2178	33916	33920	115	18.48147	659	24837	115	24819	115	213.6719	181.467	17.74696
2178	33916	33920	115	18.48147	429	24155	230	24401	230	564.889	489.06	15.50506

2179	33920	33926	115	18.43499	659	24837	115	24819	115	213.6719	181.467	17.74696
2179	33920	33926	115	18.43499	429	24155	230	24401	230	564.889	489.06	15.50506
2180	33926	33928	115	-7.19643	659	24837	115	24819	115	213.6733	181.467	17.74772
2180	33926	33928	115	-7.19643	429	24155	230	24401	230	564.8934	489.06	15.50594
2181	33926	33930	115	25.58474	659	24837	115	24819	115	213.6711	181.467	17.74651
2181	33926	33930	115	25.58474	429	24155	230	24401	230	564.8865	489.06	15.50454
2182	33930	33932	115	6.128333	659	24837	115	24819	115	213.6732	181.467	17.7477
2182	33930	33932	115	6.128333	429	24155	230	24401	230	564.8932	489.06	15.50591
2183	33932	33500	115	7.316716	659	24837	115	24819	115	213.6737	181.467	17.74796
2183	33932	33500	115	7.316716	429	24155	230	24401	230	564.8946	489.06	15.50619
2184	33932	33922	115	14.55296	659	24837	115	24819	115	213.6754	181.467	17.74892
2184	33932	33922	115	14.55296	429	24155	230	24401	230	564.9	489.06	15.5073
2185	33932	33934	115	-18.4316	659	24837	115	24819	115	213.6731	181.467	17.74765
2185	33932	33934	115	-18.4316	429	24155	230	24401	230	564.8927	489.06	15.5058
2186	33932	33936	115	2.687744	659	24837	115	24819	115	213.6738	181.467	17.74804
2186	33932	33936	115	2.687744	429	24155	230	24401	230	564.8951	489.06	15.50629
2187	33936	33947	115	15.51011	659	24837	115	24819	115	213.6732	181.467	17.74771
2187	33936	33947	115	15.51011	429	24155	230	24401	230	564.8931	489.06	15.50589
2188	33946	33944	115	26.95864	659	24837	115	24819	115	213.674	181.467	17.74811
2188	33946	33944	115	26.95864	429	24155	230	24401	230	564.8955	489.06	15.50639
2189	33947	33951	115	15.31637	659	24837	115	24819	115	213.6733	181.467	17.74772
2189	33947	33951	115	15.31637	429	24155	230	24401	230	564.8931	489.06	15.50589
2190	33948	33953	115	18.27087	659	24837	115	24819	115	213.6731	181.467	17.74765
2190	33948	33953	115	18.27087	429	24155	230	24401	230	564.8927	489.06	15.5058
2191	33950	33934	115	2.023093	659	24837	115	24819	115	213.6739	181.467	17.74805
2191	33950	33934	115	2.023093	429	24155	230	24401	230	564.8951	489.06	15.50631
2192	33950	33944	115	25.70173	659	24837	115	24819	115	213.6744	181.467	17.74833
2192	33950	33944	115	25.70173	429	24155	230	24401	230	564.8969	489.06	15.50666
2193	33951	33516	115	10.67071	659	24837	115	24819	115	213.6734	181.467	17.74782
2193	33951	33516	115	10.67071	429	24155	230	24401	230	564.8937	489.06	15.50601

2194	33951	33952	115	4.622694	659	24837	115	24819	115	213.6745	181.467	17.74843
2194	33951	33952	115	4.622694	429	24155	230	24401	230	564.8973	489.06	15.50675
2195	33953	33511	115	18.23879	659	24837	115	24819	115	213.6731	181.467	17.74765
2195	33953	33511	115	18.23879	429	24155	230	24401	230	564.8927	489.06	15.5058
2196	33959	33970	115	41.7464	659	24837	115	24819	115	213.6754	181.467	17.74892
2196	33959	33970	115	41.7464	429	24155	230	24401	230	564.9006	489.06	15.50742
2197	33960	33962	115	27.22208	659	24837	115	24819	115	213.6748	181.467	17.74859
2197	33960	33962	115	27.22208	429	24155	230	24401	230	564.8985	489.06	15.507
2198	33961	33960	115	27.2402	659	24837	115	24819	115	213.6748	181.467	17.74859
2198	33961	33960	115	27.2402	429	24155	230	24401	230	564.8985	489.06	15.507
2199	33961	33963	115	7.446691	659	24837	115	24819	115	213.6753	181.467	17.74882
2199	33961	33963	115	7.446691	429	24155	230	24401	230	564.8996	489.06	15.50723
2200	33962	33964	115	23.60363	659	24837	115	24819	115	213.6747	181.467	17.74849
2200	33962	33964	115	23.60363	429	24155	230	24401	230	564.8979	489.06	15.50687
2201	33962	33967	115	3.554757	659	24837	115	24819	115	213.6745	181.467	17.74843
2201	33962	33967	115	3.554757	429	24155	230	24401	230	564.8973	489.06	15.50676
2202	33963	33968	115	7.446872	659	24837	115	24819	115	213.6753	181.467	17.74882
2202	33963	33968	115	7.446872	429	24155	230	24401	230	564.8996	489.06	15.50723
2203	33965	33964	115	1.374492	659	24837	115	24819	115	213.6739	181.467	17.7481
2203	33965	33964	115	1.374492	429	24155	230	24401	230	564.8954	489.06	15.50637
2204	33967	33966	115	3.549924	659	24837	115	24819	115	213.6745	181.467	17.74843
2204	33967	33966	115	3.549924	429	24155	230	24401	230	564.8973	489.06	15.50675
2205	33970	33965	115	1.374882	659	24837	115	24819	115	213.6739	181.467	17.7481
2205	33970	33965	115	1.374882	429	24155	230	24401	230	564.8954	489.06	15.50637
2217	34100	34101	115	-20.4136	659	24837	115	24819	115	213.6752	181.467	17.74877
2217	34100	34101	115	-20.4136	429	24155	230	24401	230	564.8995	489.06	15.5072
2218	34101	34116	115	-19.8737	659	24837	115	24819	115	213.6752	181.467	17.7488
2218	34101	34116	115	-19.8737	429	24155	230	24401	230	564.8997	489.06	15.50724
2219	34103	34102	115	9.950666	659	24837	115	24819	115	213.6742	181.467	17.74826
2219	34103	34102	115	9.950666	429	24155	230	24401	230	564.8962	489.06	15.50651

2220	34103	34109	115	-10.493	659	24837	115	24819	115	213.6737	181.467	17.74794
2220	34103	34109	115	-10.493	429	24155	230	24401	230	564.8947	489.06	15.50622
2221	34104	34106	115	-10.2605	659	24837	115	24819	115	213.674	181.467	17.74812
2221	34104	34106	115	-10.2605	429	24155	230	24401	230	564.8956	489.06	15.50639
2222	34104	34108	115	8.103117	659	24837	115	24819	115	213.674	181.467	17.74812
2222	34104	34108	115	8.103117	429	24155	230	24401	230	564.8955	489.06	15.50639
2223	34105	34100	115	0.925496	659	24837	115	24819	115	213.6739	181.467	17.74808
2223	34105	34100	115	0.925496	429	24155	230	24401	230	564.8953	489.06	15.50634
2224	34105	34121	115	-0.92373	659	24837	115	24819	115	213.6739	181.467	17.74808
2224	34105	34121	115	-0.92373	429	24155	230	24401	230	564.8953	489.06	15.50634
2225	34106	34138	115	-10.2637	659	24837	115	24819	115	213.674	181.467	17.74812
2225	34106	34138	115	-10.2637	429	24155	230	24401	230	564.8956	489.06	15.50639
2226	34107	34101	115	0.541075	659	24837	115	24819	115	213.6739	181.467	17.74809
2226	34107	34101	115	0.541075	429	24155	230	24401	230	564.8954	489.06	15.50636
2227	34107	34103	115	-0.5409	659	24837	115	24819	115	213.6739	181.467	17.74809
2227	34107	34103	115	-0.5409	429	24155	230	24401	230	564.8954	489.06	15.50636
2228	34108	34110	115	-15.9864	659	24837	115	24819	115	213.674	181.467	17.74812
2228	34108	34110	115	-15.9864	429	24155	230	24401	230	564.8956	489.06	15.5064
2229	34108	34114	115	24.08155	659	24837	115	24819	115	213.675	181.467	17.74865
2229	34108	34114	115	24.08155	429	24155	230	24401	230	564.8981	489.06	15.50691
2230	34110	34130	115	25.10276	659	24837	115	24819	115	213.675	181.467	17.74868
2230	34110	34130	115	25.10276	429	24155	230	24401	230	564.8982	489.06	15.50694
2231	34110	34144	115	-41.1021	659	24837	115	24819	115	213.6743	181.467	17.74829
2231	34110	34144	115	-41.1021	429	24155	230	24401	230	564.8966	489.06	15.50661
2232	34111	34109	115	10.49994	659	24837	115	24819	115	213.6737	181.467	17.74794
2232	34111	34109	115	10.49994	429	24155	230	24401	230	564.8947	489.06	15.50622
2233	34112	34116	115	58.51353	2325	34321	70	34232	70	-63.7545	-9.9	543
2233	34112	34116	115	58.51353	2324	34321	70	34230	70	73.23699	38.61	89.68399
2233	34112	34116	115	58.51353	2281	34202	70	34230	70	-67.1503	39.006	72.15388
2233	34112	34116	115	58.51353	4088	34144	115	34202	70	-77.5749	49.5	56.71691

2233	34112	34116	115	58.51353	659	24837	115	24819	115	213.673	181.467	17.7476
2233	34112	34116	115	58.51353	429	24155	230	24401	230	564.8923	489.06	15.50573
2234	34114	34124	115	27.87255	659	24837	115	24819	115	213.6751	181.467	17.74874
2234	34114	34124	115	27.87255	429	24155	230	24401	230	564.8985	489.06	15.507
2235	34116	34134	115	24.35919	659	24837	115	24819	115	213.6734	181.467	17.74782
2235	34116	34134	115	24.35919	429	24155	230	24401	230	564.8938	489.06	15.50604
2236	34116	34154	115	-0.53732	659	24837	115	24819	115	213.674	181.467	17.74811
2236	34116	34154	115	-0.53732	429	24155	230	24401	230	564.8955	489.06	15.50638
2237	34118	34136	115	4.73635	659	24837	115	24819	115	213.6741	181.467	17.7482
2237	34118	34136	115	4.73635	429	24155	230	24401	230	564.8961	489.06	15.5065
2238	34118	34168	115	-4.73644	659	24837	115	24819	115	213.6741	181.467	17.7482
2238	34118	34168	115	-4.73644	429	24155	230	24401	230	564.8961	489.06	15.5065
2239	34121	34120	115	7.106814	659	24837	115	24819	115	213.6741	181.467	17.7482
2239	34121	34120	115	7.106814	429	24155	230	24401	230	564.8958	489.06	15.50645
2240	34121	34128	115	-8.03532	659	24837	115	24819	115	213.6736	181.467	17.7479
2240	34121	34128	115	-8.03532	429	24155	230	24401	230	564.8943	489.06	15.50613
2241	34122	34126	115	-21.414	659	24837	115	24819	115	213.6741	181.467	17.74818
2241	34122	34126	115	-21.414	429	24155	230	24401	230	564.8954	489.06	15.50636
2242	34123	34358	115	-53.0336	659	24837	115	24819	115	213.673	181.467	17.74756
2242	34123	34358	115	-53.0336	429	24155	230	24401	230	564.8922	489.06	15.5057
2243	34124	34140	115	16.16882	659	24837	115	24819	115	213.6746	181.467	17.74846
2243	34124	34140	115	16.16882	429	24155	230	24401	230	564.8972	489.06	15.50672
2244	34126	34128	115	-44.3002	659	24837	115	24819	115	213.6744	181.467	17.74837
2244	34126	34128	115	-44.3002	429	24155	230	24401	230	564.8959	489.06	15.50647
2245	34128	34123	115	-52.7998	659	24837	115	24819	115	213.673	181.467	17.74757
2245	34128	34123	115	-52.7998	429	24155	230	24401	230	564.8922	489.06	15.50571
2246	34130	34132	115	4.304457	659	24837	115	24819	115	213.6741	181.467	17.74819
2246	34130	34132	115	4.304457	429	24155	230	24401	230	564.8959	489.06	15.50645
2247	34134	34104	115	49.35445	659	24837	115	24819	115	213.6745	181.467	17.7484
2247	34134	34104	115	49.35445	429	24155	230	24401	230	564.8973	489.06	15.50674

2248	34134	34136	115	13.78217	659	24837	115	24819	115	213.6739	181.467	17.74808
2248	34134	34136	115	13.78217	429	24155	230	24401	230	564.8953	489.06	15.50634
2249	34134	34144	115	34.47412	659	24837	115	24819	115	213.6741	181.467	17.7482
2249	34134	34144	115	34.47412	429	24155	230	24401	230	564.8961	489.06	15.50649
2250	34136	34138	115	78.54159	659	24837	115	24819	115	213.6754	181.467	17.74888
2250	34136	34138	115	78.54159	429	24155	230	24401	230	564.9002	489.06	15.50734
2251	34136	34144	115	30.8303	659	24837	115	24819	115	213.6741	181.467	17.74819
2251	34136	34144	115	30.8303	429	24155	230	24401	230	564.896	489.06	15.50647
2253	34149	34148	115	-37.5578	659	24837	115	24819	115	213.6707	181.467	17.74631
2253	34149	34148	115	-37.5578	429	24155	230	24401	230	564.8853	489.06	15.50429
2254	34149	34158	115	28.46595	659	24837	115	24819	115	213.6734	181.467	17.74778
2254	34149	34158	115	28.46595	429	24155	230	24401	230	564.8935	489.06	15.50597
2255	34149	34354	115	9.092225	659	24837	115	24819	115	213.6741	181.467	17.74817
2255	34149	34354	115	9.092225	429	24155	230	24401	230	564.8959	489.06	15.50646
2256	34150	34154	115	23.74015	659	24837	115	24819	115	213.6753	181.467	17.74883
2256	34150	34154	115	23.74015	429	24155	230	24401	230	564.9001	489.06	15.50731
2257	34150	34178	115	-40.3255	659	24837	115	24819	115	213.6766	181.467	17.74956
2257	34150	34178	115	-40.3255	429	24155	230	24401	230	564.9047	489.06	15.50826
2258	34156	34178	115	44.46475	659	24837	115	24819	115	213.677	181.467	17.74977
2258	34156	34178	115	44.46475	429	24155	230	24401	230	564.906	489.06	15.50852
2259	34157	34156	115	68.69313	659	24837	115	24819	115	213.6776	181.467	17.75012
2259	34157	34156	115	68.69313	429	24155	230	24401	230	564.9081	489.06	15.50895
2260	34157	34158	115	-68.6905	659	24837	115	24819	115	213.6776	181.467	17.75012
2260	34157	34158	115	-68.6905	429	24155	230	24401	230	564.9081	489.06	15.50895
2261	34158	34350	115	16.69201	659	24837	115	24819	115	213.6743	181.467	17.74828
2261	34158	34350	115	16.69201	429	24155	230	24401	230	564.8966	489.06	15.5066
2262	34159	34158	115	-75.5853	659	24837	115	24819	115	213.6762	181.467	17.74936
2262	34159	34158	115	-75.5853	429	24155	230	24401	230	564.9036	489.06	15.50804
2263	34159	34160	115	62.01204	659	24837	115	24819	115	213.6754	181.467	17.74892
2263	34159	34160	115	62.01204	429	24155	230	24401	230	564.9008	489.06	15.50747

2264	34159	34180	115	13.57325	659	24837	115	24819	115	213.6751	181.467	17.74875
2264	34159	34180	115	13.57325	429	24155	230	24401	230	564.8991	489.06	15.50712
2265	34160	34161	115	53.18942	659	24837	115	24819	115	213.675	181.467	17.74869
2265	34160	34161	115	53.18942	429	24155	230	24401	230	564.8994	489.06	15.50717
2266	34161	34162	115	51.41962	659	24837	115	24819	115	213.6749	181.467	17.74865
2266	34161	34162	115	51.41962	429	24155	230	24401	230	564.8991	489.06	15.50712
2267	34161	34164	115	1.36955	659	24837	115	24819	115	213.6741	181.467	17.74816
2267	34161	34164	115	1.36955	429	24155	230	24401	230	564.8958	489.06	15.50644
2268	34162	34168	115	29.83376	659	24837	115	24819	115	213.6756	181.467	17.74898
2268	34162	34168	115	29.83376	429	24155	230	24401	230	564.9011	489.06	15.50752
2270	34180	34166	115	3.872366	659	24837	115	24819	115	213.6743	181.467	17.74828
2270	34180	34166	115	3.872366	429	24155	230	24401	230	564.8965	489.06	15.50658
2271	34180	34181	115	9.688126	659	24837	115	24819	115	213.6748	181.467	17.74856
2271	34180	34181	115	9.688126	429	24155	230	24401	230	564.898	489.06	15.5069
2272	34181	34182	115	2.981179	659	24837	115	24819	115	213.6742	181.467	17.74824
2272	34181	34182	115	2.981179	429	24155	230	24401	230	564.8962	489.06	15.50653
2273	34181	34183	115	6.705952	659	24837	115	24819	115	213.6745	181.467	17.74842
2273	34181	34183	115	6.705952	429	24155	230	24401	230	564.8972	489.06	15.50673
2274	34183	34163	115	3.301295	659	24837	115	24819	115	213.6742	181.467	17.74826
2274	34183	34163	115	3.301295	429	24155	230	24401	230	564.8963	489.06	15.50655
2275	34183	34165	115	3.401056	659	24837	115	24819	115	213.6742	181.467	17.74826
2275	34183	34165	115	3.401056	429	24155	230	24401	230	564.8963	489.06	15.50655
2326	34350	34352	115	12.79281	659	24837	115	24819	115	213.6742	181.467	17.74823
2326	34350	34352	115	12.79281	429	24155	230	24401	230	564.8962	489.06	15.50653
2327	34352	34432	115	-2.40544	659	24837	115	24819	115	213.6739	181.467	17.74809
2327	34352	34432	115	-2.40544	429	24155	230	24401	230	564.8954	489.06	15.50635
2328	34354	34432	115	4.559417	659	24837	115	24819	115	213.6739	181.467	17.74808
2328	34354	34432	115	4.559417	429	24155	230	24401	230	564.8953	489.06	15.50634
2329	34356	34358	115	4.11243	659	24837	115	24819	115	213.6739	181.467	17.74809
2329	34356	34358	115	4.11243	429	24155	230	24401	230	564.8955	489.06	15.50637

2330	34357	34361	115	23.29386	659	24837	115	24819	115	213.674	181.467	17.74814
2330	34357	34361	115	23.29386	429	24155	230	24401	230	564.8957	489.06	15.50642
2331	34357	34368	115	-46.4395	659	24837	115	24819	115	213.6742	181.467	17.74821
2331	34357	34368	115	-46.4395	429	24155	230	24401	230	564.8962	489.06	15.50652
2332	34358	34360	115	62.29841	659	24837	115	24819	115	213.6745	181.467	17.7484
2332	34358	34360	115	62.29841	429	24155	230	24401	230	564.8973	489.06	15.50674
2333	34359	34361	115	12.42135	659	24837	115	24819	115	213.674	181.467	17.74811
2333	34359	34361	115	12.42135	429	24155	230	24401	230	564.8955	489.06	15.50638
2334	34359	34408	115	48.57942	659	24837	115	24819	115	213.6744	181.467	17.74834
2334	34359	34408	115	48.57942	429	24155	230	24401	230	564.897	489.06	15.50669
2335	34360	34414	115	47.31979	659	24837	115	24819	115	213.6744	181.467	17.74833
2335	34360	34414	115	47.31979	429	24155	230	24401	230	564.8969	489.06	15.50666
2336	34362	34363	115	-82.9539	659	24837	115	24819	115	213.6748	181.467	17.74856
2336	34362	34363	115	-82.9539	429	24155	230	24401	230	564.8961	489.06	15.50649
2337	34363	34360	115	-14.5603	659	24837	115	24819	115	213.6739	181.467	17.7481
2337	34363	34360	115	-14.5603	429	24155	230	24401	230	564.8954	489.06	15.50636
2338	34363	34366	115	-68.4756	659	24837	115	24819	115	213.6751	181.467	17.74875
2338	34363	34366	115	-68.4756	429	24155	230	24401	230	564.8995	489.06	15.5072
2339	34364	34365	115	-37.8949	659	24837	115	24819	115	213.6743	181.467	17.7483
2339	34364	34365	115	-37.8949	429	24155	230	24401	230	564.8957	489.06	15.50641
2340	34365	34358	115	-17.6617	659	24837	115	24819	115	213.6739	181.467	17.74809
2340	34365	34358	115	-17.6617	429	24155	230	24401	230	564.8954	489.06	15.50636
2341	34365	34366	115	-20.25	659	24837	115	24819	115	213.6742	181.467	17.74824
2341	34365	34366	115	-20.25	429	24155	230	24401	230	564.8963	489.06	15.50654
2342	34366	34359	115	61.3272	659	24837	115	24819	115	213.6743	181.467	17.74831
2342	34366	34359	115	61.3272	429	24155	230	24401	230	564.8968	489.06	15.50664
2343	34366	34368	115	60.67371	659	24837	115	24819	115	213.6743	181.467	17.74829
2343	34366	34368	115	60.67371	429	24155	230	24401	230	564.8967	489.06	15.50661
2344	34366	34370	115	-175.329	659	24837	115	24819	115	213.6786	181.467	17.75064
2344	34366	34370	115	-175.329	429	24155	230	24401	230	564.9114	489.06	15.50964

2345	34366	34372	115	-40.0994	659	24837	115	24819	115	213.674	181.467	17.7481
2345	34366	34372	115	-40.0994	429	24155	230	24401	230	564.8955	489.06	15.50638
2346	34366	34389	115	4.530879	659	24837	115	24819	115	213.674	181.467	17.74812
2346	34366	34389	115	4.530879	429	24155	230	24401	230	564.8956	489.06	15.50639
2347	34366	34396	115	-30.1481	659	24837	115	24819	115	213.6737	181.467	17.74795
2347	34366	34396	115	-30.1481	429	24155	230	24401	230	564.8953	489.06	15.50634
2348	34370	34382	115	80.20231	659	24837	115	24819	115	213.6759	181.467	17.74918
2348	34370	34382	115	80.20231	429	24155	230	24401	230	564.9021	489.06	15.50773
2348	34370	34382	115	80.20231	2428	34487	70	34490	70	46.78435	41.58	12.51648
2349	34370	34385	115	-5.34024	659	24837	115	24819	115	213.674	181.467	17.74811
2349	34370	34385	115	-5.34024	429	24155	230	24401	230	564.8955	489.06	15.50637
2350	34370	34402	115	72.42545	659	24837	115	24819	115	213.6759	181.467	17.74915
2350	34370	34402	115	72.42545	429	24155	230	24401	230	564.902	489.06	15.5077
2351	34372	34376	115	6.246515	659	24837	115	24819	115	213.674	181.467	17.74813
2351	34372	34376	115	6.246515	429	24155	230	24401	230	564.8955	489.06	15.50638
2352	34372	34379	115	-10.823	659	24837	115	24819	115	213.6741	181.467	17.74817
2352	34372	34379	115	-10.823	429	24155	230	24401	230	564.8959	489.06	15.50645
2353	34372	34381	115	-97.8347	659	24837	115	24819	115	213.6731	181.467	17.74762
2353	34372	34381	115	-97.8347	429	24155	230	24401	230	564.895	489.06	15.50627
2354	34373	34371	115	2.700082	659	24837	115	24819	115	213.674	181.467	17.74811
2354	34373	34371	115	2.700082	429	24155	230	24401	230	564.8955	489.06	15.50637
2355	34373	34374	115	8.005789	659	24837	115	24819	115	213.674	181.467	17.74814
2355	34373	34374	115	8.005789	429	24155	230	24401	230	564.8955	489.06	15.50638
2356	34375	34377	115	-7.04194	659	24837	115	24819	115	213.674	181.467	17.74815
2356	34375	34377	115	-7.04194	429	24155	230	24401	230	564.8958	489.06	15.50643
2357	34377	34370	115	-12.1418	659	24837	115	24819	115	213.6741	181.467	17.74819
2357	34377	34370	115	-12.1418	429	24155	230	24401	230	564.896	489.06	15.50649
2358	34379	34373	115	10.71016	659	24837	115	24819	115	213.6741	181.467	17.74816
2358	34379	34373	115	10.71016	429	24155	230	24401	230	564.8955	489.06	15.50638
2359	34379	34375	115	-21.5372	659	24837	115	24819	115	213.6742	181.467	17.74825

2359	34379	34375	115	-21.5372	429	24155	230	24401	230	564.8964	489.06	15.50656
2360	34380	34384	115	-36.222	659	24837	115	24819	115	213.6745	181.467	17.7484
2360	34380	34384	115	-36.222	429	24155	230	24401	230	564.8973	489.06	15.50675
2361	34380	34394	115	-36.8402	659	24837	115	24819	115	213.6741	181.467	17.74818
2361	34380	34394	115	-36.8402	429	24155	230	24401	230	564.8959	489.06	15.50646
2362	34382	34384	115	36.33892	659	24837	115	24819	115	213.6745	181.467	17.7484
2362	34382	34384	115	36.33892	429	24155	230	24401	230	564.8973	489.06	15.50675
2363	34385	34417	115	25.21044	659	24837	115	24819	115	213.6739	181.467	17.74807
2363	34385	34417	115	25.21044	429	24155	230	24401	230	564.8953	489.06	15.50633
2364	34385	34425	115	-30.5553	659	24837	115	24819	115	213.6735	181.467	17.74783
2364	34385	34425	115	-30.5553	429	24155	230	24401	230	564.8945	489.06	15.50618
2366	34387	34425	115	-3.40845	659	24837	115	24819	115	213.674	181.467	17.74813
2366	34387	34425	115	-3.40845	429	24155	230	24401	230	564.8955	489.06	15.50639
2367	34388	34389	115	-13.8382	659	24837	115	24819	115	213.6741	181.467	17.74817
2367	34388	34389	115	-13.8382	429	24155	230	24401	230	564.8955	489.06	15.50638
2368	34389	34394	115	-9.31805	659	24837	115	24819	115	213.6739	181.467	17.74808
2368	34389	34394	115	-9.31805	429	24155	230	24401	230	564.8953	489.06	15.50635
2369	34390	34402	115	1.886446	659	24837	115	24819	115	213.674	181.467	17.7481
2369	34390	34402	115	1.886446	429	24155	230	24401	230	564.8955	489.06	15.50637
2370	34391	34392	115	11.22327	659	24837	115	24819	115	213.6748	181.467	17.74857
2370	34391	34392	115	11.22327	429	24155	230	24401	230	564.8982	489.06	15.50694
2371	34391	34426	115	-11.2232	659	24837	115	24819	115	213.6748	181.467	17.74857
2371	34391	34426	115	-11.2232	429	24155	230	24401	230	564.8982	489.06	15.50694
2373	34396	34398	115	-30.3028	659	24837	115	24819	115	213.6737	181.467	17.74795
2373	34396	34398	115	-30.3028	429	24155	230	24401	230	564.8953	489.06	15.50634
2374	34404	34370	115	-72.921	659	24837	115	24819	115	213.6759	181.467	17.74917
2374	34404	34370	115	-72.921	429	24155	230	24401	230	564.9021	489.06	15.50772
2375	34404	34407	115	5.994969	659	24837	115	24819	115	213.674	181.467	17.74811
2375	34404	34407	115	5.994969	429	24155	230	24401	230	564.8955	489.06	15.50638
2376	34407	34390	115	6.004807	659	24837	115	24819	115	213.674	181.467	17.74811

2376	34407	34390	115	6.004807	429	24155	230	24401	230	564.8955	489.06	15.50638
2377	34408	34412	115	-43.6266	659	24837	115	24819	115	213.6743	181.467	17.7483
2377	34408	34412	115	-43.6266	429	24155	230	24401	230	564.8966	489.06	15.50661
2378	34409	34413	115	60.26134	659	24837	115	24819	115	213.6745	181.467	17.74842
2378	34409	34413	115	60.26134	429	24155	230	24401	230	564.8957	489.06	15.50642
2379	34409	34416	115	35.45824	659	24837	115	24819	115	213.6742	181.467	17.74822
2379	34409	34416	115	35.45824	429	24155	230	24401	230	564.8962	489.06	15.50652
2380	34410	34357	115	-23.1026	659	24837	115	24819	115	213.674	181.467	17.74814
2380	34410	34357	115	-23.1026	429	24155	230	24401	230	564.8957	489.06	15.50643
2381	34410	34412	115	-51.6214	659	24837	115	24819	115	213.6745	181.467	17.74841
2381	34410	34412	115	-51.6214	429	24155	230	24401	230	564.8973	489.06	15.50675
2382	34411	34416	115	77.67927	659	24837	115	24819	115	213.675	181.467	17.74868
2382	34411	34416	115	77.67927	429	24155	230	24401	230	564.899	489.06	15.5071
2383	34412	34409	115	96.38164	659	24837	115	24819	115	213.6755	181.467	17.74896
2383	34412	34409	115	96.38164	429	24155	230	24401	230	564.9008	489.06	15.50746
2384	34412	34411	115	78.11081	659	24837	115	24819	115	213.675	181.467	17.74868
2384	34412	34411	115	78.11081	429	24155	230	24401	230	564.899	489.06	15.5071
2385	34412	34422	115	74.52992	659	24837	115	24819	115	213.6756	181.467	17.74903
2385	34412	34422	115	74.52992	429	24155	230	24401	230	564.9011	489.06	15.50752
2386	34414	34422	115	-70.5257	659	24837	115	24819	115	213.6755	181.467	17.74895
2386	34414	34422	115	-70.5257	429	24155	230	24401	230	564.9006	489.06	15.50742
2387	34417	34418	115	25.20293	659	24837	115	24819	115	213.6739	181.467	17.74807
2387	34417	34418	115	25.20293	429	24155	230	24401	230	564.8953	489.06	15.50633
2388	34418	34420	115	39.13482	659	24837	115	24819	115	213.6747	181.467	17.74851
2388	34418	34420	115	39.13482	429	24155	230	24401	230	564.897	489.06	15.50669
2389	34418	34423	115	-6.81078	659	24837	115	24819	115	213.6739	181.467	17.74809
2389	34418	34423	115	-6.81078	429	24155	230	24401	230	564.8954	489.06	15.50636
2390	34418	34428	115	-88.9018	659	24837	115	24819	115	213.6799	181.467	17.75137
2390	34418	34428	115	-88.9018	429	24155	230	24401	230	564.9161	489.06	15.5106
2391	34421	34424	115	3.500032	659	24837	115	24819	115	213.674	181.467	17.74813

2391	34421	34424	115	3.500032	429	24155	230	24401	230	564.8956	489.06	15.50639
2392	34423	34370	115	-10.3247	659	24837	115	24819	115	213.6739	181.467	17.74809
2392	34423	34370	115	-10.3247	429	24155	230	24401	230	564.8954	489.06	15.50636
2393	34423	34421	115	3.508387	659	24837	115	24819	115	213.674	181.467	17.74813
2393	34423	34421	115	3.508387	429	24155	230	24401	230	564.8956	489.06	15.50639
2394	34426	34700	115	-16.1633	659	24837	115	24819	115	213.6752	181.467	17.7488
2394	34426	34700	115	-16.1633	429	24155	230	24401	230	564.8996	489.06	15.50721
2396	34429	34428	115	97.49877	659	24837	115	24819	115	213.6808	181.467	17.7519
2396	34429	34428	115	97.49877	429	24155	230	24401	230	564.9194	489.06	15.51127
2397	34430	34521	115	7.317688	659	24837	115	24819	115	213.6745	181.467	17.7484
2397	34430	34521	115	7.317688	429	24155	230	24401	230	564.8974	489.06	15.50676
2449	34521	34429	115	0.635134	659	24837	115	24819	115	213.674	181.467	17.74813
2449	34521	34429	115	0.635134	429	24155	230	24401	230	564.8956	489.06	15.5064
2480	34700	34708	115	-20.8308	659	24837	115	24819	115	213.6756	181.467	17.74901
2480	34700	34708	115	-20.8308	429	24155	230	24401	230	564.9008	489.06	15.50746
2481	34701	34704	115	-21.8451	659	24837	115	24819	115	213.6756	181.467	17.74902
2481	34701	34704	115	-21.8451	429	24155	230	24401	230	564.9008	489.06	15.50747
2482	34702	34703	115	-5.53198	659	24837	115	24819	115	213.6744	181.467	17.74833
2482	34702	34703	115	-5.53198	429	24155	230	24401	230	564.8968	489.06	15.50664
2483	34703	34701	115	-21.8393	659	24837	115	24819	115	213.6756	181.467	17.74902
2483	34703	34701	115	-21.8393	429	24155	230	24401	230	564.9008	489.06	15.50747
2484	34704	34705	115	-21.8775	659	24837	115	24819	115	213.6735	181.467	17.74785
2484	34704	34705	115	-21.8775	429	24155	230	24401	230	564.8938	489.06	15.50604
2485	34704	34774	115	-14.2979	659	24837	115	24819	115	213.6742	181.467	17.74822
2485	34704	34774	115	-14.2979	429	24155	230	24401	230	564.8962	489.06	15.50652
2486	34705	34710	115	-25.4282	659	24837	115	24819	115	213.6735	181.467	17.74784
2486	34705	34710	115	-25.4282	429	24155	230	24401	230	564.8937	489.06	15.50602
2487	34706	34734	115	7.731298	659	24837	115	24819	115	213.674	181.467	17.74815
2487	34706	34734	115	7.731298	429	24155	230	24401	230	564.8958	489.06	15.50644
2488	34706	34752	115	-67.9531	659	24837	115	24819	115	213.6756	181.467	17.74903

2488	34706	34752	115	-67.9531	429	24155	230	24401	230	564.9014	489.06	15.50759
2489	34708	34742	115	-20.879	659	24837	115	24819	115	213.6756	181.467	17.74901
2489	34708	34742	115	-20.879	429	24155	230	24401	230	564.9008	489.06	15.50747
2490	34710	34712	115	-27.6434	659	24837	115	24819	115	213.6735	181.467	17.74783
2490	34710	34712	115	-27.6434	429	24155	230	24401	230	564.8937	489.06	15.50601
2491	34712	34784	115	-36.9328	659	24837	115	24819	115	213.6735	181.467	17.74783
2491	34712	34784	115	-36.9328	429	24155	230	24401	230	564.8937	489.06	15.506
2493	34714	34715	115	-37.9631	659	24837	115	24819	115	213.6744	181.467	17.74835
2493	34714	34715	115	-37.9631	429	24155	230	24401	230	564.8971	489.06	15.5067
2494	34714	34716	115	14.8932	659	24837	115	24819	115	213.674	181.467	17.74811
2494	34714	34716	115	14.8932	429	24155	230	24401	230	564.8955	489.06	15.50639
2495	34716	34718	115	-11.2261	659	24837	115	24819	115	213.6739	181.467	17.74808
2495	34716	34718	115	-11.2261	429	24155	230	24401	230	564.8953	489.06	15.50634
2496	34716	34752	115	26.09293	659	24837	115	24819	115	213.6739	181.467	17.74806
2496	34716	34752	115	26.09293	429	24155	230	24401	230	564.8952	489.06	15.50631
2497	34718	34717	115	-28.2842	659	24837	115	24819	115	213.6722	181.467	17.74711
2497	34718	34717	115	-28.2842	429	24155	230	24401	230	564.8897	489.06	15.5052
2498	34718	34720	115	-19.9892	659	24837	115	24819	115	213.6739	181.467	17.74809
2498	34718	34720	115	-19.9892	429	24155	230	24401	230	564.8954	489.06	15.50636
2499	34718	34726	115	-0.63213	659	24837	115	24819	115	213.674	181.467	17.7481
2499	34718	34726	115	-0.63213	429	24155	230	24401	230	564.8955	489.06	15.50637
2500	34720	34721	115	-56.143	659	24837	115	24819	115	213.6703	181.467	17.7461
2500	34720	34721	115	-56.143	429	24155	230	24401	230	564.8838	489.06	15.504
2501	34720	34744	115	36.14882	659	24837	115	24819	115	213.6739	181.467	17.74809
2501	34720	34744	115	36.14882	429	24155	230	24401	230	564.8954	489.06	15.50635
2502	34721	34722	115	-23.7227	659	24837	115	24819	115	213.6724	181.467	17.74727
2502	34721	34722	115	-23.7227	429	24155	230	24401	230	564.8906	489.06	15.50539
2503	34721	34723	115	-32.4971	659	24837	115	24819	115	213.6719	181.467	17.74695
2503	34721	34723	115	-32.4971	429	24155	230	24401	230	564.8888	489.06	15.505
2504	34724	34736	115	47.05291	659	24837	115	24819	115	213.6745	181.467	17.74839

2504	34724	34736	115	47.05291	429	24155	230	24401	230	564.8973	489.06	15.50675
2505	34724	34744	115	-67.6772	659	24837	115	24819	115	213.6739	181.467	17.74807
2505	34724	34744	115	-67.6772	429	24155	230	24401	230	564.8953	489.06	15.50634
2506	34724	34798	115	20.62412	659	24837	115	24819	115	213.6738	181.467	17.74805
2506	34724	34798	115	20.62412	429	24155	230	24401	230	564.8951	489.06	15.5063
2507	34726	34728	115	-11.7641	659	24837	115	24819	115	213.674	181.467	17.74812
2507	34726	34728	115	-11.7641	429	24155	230	24401	230	564.8956	489.06	15.5064
2508	34726	34810	115	11.13143	659	24837	115	24819	115	213.6747	181.467	17.7485
2508	34726	34810	115	11.13143	429	24155	230	24401	230	564.8977	489.06	15.50684
2509	34728	34752	115	31.32758	659	24837	115	24819	115	213.6738	181.467	17.74805
2509	34728	34752	115	31.32758	429	24155	230	24401	230	564.8951	489.06	15.5063
2510	34730	34752	115	183.72	659	24837	115	24819	115	213.6619	181.467	17.74144
2510	34730	34752	115	183.72	429	24155	230	24401	230	564.8567	489.06	15.49845
2511	34731	34729	115	10.61645	659	24837	115	24819	115	213.6746	181.467	17.74846
2511	34731	34729	115	10.61645	429	24155	230	24401	230	564.8975	489.06	15.5068
2512	34731	34733	115	-43.2931	659	24837	115	24819	115	213.6741	181.467	17.7482
2512	34731	34733	115	-43.2931	429	24155	230	24401	230	564.896	489.06	15.50648
2513	34732	34734	115	-40.3799	659	24837	115	24819	115	213.6743	181.467	17.74831
2513	34732	34734	115	-40.3799	429	24155	230	24401	230	564.8968	489.06	15.50664
2514	34732	34735	115	8.507968	659	24837	115	24819	115	213.674	181.467	17.74811
2514	34732	34735	115	8.507968	429	24155	230	24401	230	564.8955	489.06	15.50638
2515	34734	34731	115	-32.6603	659	24837	115	24819	115	213.6719	181.467	17.74698
2515	34734	34731	115	-32.6603	429	24155	230	24401	230	564.889	489.06	15.50505
2516	34736	34735	115	0.306207	659	24837	115	24819	115	213.674	181.467	17.7481
2516	34736	34735	115	0.306207	429	24155	230	24401	230	564.8954	489.06	15.50637
2517	34737	34739	115	4.701192	659	24837	115	24819	115	213.6742	181.467	17.74825
2517	34737	34739	115	4.701192	429	24155	230	24401	230	564.8963	489.06	15.50654
2518	34737	34758	115	31.64476	659	24837	115	24819	115	213.6759	181.467	17.7492
2518	34737	34758	115	31.64476	429	24155	230	24401	230	564.9018	489.06	15.50767
2519	34738	34735	115	-8.80003	659	24837	115	24819	115	213.6745	181.467	17.7484

2519	34738	34735	115	-8.80003	429	24155	230	24401	230	564.8972	489.06	15.50672
2520	34741	34807	115	62.21581	659	24837	115	24819	115	213.6783	181.467	17.75048
2520	34741	34807	115	62.21581	429	24155	230	24401	230	564.9093	489.06	15.50921
2521	34742	34704	115	2.688739	659	24837	115	24819	115	213.674	181.467	17.74812
2521	34742	34704	115	2.688739	429	24155	230	24401	230	564.8955	489.06	15.50639
2522	34742	34746	115	-23.5873	659	24837	115	24819	115	213.6743	181.467	17.74831
2522	34742	34746	115	-23.5873	429	24155	230	24401	230	564.8968	489.06	15.50664
2523	34746	34774	115	-27.165	659	24837	115	24819	115	213.6744	181.467	17.74835
2523	34746	34774	115	-27.165	429	24155	230	24401	230	564.8971	489.06	15.5067
2524	34749	34750	115	17.51725	659	24837	115	24819	115	213.6753	181.467	17.74886
2524	34749	34750	115	17.51725	429	24155	230	24401	230	564.8999	489.06	15.50728
2525	34749	34761	115	41.41601	659	24837	115	24819	115	213.6774	181.467	17.74999
2525	34749	34761	115	41.41601	429	24155	230	24401	230	564.9067	489.06	15.50866
2526	34750	34787	115	5.275731	659	24837	115	24819	115	213.6744	181.467	17.74832
2526	34750	34787	115	5.275731	429	24155	230	24401	230	564.8967	489.06	15.50664
2527	34751	34775	115	42.80145	659	24837	115	24819	115	213.6746	181.467	17.74848
2527	34751	34775	115	42.80145	429	24155	230	24401	230	564.8979	489.06	15.50687
2528	34752	34753	115	59.36466	659	24837	115	24819	115	213.6781	181.467	17.75039
2528	34752	34753	115	59.36466	429	24155	230	24401	230	564.9089	489.06	15.50911
2529	34752	34755	115	82.465	659	24837	115	24819	115	213.6799	181.467	17.75136
2529	34752	34755	115	82.465	429	24155	230	24401	230	564.9145	489.06	15.51027
2530	34752	34798	115	-19.3176	659	24837	115	24819	115	213.6739	181.467	17.74805
2530	34752	34798	115	-19.3176	429	24155	230	24401	230	564.8951	489.06	15.5063
2531	34752	34808	115	31.76992	659	24837	115	24819	115	213.6761	181.467	17.74929
2531	34752	34808	115	31.76992	429	24155	230	24401	230	564.9024	489.06	15.50779
2532	34753	34740	115	19.05433	659	24837	115	24819	115	213.6752	181.467	17.74879
2532	34753	34740	115	19.05433	429	24155	230	24401	230	564.8994	489.06	15.50719
2533	34753	34754	115	40.15877	659	24837	115	24819	115	213.6767	181.467	17.7496
2533	34753	34754	115	40.15877	429	24155	230	24401	230	564.9042	489.06	15.50816
2534	34755	34741	115	62.26585	659	24837	115	24819	115	213.6783	181.467	17.75048

2534	34755	34741	115	62.26585	429	24155	230	24401	230	564.9093	489.06	15.50921
2535	34755	34757	115	19.89702	659	24837	115	24819	115	213.6752	181.467	17.74881
2535	34755	34757	115	19.89702	429	24155	230	24401	230	564.8996	489.06	15.50721
2537	34760	34766	115	-16.0536	659	24837	115	24819	115	213.6741	181.467	17.74816
2537	34760	34766	115	-16.0536	429	24155	230	24401	230	564.8958	489.06	15.50645
2538	34761	34762	115	41.2137	659	24837	115	24819	115	213.6774	181.467	17.74998
2538	34761	34762	115	41.2137	429	24155	230	24401	230	564.9066	489.06	15.50865
2539	34763	34767	115	42.62839	659	24837	115	24819	115	213.6775	181.467	17.75004
2539	34763	34767	115	42.62839	429	24155	230	24401	230	564.907	489.06	15.50873
2540	34766	34774	115	-28.3013	659	24837	115	24819	115	213.6743	181.467	17.74828
2540	34766	34774	115	-28.3013	429	24155	230	24401	230	564.8966	489.06	15.50661
2541	34774	34749	115	59.65522	659	24837	115	24819	115	213.6791	181.467	17.75093
2541	34774	34749	115	59.65522	429	24155	230	24401	230	564.9123	489.06	15.50981
2542	34774	34780	115	-38.7672	659	24837	115	24819	115	213.673	181.467	17.7476
2542	34774	34780	115	-38.7672	429	24155	230	24401	230	564.8923	489.06	15.50572
2543	34774	34804	115	-21.6911	659	24837	115	24819	115	213.6722	181.467	17.74715
2543	34774	34804	115	-21.6911	429	24155	230	24401	230	564.8893	489.06	15.50511
2544	34774	34811	115	51.35843	659	24837	115	24819	115	213.675	181.467	17.74868
2544	34774	34811	115	51.35843	429	24155	230	24401	230	564.8991	489.06	15.50712
2544	34774	34811	115	51.35843	2540	34766	115	34774	115	-75.0952	67.221	11.71391
2545	34774	34816	115	19.59555	659	24837	115	24819	115	213.6749	181.467	17.74864
2545	34774	34816	115	19.59555	429	24155	230	24401	230	564.8989	489.06	15.50707
2546	34775	34760	115	-0.04312	659	24837	115	24819	115	213.674	181.467	17.7481
2546	34775	34760	115	-0.04312	429	24155	230	24401	230	564.8954	489.06	15.50637
2547	34775	34763	115	42.81754	659	24837	115	24819	115	213.6775	181.467	17.75005
2547	34775	34763	115	42.81754	429	24155	230	24401	230	564.907	489.06	15.50874
2548	34776	34786	115	-76.5639	659	24837	115	24819	115	213.6688	181.467	17.74526
2548	34776	34786	115	-76.5639	429	24155	230	24401	230	564.8789	489.06	15.50298
2549	34776	34816	115	51.86266	659	24837	115	24819	115	213.6733	181.467	17.74777
2549	34776	34816	115	51.86266	429	24155	230	24401	230	564.8933	489.06	15.50593

2550	34778	34800	115	-0.56373	659	24837	115	24819	115	213.6739	181.467	17.74809
2550	34778	34800	115	-0.56373	429	24155	230	24401	230	564.8954	489.06	15.50636
2551	34779	34778	115	6.665981	659	24837	115	24819	115	213.6741	181.467	17.74819
2551	34779	34778	115	6.665981	429	24155	230	24401	230	564.896	489.06	15.50648
2552	34780	34781	115	-25.8906	659	24837	115	24819	115	213.6734	181.467	17.74777
2552	34780	34781	115	-25.8906	429	24155	230	24401	230	564.8933	489.06	15.50594
2553	34781	34779	115	-17.8113	659	24837	115	24819	115	213.6735	181.467	17.74787
2553	34781	34779	115	-17.8113	429	24155	230	24401	230	564.894	489.06	15.50607
2554	34784	34715	115	-40.2518	659	24837	115	24819	115	213.6735	181.467	17.74783
2554	34784	34715	115	-40.2518	429	24155	230	24401	230	564.8937	489.06	15.50601
2555	34787	34790	115	1.450589	659	24837	115	24819	115	213.6741	181.467	17.74816
2555	34787	34790	115	1.450589	429	24155	230	24401	230	564.8958	489.06	15.50644
2556	34788	34787	115	-3.82025	659	24837	115	24819	115	213.6742	181.467	17.74826
2556	34788	34787	115	-3.82025	429	24155	230	24401	230	564.8964	489.06	15.50656
2557	34792	34794	115	18.39992	659	24837	115	24819	115	213.6725	181.467	17.74732
2557	34792	34794	115	18.39992	429	24155	230	24401	230	564.8908	489.06	15.50542
2558	34794	34796	115	21.61362	659	24837	115	24819	115	213.6745	181.467	17.74841
2558	34794	34796	115	21.61362	429	24155	230	24401	230	564.8975	489.06	15.50679
2559	34794	34804	115	32.04168	659	24837	115	24819	115	213.6716	181.467	17.74679
2559	34794	34804	115	32.04168	429	24155	230	24401	230	564.887	489.06	15.50464
2560	34800	34802	115	-2.92505	659	24837	115	24819	115	213.6739	181.467	17.74807
2560	34800	34802	115	-2.92505	429	24155	230	24401	230	564.8953	489.06	15.50633
2561	34802	34776	115	30.47495	659	24837	115	24819	115	213.6745	181.467	17.74842
2561	34802	34776	115	30.47495	429	24155	230	24401	230	564.8975	489.06	15.50678
2562	34807	34737	115	36.3934	659	24837	115	24819	115	213.6763	181.467	17.74939
2562	34807	34737	115	36.3934	429	24155	230	24401	230	564.9029	489.06	15.50789
2563	34807	34806	115	25.51065	659	24837	115	24819	115	213.6755	181.467	17.74897
2563	34807	34806	115	25.51065	429	24155	230	24401	230	564.9005	489.06	15.5074
2564	34808	34809	115	11.20139	659	24837	115	24819	115	213.6747	181.467	17.74851
2564	34808	34809	115	11.20139	429	24155	230	24401	230	564.8978	489.06	15.50686

2565	34810	34812	115	1.150228	659	24837	115	24819	115	213.674	181.467	17.74814
2565	34810	34812	115	1.150228	429	24155	230	24401	230	564.8957	489.06	15.50642
2566	34811	34813	115	46.73311	659	24837	115	24819	115	213.6748	181.467	17.74859
2566	34811	34813	115	46.73311	429	24155	230	24401	230	564.8986	489.06	15.50701
2567	34813	34751	115	42.91077	659	24837	115	24819	115	213.6746	181.467	17.74848
2567	34813	34751	115	42.91077	429	24155	230	24401	230	564.8979	489.06	15.50687
2568	34813	34814	115	3.608321	659	24837	115	24819	115	213.6742	181.467	17.74826
2568	34813	34814	115	3.608321	429	24155	230	24401	230	564.8964	489.06	15.50656
2569	34814	34815	115	5.41922	659	24837	115	24819	115	213.6744	181.467	17.74834
2569	34814	34815	115	5.41922	429	24155	230	24401	230	564.8968	489.06	15.50665
2641	35101	35113	115	86.18479	659	24837	115	24819	115	213.6759	181.467	17.74918
2641	35101	35113	115	86.18479	429	24155	230	24401	230	564.902	489.06	15.50772
2641	35101	35113	115	86.18479	1849	33020	115	32792	115	144.5562	126.027	14.70254
2642	35104	35105	115	-43.2871	659	24837	115	24819	115	213.6765	181.467	17.74953
2642	35104	35105	115	-43.2871	429	24155	230	24401	230	564.9028	489.06	15.50787
2643	35105	35106	115	94.90436	659	24837	115	24819	115	213.6799	181.467	17.7514
2643	35105	35106	115	94.90436	429	24155	230	24401	230	564.9126	489.06	15.50988
2644	35105	35107	115	19.24728	659	24837	115	24819	115	213.6745	181.467	17.74839
2644	35105	35107	115	19.24728	429	24155	230	24401	230	564.8972	489.06	15.50673
2645	35107	35120	115	-54.3761	659	24837	115	24819	115	213.6734	181.467	17.74778
2645	35107	35120	115	-54.3761	429	24155	230	24401	230	564.8935	489.06	15.50598
2646	35111	35115	115	7.094193	659	24837	115	24819	115	213.6743	181.467	17.74828
2646	35111	35115	115	7.094193	429	24155	230	24401	230	564.8963	489.06	15.50654
2647	35111	35116	115	0.168678	659	24837	115	24819	115	213.674	181.467	17.74811
2647	35111	35116	115	0.168678	429	24155	230	24401	230	564.8955	489.06	15.50637
2648	35120	35111	115	39.1538	659	24837	115	24819	115	213.6744	181.467	17.74834
2648	35120	35111	115	39.1538	429	24155	230	24401	230	564.8969	489.06	15.50667
2649	35120	35121	115	17.02553	659	24837	115	24819	115	213.6743	181.467	17.74828
2649	35120	35121	115	17.02553	429	24155	230	24401	230	564.8965	489.06	15.50659
2650	35120	35124	115	39.15717	659	24837	115	24819	115	213.6744	181.467	17.74834

2650	35120	35124	115	39.15717	429	24155	230	24401	230	564.8969	489.06	15.50667
2651	35120	36851	115	17.32726	659	24837	115	24819	115	213.6743	181.467	17.74829
2651	35120	36851	115	17.32726	429	24155	230	24401	230	564.8966	489.06	15.50661
2652	35121	35110	115	70.82713	659	24837	115	24819	115	213.677	181.467	17.74981
2652	35121	35110	115	70.82713	429	24155	230	24401	230	564.9036	489.06	15.50805
2653	35121	35122	115	-0.35289	659	24837	115	24819	115	213.6739	181.467	17.74809
2653	35121	35122	115	-0.35289	429	24155	230	24401	230	564.8954	489.06	15.50636
2654	35121	35350	115	75.26833	659	24837	115	24819	115	213.6733	181.467	17.74777
2654	35121	35350	115	75.26833	429	24155	230	24401	230	564.8934	489.06	15.50595
2655	35121	35351	115	38.0592	659	24837	115	24819	115	213.6737	181.467	17.74798
2655	35121	35351	115	38.0592	429	24155	230	24401	230	564.8947	489.06	15.50621
2656	35122	35126	115	38.94517	659	24837	115	24819	115	213.6756	181.467	17.74901
2656	35122	35126	115	38.94517	429	24155	230	24401	230	564.8998	489.06	15.50726
2657	35122	35357	115	31.82578	659	24837	115	24819	115	213.6746	181.467	17.74846
2657	35122	35357	115	31.82578	429	24155	230	24401	230	564.8976	489.06	15.5068
2658	35122	35360	115	27.22167	659	24837	115	24819	115	213.6745	181.467	17.74839
2658	35122	35360	115	27.22167	429	24155	230	24401	230	564.8972	489.06	15.50673
2659	35122	35600	115	30.58721	659	24837	115	24819	115	213.6748	181.467	17.74858
2659	35122	35600	115	30.58721	429	24155	230	24401	230	564.8983	489.06	15.50696
2660	35122	35602	115	32.41069	659	24837	115	24819	115	213.6743	181.467	17.7483
2660	35122	35602	115	32.41069	429	24155	230	24401	230	564.8967	489.06	15.50662
2661	35122	35603	115	14.26345	659	24837	115	24819	115	213.6741	181.467	17.7482
2661	35122	35603	115	14.26345	429	24155	230	24401	230	564.896	489.06	15.50649
2662	35122	35624	115	50.39884	659	24837	115	24819	115	213.6756	181.467	17.74899
2662	35122	35624	115	50.39884	429	24155	230	24401	230	564.9008	489.06	15.50746
2663	35122	36853	115	22.70399	659	24837	115	24819	115	213.6742	181.467	17.74821
2663	35122	36853	115	22.70399	429	24155	230	24401	230	564.8961	489.06	15.50651
2664	35124	35111	115	39.10683	659	24837	115	24819	115	213.6744	181.467	17.74834
2664	35124	35111	115	39.10683	429	24155	230	24401	230	564.8969	489.06	15.50667
2665	35126	35127	115	38.81183	659	24837	115	24819	115	213.6756	181.467	17.74901

2665	35126	35127	115	38.81183	429	24155	230	24401	230	564.8998	489.06	15.50726
2666	35127	35112	115	32.61663	659	24837	115	24819	115	213.6753	181.467	17.74886
2666	35127	35112	115	32.61663	429	24155	230	24401	230	564.8991	489.06	15.50711
2692	35349	35121	115	-37.5501	659	24837	115	24819	115	213.6737	181.467	17.74798
2692	35349	35121	115	-37.5501	429	24155	230	24401	230	564.8947	489.06	15.50622
2693	35350	35351	115	5.84077	659	24837	115	24819	115	213.674	181.467	17.7481
2693	35350	35351	115	5.84077	429	24155	230	24401	230	564.8955	489.06	15.50637
2694	35351	35349	115	-25.2187	659	24837	115	24819	115	213.6738	181.467	17.748
2694	35351	35349	115	-25.2187	429	24155	230	24401	230	564.8948	489.06	15.50624
2695	35352	35356	115	-58.5675	659	24837	115	24819	115	213.6744	181.467	17.74833
2695	35352	35356	115	-58.5675	429	24155	230	24401	230	564.8969	489.06	15.50666
2696	35353	35356	115	-73.7407	659	24837	115	24819	115	213.6746	181.467	17.74847
2696	35353	35356	115	-73.7407	429	24155	230	24401	230	564.8977	489.06	15.50682
2697	35354	35355	115	7.73792	659	24837	115	24819	115	213.674	181.467	17.7481
2697	35354	35355	115	7.73792	429	24155	230	24401	230	564.8955	489.06	15.50637
2698	35354	35356	115	-81.6387	659	24837	115	24819	115	213.6744	181.467	17.74833
2698	35354	35356	115	-81.6387	429	24155	230	24401	230	564.8969	489.06	15.50666
2699	35355	35356	115	-54.6323	659	24837	115	24819	115	213.6741	181.467	17.74821
2699	35355	35356	115	-54.6323	429	24155	230	24401	230	564.8961	489.06	15.5065
2700	35356	35367	115	82.05939	659	24837	115	24819	115	213.6743	181.467	17.74828
2700	35356	35367	115	82.05939	429	24155	230	24401	230	564.8966	489.06	15.5066
2701	35356	35368	115	100.6774	659	24837	115	24819	115	213.6748	181.467	17.74856
2701	35356	35368	115	100.6774	429	24155	230	24401	230	564.8983	489.06	15.50696
2702	35357	35358	115	22.62116	659	24837	115	24819	115	213.6748	181.467	17.74857
2702	35357	35358	115	22.62116	429	24155	230	24401	230	564.8976	489.06	15.50681
2703	35357	35363	115	9.07296	659	24837	115	24819	115	213.6741	181.467	17.74818
2703	35357	35363	115	9.07296	429	24155	230	24401	230	564.8959	489.06	15.50647
2704	35358	35359	115	4.460127	659	24837	115	24819	115	213.6741	181.467	17.74819
2704	35358	35359	115	4.460127	429	24155	230	24401	230	564.8959	489.06	15.50645
2705	35358	35361	115	18.15039	659	24837	115	24819	115	213.6746	181.467	17.74848

2705	35358	35361	115	18.15039	429	24155	230	24401	230	564.8972	489.06	15.50672
2706	35360	35362	115	23.7498	659	24837	115	24819	115	213.6748	181.467	17.74859
2706	35360	35362	115	23.7498	429	24155	230	24401	230	564.8977	489.06	15.50683
2707	35360	35365	115	3.359034	659	24837	115	24819	115	213.674	181.467	17.74813
2707	35360	35365	115	3.359034	429	24155	230	24401	230	564.8956	489.06	15.5064
2708	35363	35367	115	-79.4157	659	24837	115	24819	115	213.6742	181.467	17.74826
2708	35363	35367	115	-79.4157	429	24155	230	24401	230	564.8965	489.06	15.50658
2709	35364	35365	115	-7.84605	659	24837	115	24819	115	213.6742	181.467	17.74825
2709	35364	35365	115	-7.84605	429	24155	230	24401	230	564.8961	489.06	15.50651
2710	35366	35367	115	-1.73599	659	24837	115	24819	115	213.674	181.467	17.74813
2710	35366	35367	115	-1.73599	429	24155	230	24401	230	564.8956	489.06	15.5064
2711	35368	35369	115	16.73469	659	24837	115	24819	115	213.6738	181.467	17.74801
2711	35368	35369	115	16.73469	429	24155	230	24401	230	564.8949	489.06	15.50625
2712	35369	35365	115	4.492678	659	24837	115	24819	115	213.6739	181.467	17.74807
2712	35369	35365	115	4.492678	429	24155	230	24401	230	564.8953	489.06	15.50633
2713	35370	35353	115	2.833508	659	24837	115	24819	115	213.674	181.467	17.7481
2713	35370	35353	115	2.833508	429	24155	230	24401	230	564.8955	489.06	15.50637
2714	35370	35371	115	-2.83533	659	24837	115	24819	115	213.674	181.467	17.7481
2714	35370	35371	115	-2.83533	429	24155	230	24401	230	564.8955	489.06	15.50637
2715	35371	35352	115	-2.83328	659	24837	115	24819	115	213.674	181.467	17.7481
2715	35371	35352	115	-2.83328	429	24155	230	24401	230	564.8955	489.06	15.50637
2726	35600	35629	115	-24.094	659	24837	115	24819	115	213.6736	181.467	17.74789
2726	35600	35629	115	-24.094	429	24155	230	24401	230	564.8942	489.06	15.50611
2727	35602	35604	115	3.470188	659	24837	115	24819	115	213.6741	181.467	17.74817
2727	35602	35604	115	3.470188	429	24155	230	24401	230	564.8958	489.06	15.50644
2728	35602	36850	115	28.81477	659	24837	115	24819	115	213.6742	181.467	17.74826
2728	35602	36850	115	28.81477	429	24155	230	24401	230	564.8964	489.06	15.50657
2729	35603	35605	115	0.000303	659	24837	115	24819	115	213.674	181.467	17.7481
2729	35603	35605	115	0.000303	429	24155	230	24401	230	564.8954	489.06	15.50637
2730	35603	35612	115	14.19643	659	24837	115	24819	115	213.6741	181.467	17.7482

2730	35603	35612	115	14.19643	429	24155	230	24401	230	564.896	489.06	15.50649
2731	35612	35610	115	-7.77865	659	24837	115	24819	115	213.674	181.467	17.74811
2731	35612	35610	115	-7.77865	429	24155	230	24401	230	564.8955	489.06	15.50638
2732	35612	35616	115	30.3228	659	24837	115	24819	115	213.6744	181.467	17.74836
2732	35612	35616	115	30.3228	429	24155	230	24401	230	564.897	489.06	15.50668
2733	35613	35614	115	-130.596	659	24837	115	24819	115	213.6744	181.467	17.74833
2733	35613	35614	115	-130.596	429	24155	230	24401	230	564.897	489.06	15.50669
2734	35615	35616	115	-42.6576	659	24837	115	24819	115	213.6738	181.467	17.74801
2734	35615	35616	115	-42.6576	429	24155	230	24401	230	564.8949	489.06	15.50626
2735	35615	35617	115	1.545169	659	24837	115	24819	115	213.6739	181.467	17.74809
2735	35615	35617	115	1.545169	429	24155	230	24401	230	564.8954	489.06	15.50636
2736	35616	35619	115	-82.7728	659	24837	115	24819	115	213.6728	181.467	17.74748
2736	35616	35619	115	-82.7728	429	24155	230	24401	230	564.8918	489.06	15.50563
2737	35618	35613	115	-130.426	659	24837	115	24819	115	213.6744	181.467	17.74833
2737	35618	35613	115	-130.426	429	24155	230	24401	230	564.897	489.06	15.50669
2738	35618	35619	115	82.41589	659	24837	115	24819	115	213.6737	181.467	17.74795
2738	35618	35619	115	82.41589	429	24155	230	24401	230	564.8947	489.06	15.50621
2739	35619	35631	115	-73.8114	659	24837	115	24819	115	213.6738	181.467	17.74804
2739	35619	35631	115	-73.8114	429	24155	230	24401	230	564.8952	489.06	15.50631
2740	35620	35614	115	130.9139	659	24837	115	24819	115	213.6744	181.467	17.74833
2740	35620	35614	115	130.9139	429	24155	230	24401	230	564.897	489.06	15.5067
2741	35620	35621	115	-119.723	659	24837	115	24819	115	213.6753	181.467	17.74887
2741	35620	35621	115	-119.723	429	24155	230	24401	230	564.9002	489.06	15.50734
2742	35620	35651	115	-119.713	659	24837	115	24819	115	213.6753	181.467	17.74887
2742	35620	35651	115	-119.713	429	24155	230	24401	230	564.9002	489.06	15.50734
2743	35621	35642	115	-122.06	659	24837	115	24819	115	213.6754	181.467	17.74888
2743	35621	35642	115	-122.06	429	24155	230	24401	230	564.9003	489.06	15.50736
2744	35622	35624	115	66.57648	659	24837	115	24819	115	213.6735	181.467	17.74783
2744	35622	35624	115	66.57648	429	24155	230	24401	230	564.8939	489.06	15.50605
2745	35622	35643	115	-159.23	659	24837	115	24819	115	213.6762	181.467	17.74933

2745	35622	35643	115	-159.23	429	24155	230	24401	230	564.9031	489.06	15.50793
2746	35625	35645	115	-43.5377	659	24837	115	24819	115	213.6753	181.467	17.74886
2746	35625	35645	115	-43.5377	429	24155	230	24401	230	564.8987	489.06	15.50704
2747	35626	35629	115	40.43863	659	24837	115	24819	115	213.6735	181.467	17.74783
2747	35626	35629	115	40.43863	429	24155	230	24401	230	564.8939	489.06	15.50604
2748	35626	35656	115	-124.776	659	24837	115	24819	115	213.6751	181.467	17.74872
2748	35626	35656	115	-124.776	429	24155	230	24401	230	564.8993	489.06	15.50716
2749	35629	35630	115	16.17971	659	24837	115	24819	115	213.6745	181.467	17.74841
2749	35629	35630	115	16.17971	429	24155	230	24401	230	564.8968	489.06	15.50665
2750	35631	35632	115	6.876156	659	24837	115	24819	115	213.6742	181.467	17.74821
2750	35631	35632	115	6.876156	429	24155	230	24401	230	564.8959	489.06	15.50646
2751	35631	35636	115	-80.7653	659	24837	115	24819	115	213.6739	181.467	17.7481
2751	35631	35636	115	-80.7653	429	24155	230	24401	230	564.8955	489.06	15.50638
2752	35633	35636	115	30.47331	659	24837	115	24819	115	213.6739	181.467	17.74808
2752	35633	35636	115	30.47331	429	24155	230	24401	230	564.8953	489.06	15.50634
2753	35633	35645	115	-62.2316	659	24837	115	24819	115	213.6742	181.467	17.74823
2753	35633	35645	115	-62.2316	429	24155	230	24401	230	564.8963	489.06	15.50654
2754	35634	35625	115	-43.5276	659	24837	115	24819	115	213.6753	181.467	17.74886
2754	35634	35625	115	-43.5276	429	24155	230	24401	230	564.8987	489.06	15.50704
2755	35634	35635	115	2.109951	659	24837	115	24819	115	213.674	181.467	17.74813
2755	35634	35635	115	2.109951	429	24155	230	24401	230	564.8956	489.06	15.5064
2756	35634	36420	115	41.41459	659	24837	115	24819	115	213.6752	181.467	17.74882
2756	35634	36420	115	41.41459	429	24155	230	24401	230	564.8985	489.06	15.507
2757	35636	35643	115	-106.423	659	24837	115	24819	115	213.6753	181.467	17.74883
2757	35636	35643	115	-106.423	429	24155	230	24401	230	564.9	489.06	15.50729
2758	35637	35649	115	-31.1116	659	24837	115	24819	115	213.6751	181.467	17.74874
2758	35637	35649	115	-31.1116	429	24155	230	24401	230	564.8984	489.06	15.50697
2759	35638	35649	115	-37.16	659	24837	115	24819	115	213.674	181.467	17.74815
2759	35638	35649	115	-37.16	429	24155	230	24401	230	564.8957	489.06	15.50643
2760	35638	35653	115	-72.296	659	24837	115	24819	115	213.6743	181.467	17.74827

2760	35638	35653	115	-72.296	429	24155	230	24401	230	564.8965	489.06	15.50658
2761	35639	35641	115	-6.30015	659	24837	115	24819	115	213.6742	181.467	17.74823
2761	35639	35641	115	-6.30015	429	24155	230	24401	230	564.896	489.06	15.50649
2762	35640	35652	115	-5.81998	659	24837	115	24819	115	213.6742	181.467	17.74822
2762	35640	35652	115	-5.81998	429	24155	230	24401	230	564.896	489.06	15.50648
2763	35641	35642	115	-74.6206	659	24837	115	24819	115	213.6743	181.467	17.74829
2763	35641	35642	115	-74.6206	429	24155	230	24401	230	564.8966	489.06	15.5066
2764	35641	35649	115	68.31979	659	24837	115	24819	115	213.6742	181.467	17.74826
2764	35641	35649	115	68.31979	429	24155	230	24401	230	564.8964	489.06	15.50656
2765	35642	35643	115	124.829	659	24837	115	24819	115	213.6723	181.467	17.74722
2765	35642	35643	115	124.829	429	24155	230	24401	230	564.8901	489.06	15.50527
2766	35642	35646	115	-27.2626	659	24837	115	24819	115	213.6731	181.467	17.74761
2766	35642	35646	115	-27.2626	429	24155	230	24401	230	564.8925	489.06	15.50577
2767	35642	35651	115	122.8511	659	24837	115	24819	115	213.6754	181.467	17.74889
2767	35642	35651	115	122.8511	429	24155	230	24401	230	564.9003	489.06	15.50737
2768	35642	35653	115	78.26959	659	24837	115	24819	115	213.6743	181.467	17.74831
2768	35642	35653	115	78.26959	429	24155	230	24401	230	564.8967	489.06	15.50663
2769	35642	35654	115	-70.839	2772	35646	115	35648	115	-174.548	124.74	39.92982
2769	35642	35654	115	-70.839	659	24837	115	24819	115	213.6725	181.467	17.74729
2769	35642	35654	115	-70.839	429	24155	230	24401	230	564.8905	489.06	15.50536
2770	35643	35644	115	4.903447	659	24837	115	24819	115	213.6741	181.467	17.7482
2770	35643	35644	115	4.903447	429	24155	230	24401	230	564.8959	489.06	15.50647
2771	35645	35643	115	-105.879	659	24837	115	24819	115	213.6753	181.467	17.74883
2771	35645	35643	115	-105.879	429	24155	230	24401	230	564.9	489.06	15.50729
2772	35646	35648	115	-107.471	659	24837	115	24819	115	213.6731	181.467	17.74764
2772	35646	35648	115	-107.471	2773	35648	115	35655	115	174.1361	149.49	16.48676
2772	35646	35648	115	-107.471	429	24155	230	24401	230	564.8926	489.06	15.5058
2773	35648	35655	115	72.25962	2772	35646	115	35648	115	-175.894	124.74	41.00825
2773	35648	35655	115	72.25962	659	24837	115	24819	115	213.6724	181.467	17.74727
2773	35648	35655	115	72.25962	429	24155	230	24401	230	564.8904	489.06	15.50534

2774	35648	35660	115	-255.094	2784	35660	115	35650	115	195.9689	87.12	124.9413
2774	35648	35660	115	-255.094	659	24837	115	24819	115	213.6667	181.467	17.74413
2774	35648	35660	115	-255.094	429	24155	230	24401	230	564.8789	489.06	15.50299
2775	35652	35653	115	-5.81583	659	24837	115	24819	115	213.6742	181.467	17.74822
2775	35652	35653	115	-5.81583	429	24155	230	24401	230	564.896	489.06	15.50648
2776	35654	35655	115	-71.4883	2772	35646	115	35648	115	-175.163	124.74	40.42277
2776	35654	35655	115	-71.4883	659	24837	115	24819	115	213.6725	181.467	17.74728
2776	35654	35655	115	-71.4883	429	24155	230	24401	230	564.8905	489.06	15.50535
2777	35656	35643	115	-156.556	659	24837	115	24819	115	213.6765	181.467	17.74949
2777	35656	35643	115	-156.556	429	24155	230	24401	230	564.9041	489.06	15.50813
2778	35658	35606	115	36.28624	659	24837	115	24819	115	213.6755	181.467	17.74894
2778	35658	35606	115	36.28624	429	24155	230	24401	230	564.8994	489.06	15.50718
2779	35658	35610	115	105.5195	659	24837	115	24819	115	213.6752	181.467	17.74878
2779	35658	35610	115	105.5195	429	24155	230	24401	230	564.8995	489.06	15.5072
2780	35658	35612	115	131.0162	659	24837	115	24819	115	213.6756	181.467	17.74901
2780	35658	35612	115	131.0162	429	24155	230	24401	230	564.9009	489.06	15.50748
2781	35659	35666	115	-118.226	659	24837	115	24819	115	213.6751	181.467	17.74874
2781	35659	35666	115	-118.226	429	24155	230	24401	230	564.8993	489.06	15.50716
2782	35659	36853	115	105.2268	659	24837	115	24819	115	213.6748	181.467	17.74859
2782	35659	36853	115	105.2268	429	24155	230	24401	230	564.8983	489.06	15.50696
2783	35660	35647	115	-118.328	659	24837	115	24819	115	213.6707	181.467	17.74632
2783	35660	35647	115	-118.328	429	24155	230	24401	230	564.8881	489.06	15.50488
2784	35660	35650	115	8.570696	659	24837	115	24819	115	213.6742	181.467	17.74823
2784	35660	35650	115	8.570696	429	24155	230	24401	230	564.896	489.06	15.50648
2785	35661	35660	115	146.0938	659	24837	115	24819	115	213.6726	181.467	17.74738
2785	35661	35660	115	146.0938	429	24155	230	24401	230	564.8957	489.06	15.50641
2786	35666	35657	115	-194.373	659	24837	115	24819	115	213.6663	181.467	17.74386
2786	35666	35657	115	-194.373	429	24155	230	24401	230	564.8757	489.06	15.50233
2787	35666	35658	115	76.00439	659	24837	115	24819	115	213.6732	181.467	17.74766
2787	35666	35658	115	76.00439	429	24155	230	24401	230	564.8928	489.06	15.50583

2795	35901	35903	115	-11.6137	659	24837	115	24819	115	213.674	181.467	17.74812
2795	35901	35903	115	-11.6137	429	24155	230	24401	230	564.8956	489.06	15.50639
2796	35901	35908	115	71.50917	659	24837	115	24819	115	213.6757	181.467	17.74907
2796	35901	35908	115	71.50917	429	24155	230	24401	230	564.9015	489.06	15.5076
2797	35901	35922	115	-82.7447	659	24837	115	24819	115	213.6758	181.467	17.74915
2797	35901	35922	115	-82.7447	429	24155	230	24401	230	564.9019	489.06	15.50769
2798	35903	35905	115	51.36197	659	24837	115	24819	115	213.6749	181.467	17.74861
2798	35903	35905	115	51.36197	429	24155	230	24401	230	564.8986	489.06	15.50702
2799	35903	35922	115	-82.6795	659	24837	115	24819	115	213.6758	181.467	17.74914
2799	35903	35922	115	-82.6795	429	24155	230	24401	230	564.9019	489.06	15.50769
2800	35905	35907	115	14.08969	659	24837	115	24819	115	213.674	181.467	17.74814
2800	35905	35907	115	14.08969	429	24155	230	24401	230	564.8957	489.06	15.50642
2801	35907	35908	115	-58.2677	659	24837	115	24819	115	213.6751	181.467	17.74876
2801	35907	35908	115	-58.2677	429	24155	230	24401	230	564.8995	489.06	15.5072
2802	35907	36218	115	0.004277	659	24837	115	24819	115	213.674	181.467	17.7481
2802	35907	36218	115	0.004277	429	24155	230	24401	230	564.8954	489.06	15.50637
2803	35911	35914	115	25.2141	659	24837	115	24819	115	213.6741	181.467	17.74819
2803	35911	35914	115	25.2141	429	24155	230	24401	230	564.896	489.06	15.50648
2804	35911	35915	115	-57.1234	659	24837	115	24819	115	213.6747	181.467	17.74853
2804	35911	35915	115	-57.1234	429	24155	230	24401	230	564.8981	489.06	15.50691
2805	35912	35913	115	35.50647	659	24837	115	24819	115	213.6743	181.467	17.74827
2805	35912	35913	115	35.50647	429	24155	230	24401	230	564.8965	489.06	15.50658
2806	35912	35917	115	-61.3704	659	24837	115	24819	115	213.6748	181.467	17.7486
2806	35912	35917	115	-61.3704	429	24155	230	24401	230	564.8985	489.06	15.507
2807	35913	35918	115	8.207684	659	24837	115	24819	115	213.674	181.467	17.74811
2807	35913	35918	115	8.207684	429	24155	230	24401	230	564.8955	489.06	15.50638
2808	35913	35919	115	27.15448	659	24837	115	24819	115	213.6744	181.467	17.74834
2808	35913	35919	115	27.15448	429	24155	230	24401	230	564.8969	489.06	15.50667
2809	35914	35919	115	25.84604	659	24837	115	24819	115	213.6743	181.467	17.74832
2809	35914	35919	115	25.84604	429	24155	230	24401	230	564.8968	489.06	15.50664

2810	35914	35920	115	-0.70022	659	24837	115	24819	115	213.6739	181.467	17.7481
2810	35914	35920	115	-0.70022	429	24155	230	24401	230	564.8954	489.06	15.50637
2811	35915	35916	115	18.27858	659	24837	115	24819	115	213.6752	181.467	17.74881
2811	35915	35916	115	18.27858	429	24155	230	24401	230	564.8993	489.06	15.50716
2812	35915	35922	115	-75.6293	659	24837	115	24819	115	213.6753	181.467	17.74884
2812	35915	35922	115	-75.6293	429	24155	230	24401	230	564.9	489.06	15.5073
2813	35917	35922	115	-61.6358	659	24837	115	24819	115	213.6749	181.467	17.7486
2813	35917	35922	115	-61.6358	429	24155	230	24401	230	564.8985	489.06	15.507
2814	35918	35920	115	-20.7113	659	24837	115	24819	115	213.674	181.467	17.74812
2814	35918	35920	115	-20.7113	429	24155	230	24401	230	564.8955	489.06	15.50639
2815	35918	35928	115	-72.3456	659	24837	115	24819	115	213.6749	181.467	17.7486
2815	35918	35928	115	-72.3456	429	24155	230	24401	230	564.8986	489.06	15.50701
2816	35920	35927	115	-71.4704	659	24837	115	24819	115	213.6748	181.467	17.74859
2816	35920	35927	115	-71.4704	429	24155	230	24401	230	564.8985	489.06	15.50699
2817	35921	35922	115	145.9269	659	24837	115	24819	115	213.6746	181.467	17.74848
2817	35921	35922	115	145.9269	429	24155	230	24401	230	564.8978	489.06	15.50685
2818	35921	35923	115	49.12958	659	24837	115	24819	115	213.6748	181.467	17.74859
2818	35921	35923	115	49.12958	429	24155	230	24401	230	564.8985	489.06	15.50699
2819	35921	35925	115	62.82029	659	24837	115	24819	115	213.6754	181.467	17.74888
2819	35921	35925	115	62.82029	429	24155	230	24401	230	564.9003	489.06	15.50736
2820	35921	35927	115	82.11597	659	24837	115	24819	115	213.6751	181.467	17.74873
2820	35921	35927	115	82.11597	429	24155	230	24401	230	564.8994	489.06	15.50717
2821	35921	35928	115	73.30756	659	24837	115	24819	115	213.6749	181.467	17.74861
2821	35921	35928	115	73.30756	429	24155	230	24401	230	564.8986	489.06	15.50701
2822	35923	35929	115	49.07478	659	24837	115	24819	115	213.6748	181.467	17.74859
2822	35923	35929	115	49.07478	429	24155	230	24401	230	564.8985	489.06	15.50699
2823	35924	35925	115	-16.1447	659	24837	115	24819	115	213.6751	181.467	17.74875
2823	35924	35925	115	-16.1447	429	24155	230	24401	230	564.899	489.06	15.5071
2824	35925	35929	115	46.58269	659	24837	115	24819	115	213.6747	181.467	17.74854
2824	35925	35929	115	46.58269	429	24155	230	24401	230	564.8982	489.06	15.50693

2825	35926	35927	115	-9.68323	659	24837	115	24819	115	213.6747	181.467	17.7485
2825	35926	35927	115	-9.68323	429	24155	230	24401	230	564.8976	489.06	15.50681
2826	35936	35909	115	25.63784	659	24837	115	24819	115	213.6757	181.467	17.74909
2826	35936	35909	115	25.63784	429	24155	230	24401	230	564.9009	489.06	15.50748
2827	35936	35912	115	-25.6379	659	24837	115	24819	115	213.6757	181.467	17.74909
2827	35936	35912	115	-25.6379	429	24155	230	24401	230	564.9009	489.06	15.50748
2828	35940	35911	115	-31.412	659	24837	115	24819	115	213.6762	181.467	17.74931
2828	35940	35911	115	-31.412	429	24155	230	24401	230	564.9021	489.06	15.50772
2911	36251	36254	115	48.28554	659	24837	115	24819	115	213.6747	181.467	17.7485
2911	36251	36254	115	48.28554	429	24155	230	24401	230	564.898	489.06	15.50689
2912	36252	36303	115	63.80311	659	24837	115	24819	115	213.6751	181.467	17.74875
2912	36252	36303	115	63.80311	429	24155	230	24401	230	564.8996	489.06	15.50722
2913	36252	36304	115	60.8723	659	24837	115	24819	115	213.675	181.467	17.7487
2913	36252	36304	115	60.8723	429	24155	230	24401	230	564.8993	489.06	15.50715
2914	36253	36250	115	7.918305	659	24837	115	24819	115	213.6744	181.467	17.74834
2914	36253	36250	115	7.918305	429	24155	230	24401	230	564.8968	489.06	15.50664
2915	36253	36254	115	52.49431	659	24837	115	24819	115	213.6748	181.467	17.74857
2915	36253	36254	115	52.49431	429	24155	230	24401	230	564.8984	489.06	15.50698
2916	36254	34796	115	-20.7592	659	24837	115	24819	115	213.6745	181.467	17.74839
2916	36254	34796	115	-20.7592	429	24155	230	24401	230	564.8974	489.06	15.50677
2917	36254	36266	115	23.15124	659	24837	115	24819	115	213.6745	181.467	17.74842
2917	36254	36266	115	23.15124	429	24155	230	24401	230	564.8975	489.06	15.50679
2918	36254	36278	115	30.67352	659	24837	115	24819	115	213.6749	181.467	17.7486
2918	36254	36278	115	30.67352	429	24155	230	24401	230	564.8986	489.06	15.50702
2919	36256	36258	115	31.30541	659	24837	115	24819	115	213.6742	181.467	17.74825
2919	36256	36258	115	31.30541	429	24155	230	24401	230	564.8964	489.06	15.50656
2920	36256	36267	115	80.0435	659	24837	115	24819	115	213.6749	181.467	17.74864
2920	36256	36267	115	80.0435	429	24155	230	24401	230	564.8988	489.06	15.50706
2922	36256	36280	115	18.93937	659	24837	115	24819	115	213.674	181.467	17.74811
2922	36256	36280	115	18.93937	429	24155	230	24401	230	564.8955	489.06	15.50638

2923	36258	36260	115	36.61129	659	24837	115	24819	115	213.6742	181.467	17.74827
2923	36258	36260	115	36.61129	429	24155	230	24401	230	564.8965	489.06	15.50658
2924	36260	36262	115	2.280887	659	24837	115	24819	115	213.674	181.467	17.74815
2924	36260	36262	115	2.280887	429	24155	230	24401	230	564.8957	489.06	15.50641
2925	36260	36286	115	28.4058	659	24837	115	24819	115	213.6745	181.467	17.74838
2925	36260	36286	115	28.4058	429	24155	230	24401	230	564.8972	489.06	15.50673
2926	36264	36274	115	14.5998	659	24837	115	24819	115	213.6744	181.467	17.74836
2926	36264	36274	115	14.5998	429	24155	230	24401	230	564.8968	489.06	15.50664
2927	36264	36288	115	-19.8612	659	24837	115	24819	115	213.6742	181.467	17.74824
2927	36264	36288	115	-19.8612	429	24155	230	24401	230	564.8964	489.06	15.50655
2928	36264	36290	115	21.51621	659	24837	115	24819	115	213.6747	181.467	17.74851
2928	36264	36290	115	21.51621	429	24155	230	24401	230	564.8975	489.06	15.50679
2929	36264	36294	115	-16.2545	659	24837	115	24819	115	213.6741	181.467	17.74818
2929	36264	36294	115	-16.2545	429	24155	230	24401	230	564.8959	489.06	15.50647
2930	36266	36267	115	-42.6638	659	24837	115	24819	115	213.6741	181.467	17.74821
2930	36266	36267	115	-42.6638	429	24155	230	24401	230	564.8961	489.06	15.5065
2931	36266	36269	115	8.330816	659	24837	115	24819	115	213.674	181.467	17.74812
2931	36266	36269	115	8.330816	429	24155	230	24401	230	564.8956	489.06	15.5064
2932	36267	36270	115	36.97576	659	24837	115	24819	115	213.6755	181.467	17.74897
2932	36267	36270	115	36.97576	429	24155	230	24401	230	564.9001	489.06	15.50732
2933	36268	36296	115	43.14373	659	24837	115	24819	115	213.6757	181.467	17.74908
2933	36268	36296	115	43.14373	429	24155	230	24401	230	564.9006	489.06	15.50743
2934	36268	36300	115	23.32973	659	24837	115	24819	115	213.6742	181.467	17.74826
2934	36268	36300	115	23.32973	429	24155	230	24401	230	564.8965	489.06	15.50658
2935	36269	36260	115	8.328062	659	24837	115	24819	115	213.674	181.467	17.74812
2935	36269	36260	115	8.328062	429	24155	230	24401	230	564.8956	489.06	15.5064
2936	36276	36292	115	11.70227	659	24837	115	24819	115	213.6743	181.467	17.7483
2936	36276	36292	115	11.70227	429	24155	230	24401	230	564.8965	489.06	15.50658
2937	36276	36296	115	-37.4981	659	24837	115	24819	115	213.6754	181.467	17.74892
2937	36276	36296	115	-37.4981	429	24155	230	24401	230	564.8997	489.06	15.50725

2938	36276	38030	115	25.796	659	24837	115	24819	115	213.6749	181.467	17.74861
2938	36276	38030	115	25.796	429	24155	230	24401	230	564.8981	489.06	15.50691
2939	36278	36280	115	-16.5688	659	24837	115	24819	115	213.6739	181.467	17.74807
2939	36278	36280	115	-16.5688	429	24155	230	24401	230	564.8953	489.06	15.50633
2940	36282	36284	115	1.080283	659	24837	115	24819	115	213.674	181.467	17.74812
2940	36282	36284	115	1.080283	429	24155	230	24401	230	564.8955	489.06	15.50639
2941	36282	36300	115	-23.2464	659	24837	115	24819	115	213.6742	181.467	17.74826
2941	36282	36300	115	-23.2464	429	24155	230	24401	230	564.8965	489.06	15.50658
2942	36282	38031	115	22.16623	659	24837	115	24819	115	213.6742	181.467	17.74825
2942	36282	38031	115	22.16623	429	24155	230	24401	230	564.8964	489.06	15.50656
2943	36286	36288	115	26.62997	659	24837	115	24819	115	213.6744	181.467	17.74835
2943	36286	36288	115	26.62997	429	24155	230	24401	230	564.897	489.06	15.50669
2944	36296	36298	115	5.381009	659	24837	115	24819	115	213.6741	181.467	17.74819
2944	36296	36298	115	5.381009	429	24155	230	24401	230	564.8959	489.06	15.50646
2945	36303	36251	115	48.30286	659	24837	115	24819	115	213.6747	181.467	17.7485
2945	36303	36251	115	48.30286	429	24155	230	24401	230	564.898	489.06	15.50689
2946	36303	36302	115	15.03337	659	24837	115	24819	115	213.6748	181.467	17.74856
2946	36303	36302	115	15.03337	429	24155	230	24401	230	564.898	489.06	15.50689
2947	36304	36253	115	60.57446	659	24837	115	24819	115	213.675	181.467	17.7487
2947	36304	36253	115	60.57446	429	24155	230	24401	230	564.8993	489.06	15.50715
2971	36850	35617	115	-1.51066	659	24837	115	24819	115	213.6739	181.467	17.74809
2971	36850	35617	115	-1.51066	429	24155	230	24401	230	564.8954	489.06	15.50636
2972	36850	36861	115	-134.4	659	24837	115	24819	115	213.675	181.467	17.7487
2972	36850	36861	115	-134.4	429	24155	230	24401	230	564.8991	489.06	15.50711
2973	36851	36852	115	111.2978	659	24837	115	24819	115	213.6758	181.467	17.74914
2973	36851	36852	115	111.2978	429	24155	230	24401	230	564.9018	489.06	15.50768
2974	36853	36852	115	52.40573	659	24837	115	24819	115	213.6742	181.467	17.74824
2974	36853	36852	115	52.40573	429	24155	230	24401	230	564.8963	489.06	15.50654
2976	36861	36852	115	-20.9976	659	24837	115	24819	115	213.6741	181.467	17.74819
2976	36861	36852	115	-20.9976	429	24155	230	24401	230	564.896	489.06	15.50649

3010	36964	38230	115	83.49155	659	24837	115	24819	115	213.6694	181.467	17.74558
3010	36964	38230	115	83.49155	429	24155	230	24401	230	564.8803	489.06	15.50327
3043	37051	37053	115	-88.0647	659	24837	115	24819	115	213.6743	181.467	17.74829
3043	37051	37053	115	-88.0647	429	24155	230	24401	230	564.8967	489.06	15.50663
3044	37051	37054	115	-16.5642	659	24837	115	24819	115	213.674	181.467	17.74815
3044	37051	37054	115	-16.5642	429	24155	230	24401	230	564.8957	489.06	15.50643
3045	37051	37055	115	63.12485	659	24837	115	24819	115	213.6741	181.467	17.7482
3045	37051	37055	115	63.12485	429	24155	230	24401	230	564.8961	489.06	15.5065
3046	37052	37056	115	66.76443	659	24837	115	24819	115	213.676	181.467	17.74922
3046	37052	37056	115	66.76443	429	24155	230	24401	230	564.9022	489.06	15.50776
3047	37053	37057	115	111.3705	659	24837	115	24819	115	213.6748	181.467	17.74858
3047	37053	37057	115	111.3705	429	24155	230	24401	230	564.8985	489.06	15.507
3048	37054	37056	115	95.81971	659	24837	115	24819	115	213.6752	181.467	17.74878
3048	37054	37056	115	95.81971	429	24155	230	24401	230	564.8996	489.06	15.50723
3049	37055	37059	115	0.809469	659	24837	115	24819	115	213.6739	181.467	17.7481
3049	37055	37059	115	0.809469	429	24155	230	24401	230	564.8954	489.06	15.50637
3050	37056	37058	115	60.6736	659	24837	115	24819	115	213.674	181.467	17.74814
3050	37056	37058	115	60.6736	429	24155	230	24401	230	564.8957	489.06	15.50642
3051	37056	37059	115	25.7385	659	24837	115	24819	115	213.674	181.467	17.74813
3051	37056	37059	115	25.7385	429	24155	230	24401	230	564.8956	489.06	15.5064
3052	37057	37059	115	44.7722	659	24837	115	24819	115	213.6739	181.467	17.74807
3052	37057	37059	115	44.7722	429	24155	230	24401	230	564.8953	489.06	15.50635
3053	37058	37060	115	15.94768	659	24837	115	24819	115	213.674	181.467	17.74811
3053	37058	37060	115	15.94768	429	24155	230	24401	230	564.8955	489.06	15.50637
3054	37059	37060	115	30.84227	659	24837	115	24819	115	213.674	181.467	17.74811
3054	37059	37060	115	30.84227	429	24155	230	24401	230	564.8955	489.06	15.50638
3062	37505	37648	115	6.154894	659	24837	115	24819	115	213.6739	181.467	17.74808
3062	37505	37648	115	6.154894	429	24155	230	24401	230	564.8953	489.06	15.50635
3063	37505	37922	115	65.40123	659	24837	115	24819	115	213.6752	181.467	17.74878
3063	37505	37922	115	65.40123	429	24155	230	24401	230	564.8996	489.06	15.50722

3064	37505	37937	115	52.91984	659	24837	115	24819	115	213.6748	181.467	17.74855
3064	37505	37937	115	52.91984	429	24155	230	24401	230	564.8983	489.06	15.50694
3087	37570	37571	115	12.62929	659	24837	115	24819	115	213.674	181.467	17.74812
3087	37570	37571	115	12.62929	429	24155	230	24401	230	564.8956	489.06	15.5064
3088	37570	37648	115	12.42312	659	24837	115	24819	115	213.674	181.467	17.74812
3088	37570	37648	115	12.42312	429	24155	230	24401	230	564.8956	489.06	15.5064
3089	37571	37648	115	-5.05539	659	24837	115	24819	115	213.6739	181.467	17.7481
3089	37571	37648	115	-5.05539	429	24155	230	24401	230	564.8954	489.06	15.50637
3100	37649	33574	115	9.000232	659	24837	115	24819	115	213.6745	181.467	17.7484
3100	37649	33574	115	9.000232	429	24155	230	24401	230	564.8973	489.06	15.50675
3101	37901	37903	115	74.03054	659	24837	115	24819	115	213.6761	181.467	17.74931
3101	37901	37903	115	74.03054	429	24155	230	24401	230	564.9029	489.06	15.50789
3102	37901	37904	115	-4.34074	659	24837	115	24819	115	213.6739	181.467	17.74808
3102	37901	37904	115	-4.34074	429	24155	230	24401	230	564.8953	489.06	15.50634
3103	37902	37903	115	-22.3583	659	24837	115	24819	115	213.6796	181.467	17.75123
3103	37902	37903	115	-22.3583	429	24155	230	24401	230	564.9132	489.06	15.51001
3104	37907	37937	115	-52.6253	659	24837	115	24819	115	213.6748	181.467	17.74855
3104	37907	37937	115	-52.6253	429	24155	230	24401	230	564.8982	489.06	15.50694
3105	37907	37951	115	7.387976	659	24837	115	24819	115	213.674	181.467	17.74812
3105	37907	37951	115	7.387976	429	24155	230	24401	230	564.8956	489.06	15.5064
3106	37910	37919	115	-51.1036	659	24837	115	24819	115	213.675	181.467	17.74868
3106	37910	37919	115	-51.1036	429	24155	230	24401	230	564.899	489.06	15.5071
3107	37914	37904	115	4.348901	659	24837	115	24819	115	213.6739	181.467	17.74808
3107	37914	37904	115	4.348901	429	24155	230	24401	230	564.8953	489.06	15.50634
3108	37916	37931	115	-33.4009	659	24837	115	24819	115	213.6741	181.467	17.74817
3108	37916	37931	115	-33.4009	429	24155	230	24401	230	564.8958	489.06	15.50645
3109	37919	37916	115	-17.6285	659	24837	115	24819	115	213.6739	181.467	17.7481
3109	37919	37916	115	-17.6285	429	24155	230	24401	230	564.8954	489.06	15.50636
3110	37919	37925	115	-51.4474	659	24837	115	24819	115	213.6752	181.467	17.74877
3110	37919	37925	115	-51.4474	429	24155	230	24401	230	564.8996	489.06	15.50721

3111	37922	37934	115	50.93976	659	24837	115	24819	115	213.6747	181.467	17.74852
3111	37922	37934	115	50.93976	429	24155	230	24401	230	564.898	489.06	15.50689
3112	37925	37903	115	-51.5342	659	24837	115	24819	115	213.6752	181.467	17.74877
3112	37925	37903	115	-51.5342	429	24155	230	24401	230	564.8996	489.06	15.50722
3113	37928	37914	115	4.356093	659	24837	115	24819	115	213.6739	181.467	17.74808
3113	37928	37914	115	4.356093	429	24155	230	24401	230	564.8953	489.06	15.50634
3114	37928	37943	115	-27.6861	659	24837	115	24819	115	213.6739	181.467	17.74807
3114	37928	37943	115	-27.6861	429	24155	230	24401	230	564.8953	489.06	15.50633
3115	37931	37907	115	-33.4569	659	24837	115	24819	115	213.6742	181.467	17.74821
3115	37931	37907	115	-33.4569	429	24155	230	24401	230	564.8961	489.06	15.50651
3116	37934	37955	115	34.53704	659	24837	115	24819	115	213.6743	181.467	17.74829
3116	37934	37955	115	34.53704	429	24155	230	24401	230	564.8966	489.06	15.50661
3117	37947	37948	115	5.163968	659	24837	115	24819	115	213.6739	181.467	17.74809
3117	37947	37948	115	5.163968	429	24155	230	24401	230	564.8954	489.06	15.50636
3118	37947	37951	115	-40.8816	659	24837	115	24819	115	213.6743	181.467	17.74829
3118	37947	37951	115	-40.8816	429	24155	230	24401	230	564.8966	489.06	15.5066
3119	37948	37910	115	5.163087	659	24837	115	24819	115	213.6739	181.467	17.74809
3119	37948	37910	115	5.163087	429	24155	230	24401	230	564.8954	489.06	15.50636
3120	37951	37943	115	-41.8582	659	24837	115	24819	115	213.674	181.467	17.74815
3120	37951	37943	115	-41.8582	429	24155	230	24401	230	564.8957	489.06	15.50643
3121	37955	37928	115	2.063717	659	24837	115	24819	115	213.674	181.467	17.7481
3121	37955	37928	115	2.063717	429	24155	230	24401	230	564.8955	489.06	15.50637
3123	38022	38026	115	-36.6201	659	24837	115	24819	115	213.6761	181.467	17.74929
3123	38022	38026	115	-36.6201	429	24155	230	24401	230	564.9015	489.06	15.5076
3124	38031	36294	115	22.16081	659	24837	115	24819	115	213.6742	181.467	17.74825
3124	38031	36294	115	22.16081	429	24155	230	24401	230	564.8964	489.06	15.50656
3152	38222	38230	115	-23.6131	659	24837	115	24819	115	213.6739	181.467	17.74807
3152	38222	38230	115	-23.6131	429	24155	230	24401	230	564.8953	489.06	15.50633
3154	38224	38230	115	-0.61004	659	24837	115	24819	115	213.6739	181.467	17.7481
3154	38224	38230	115	-0.61004	429	24155	230	24401	230	564.8954	489.06	15.50637

3155	38224	38238	115	14.23133	659	24837	115	24819	115	213.6755	181.467	17.74894
3155	38224	38238	115	14.23133	429	24155	230	24401	230	564.9001	489.06	15.50732
3158	38238	38240	115	6.314444	659	24837	115	24819	115	213.6746	181.467	17.74847
3158	38238	38240	115	6.314444	429	24155	230	24401	230	564.8975	489.06	15.50678
3213	38410	38412	115	26.89243	659	24837	115	24819	115	213.675	181.467	17.74869
3213	38410	38412	115	26.89243	429	24155	230	24401	230	564.8992	489.06	15.50713
3214	38412	38436	115	18.36543	659	24837	115	24819	115	213.6746	181.467	17.74847
3214	38412	38436	115	18.36543	429	24155	230	24401	230	564.8978	489.06	15.50685
3215	38420	38470	115	22.32332	659	24837	115	24819	115	213.6734	181.467	17.74778
3215	38420	38470	115	22.32332	429	24155	230	24401	230	564.8935	489.06	15.50597
3216	38426	38420	115	-11.2458	659	24837	115	24819	115	213.6736	181.467	17.74791
3216	38426	38420	115	-11.2458	429	24155	230	24401	230	564.8943	489.06	15.50613
3217	38428	38430	115	-50.0483	659	24837	115	24819	115	213.677	181.467	17.74977
3217	38428	38430	115	-50.0483	429	24155	230	24401	230	564.9059	489.06	15.5085
3218	38432	38420	115	51.17391	659	24837	115	24819	115	213.671	181.467	17.74646
3218	38432	38420	115	51.17391	429	24155	230	24401	230	564.8855	489.06	15.50434
3219	38436	38434	115	-4.97581	659	24837	115	24819	115	213.6741	181.467	17.74819
3219	38436	38434	115	-4.97581	429	24155	230	24401	230	564.896	489.06	15.50648
3220	38436	38440	115	-73.5192	659	24837	115	24819	115	213.6683	181.467	17.745
3220	38436	38440	115	-73.5192	429	24155	230	24401	230	564.8761	489.06	15.50241
3221	38436	38442	115	102.7619	659	24837	115	24819	115	213.6828	181.467	17.75297
3221	38436	38442	115	102.7619	429	24155	230	24401	230	564.9259	489.06	15.51259
3222	38438	38428	115	-31.4951	659	24837	115	24819	115	213.6756	181.467	17.749
3222	38438	38428	115	-31.4951	429	24155	230	24401	230	564.9011	489.06	15.50752
3223	38440	38430	115	82.48161	659	24837	115	24819	115	213.6802	181.467	17.75152
3223	38440	38430	115	82.48161	429	24155	230	24401	230	564.9168	489.06	15.51074
3224	38442	38426	115	79.90195	659	24837	115	24819	115	213.68	181.467	17.75144
3224	38442	38426	115	79.90195	429	24155	230	24401	230	564.9163	489.06	15.51063
3243	38470	38438	115	-8.19118	659	24837	115	24819	115	213.6743	181.467	17.74828
3243	38470	38438	115	-8.19118	429	24155	230	24401	230	564.8966	489.06	15.5066

3437	24041	24043	115	-9.96943	659	24837	115	24819	115	213.6491	181.467	17.73443
3437	24041	24043	115	-9.96943	429	24155	230	24401	230	564.8754	489.06	15.50227
3522	24151	24160	115	794.2964	659	24837	115	24819	115	215.007	181.467	18.48272
3522	24151	24160	115	794.2964	429	24155	230	24401	230	567.0781	489.06	15.95266
3523	24151	24229	115	771.7502	659	24837	115	24819	115	214.9692	181.467	18.46184
3523	24151	24229	115	771.7502	429	24155	230	24401	230	567.016	489.06	15.93998
3572	24601	24602	115	328.901	659	24837	115	24819	115	214.3064	181.467	18.09661
3572	24601	24602	115	328.901	429	24155	230	24401	230	565.5317	489.06	15.63646
3572	24601	24602	115	328.901	559	24614	115	24702	115	-247.776	214.929	15.28251
3572	24601	24602	115	328.901	554	24602	115	24702	115	-243.323	214.929	13.21078
3579	24716	24715	13.8	-75	659	24837	115	24819	115	213.674	181.467	17.7481
3579	24716	24715	13.8	-75	429	24155	230	24401	230	564.8954	489.06	15.50637
3588	24723	24722	55	2.363834	659	24837	115	24819	115	213.6747	181.467	17.7485
3588	24723	24722	55	2.363834	429	24155	230	24401	230	564.8981	489.06	15.5069
3589	24725	24786	34.5	27.53702	659	24837	115	24819	115	213.6832	181.467	17.7532
3589	24725	24786	34.5	27.53702	429	24155	230	24401	230	564.9288	489.06	15.5132
3590	24728	24730	115	48.41318	659	24837	115	24819	115	213.701	181.467	17.76301
3590	24728	24730	115	48.41318	429	24155	230	24401	230	564.79	489.06	15.48481
3591	24729	24730	115	-48.4132	659	24837	115	24819	115	213.701	181.467	17.76301
3591	24729	24730	115	-48.4132	429	24155	230	24401	230	564.79	489.06	15.48481
3599	24749	24785	34.5	-23	659	24837	115	24819	115	213.655	181.467	17.73764
3599	24749	24785	34.5	-23	429	24155	230	24401	230	564.8797	489.06	15.50316
3607	24760	24724	115	48.97911	659	24837	115	24819	115	213.6573	181.467	17.73894
3607	24760	24724	115	48.97911	429	24155	230	24401	230	564.835	489.06	15.49401
3609	24776	24784	6.9	-13	659	24837	115	24819	115	213.6733	181.467	17.74775
3609	24776	24784	6.9	-13	429	24155	230	24401	230	564.894	489.06	15.50608
3619	24805	24804	230	-569.518	429	24155	230	24401	230	565.4163	489.06	15.61288
3620	24806	24807	115	193.6203	429	24155	230	24401	230	565.0115	489.06	15.53011
3621	24806	24837	115	180.1628	429	24155	230	24401	230	564.9977	489.06	15.52728
3624	24850	28280	33	-0.00653	659	24837	115	24819	115	213.674	181.467	17.7481

3624	24850	28280	33	-0.00653	429	24155	230	24401	230	564.8954	489.06	15.50637
3626	24901	24903	115	292.2936	659	24837	115	24819	115	215.8046	181.467	18.92224
3626	24901	24903	115	292.2936	429	24155	230	24401	230	565.3896	489.06	15.60741
3668	25637	28280	33	0.006566	659	24837	115	24819	115	213.674	181.467	17.7481
3668	25637	28280	33	0.006566	429	24155	230	24401	230	564.8954	489.06	15.50637
3688	26052	26053	115	-25.8337	659	24837	115	24819	115	213.6859	181.467	17.75466
3688	26052	26053	115	-25.8337	429	24155	230	24401	230	564.8783	489.06	15.50287
3689	26052	26054	115	-23.474	659	24837	115	24819	115	213.6847	181.467	17.75405
3689	26052	26054	115	-23.474	429	24155	230	24401	230	564.8799	489.06	15.50319
3690	26057	26058	7.5	-39.8531	659	24837	115	24819	115	213.7144	181.467	17.77041
3690	26057	26058	7.5	-39.8531	429	24155	230	24401	230	564.7934	489.06	15.4855
3691	26059	26060	7.5	-9.98829	659	24837	115	24819	115	213.684	181.467	17.75366
3691	26059	26060	7.5	-9.98829	429	24155	230	24401	230	564.8699	489.06	15.50115
3771	30790	34158	115	83.86755	659	24837	115	24819	115	213.6791	181.467	17.75095
3771	30790	34158	115	83.86755	429	24155	230	24401	230	564.9134	489.06	15.51004
3772	30835	34412	115	345.0143	659	24837	115	24819	115	213.6996	181.467	17.76223
3772	30835	34412	115	345.0143	429	24155	230	24401	230	564.9809	489.06	15.52383
3774	30875	34370	115	464.277	659	24837	115	24819	115	213.7339	181.467	17.78111
3774	30875	34370	115	464.277	429	24155	230	24401	230	565.1001	489.06	15.54822
3774	30875	34370	115	464.277	2396	34429	115	34428	115	180.7308	162.36	11.31484
3774	30875	34370	115	464.277	2390	34418	115	34428	115	-173.143	156.42	10.69122
3775	30881	34430	115	7.331315	659	24837	115	24819	115	213.6745	181.467	17.74841
3775	30881	34430	115	7.331315	429	24155	230	24401	230	564.8974	489.06	15.50676
3781	31080	31000	115	17.32943	659	24837	115	24819	115	213.6719	181.467	17.74697
3781	31080	31000	115	17.32943	429	24155	230	24401	230	564.8888	489.06	15.50501
3784	31110	31015	115	-6.59465	659	24837	115	24819	115	213.6745	181.467	17.74843
3784	31110	31015	115	-6.59465	429	24155	230	24401	230	564.8974	489.06	15.50677
3792	31236	30430	230	-309.715	659	24837	115	24819	115	213.7063	181.467	17.76591
3792	31236	30430	230	-309.715	429	24155	230	24401	230	565.0007	489.06	15.52789
3793	31255	30435	230	-191.519	659	24837	115	24819	115	213.6902	181.467	17.75704

3793	31255	30435	230	-191.519	429	24155	230	24401	230	564.9495	489.06	15.51741
3794	31300	31200	115	-32.2572	659	24837	115	24819	115	213.6741	181.467	17.74816
3794	31300	31200	115	-32.2572	429	24155	230	24401	230	564.8958	489.06	15.50644
3802	31336	31206	115	-17.2711	659	24837	115	24819	115	213.6741	181.467	17.74816
3802	31336	31206	115	-17.2711	429	24155	230	24401	230	564.8958	489.06	15.50644
3803	31344	31220	115	-38.9477	659	24837	115	24819	115	213.6751	181.467	17.74874
3803	31344	31220	115	-38.9477	429	24155	230	24401	230	564.8991	489.06	15.50712
3804	31378	31236	115	-139.553	1242	31336	60	31370	60	49.80481	28.71	73.47549
3804	31378	31236	115	-139.553	1265	31374	60	31382	60	49.78332	30.492	63.26683
3804	31378	31236	115	-139.553	1269	31378	60	31382	60	-49.7721	30.591	62.70172
3804	31378	31236	115	-139.553	1263	31370	60	31374	60	49.79243	30.69	62.24317
3804	31378	31236	115	-139.553	659	24837	115	24819	115	213.6824	181.467	17.75276
3804	31378	31236	115	-139.553	429	24155	230	24401	230	564.9208	489.06	15.51155
3820	31428	31260	115	7.00E-06	659	24837	115	24819	115	213.6739	181.467	17.7481
3820	31428	31260	115	7.00E-06	429	24155	230	24401	230	564.8954	489.06	15.50637
3827	31463	31465	9.1	-52.98	659	24837	115	24819	115	213.6606	181.467	17.74072
3827	31463	31465	9.1	-52.98	429	24155	230	24401	230	564.8534	489.06	15.49777
3828	31464	30105	230	11.03697	659	24837	115	24819	115	213.6738	181.467	17.74801
3828	31464	30105	230	11.03697	429	24155	230	24401	230	564.8948	489.06	15.50625
3829	31464	30106	230	24.57354	659	24837	115	24819	115	213.673	181.467	17.7476
3829	31464	30106	230	24.57354	429	24155	230	24401	230	564.8923	489.06	15.50574
3830	31469	31471	9.1	1.140003	659	24837	115	24819	115	213.6742	181.467	17.74826
3830	31469	31471	9.1	1.140003	429	24155	230	24401	230	564.8963	489.06	15.50655
3833	31482	30325	230	-108.093	659	24837	115	24819	115	213.6786	181.467	17.75064
3833	31482	30325	230	-108.093	429	24155	230	24401	230	564.9107	489.06	15.50949
3834	31486	30255	230	59.01241	1331	31516	115	31512	115	-95.3429	64.35	48.16305
3834	31486	30255	230	59.01241	1310	31482	115	31516	115	-95.2458	64.35	48.01211
3834	31486	30255	230	59.01241	1316	31488	115	31512	115	96.38213	79.2	21.6946
3834	31486	30255	230	59.01241	659	24837	115	24819	115	213.6731	181.467	17.74766
3834	31486	30255	230	59.01241	429	24155	230	24401	230	564.8928	489.06	15.50583

3836	31504	30300	230	-124.478	659	24837	115	24819	115	213.6804	181.467	17.75166
3836	31504	30300	230	-124.478	429	24155	230	24401	230	564.9171	489.06	15.5108
3837	31504	30303	230	-127.64	659	24837	115	24819	115	213.6865	181.467	17.75504
3837	31504	30303	230	-127.64	429	24155	230	24401	230	564.9367	489.06	15.51481
3838	31556	31452	115	-17.2277	659	24837	115	24819	115	213.6747	181.467	17.74854
3838	31556	31452	115	-17.2277	429	24155	230	24401	230	564.8981	489.06	15.5069
3839	31580	31468	115	-38.6521	659	24837	115	24819	115	213.6757	181.467	17.74905
3839	31580	31468	115	-38.6521	429	24155	230	24401	230	564.9013	489.06	15.50756
3848	31712	31500	115	-24.284	659	24837	115	24819	115	213.6743	181.467	17.7483
3848	31712	31500	115	-24.284	429	24155	230	24401	230	564.8958	489.06	15.50644
3865	31800	31462	115	41.12	659	24837	115	24819	115	213.6636	181.467	17.74238
3865	31800	31462	115	41.12	429	24155	230	24401	230	564.8629	489.06	15.49971
3897	31950	30450	230	-55.9334	659	24837	115	24819	115	213.6847	181.467	17.75404
3897	31950	30450	230	-55.9334	429	24155	230	24401	230	564.9308	489.06	15.5136
3898	31951	30451	230	-6.66601	659	24837	115	24819	115	213.675	181.467	17.74865
3898	31951	30451	230	-6.66601	429	24155	230	24401	230	564.8985	489.06	15.507
3899	31984	30348	230	-176.426	1460	31962	115	31992	115	152.4969	123.75	23.22981
3899	31984	30348	230	-176.426	1569	32214	115	31986	115	107.125	87.12	22.96261
3899	31984	30348	230	-176.426	1476	31990	115	31992	115	-151.904	123.75	22.75051
3899	31984	30348	230	-176.426	659	24837	115	24819	115	213.6896	181.467	17.75675
3899	31984	30348	230	-176.426	429	24155	230	24401	230	564.9481	489.06	15.51713
3900	31998	30460	230	-246.327	1488	31999	115	31998	115	317.5459	236.61	34.20644
3900	31998	30460	230	-246.327	659	24837	115	24819	115	213.6776	181.467	17.75013
3900	31998	30460	230	-246.327	429	24155	230	24401	230	564.9082	489.06	15.50899
3901	31999	30460	230	-38.171	659	24837	115	24819	115	213.6758	181.467	17.74914
3901	31999	30460	230	-38.171	429	24155	230	24401	230	564.9019	489.06	15.50769
3902	32018	30337	230	-337.385	1576	32224	115	32232	115	227.9601	128.7	77.12518
3902	32018	30337	230	-337.385	1572	32218	115	32220	115	169.0407	96.822	74.58918
3902	32018	30337	230	-337.385	1585	32232	115	32238	115	205.9106	128.7	59.99272
3902	32018	30337	230	-337.385	1575	32220	115	32224	115	190.5962	123.849	53.894

3902	32018	30337	230	-337.385	1580	32228	115	32238	115	-184.426	128.205	43.85273
3902	32018	30337	230	-337.385	659	24837	115	24819	115	213.7143	181.467	17.77032
3902	32018	30337	230	-337.385	429	24155	230	24401	230	565.0246	489.06	15.53277
3904	32088	31998	115	-73.81	659	24837	115	24819	115	213.6829	181.467	17.75305
3904	32088	31998	115	-73.81	429	24155	230	24401	230	564.9228	489.06	15.51196
3905	32110	32018	115	-9.86811	659	24837	115	24819	115	213.674	181.467	17.74813
3905	32110	32018	115	-9.86811	429	24155	230	24401	230	564.8953	489.06	15.50634
3908	32156	31962	115	23.51	659	24837	115	24819	115	213.6735	181.467	17.74786
3908	32156	31962	115	23.51	429	24155	230	24401	230	564.8948	489.06	15.50623
3919	32185	32011	115	48.7	659	24837	115	24819	115	213.6687	181.467	17.74519
3919	32185	32011	115	48.7	429	24155	230	24401	230	564.8795	489.06	15.50312
3920	32214	30330	230	-105.112	1469	31978	115	31984	115	-107.688	87.12	23.6085
3920	32214	30330	230	-105.112	659	24837	115	24819	115	213.6822	181.467	17.75263
3920	32214	30330	230	-105.112	429	24155	230	24401	230	564.9229	489.06	15.51198
3921	32218	32242	115	-24.6191	659	24837	115	24819	115	213.6738	181.467	17.748
3921	32218	32242	115	-24.6191	429	24155	230	24401	230	564.8948	489.06	15.50625
3922	32218	32246	115	-24.715	659	24837	115	24819	115	213.6738	181.467	17.748
3922	32218	32246	115	-24.715	429	24155	230	24401	230	564.8948	489.06	15.50624
3926	32292	32451	13.8	-48.4721	659	24837	115	24819	115	213.6729	181.467	17.74753
3926	32292	32451	13.8	-48.4721	429	24155	230	24401	230	564.8936	489.06	15.50599
3929	32330	32200	115	-8.08568	659	24837	115	24819	115	213.6742	181.467	17.74821
3929	32330	32200	115	-8.08568	429	24155	230	24401	230	564.8961	489.06	15.5065
3931	32342	32212	115	-22.7796	659	24837	115	24819	115	213.6748	181.467	17.74859
3931	32342	32212	115	-22.7796	429	24155	230	24401	230	564.8983	489.06	15.50696
3931	32342	32212	115	-22.7796	1636	32320	60	32344	60	33.54428	30.492	10.0101
3932	32374	32242	115	-1.07613	659	24837	115	24819	115	213.674	181.467	17.74811
3932	32374	32242	115	-1.07613	429	24155	230	24401	230	564.8955	489.06	15.50637
3933	32374	32246	115	-1.57585	659	24837	115	24819	115	213.674	181.467	17.74811
3933	32374	32246	115	-1.57585	429	24155	230	24401	230	564.8955	489.06	15.50638
3935	32394	32228	115	-65.2452	659	24837	115	24819	115	213.6741	181.467	17.74819

3935	32394	32228	115	-65.2452	429	24155	230	24401	230	564.8938	489.06	15.50604
3953	32490	32210	115	48.83001	659	24837	115	24819	115	213.6729	181.467	17.7475
3953	32490	32210	115	48.83001	429	24155	230	24401	230	564.8935	489.06	15.50596
3962	32513	32250	115	9.920004	659	24837	115	24819	115	213.674	181.467	17.74813
3962	32513	32250	115	9.920004	429	24155	230	24401	230	564.896	489.06	15.50647
3963	32514	32250	115	9.920004	659	24837	115	24819	115	213.674	181.467	17.74813
3963	32514	32250	115	9.920004	429	24155	230	24401	230	564.896	489.06	15.50647
3964	32568	30445	230	-287.52	659	24837	115	24819	115	213.6984	181.467	17.76158
3964	32568	30445	230	-287.52	429	24155	230	24401	230	564.9676	489.06	15.52113
3966	32666	32568	115	-106.487	659	24837	115	24819	115	213.6814	181.467	17.75221
3966	32666	32568	115	-106.487	429	24155	230	24401	230	564.9168	489.06	15.51073
3970	32786	32908	12	16.18168	659	24837	115	24819	115	213.6749	181.467	17.74864
3970	32786	32908	12	16.18168	429	24155	230	24401	230	564.8982	489.06	15.50693
3971	32852	32756	115	-3.16402	659	24837	115	24819	115	213.6741	181.467	17.7482
3971	32852	32756	115	-3.16402	429	24155	230	24401	230	564.8959	489.06	15.50646
3975	32911	32910	12	-29.2365	659	24837	115	24819	115	213.6725	181.467	17.74731
3975	32911	32910	12	-29.2365	429	24155	230	24401	230	564.8916	489.06	15.50557
3977	32950	30526	230	-192.698	659	24837	115	24819	115	213.6892	181.467	17.7565
3977	32950	30526	230	-192.698	429	24155	230	24401	230	564.9466	489.06	15.51684
3981	32990	33142	12.47	-8.95515	659	24837	115	24819	115	213.6738	181.467	17.74804
3981	32990	33142	12.47	-8.95515	429	24155	230	24401	230	564.8951	489.06	15.50629
3982	32991	33142	12.47	-8.80082	659	24837	115	24819	115	213.6738	181.467	17.74804
3982	32991	33142	12.47	-8.80082	429	24155	230	24401	230	564.8951	489.06	15.5063
3983	32996	33141	12.47	1.056475	659	24837	115	24819	115	213.674	181.467	17.74811
3983	32996	33141	12.47	1.056475	429	24155	230	24401	230	564.8955	489.06	15.50638
3984	32996	33143	12.47	-8.91393	659	24837	115	24819	115	213.6738	181.467	17.74804
3984	32996	33143	12.47	-8.91393	429	24155	230	24401	230	564.8951	489.06	15.50629
3985	32997	33141	12.47	1.183526	659	24837	115	24819	115	213.674	181.467	17.74811
3985	32997	33141	12.47	1.183526	429	24155	230	24401	230	564.8955	489.06	15.50638
3986	32997	33143	12.47	-8.75947	659	24837	115	24819	115	213.6738	181.467	17.74804

3986	32997	33143	12.47	-8.75947	429	24155	230	24401	230	564.8951	489.06	15.5063
3987	33000	30523	230	-23.6707	659	24837	115	24819	115	213.677	181.467	17.74979
3987	33000	30523	230	-23.6707	429	24155	230	24401	230	564.905	489.06	15.50833
3988	33010	30540	230	-462.488	3990	33020	115	30551	230	-178.027	133.056	33.79861
3988	33010	30540	230	-462.488	3991	33020	115	30552	230	-175.329	133.056	31.77095
3988	33010	30540	230	-462.488	659	24837	115	24819	115	213.707	181.467	17.76633
3988	33010	30540	230	-462.488	429	24155	230	24401	230	565.0062	489.06	15.52901
3989	33020	30550	230	-143.567	659	24837	115	24819	115	213.6802	181.467	17.75153
3989	33020	30550	230	-143.567	429	24155	230	24401	230	564.9165	489.06	15.51067
3990	33020	30551	230	-52.0279	659	24837	115	24819	115	213.6769	181.467	17.74971
3990	33020	30551	230	-52.0279	429	24155	230	24401	230	564.9053	489.06	15.50838
3991	33020	30552	230	-51.182	659	24837	115	24819	115	213.6768	181.467	17.74967
3991	33020	30552	230	-51.182	429	24155	230	24401	230	564.9051	489.06	15.50834
3992	33050	33000	115	2.716276	659	24837	115	24819	115	213.6736	181.467	17.74792
3992	33050	33000	115	2.716276	429	24155	230	24401	230	564.8944	489.06	15.50616
4003	33132	32960	115	9.38	659	24837	115	24819	115	213.6737	181.467	17.74797
4003	33132	32960	115	9.38	429	24155	230	24401	230	564.8949	489.06	15.50627
4004	33133	33002	115	16.19	659	24837	115	24819	115	213.6721	181.467	17.74709
4004	33133	33002	115	16.19	429	24155	230	24401	230	564.8898	489.06	15.50522
4006	33136	33041	115	1.390001	659	24837	115	24819	115	213.6739	181.467	17.74807
4006	33136	33041	115	1.390001	429	24155	230	24401	230	564.8953	489.06	15.50634
4009	33160	32956	115	44.29359	659	24837	115	24819	115	213.6728	181.467	17.74745
4009	33160	32956	115	44.29359	429	24155	230	24401	230	564.8929	489.06	15.50585
4010	33178	33049	115	-1.30001	659	24837	115	24819	115	213.6741	181.467	17.74818
4010	33178	33049	115	-1.30001	429	24155	230	24401	230	564.8959	489.06	15.50646
4011	33205	33271	12	23.75158	659	24837	115	24819	115	213.6747	181.467	17.74849
4011	33205	33271	12	23.75158	429	24155	230	24401	230	564.8971	489.06	15.5067
4012	33208	30695	230	-177.373	659	24837	115	24819	115	213.6817	181.467	17.75235
4012	33208	30695	230	-177.373	429	24155	230	24401	230	564.9216	489.06	15.51171
4013	33209	33208	115	-12.6053	659	24837	115	24819	115	213.6743	181.467	17.74831

4013	33209	33208	115	-12.6053	429	24155	230	24401	230	564.8963	489.06	15.50655
4014	33218	33200	115	-34.7745	659	24837	115	24819	115	213.6746	181.467	17.74847
4014	33218	33200	115	-34.7745	429	24155	230	24401	230	564.8977	489.06	15.50683
4015	33218	33201	115	-34.3113	659	24837	115	24819	115	213.6746	181.467	17.74846
4015	33218	33201	115	-34.3113	429	24155	230	24401	230	564.8977	489.06	15.50682
4016	33218	33202	115	-34.2881	659	24837	115	24819	115	213.6747	181.467	17.74849
4016	33218	33202	115	-34.2881	429	24155	230	24401	230	564.8978	489.06	15.50685
4017	33219	33200	115	-33.2501	659	24837	115	24819	115	213.6746	181.467	17.74844
4017	33219	33200	115	-33.2501	429	24155	230	24401	230	564.8975	489.06	15.50679
4018	33219	33201	115	-33.6543	659	24837	115	24819	115	213.6746	181.467	17.74844
4018	33219	33201	115	-33.6543	429	24155	230	24401	230	564.8975	489.06	15.5068
4019	33219	33202	115	-36.4696	659	24837	115	24819	115	213.6747	181.467	17.74852
4019	33219	33202	115	-36.4696	429	24155	230	24401	230	564.898	489.06	15.50689
4020	33252	33204	115	206.37	659	24837	115	24819	115	213.6681	181.467	17.74487
4020	33252	33204	115	206.37	429	24155	230	24401	230	564.8822	489.06	15.50367
4027	33307	33353	60	19.27316	659	24837	115	24819	115	213.6746	181.467	17.74848
4027	33307	33353	60	19.27316	429	24155	230	24401	230	564.8972	489.06	15.50672
4028	33310	30700	230	-604.576	1981	33378	60	33380	60	-69.2055	55.341	25.05282
4028	33310	30700	230	-604.576	1960	33361	60	33378	60	-68.286	55.341	23.39128
4028	33310	30700	230	-604.576	659	24837	115	24819	115	213.7127	181.467	17.76947
4028	33310	30700	230	-604.576	429	24155	230	24401	230	565.0257	489.06	15.533
4028	33310	30700	230	-604.576	1958	33360	60	33361	60	-57.8271	50.193	15.20947
4028	33310	30700	230	-604.576	1965	33365	60	33367	60	-57.1674	50.886	12.3441
4029	33310	33318	115	5.903903	659	24837	115	24819	115	213.6739	181.467	17.7481
4029	33310	33318	115	5.903903	429	24155	230	24401	230	564.8954	489.06	15.50637
4030	33315	30703	230	-190.589	659	24837	115	24819	115	213.6862	181.467	17.75484
4030	33315	30703	230	-190.589	429	24155	230	24401	230	564.9367	489.06	15.51481
4031	33321	30703	230	-188.311	659	24837	115	24819	115	213.6802	181.467	17.75153
4031	33321	30703	230	-188.311	429	24155	230	24401	230	564.9166	489.06	15.5107
4032	33357	33310	115	-16.7246	659	24837	115	24819	115	213.6739	181.467	17.7481

4032	33357	33310	115	-16.7246	429	24155	230	24401	230	564.8954	489.06	15.50636
4033	33357	33318	115	-5.90259	659	24837	115	24819	115	213.6739	181.467	17.7481
4033	33357	33318	115	-5.90259	429	24155	230	24401	230	564.8954	489.06	15.50637
4034	33367	33313	115	-43.1261	659	24837	115	24819	115	213.6746	181.467	17.74848
4034	33367	33313	115	-43.1261	429	24155	230	24401	230	564.8977	489.06	15.50683
4035	33375	33316	115	-46.1817	659	24837	115	24819	115	213.6746	181.467	17.74846
4035	33375	33316	115	-46.1817	429	24155	230	24401	230	564.8976	489.06	15.50682
4036	33375	33317	115	-50.5271	659	24837	115	24819	115	213.6747	181.467	17.74852
4036	33375	33317	115	-50.5271	429	24155	230	24401	230	564.898	489.06	15.50689
4042	33540	30625	230	-287.074	4359	37560	230	37649	115	215.2924	178.2	20.81506
4042	33540	30625	230	-287.074	659	24837	115	24819	115	213.7094	181.467	17.76761
4042	33540	30625	230	-287.074	429	24155	230	24401	230	565.0159	489.06	15.531
4043	33562	30500	230	-50.5368	659	24837	115	24819	115	213.6743	181.467	17.74829
4043	33562	30500	230	-50.5368	429	24155	230	24401	230	564.8966	489.06	15.50661
4044	33562	30501	230	-51.1074	659	24837	115	24819	115	213.6743	181.467	17.74829
4044	33562	30501	230	-51.1074	429	24155	230	24401	230	564.8966	489.06	15.50661
4045	33584	30486	230	35.55808	659	24837	115	24819	115	213.6711	181.467	17.74653
4045	33584	30486	230	35.55808	429	24155	230	24401	230	564.887	489.06	15.50464
4054	33742	33514	115	-19.2393	659	24837	115	24819	115	213.6741	181.467	17.74818
4054	33742	33514	115	-19.2393	429	24155	230	24401	230	564.8959	489.06	15.50647
4055	33756	33528	115	-43.8715	4054	33742	60	33514	115	-60.1494	30.888	94.7338
4055	33756	33528	115	-43.8715	2147	33742	60	33703	60	41.77017	28.71	45.48997
4055	33756	33528	115	-43.8715	659	24837	115	24819	115	213.676	181.467	17.74922
4055	33756	33528	115	-43.8715	429	24155	230	24401	230	564.9025	489.06	15.50781
4057	33800	33582	115	36.26904	659	24837	115	24819	115	213.671	181.467	17.7465
4057	33800	33582	115	36.26904	429	24155	230	24401	230	564.8868	489.06	15.50461
4064	33814	33958	115	42.81004	659	24837	115	24819	115	213.6708	181.467	17.74636
4064	33814	33958	115	42.81004	429	24155	230	24401	230	564.8862	489.06	15.50448
4079	34002	33964	115	-24.8527	659	24837	115	24819	115	213.6783	181.467	17.75048
4079	34002	33964	115	-24.8527	429	24155	230	24401	230	564.9093	489.06	15.50919

4084	34112	34232	70	-58.5135	2325	34321	70	34232	70	-63.7545	28.71	122.0636
4084	34112	34232	70	-58.5135	2324	34321	70	34230	70	73.23699	38.61	89.68399
4084	34112	34232	70	-58.5135	2281	34202	70	34230	70	-67.1503	39.006	72.15388
4084	34112	34232	70	-58.5135	4088	34144	115	34202	70	-77.5749	49.5	56.71691
4084	34112	34232	70	-58.5135	659	24837	115	24819	115	213.673	181.467	17.7476
4084	34112	34232	70	-58.5135	429	24155	230	24401	230	564.8923	489.06	15.50573
4085	34134	30800	230	-90.7969	659	24837	115	24819	115	213.6752	181.467	17.74882
4085	34134	30800	230	-90.7969	429	24155	230	24401	230	564.8998	489.06	15.50727
4086	34136	30800	230	-90.9246	659	24837	115	24819	115	213.6752	181.467	17.74881
4086	34136	30800	230	-90.9246	429	24155	230	24401	230	564.8998	489.06	15.50726
4087	34142	34141	115	49	659	24837	115	24819	115	213.674	181.467	17.7481
4087	34142	34141	115	49	429	24155	230	24401	230	564.8954	489.06	15.50637
4088	34144	34202	70	-24.7611	2233	34112	115	34116	115	81.4322	67.221	21.14101
4088	34144	34202	70	-24.7611	659	24837	115	24819	115	213.6734	181.467	17.74782
4088	34144	34202	70	-24.7611	429	24155	230	24401	230	564.8937	489.06	15.50602
4089	34178	34179	13.8	3.600003	659	24837	115	24819	115	213.6742	181.467	17.74822
4089	34178	34179	13.8	3.600003	429	24155	230	24401	230	564.8961	489.06	15.5065
4091	34200	34162	115	-21.2901	659	24837	115	24819	115	213.6734	181.467	17.7478
4091	34200	34162	115	-21.2901	429	24155	230	24401	230	564.8936	489.06	15.50599
4094	34268	34156	115	-1.16977	659	24837	115	24819	115	213.674	181.467	17.7481
4094	34268	34156	115	-1.16977	429	24155	230	24401	230	564.8955	489.06	15.50637
4096	34305	34111	115	10.5	659	24837	115	24819	115	213.6737	181.467	17.74794
4096	34305	34111	115	10.5	429	24155	230	24401	230	564.8947	489.06	15.50622
4105	34356	34344	6.6	-4.113	659	24837	115	24819	115	213.6739	181.467	17.74809
4105	34356	34344	6.6	-4.113	429	24155	230	24401	230	564.8955	489.06	15.50637
4107	34366	34488	70	4.011615	659	24837	115	24819	115	213.674	181.467	17.7481
4107	34366	34488	70	4.011615	429	24155	230	24401	230	564.8955	489.06	15.50637
4108	34366	34590	115	5.268763	659	24837	115	24819	115	213.674	181.467	17.74812
4108	34366	34590	115	5.268763	429	24155	230	24401	230	564.8956	489.06	15.50639
4109	34378	30901	230	-32.6292	659	24837	115	24819	115	213.6757	181.467	17.74906

4109	34378	30901	230	-32.6292	429	24155	230	24401	230	564.9016	489.06	15.50764
4110	34398	34624	13.2	-30.736	659	24837	115	24819	115	213.6737	181.467	17.74795
4110	34398	34624	13.2	-30.736	429	24155	230	24401	230	564.8953	489.06	15.50634
4112	34418	34576	70	26.35127	659	24837	115	24819	115	213.6744	181.467	17.74837
4112	34418	34576	70	26.35127	429	24155	230	24401	230	564.8964	489.06	15.50657
4118	34492	34380	115	-50.7754	2428	34487	70	34490	70	61.72897	41.58	48.45832
4118	34492	34380	115	-50.7754	659	24837	115	24819	115	213.675	181.467	17.74867
4118	34492	34380	115	-50.7754	429	24155	230	24401	230	564.8989	489.06	15.50707
4118	34492	34380	115	-50.7754	2430	34490	70	34492	70	44.98232	40.887	10.01619
4119	34528	34420	115	-8.74016	659	24837	115	24819	115	213.6741	181.467	17.74817
4119	34528	34420	115	-8.74016	429	24155	230	24401	230	564.8956	489.06	15.50641
4123	34552	34378	115	-14.9308	659	24837	115	24819	115	213.6746	181.467	17.74847
4123	34552	34378	115	-14.9308	429	24155	230	24401	230	564.8978	489.06	15.50686
4125	34562	34354	115	5.597939	659	24837	115	24819	115	213.6738	181.467	17.74804
4125	34562	34354	115	5.597939	429	24155	230	24401	230	564.8951	489.06	15.50629
4127	34590	34488	70	-12.0704	659	24837	115	24819	115	213.6739	181.467	17.74808
4127	34590	34488	70	-12.0704	429	24155	230	24401	230	564.8953	489.06	15.50634
4147	34671	34381	115	48.95001	659	24837	115	24819	115	213.6735	181.467	17.74786
4147	34671	34381	115	48.95001	429	24155	230	24401	230	564.8952	489.06	15.50632
4148	34672	34381	115	48.95001	659	24837	115	24819	115	213.6735	181.467	17.74786
4148	34672	34381	115	48.95001	429	24155	230	24401	230	564.8952	489.06	15.50632
4152	34752	30945	230	-106.158	659	24837	115	24819	115	213.6849	181.467	17.75413
4152	34752	30945	230	-106.158	429	24155	230	24401	230	564.9336	489.06	15.51417
4153	34752	34768	115	38.40674	659	24837	115	24819	115	213.6742	181.467	17.74825
4153	34752	34768	115	38.40674	429	24155	230	24401	230	564.8964	489.06	15.50657
4154	34752	34770	115	38.64653	659	24837	115	24819	115	213.6742	181.467	17.74826
4154	34752	34770	115	38.64653	429	24155	230	24401	230	564.8964	489.06	15.50657
4155	34774	30970	230	-121.083	659	24837	115	24819	115	213.6867	181.467	17.75513
4155	34774	30970	230	-121.083	429	24155	230	24401	230	564.9401	489.06	15.51551
4156	34776	34860	70	32.85643	659	24837	115	24819	115	213.6756	181.467	17.74902

4156	34776	34860	70	32.85643	429	24155	230	24401	230	564.9012	489.06	15.50754
4157	34783	34781	115	8.099924	659	24837	115	24819	115	213.674	181.467	17.7481
4157	34783	34781	115	8.099924	429	24155	230	24401	230	564.8954	489.06	15.50637
4159	34792	34793	69	-9	659	24837	115	24819	115	213.6734	181.467	17.74778
4159	34792	34793	69	-9	429	24155	230	24401	230	564.8936	489.06	15.50599
4163	34914	34768	115	-38.2862	659	24837	115	24819	115	213.6742	181.467	17.74825
4163	34914	34768	115	-38.2862	429	24155	230	24401	230	564.8964	489.06	15.50657
4164	34918	34770	115	-38.5415	659	24837	115	24819	115	213.6742	181.467	17.74825
4164	34918	34770	115	-38.5415	429	24155	230	24401	230	564.8964	489.06	15.50657
4165	34934	34704	115	-12.5415	659	24837	115	24819	115	213.6743	181.467	17.7483
4165	34934	34704	115	-12.5415	429	24155	230	24401	230	564.8967	489.06	15.50663
4171	35024	34717	115	28.288	659	24837	115	24819	115	213.6722	181.467	17.74711
4171	35024	34717	115	28.288	429	24155	230	24401	230	564.8897	489.06	15.5052
4172	35026	34730	115	47.01999	659	24837	115	24819	115	213.6709	181.467	17.7464
4172	35026	34730	115	47.01999	429	24155	230	24401	230	564.8855	489.06	15.50434
4174	35032	34780	115	13.1	659	24837	115	24819	115	213.673	181.467	17.74755
4174	35032	34780	115	13.1	429	24155	230	24401	230	564.8922	489.06	15.5057
4178	35038	34786	115	43.24	659	24837	115	24819	115	213.671	181.467	17.7465
4178	35038	34786	115	43.24	429	24155	230	24401	230	564.8861	489.06	15.50445
4181	35046	34722	115	25.1	659	24837	115	24819	115	213.6724	181.467	17.74723
4181	35046	34722	115	25.1	429	24155	230	24401	230	564.8904	489.06	15.50533
4182	35048	34814	115	1.799999	659	24837	115	24819	115	213.6738	181.467	17.74802
4182	35048	34814	115	1.799999	429	24155	230	24401	230	564.895	489.06	15.50627
4186	35060	34794	115	43.14	659	24837	115	24819	115	213.671	181.467	17.7465
4186	35060	34794	115	43.14	429	24155	230	24401	230	564.8861	489.06	15.50446
4187	35062	34723	115	32.5	659	24837	115	24819	115	213.6719	181.467	17.74695
4187	35062	34723	115	32.5	429	24155	230	24401	230	564.8888	489.06	15.505
4199	35105	30560	230	-157.543	659	24837	115	24819	115	213.683	181.467	17.75309
4199	35105	30560	230	-157.543	429	24155	230	24401	230	564.9259	489.06	15.51261
4200	35120	30630	230	-201.709	659	24837	115	24819	115	213.686	181.467	17.75477

4200	35120	30630	230	-201.709	429	24155	230	24401	230	564.9364	489.06	15.51473
4201	35120	35109	115	-2.98413	659	24837	115	24819	115	213.6741	181.467	17.74817
4201	35120	35109	115	-2.98413	429	24155	230	24401	230	564.8959	489.06	15.50646
4202	35121	30630	230	-204.571	659	24837	115	24819	115	213.6873	181.467	17.75547
4202	35121	30630	230	-204.571	429	24155	230	24401	230	564.9406	489.06	15.5156
4203	35122	30631	230	-248.754	659	24837	115	24819	115	213.6891	181.467	17.75645
4203	35122	30631	230	-248.754	429	24155	230	24401	230	564.9467	489.06	15.51685
4205	35217	35109	115	3.074677	659	24837	115	24819	115	213.6741	181.467	17.74818
4205	35217	35109	115	3.074677	429	24155	230	24401	230	564.8959	489.06	15.50646
4209	35356	30705	230	-509.308	4210	35455	60	30705	230	-245.028	133.056	84.15405
4209	35356	30705	230	-509.308	659	24837	115	24819	115	213.6995	181.467	17.76218
4209	35356	30705	230	-509.308	429	24155	230	24401	230	564.9825	489.06	15.52418
4211	35455	35356	115	-56.8212	659	24837	115	24819	115	213.6728	181.467	17.74748
4211	35455	35356	115	-56.8212	429	24155	230	24401	230	564.8915	489.06	15.50557
4212	35642	30735	230	-425.425	659	24837	115	24819	115	213.6973	181.467	17.76098
4212	35642	30735	230	-425.425	429	24155	230	24401	230	564.9755	489.06	15.52274
4213	35643	30735	230	-416.261	659	24837	115	24819	115	213.6994	181.467	17.76215
4213	35643	30735	230	-416.261	429	24155	230	24401	230	564.9827	489.06	15.52421
4214	35657	35854	13.8	-48.7	659	24837	115	24819	115	213.672	181.467	17.74704
4214	35657	35854	13.8	-48.7	429	24155	230	24401	230	564.8905	489.06	15.50536
4215	35657	35855	13.8	-48.7	659	24837	115	24819	115	213.672	181.467	17.74704
4215	35657	35855	13.8	-48.7	429	24155	230	24401	230	564.8905	489.06	15.50536
4216	35657	35856	13.8	-48.7	659	24837	115	24819	115	213.672	181.467	17.74704
4216	35657	35856	13.8	-48.7	429	24155	230	24401	230	564.8905	489.06	15.50536
4217	35657	35857	13.8	-48.7	659	24837	115	24819	115	213.672	181.467	17.74704
4217	35657	35857	13.8	-48.7	429	24155	230	24401	230	564.8905	489.06	15.50536
4218	35658	30731	230	-196.879	659	24837	115	24819	115	213.6892	181.467	17.75651
4218	35658	30731	230	-196.879	429	24155	230	24401	230	564.9473	489.06	15.51697
4222	35753	35633	115	-31.6515	659	24837	115	24819	115	213.6749	181.467	17.74863
4222	35753	35633	115	-31.6515	429	24155	230	24401	230	564.8977	489.06	15.50684

4223	35850	35647	115	118.93	659	24837	115	24819	115	213.6707	181.467	17.74631
4223	35850	35647	115	118.93	429	24155	230	24401	230	564.8881	489.06	15.50487
4224	35860	35606	115	27.09999	659	24837	115	24819	115	213.6729	181.467	17.74753
4224	35860	35606	115	27.09999	429	24155	230	24401	230	564.8928	489.06	15.50583
4225	35861	35604	115	-3.47001	659	24837	115	24819	115	213.6741	181.467	17.74817
4225	35861	35604	115	-3.47001	429	24155	230	24401	230	564.8958	489.06	15.50644
4226	35863	35632	115	-6.87001	659	24837	115	24819	115	213.6742	181.467	17.74821
4226	35863	35632	115	-6.87001	429	24155	230	24401	230	564.8959	489.06	15.50646
4230	35919	35930	115	17.32378	659	24837	115	24819	115	213.6741	181.467	17.74818
4230	35919	35930	115	17.32378	429	24155	230	24401	230	564.8959	489.06	15.50647
4231	35919	35931	115	17.32853	659	24837	115	24819	115	213.6741	181.467	17.74818
4231	35919	35931	115	17.32853	429	24155	230	24401	230	564.8959	489.06	15.50647
4232	35921	30750	230	-206.179	659	24837	115	24819	115	213.6784	181.467	17.75054
4232	35921	30750	230	-206.179	429	24155	230	24401	230	564.9107	489.06	15.5095
4233	35921	30755	230	-207.107	659	24837	115	24819	115	213.6765	181.467	17.74948
4233	35921	30755	230	-207.107	429	24155	230	24401	230	564.9041	489.06	15.50814
4234	35922	30750	230	-80.1813	659	24837	115	24819	115	213.675	181.467	17.74869
4234	35922	30750	230	-80.1813	429	24155	230	24401	230	564.8992	489.06	15.50713
4235	35922	30755	230	-80.7265	659	24837	115	24819	115	213.675	181.467	17.7487
4235	35922	30755	230	-80.7265	429	24155	230	24401	230	564.8992	489.06	15.50714
4236	36008	35901	115	-3.5353	659	24837	115	24819	115	213.674	181.467	17.74815
4236	36008	35901	115	-3.5353	429	24155	230	24401	230	564.8958	489.06	15.50643
4237	36025	35918	115	-45.9385	659	24837	115	24819	115	213.6743	181.467	17.74829
4237	36025	35918	115	-45.9385	429	24155	230	24401	230	564.8966	489.06	15.50661
4238	36027	35920	115	-49.9605	659	24837	115	24819	115	213.6744	181.467	17.74833
4238	36027	35920	115	-49.9605	429	24155	230	24401	230	564.8969	489.06	15.50666
4239	36035	35929	115	-55.9506	659	24837	115	24819	115	213.678	181.467	17.75036
4239	36035	35929	115	-55.9506	429	24155	230	24401	230	564.9078	489.06	15.5089
4240	36064	35930	115	-17.3043	659	24837	115	24819	115	213.6741	181.467	17.74818
4240	36064	35930	115	-17.3043	429	24155	230	24401	230	564.8959	489.06	15.50647

4241	36064	35931	115	-17.2806	659	24837	115	24819	115	213.6741	181.467	17.74818
4241	36064	35931	115	-17.2806	429	24155	230	24401	230	564.8959	489.06	15.50647
4256	36252	30915	230	-135.262	659	24837	115	24819	115	213.6806	181.467	17.75176
4256	36252	30915	230	-135.262	429	24155	230	24401	230	564.9187	489.06	15.51112
4257	36256	30930	230	-229.764	2917	36254	115	36266	115	131.8668	86.328	52.75097
4257	36256	30930	230	-229.764	659	24837	115	24819	115	213.6899	181.467	17.75686
4257	36256	30930	230	-229.764	429	24155	230	24401	230	564.9509	489.06	15.51771
4257	36256	30930	230	-229.764	2918	36254	115	36278	115	97.93811	87.12	12.41748
4260	36376	36254	115	-23.0329	659	24837	115	24819	115	213.6742	181.467	17.74825
4260	36376	36254	115	-23.0329	429	24155	230	24401	230	564.8964	489.06	15.50657
4261	36378	36268	115	-32.0292	659	24837	115	24819	115	213.6752	181.467	17.74878
4261	36378	36268	115	-32.0292	429	24155	230	24401	230	564.899	489.06	15.5071
4270	36416	36258	115	5.4	659	24837	115	24819	115	213.6737	181.467	17.74799
4270	36416	36258	115	5.4	429	24155	230	24401	230	564.8949	489.06	15.50625
4271	36418	36262	115	-2.28	659	24837	115	24819	115	213.674	181.467	17.74814
4271	36418	36262	115	-2.28	429	24155	230	24401	230	564.8957	489.06	15.50641
4272	36850	36878	60	164.6468	659	24837	115	24819	115	213.6766	181.467	17.74956
4272	36850	36878	60	164.6468	429	24155	230	24401	230	564.9044	489.06	15.50821
4272	36850	36878	60	164.6468	3000	36892	60	36888	60	207.8315	183.546	13.2313
4273	36851	36892	60	87.35009	659	24837	115	24819	115	213.6752	181.467	17.74877
4273	36851	36892	60	87.35009	429	24155	230	24401	230	564.8996	489.06	15.50721
4274	36852	36886	60	142.0384	659	24837	115	24819	115	213.6759	181.467	17.74917
4274	36852	36886	60	142.0384	429	24155	230	24401	230	564.902	489.06	15.50771
4275	36853	36862	60	74.96898	659	24837	115	24819	115	213.6746	181.467	17.74847
4275	36853	36862	60	74.96898	429	24155	230	24401	230	564.8977	489.06	15.50683
4290	36964	30515	230	-83.4915	659	24837	115	24819	115	213.6694	181.467	17.74558
4290	36964	30515	230	-83.4915	429	24155	230	24401	230	564.8803	489.06	15.50327
4296	37005	37052	115	66.82719	659	24837	115	24819	115	213.676	181.467	17.74922
4296	37005	37052	115	66.82719	429	24155	230	24401	230	564.9022	489.06	15.50776
4297	37009	37053	115	199.9676	4298	37010	230	37054	115	241.9618	198	22.20293

4297	37009	37053	115	199.9676	659	24837	115	24819	115	213.6769	181.467	17.74972
4297	37009	37053	115	199.9676	429	24155	230	24401	230	564.906	489.06	15.50853
4298	37010	37054	115	112.5788	659	24837	115	24819	115	213.6782	181.467	17.75042
4298	37010	37054	115	112.5788	429	24155	230	24401	230	564.9098	489.06	15.50929
4330	37201	37051	115	-41.3613	659	24837	115	24819	115	213.6769	181.467	17.74974
4330	37201	37051	115	-41.3613	429	24155	230	24401	230	564.9039	489.06	15.50809
4331	37202	37055	115	-30.7559	659	24837	115	24819	115	213.6761	181.467	17.7493
4331	37202	37055	115	-30.7559	429	24155	230	24401	230	564.9016	489.06	15.50762
4332	37203	37055	115	-42.4219	659	24837	115	24819	115	213.677	181.467	17.74977
4332	37203	37055	115	-42.4219	429	24155	230	24401	230	564.904	489.06	15.50811
4333	37204	37056	115	-39.2402	659	24837	115	24819	115	213.6768	181.467	17.74965
4333	37204	37056	115	-39.2402	429	24155	230	24401	230	564.9034	489.06	15.508
4334	37205	37056	115	-36.0586	659	24837	115	24819	115	213.6765	181.467	17.74953
4334	37205	37056	115	-36.0586	429	24155	230	24401	230	564.9028	489.06	15.50787
4335	37207	37057	115	-65.7539	659	24837	115	24819	115	213.6788	181.467	17.75075
4335	37207	37057	115	-65.7539	429	24155	230	24401	230	564.9091	489.06	15.50916
4336	37208	37060	115	-37.1191	659	24837	115	24819	115	213.6766	181.467	17.74956
4336	37208	37060	115	-37.1191	429	24155	230	24401	230	564.9029	489.06	15.50789
4337	37209	37060	115	-9.54492	659	24837	115	24819	115	213.6746	181.467	17.74847
4337	37209	37060	115	-9.54492	429	24155	230	24401	230	564.8973	489.06	15.50675
4338	37210	37055	115	11.19397	659	24837	115	24819	115	213.6732	181.467	17.74767
4338	37210	37055	115	11.19397	429	24155	230	24401	230	564.8933	489.06	15.50593
4342	37401	37058	115	-7.42383	659	24837	115	24819	115	213.6745	181.467	17.74839
4342	37401	37058	115	-7.42383	429	24155	230	24401	230	564.8969	489.06	15.50666
4343	37402	37058	115	-7.42383	659	24837	115	24819	115	213.6745	181.467	17.74839
4343	37402	37058	115	-7.42383	429	24155	230	24401	230	564.8969	489.06	15.50666
4344	37403	37058	115	-7.42382	659	24837	115	24819	115	213.6745	181.467	17.74839
4344	37403	37058	115	-7.42382	429	24155	230	24401	230	564.8969	489.06	15.50666
4345	37404	37058	115	-7.42382	659	24837	115	24819	115	213.6745	181.467	17.74839
4345	37404	37058	115	-7.42382	429	24155	230	24401	230	564.8969	489.06	15.50666

4346	37405	37058	115	-7.42382	659	24837	115	24819	115	213.6745	181.467	17.74839
4346	37405	37058	115	-7.42382	429	24155	230	24401	230	564.8969	489.06	15.50666
4347	37406	37058	115	-7.42382	659	24837	115	24819	115	213.6745	181.467	17.74839
4347	37406	37058	115	-7.42382	429	24155	230	24401	230	564.8969	489.06	15.50666
4348	37407	37059	115	-40.3008	659	24837	115	24819	115	213.6768	181.467	17.74969
4348	37407	37059	115	-40.3008	429	24155	230	24401	230	564.9036	489.06	15.50803
4352	37544	37901	115	69.69027	659	24837	115	24819	115	213.677	181.467	17.74976
4352	37544	37901	115	69.69027	429	24155	230	24401	230	564.9057	489.06	15.50847
4358	37558	37505	115	62.8729	659	24837	115	24819	115	213.6757	181.467	17.74904
4358	37558	37505	115	62.8729	429	24155	230	24401	230	564.9013	489.06	15.50757
4359	37560	37649	115	86.06094	659	24837	115	24819	115	213.6823	181.467	17.75272
4359	37560	37649	115	86.06094	429	24155	230	24401	230	564.9243	489.06	15.51228
4366	37569	37570	115	25.06919	659	24837	115	24819	115	213.6744	181.467	17.74833
4366	37569	37570	115	25.06919	429	24155	230	24401	230	564.8969	489.06	15.50666
4375	37905	37902	115	-11	659	24837	115	24819	115	213.6767	181.467	17.74963
4375	37905	37902	115	-11	429	24155	230	24401	230	564.9041	489.06	15.50815
4376	37906	37902	115	-11.3	659	24837	115	24819	115	213.6768	181.467	17.74967
4376	37906	37902	115	-11.3	429	24155	230	24401	230	564.9044	489.06	15.5082
4377	37908	37907	115	-11.7	659	24837	115	24819	115	213.6769	181.467	17.74971
4377	37908	37907	115	-11.7	429	24155	230	24401	230	564.9046	489.06	15.50824
4378	37911	37910	115	-11.2	659	24837	115	24819	115	213.6767	181.467	17.74962
4378	37911	37910	115	-11.2	429	24155	230	24401	230	564.9041	489.06	15.50813
4379	37912	37910	115	-16.9	659	24837	115	24819	115	213.6781	181.467	17.7504
4379	37912	37910	115	-16.9	429	24155	230	24401	230	564.9085	489.06	15.50904
4380	37913	37910	115	-16.8	659	24837	115	24819	115	213.6781	181.467	17.75039
4380	37913	37910	115	-16.8	429	24155	230	24401	230	564.9084	489.06	15.50902
4381	37917	37916	115	-15.7	659	24837	115	24819	115	213.6779	181.467	17.75025
4381	37917	37916	115	-15.7	429	24155	230	24401	230	564.9077	489.06	15.50887
4382	37920	37919	115	-17.8	659	24837	115	24819	115	213.6784	181.467	17.75054
4382	37920	37919	115	-17.8	429	24155	230	24401	230	564.9093	489.06	15.5092

4383	37923	37922	115	-14.2	659	24837	115	24819	115	213.6775	181.467	17.75008
4383	37923	37922	115	-14.2	429	24155	230	24401	230	564.9067	489.06	15.50867
4384	37929	37928	115	-13.4	659	24837	115	24819	115	213.6773	181.467	17.74994
4384	37929	37928	115	-13.4	429	24155	230	24401	230	564.9059	489.06	15.50851
4385	37930	37928	115	-11.9	659	24837	115	24819	115	213.6769	181.467	17.74974
4385	37930	37928	115	-11.9	429	24155	230	24401	230	564.9047	489.06	15.50827
4386	37932	37931	115	-1.00E-06	659	24837	115	24819	115	213.674	181.467	17.7481
4386	37932	37931	115	-1.00E-06	429	24155	230	24401	230	564.8954	489.06	15.50637
4387	37935	37934	115	-16.2	659	24837	115	24819	115	213.678	181.467	17.75034
4387	37935	37934	115	-16.2	429	24155	230	24401	230	564.9082	489.06	15.50897
4388	37943	37941	13.8	-27.8996	659	24837	115	24819	115	213.674	181.467	17.7481
4388	37943	37941	13.8	-27.8996	429	24155	230	24401	230	564.8954	489.06	15.50637
4389	37949	37947	115	-21	659	24837	115	24819	115	213.6791	181.467	17.75096
4389	37949	37947	115	-21	429	24155	230	24401	230	564.9117	489.06	15.50969
4390	37950	37947	115	-14.5	659	24837	115	24819	115	213.6775	181.467	17.75007
4390	37950	37947	115	-14.5	429	24155	230	24401	230	564.9066	489.06	15.50865
4391	37952	37951	115	-8.1	659	24837	115	24819	115	213.676	181.467	17.74921
4391	37952	37951	115	-8.1	429	24155	230	24401	230	564.9017	489.06	15.50765
4392	37956	37955	115	-13.4	659	24837	115	24819	115	213.6773	181.467	17.74995
4392	37956	37955	115	-13.4	429	24155	230	24401	230	564.9059	489.06	15.50851
4393	37957	37955	115	-18.9	659	24837	115	24819	115	213.6787	181.467	17.75071
4393	37957	37955	115	-18.9	429	24155	230	24401	230	564.9103	489.06	15.50941
4395	37959	37910	115	-11.1	659	24837	115	24819	115	213.6767	181.467	17.7496
4395	37959	37910	115	-11.1	429	24155	230	24401	230	564.904	489.06	15.50811
4413	38252	38230	115	-53.1994	659	24837	115	24819	115	213.6734	181.467	17.7478
4413	38252	38230	115	-53.1994	429	24155	230	24401	230	564.8936	489.06	15.50599
4415	38276	38224	115	-29.316	659	24837	115	24819	115	213.6734	181.467	17.74779
4415	38276	38224	115	-29.316	429	24155	230	24401	230	564.8935	489.06	15.50598

4428	38410	30670	230	-78.9502	659	24837	115	24819	115	213.6797	181.467	17.75125
4428	38410	30670	230	-78.9502	429	24155	230	24401	230	564.9153	489.06	15.51043
4429	38436	38400	230	-5.95907	659	24837	115	24819	115	213.6741	181.467	17.74821
4429	38436	38400	230	-5.95907	429	24155	230	24401	230	564.8961	489.06	15.50651
4430	38440	38570	13.8	-68.4521	659	24837	115	24819	115	213.6651	181.467	17.74322
4430	38440	38570	13.8	-68.4521	429	24155	230	24401	230	564.8676	489.06	15.50068
4436	38462	38420	115	-17.1833	659	24837	115	24819	115	213.6741	181.467	17.74821
4436	38462	38420	115	-17.1833	429	24155	230	24401	230	564.8961	489.06	15.50651
4467	38900	36851	115	181.3954	659	24837	115	24819	115	213.685	181.467	17.7542
4467	38900	36851	115	181.3954	429	24155	230	24401	230	564.933	489.06	15.51405

Appendix B: LOF Settings

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
36412	25	1	1	0.0117	0.0321	-0.0102	0.0219	30057	500	30060 (ck1)	30060 (ck2)	30055						
36411	25	1	1															
36412	25	1	1	0.0117	0.0382	-0.0133	0.02495	30057	500	30060 (ck1)	30060 (ck2)	30055						
36411	25	1	1							X								
36412	25	1	1	0.0117	0.0387	-0.0135	0.0252	30057	500	30060 (ck1)	30060 (ck2)	30055						
36411	25	1	1								X							
36412	25	1	1	0.0117	0.0396	-0.014	0.02565	30057	500	30060 (ck1)	30060 (ck2)	30055						
36411	25	1	1									X						
24130	22	3	1	0.024	0.0371	-0.0066	0.03055	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654
24129	22	2	1															
24130	22	3	1	0.024	0.398	-0.187	0.211	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654
24129	22	2	1							X								
24130	22	3	1	0.024	0.0471	-0.0116	0.03555	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24129	22	2	1								X							
24130	22	3	1	0.024	0.0482	-0.0121	0.0361	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654
24129	22	2	1									X						
24130	22	3	1	0.024	0.03955	-0.0078	0.03178	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654
24129	22	2	1										X					
24130	22	3	1	0.024	0.054	-0.015	0.039	24131	230	22716 (ck1)	22716 (ck2)	22716 (ck3)	22844 (ck1)	22844 (ck2)	24134 (ck1)	24134 (ck2)	24137	25654
24129	22	2	1											X				
24107	26	1	1	0.0101	0.0424	-0.0162	0.02625	24106	230	24099 (ck1)	24099 (ck2)	24099 (ck3)	24099 (ck4)					
24108	26	2	1															
24107	26	1	1	0.0101	0.0493	-0.0196	0.0297	24106	230	24099 (ck1)	24099 (ck2)	24099 (ck3)	24099 (ck4)					
24108	26	2	1							X								
24107	26	1	1	0.0101	0.053	-0.0215	0.03155	24106	230	24099 (ck1)	24099 (ck2)	24099 (ck3)	24099 (ck4)					
24108	26	2	1								X							
36405	22	1	1	0.0231	0.0384	-0.0077	0.03075	30045	500	30042	30050	30751						
36406	22	1	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
36405	22	1	1	0.0231	0.0473	-0.0121	0.0352	30045	500	30042	30050	30751						
36406	22	1	1								X							
36405	22	1	1	0.0231	0.0495	-0.0132	0.0363	30045	500	30042	30050	30751						
36406	22	1	1							X								
28041	19	1	1	0.0223	0.0394	-0.0086	0.03085	28040	500	24151								
28042	19	2	1															
28041	19	1	1	0.0223	0.042	-0.0099	0.03215	28040	500	24151								
28042	19	2	1							X								
24005	20	5	1	0.033	0.0498	-0.0084	0.0414	24006	230	24016	24021							
24161	20	6	1															
24005	20	5	1	0.033	0.058	-0.0125	0.0455	24006	230	24016	24021							
24161	20	6	1							X								
24005	20	5	1	0.033	0.0596	-0.0133	0.0463	24006	230	24016	24021							
24161	20	6	1								X							
33117	18	1	1	0.0152	0.0435	-0.0142	0.02935	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1															
33117	18	1	1	0.0152	0.0474	-0.0161	0.0313	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1							X								
33117	18	1	1	0.0152	0.0498	-0.0173	0.0325	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
33116	18	1	1								X							
33117	18	1	1	0.0152	0.052	-0.0184	0.0336	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1									X						
33117	18	1	1	0.0152	0.0488	-0.0168	0.032	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1										X					
33117	18	1	1	0.0152	0.0469	-0.0159	0.03105	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1											X				
33117	18	1	1	0.0152	0.0566	-0.0207	0.0359	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1												X			
33117	18	1	1	0.0152	0.059	-0.0219	0.0371	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1													X		
33117	18	1	1	0.0152	0.0476	-0.0162	0.0314	30525	230	30479	30523	30543	30565	30566	30567	30575	30585	
33116	18	1	1														X	
36409	18	1	1	0.0325	0.0376	-0.0026	0.03505	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1															
36409	18	1	1	0.0325	0.0395	-0.0035	0.036	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1							X								
36409	18	1	1	0.0325	0.0385	-0.003	0.0355	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1								X							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
36409	18	1	1	0.0325	0.0421	-0.0048	0.0373	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1									X						
36409	18	1	1	0.0325	0.0433	-0.0054	0.0379	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1										X					
36409	18	1	1	0.0325	0.0399	-0.0037	0.0362	30915	230	30900	30905	30925	30930	30970	36252			
36410	18	1	1											X				
24089	13	1	1	0.017	0.0412	-0.0121	0.0291	24088	230	24128 (ck1)	24128 (ck2)							
24090	13	2	1															
24089	13	1	1	0.017	0.0422	-0.0126	0.0296	24088	230	24128 (ck1)	24128 (ck2)							
24090	13	2	1							X								
24089	13	1	1	0.017	0.0426	-0.0128	0.0298	24088	230	24128 (ck1)	24128 (ck2)							
24090	13	2	1								X							
34600	18	1	1	0.0313	0.0376	-0.0032	0.03445	30820	230	30810								
34602	18	1	1															
34600	18	1	1	0.0313	0.0426	-0.0057	0.03695	30820	230	30810								
34602	18	1	1							X								
24066	13	1	1	0.0311	0.0465	-0.0077	0.0388	24069	230	24044	24044							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
										(ck1)	(ck2)							
24067	13	2	1															
24066	13	1	1	0.0311	0.0471	-0.008	0.0391	24069	230	24044 (ck1)	24044 (ck2)							
24067	13	2	1							X								
24066	13	1	1	0.0311	0.0483	-0.0086	0.0397	24069	230	24044 (ck1)	24044 (ck2)							
24067	13	2	1								X							
24047	18	3	1	0.0315	0.0353	-0.0019	0.0334	24049	230	24040	24198							
24048	18	4	1															
24047	18	3	1	0.0315	0.0366	-0.0026	0.03405	24049	230	24040	24198							
24048	18	4	1							X								
24047	18	3	1	0.0315	0.0398	-0.0042	0.03565	24049	230	24040	24198							
24048	18	4	1								X							
24167	13	3	1	0.0423	0.0588	-0.0083	0.05055	24369	230	24044 (ck1)	24044 (ck2)							
24168	13	4	1															
24167	13	3	1	0.0423	0.0601	-0.0089	0.0512	24369	230	24044 (ck1)	24044 (ck2)							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24168	13	4	1							X								
24167	13	3	1	0.0423	0.0596	-0.0087	0.05095	24369	230	24044 (ck1)	24044 (ck2)							
24168	13	4	1								X							
37561	13	1	1	0.0178	0.0417	-0.012	0.02975	37563	230	30800	38206							
37562	13	2	1															
37561	13	1	1	0.0178	0.0433	-0.0128	0.03055	37563	230	30800	38206							
37562	13	2	1							X								
37561	13	1	1	0.0178	0.0425	-0.0124	0.03015	37563	230	30800	38206							
37562	13	2	1								X							
24052	18	3	1	0.0323	0.0362	-0.002	0.03425	24056	230	24112	24132	24901	25656					
24053	18	4	1															
24052	18	3	1	0.0323	0.0378	-0.0028	0.03505	24056	230	24112	24132	24901	25656					
24053	18	4	1							X								
24052	18	3	1	0.0323	0.0389	-0.0033	0.0356	24056	230	24112	24132	24901	25656					
24053	18	4	1								X							
24052	18	3	1	0.0323	0.0425	-0.0051	0.0374	24056	230	24112	24132	24901	25656					
24053	18	4	1									X						
24052	18	3	1	0.0323	0.0386	-0.0032	0.03545	24056	230	24112	24132	24901	25656					

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24053	18	4	1										X					
22996	18	1	1	0.021	0.0373	-0.0082	0.02915	22998	230	22356 (ck1)	22356 (ck2)							
22997	16	1	1															
22996	18	1	1	0.021	0.0415	-0.0103	0.03125	22998	230	22356 (ck1)	22356 (ck2)							
22997	16	1	1							X								
22996	18	1	1	0.021	0.0397	-0.0094	0.03035	22998	230	22356 (ck1)	22356 (ck2)							
22997	16	1	1								X							
37575	13	1	1	0.0215	0.048	-0.0133	0.03475	37586	230	37545								
37576	13	2	1															
38830	12	1	1	0.221	0.0435	0.0888	0.13225	38620	230	38635								
38825	12	1	1															
34308	13	1	1	0.035	0.0532	-0.0091	0.0441	34358	115	34123	34356	34360	34365					
38845	12	1	1	0.041	0.055	-0.007	0.048	38622	230	38623								
38840	12	1	1	0.041	0.0532	-0.0061	0.0471	38621	230	30303								
22244	24	1	1	0.0577	0.051	0.0034	0.05435	22232	230	22227	22652	22716						
22244	24	1	1	0.0577	0.0526	0.0026	0.05515	22232	230	X	22652	22716						
22244	24	1	1	0.0577	0.0534	0.0022	0.05555	22232	230	22227	X	22716						

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
22244	24	1	1	0.0577	0.056	0.0009	0.05685	22232	230	22227	22652	X						
26067	24	3	1	0.0451	0.0532	-0.0041	0.04915	26066	230	26087	26065							
26067	24	3	1	0.0451	0.0558	-0.0054	0.05045	26066	230	X	26065							
26067	24	3	1	0.0451	0.0564	-0.0057	0.05075	26066	230	26087	X							
32900	18	1	1	0.0502	0.0588	-0.0043	0.0545	30438	230	30437								
32900	18	1	1	0.0502	0.06	-0.0049	0.0551	30438	230	X								
30000	20	1	1	0.0221	0.0306	-0.0043	0.02635	30527	230	300526	30535	30536	30560	30595	30600	30700		
33105	18	1	1															
33106	18	1	1															
30000	20	1	1	0.0221	0.0435	-0.0107	0.0328	30527	230	300526	30535	30536	30560	30595	30600	30700		
33105	18	1	1							X								
33106	18	1	1															
30000	20	1	1	0.0221	0.0489	-0.0134	0.0355	30527	230	300526	30535	30536	30560	30595	30600	30700		
33105	18	1	1								X							
33106	18	1	1															
22262	18	1	1	0.0227	0.0383	-0.0078	0.0305	22261	230	22227	22260 (ck1)	22260 (ck2)						
22263	18	1	1															
22265	18	1	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
22262	18	1	1	0.0227	0.0396	-0.0085	0.03115	22261	230	22227	22260 (ck1)	22260 (ck2)						
22263	18	1	1							X								
22265	18	1	1															
22262	18	1	1	0.0227	0.0413	-0.0093	0.032	22261	230	22227	22260 (ck1)	22260 (ck2)						
22263	18	1	1								X							
22265	18	1	1															
22262	18	1	1	0.0227	0.0407	-0.009	0.0317	22261	230	22227	22260 (ck1)	22260 (ck2)						
22263	18	1	1									X						
22265	18	1	1															
22784	15	1	1	0.0362	0.0735	-0.0187	0.05485	22772	115	22412	22424	22428	22852	22865				
22788	20	1	1															
22792	20	1	1															
22784	15	1	1	0.0362	0.0771	-0.0205	0.05665	22772	115	22412	22424	22428	22852	22865				
22788	20	1	1							X								
22792	20	1	1															
22784	15	1	1	0.0362	0.0784	-0.0211	0.0573	22772	115	22412	22424	22428	22852	22865				
22788	20	1	1								X							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
22792	20	1	1															
22784	15	1	1					22772	115	22412	22424	22428	22852	22865				
22788	20	1	1	0.0362	0.0752	-0.0195	0.0557					X						
22792	20	1	1															
22784	15	1	1					22772	115	22412	22424	22428	22852	22865				
22788	20	1	1	0.0362	0.0787	-0.0213	0.05745						X					
22792	20	1	1															
22784	15	1	1					22772	115	22412	22424	22428	22852	22865				
22788	20	1	1	0.0362	0.0802	-0.022	0.0582							X				
22792	20	1	1															
35882	18	1	1					30741	230	30735	30705							
35881	18	1	1	0.0294	0.0481	-0.0094	0.03875											
35883	18	1	1															
35882	18	1	1					30741	230	30735	30705							
35881	18	1	1	0.0294	0.0509	-0.0108	0.04015			X								
35883	18	1	1															
35882	18	1	1					30741	230	30735	30705							
35881	18	1	1	0.0294	0.0512	-0.0109	0.0403				X							
35883	18	1	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
35074	18	1	1	0.0234	0.0372	-0.0069	0.0303	30947	230	30946 (ck1)	30946 (ck2)							
35075	18	1	1							X								
35079	18	1	1															
35074	18	1	1	0.0234	0.0422	-0.0094	0.0328	30947	230	30946 (ck1)	30946 (ck2)							
35075	18	1	1								X							
35079	18	1	1															
35077	18	1	1	0.02017	0.0388	-0.0093	0.02949	30948	230	30970 (ck1)	30970 (ck2)							
35076	18	1	1															
35078	18	1	1															
35077	18	1	1	0.02017	0.0415	-0.0107	0.03084	30948	230	30970 (ck1)	30970 (ck2)							
35076	18	1	1							X								
35078	18	1	1															
35077	18	1	1	0.02017	0.0397	-0.0098	0.02994	30948	230	30970 (ck1)	30970 (ck2)							
35076	18	1	1								X							
35078	18	1	1															
22981	21	1	1	0.0314	0.0457	-0.0072	0.03855	22984	230	22356	22356							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
										(ck1)	(ck2)							
22982	18	1	1															
22983	18	1	1															
22981	21	1	1	0.0314	0.0479	-0.0083	0.03965	22984	230	22356 (ck1)	22356 (ck2)							
22982	18	1	1							X								
22983	18	1	1															
22981	21	1	1	0.0314	0.0508	-0.0097	0.0411	22984	230	22356 (ck1)	22356 (ck2)							
22982	18	1	1								X							
22983	18	1	1															
33111	18	1	1	0.0328	0.0619	-0.0146	0.04735	32978	115	32950 (ck1)	32950 (ck2)							
33112	18	1	1															
33113	18	1	1															
33111	18	1	1	0.0328	0.0633	-0.0153	0.04805	32978	115	32950 (ck1)	32950 (ck2)							
33112	18	1	1							X								
33113	18	1	1															
33111	18	1	1	0.0328	0.0648	-0.016	0.0488	32978	115	32950 (ck1)	32950 (ck2)							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
33112	18	1	1								X							
33113	18	1	1															
36221	18	1	1	0.0304	0.0487	-0.0092	0.03955	30780	230	30755								
36222	18	1	1															
36223	18	1	1															
36224	18	1	1	0.0208	0.0418	-0.0105	0.0313	30787	230	30750								
36225	18	1	1															
36226	18	1	1															
37522	18	2	1	0.027	0.0471	-0.0101	0.03705	37524	230	37520								
37521	18	1	1															
37523	18	3	1															
24001	18	1	1	0.0221	0.0306	-0.0043	0.02635	24008	230	24007 (ck1)	24007 (ck2)	24016	24084					
24002	18	2	1															
24003	18	3	1															
24004	18	4	1															
24001	18	1	1	0.0221	0.0436	-0.0108	0.03285	24008	230	24007 (ck1)	24007 (ck2)	24016	24084					
24002	18	2	1							X								
24003	18	3	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24004	18	4	1															
24001	18	1	1	0.0221	0.0376	-0.0078	0.02985	24008	230	24007 (ck1)	24007 (ck2)	24016	24084					
24002	18	2	1								X							
24003	18	3	1															
24004	18	4	1															
24001	18	1	1	0.0221	0.0398	-0.0089	0.03095	24008	230	24007 (ck1)	24007 (ck2)	24016	24084					
24002	18	2	1									X						
24003	18	3	1															
24004	18	4	1															
24001	18	1	1	0.0221	0.0411	-0.0095	0.0316	24008	230	24007 (ck1)	24007 (ck2)	24016	24084					
24002	18	2	1										X					
24003	18	3	1															
24004	18	4	1															
26006	18	3	1	0.0217	0.0405	-0.0094	0.0311	26010	230	26052	26086	26094						
26004	18	1	1															
26005	18	2	1															
26007	18	4	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
26006	18	3	1	0.0217	0.0415	-0.0099	0.0316	26010	230	26052	26086	26094						
26004	18	1	1							X								
26005	18	2	1															
26007	18	4	1															
26006	18	3	1	0.0217	0.0437	-0.011	0.0327	26010	230	26052	26086	26094						
26004	18	1	1								X							
26005	18	2	1															
26007	18	4	1															
26006	18	3	1	0.0217	0.0419	-0.0101	0.0318	26010	230	26052	26086	26094						
26004	18	1	1									X						
26005	18	2	1															
26007	18	4	1															
28000	20	1	1	0.0215	0.0369	-0.0077	0.0292	28000	230	24601								
28001	15	1	1															
28002	15	1	1															
28003	15	1	1															
28000	20	1	1	0.0215	0.0455	-0.012	0.0335	28000	230	24601								
28001	15	1	1							X								
28002	15	1	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
28003	15	1	1															
24121	18	5	1	0.0253	0.0419	-0.0083	0.0336	24125	230	24074	24084	24091						
24122	18	6	1															
24123	20	7	1															
24124	20	8	1															
24121	18	5	1	0.0253	0.0456	-0.0102	0.03545	24125	230	24074	24084	24091						
24122	18	6	1							X								
24123	20	7	1															
24124	20	8	1															
24121	18	5	1	0.0253	0.0469	-0.0108	0.0361	24125	230	24074	24084	24091						
24122	18	6	1								X							
24123	20	7	1															
24124	20	8	1															
24121	18	5	1	0.0253	0.051	-0.0129	0.03815	24125	230	24074	24084	24091						
24122	18	6	1									X						
24123	20	7	1															
24124	20	8	1															
33107	24	1	1	0.0268	0.0358	-0.0045	0.0313	30528	230	30526 (ck1)	30526 (ck2)							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
33108	18	1	1															
33109	18	1	1															
33110	18	1	1															
33107	24	1	1	0.0268	0.0378	-0.0055	0.0323	30528	230	30526 (ck1)	30526 (ck2)							
33108	18	1	1							X								
33109	18	1	1															
33110	18	1	1															
33107	24	1	1	0.0268	0.041	-0.0071	0.0339	30528	230	30526 (ck1)	30526 (ck2)							
33108	18	1	1								X							
33109	18	1	1															
33110	18	1	1															
35070	21	1	1	0.02314	0.0454	-0.0111	0.03427	30946	230	30947 (ck1)	30947 (ck2)	30970 (ck1)	30970 (ck2)					
35071	21	1	1															
35072	21	1	1															
35073	21	1	1															
35070	21	1	1	0.02314	0.0467	-0.0118	0.03492	30946	230	30947 (ck1)	30947 (ck2)	30970 (ck1)	30970 (ck2)					

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
35071	21	1	1															
35072	21	1	1							X								
35073	21	1	1															
35070	21	1	1					30946	230	30947 (ck1)	30947 (ck2)	30970 (ck1)	30970 (ck2)					
35071	21	1	1	0.02314	0.0488	-0.0128	0.03597											
35072	21	1	1								X							
35073	21	1	1															
35070	21	1	1					30946	230	30947 (ck1)	30947 (ck2)	30970 (ck1)	30970 (ck2)					
35071	21	1	1	0.02314	0.0469	-0.0119	0.03504											
35072	21	1	1									X						
35073	21	1	1															
35070	21	1	1					30946	230	30947 (ck1)	30947 (ck2)	30970 (ck1)	30970 (ck2)					
35071	21	1	1	0.02314	0.0497	-0.0133	0.03642											
35072	21	1	1										X					
35073	21	1	1															
22233	14	1	1	0.035	0.076	-0.0205	0.0555	22228	115	22052	22108	22580	22632					
22234	14	1	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
22236	14	1	1															
22240	14	1	1															
26026	18	1	1					26025	230	26063	26068	26080	26081					
26030	18	5	1															
26151	18	8	1	0.0317	0.0607	-0.0145	0.0462			X								
26152	18	9	1															
26153	18	10	1															
26026	18	1	1					26025	230	26063	26068	26080	26081					
26030	18	5	1															
26151	18	8	1	0.0317	0.0635	-0.0159	0.0476				X							
26152	18	9	1															
26153	18	10	1															
26026	18	1	1					26025	230	26063	26068	26080	26081					
26030	18	5	1															
26151	18	8	1	0.0317	0.0615	-0.0149	0.0466					X						
26152	18	9	1															
26153	18	10	1															
24921	18	1	1	0.0335	0.0615	-0.014	0.0475	24920	230	24132 (ck1)	24132 (ck2)							

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24922	18	1	1															
24923	18	1	1															
24924	18	1	1															
24925	18	1	1															
24926	18	1	1															
24921	18	1	1					24920	230	24132 (ck1)	24132 (ck2)							
24922	18	1	1															
24923	18	1	1	0.0335	0.066	-0.0163	0.04975											
24924	18	1	1							X								
24925	18	1	1															
24926	18	1	1															
24921	18	1	1					24920	230	24132 (ck1)	24132 (ck2)							
24922	18	1	1															
24923	18	1	1	0.0335	0.071	-0.0188	0.05225											
24924	18	1	1								X							
24925	18	1	1															
24926	18	1	1															
28051	18	G	1	0.0233	0.0439	-0.0103	0.0336	28050	230	24115								

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
		1																
28052	18	G 2	1															
28053	18	S1	1															
28054	18	G 3	1															
28055	18	S2	1															
24718	13	31	1	0.0325	0.0535	-0.0105	0.043	24717	230	24701 (ck1)	24701 (ck2)							
24719	13	3	1															
24720	13	41	1															
24721	13	4	1															
24734	13	32	1															
24735	13	42	1															
24718	13	31	1	0.0325	0.0582	-0.0129	0.04535	24717	230	24701 (ck1)	24701 (ck2)							
24719	13	3	1							X								
24720	13	41	1															
24721	13	4	1															
24734	13	32	1															

GEN-BUS-NO	KV	ID	ST	X_s(PU)	X_t(PU)	X_0	Z_0	MAIN-BUS-NO	MAIN-BUS-KV	To-Bus-NO (1)	To-Bus-NO (2)	To-Bus-NO (3)	To-Bus-NO (4)	To-Bus-NO (5)	To-Bus-NO (6)	To-Bus-NO (7)	To-Bus-NO (8)	To-Bus-NO (9)
24735	13	42	1															
24718	13	31	1					24717	230	24701 (ck1)	24701 (ck2)							
24719	13	3	1															
24720	13	41	1	0.0325	0.0612	-0.0144	0.04685											
24721	13	4	1								X							
24734	13	32	1															
24735	13	42	1															

Table Description:

- Each colors yellow or blue represents all LOF settings for different operating points for a generator coherent group where a single or multiple generators are connected to a main bus through their GSUs. Each of those main buses is connected to different buses as adjacent transmission lines. If we have an operating point where one of those adjacent lines is out of service, we have an "X" sign below the "To Bus (#)". If we do not have any "X" sign below the "To Bus (#)", all the lines are in-service.

- Each bordered group inside a generator coherent group (colored group) represents an operating point and the LOF settings for that particular operating point.

Look-up Table for Bus Names:

Gen Bus No	Gen Bus Name	Gen Bus No	Gen Bus Name	Non-gen Bus No	Non-gen Bus Name	Non-gen Bus No	Non-gen Bus Name
22233	ENCINA 1	28053	PSTRIAS1	22052	BATIQTP	30042	METCALF
22234	ENCINA 2	28054	PSTRIAG3	22108	CANNON	30045	MOSSLAND
22236	ENCINA 3	28055	PSTRIAG2	22227	ENCINATP	30050	LOSBANOS
22240	ENCINA 4	30000	PTSB 7	22228	ENCINA 1	30055	GATES
22244	ENCINA 5	32900	CRCKTCOG	22232	ECINA	30057	DIABLO
22262	PEN_CT1	33105	PTSB 5	22260	ESCNDIDO	30060	MIDWAY
22263	PEN_CT2	33106	PTSB 6	22261	PEN	30303	TBL MT E
22265	PEN_ST	33107	DEC STG1	22356	IMPRLVLY	30437	CROCKETT
22784	SOUTHBY2	33108	DEC CTG1	22412	LOSCOCHS	30438	C&H
22788	SOUTHBY3	33109	DEC CTG2	22424	MAINST50	30479	BDLSWETA
22792	SOUTHBY4	33110	DEC CTG3	22428	MAINST51	30523	CCSUB
22981	IV GEN1	33111	LMECCT2	22580	NORTHCTY	30525	C COSTA
22982	IV GEN2	33112	LMECCT1	22632	PALOMAR	30526	PITSBG D
22983	IV GEN3	33113	LMECST1	22652	PENSQTOS	30527	PITSBG E
22996	INTBST	33116	C.COS 6	22716	SANLUSRY	30528	DEC PTSG
22997	INTBCT	33117	C.COS 7	22772	SOUTHBAY	30535	TIDEWATR
24001	ALAMT1 G	34308	KERCKHOF	22844	TALEGA	30536	TESORO
24002	ALAMT2 G	34600	HELMS 1	22852	TELECYN	30543	ROSSTAP1

Gen Bus No	Gen Bus Name	Gen Bus No	Gen Bus Name	Non-gen Bus No	Non-gen Bus Name	Non-gen Bus No	Non-gen Bus Name
24003	ALAMT3 G	34602	HELMS 2	22865	GRNT HLL	30560	E SHORE
24004	ALAMT4 G	35070	LAPLM_G1	22984	IV GEN	30565	ROSSTAP2
24005	ALAMT5 G	35071	LAPLM_G2	22998	INTB	30566	BRENTWOD
24047	ELSEG3 G	35072	LAPLM_G3	24006	ALMATOSE	30567	LONETREE
24048	ELSEG4 G	35073	LAPLM_G4	24007	ALMITOSW	30575	WND NSTR
24052	MTNVIST3	35074	TEXSUN1G	24008	ALMITOSW	30585	LS PSTAS
24053	MTNVIST4	35075	TEXSUN2G	24016	BARRE	30595	FLOWIND2
24066	HUNT1 G	35076	ELKHIL1G	24021	CENTER S	30600	TRE VAQ
24067	HUNT2 G	35077	ELKHIL2G	24040	EL NIDO	30700	SANMATEO
24089	MANDLY1G	35078	ELKHIL3G	24044	ELLIS	30705	MONTAVIS
24090	MANDLY2G	35079	TEXSUNST	24049	ELSEGNDO	30735	METCALF
24107	ORMOND1G	35881	MEC CTG1	24056	ETIWANDA	30741	CAL MEC
24108	ORMOND2G	35882	MEC CTG2	24069	HUNTGBCH	30750	MOSSLND2
24121	REDON5 G	35883	MEC STG1	24074	LA FRESA	30751	MOSSL-CB
24122	REDON6 G	36221	DUKMOSS1	24084	LITEHIPE	30755	MOSSLND1
24123	REDON7 G	36222	DUKMOSS2	24088	MANDALAY	30780	DUKE ML1
24124	REDON8 G	36223	DUKMOSS3	24091	MESA CAL	30787	DUKE ML2
24129	S.ONOFR2	36224	DUKMOSS4	24099	MOORPARK	30800	WILSON
24130	S.ONOFR3	36225	DUKMOSS5	24106	OPMOND	30810	GREGG
24161	ALAMT6 G	36226	DUKMOSS6	24112	PADUA	30820	HELMS PP
24167	HUNT3 G	36405	MOSSLND6	24115	PASTORIA	30900	GATES
24168	HUNT4 G	36406	MOSSLND7	24125	REDONDO	30905	TEMPLENTN
24718	ALTA31GT	36409	MORRO 3	24128	S CLARA	30915	MORROBAY
24719	ALTA 3ST	36410	MORRO 4	24131	S.ONOFRE	30925	DIABLOCN
24720	ALTA41GT	36411	DIABLO 1	24132	SANBRDNO	30930	MESA PGE
24721	ALTA 4ST	36412	DIABLO 2	24134	SANTIAGO	30946	LAPALOMA
24734	ALTA32GT	37521	SUTTER1	24137	SERANO	30946	LAPALOMA

Gen Bus No	Gen Bus Name	Gen Bus No	Gen Bus Name	Non-gen Bus No	Non-gen Bus Name	Non-gen Bus No	Non-gen Bus Name
24735	ALTA42GT	37522	SUTTER2	24151	VALLEYSC	30947	TEX SUN
24921	MNTV-CT1	37523	SUTTER3	24198	CHEVNAIN	30948	ELKHIL G
24922	MNTV-CT2	37561	MELONE1	24369	HUNTBCH1	30970	MIDWAY
24923	MNTV-ST1	37562	MELONE2	24601	VICTOR	30970	MIDWAY
24924	MNTV-CT3	37575	SHASTA1	24701	KRAMER	32950	PITSBURG
24925	MNTV-CT4	37576	SHASTA2	24717	COLWATER	32978	LMEC
24926	MNTV-ST2	38825	HYATT 1	24901	VISTA	34123	K1 JCT
26004	CASTAI1G	38830	HYATT 2	24920	MNTVIEW	34356	KERCKHF1
26005	CASTAI2G	38840	HYATT 4	25654	VIEJOSC	34358	KERCKHF2
26006	CASTAI3G	38845	HYATT 5	25656	MIRALOME	34360	WWARD JT
26007	CASTAI4G			26010	CASTAIC	34365	CLOVISJ2
26026	HAYNES1G			26025	HAYNES	36252	MORRO BY
26030	HAYNES5G			26052	OLIVE	37520	OBANION
26067	SCATT3G			26063	RIVER	37524	SUTTER
26151	HAYNES8G			26065	SCTERGD	37545	COTWDWAP
26152	HAYNES9G			26066	SCATERGD	37563	MELONES
26153	HAYNS10G			26068	STJOHN	37586	SHACW1
28000	HIDEDST1			26080	VELASCO	38206	COTTLE A
28001	HIDEDCT3			26081	ATWATER	38620	HYATT
28002	HIDEDCT2			26086	NRTHDGE	38621	HYATT2
28003	HIDEDCT1			26087	OLYMPC	38622	HYATT3
28041	IEEC-G1			26094	SYLMARLA	38623	THM JCT2
28042	IEEC-G2			28000	HIDESERT	38635	THM JCT
28051	PSTRIAG1			28040	IEEC		
28052	PSTRIAG2			28050	PSTRIA		

Appendix C: PSLF EPCL Code

Program ilsmain_v1.p

```
/*-----------------------------------------------------------------------------------------------------------------------------------
--*/
/*
                                        */
/*                                              Simulation for shedding load algorithm in PSLF
                                                */
/*
                                        */
/*-----------------------------------------------------------------------------------------------------------------------------------
--*/

/*                      Files                           */

$base = "08hw2.sav"                                                     /* Load-Flow Data               */
$basedy = "08hw2.dyd"                                                           /* Dynamic Data
        */
$outchan = "pslf.chf"                                                   /* Output Channel               */
$initrep = "pslf.rep"                                                   /* Init Report                  */
$dynrep = "pslf2.rep"                                                   /* Dynamic Report               */
$inrun1 = "ilsin_v3.p"                                                  /* Intelligent Load Shedding */
$inrun2 = "nilsin_v1.p"                                                         /* Without ILS
        */

/*                      Initializations             */

@tinit = 1

@ret = getf($base)
@ret = soln()
@ret = flowcalc(1)
@ret = buildeff(0)


@ret = psds()
@ret = rdyd($basedy,$dynrep,1,1,1)
dypar[0].run_epcl = $inrun2
@ret = init($outchan,$initrep,"1","0")

dypar[0].tpause = @tinit
dypar[0].nscreen = 999999
@ret = run()
```

```
dcl[0].st = 0
/*dcl[1].st = 0
dcl[2].st = 0
dcl[3].st = 0
dcl[4].st = 0
dcl[5].st = 0
dcl[6].st = 0
dcl[7].st = 0
dcl[8].st = 0

/*gens[2016].st = 0
/*load[7008].p = 1500            /* random load in San Diego */

/*secdd[13526].st = 0            /* Moenkopi-Eldordo          */
/*secdd[13529].st = 0            /* PaloVerde - Devers                  */
/*secdd[13385].st = 0            /* Navajo - Crystal          */
/*secdd[13406].st = 0            /* Mead - Marketplace                  */

dypar[0].tpause = 30
dypar[0].nscreen = 999999
@ret = run()
@ret = dsst()

end
```

Program nilsin_v1.p

```
dim #tie[2][10]
dim #swings[1][21]
$output1 = "FlowNILS.txt"
$output2 = "FreqNILS.txt"
@tieno = 8                                                          /* No. of tie lines
being monitored        */

/* tie lines being monitored - internal number
Column 1 -> Capt. Jack - Olinda
Column 2 -> Malin - RoundMt. 1
Column 3 -> Malin - RoundMt. 2
Column 4 -> Paloverde - Devers
Column 5 -> Moenkopi - ElDordo
Column 6 -> Hassyamp - North Gila
Column 7 -> Navajo - Crystal
Column 8 -> Mead - Marketplace 500*/

#tie[0][1] =      13497
#tie[0][2] =      13491
#tie[0][3] =      13494
```

```
#tie[0][4] =      13529
#tie[0][5] =      13526
#tie[0][6] =      13503
#tie[0][7] =      13385
#tie[0][8] =      13406


if(dypar[0].time < -0.0041)

        /* Nominal Flows */
        for @t2 = 1 to @tieno
                        @indx = #tie[0][@t2]
                        @fr = secdd[@indx].ifrom
                        @to = secdd[@indx].ito
                        $ckt = secdd[@indx].ck
                        #tie[1][@t2] = flow(0,@fr,@to,$ckt,1)  /* Nominal flows: Index 11 through
18 */
        next


        @ret = openlog($output1)
        logprint($output1,"<", "  Time  ", ">","  Tie1  ","  Tie2  ", ">","  Tie3  ", ">","  Tie4  ", ">","
Tie5  ", ">","  Tie6  ", ">","  Tie7  ", ">","  Tie8  ")
        @ret = close($output1)

        @ret = openlog($output2)
        logprint($output2,"<", "  Time  ")
        @ret = close($output2)

        for @aa = 0 to casepar[0].narea-1

                @ret = setlog($output2)
                logprint($output2,">", area[@aa].arname)
                @ret = close($output2)
        Next
```

Program ilsin_v3.p

```
/* with subroutines    */

/* 4.2 milli second a time step; therefore, there are 476 time steps in 2 seconds...  */

dim #tie[4][10]


/* Output Files          */
```

```
$output1 = "FlowILS.txt"

$output2 = "FreqILS.txt"

$output3 = "LoadILS.txt"


/* Arbitrary Paramters          */

@overflow = 0.10                                                    /* Overflow
Threshold       */

@tcutoff = 2                                                        /* Timer Threshold
*/

@ovrflwsh = 0.10                                                    /* % of overflow to
be shed           */


/* Tie Matrix */

/*

Row 1 -> Internal Numbers of tie lines

Row 2 -> Nominal Tie flows

Row 3 -> Amount of overflow

Row 4 -> Is overload persistent? yes ->1; no -> 0

*/

/*

Column 1 -> Capt. Jack - Olinda

Column 2 -> Malin - RoundMt. 1

Column 3 -> Malin - RoundMt. 2

Column 4 -> Paloverde - Devers

Column 5 -> Moenkopi - ElDordo

Column 6 -> Hassyamp - North Gila

Column 7 -> Navajo - Crystal

Column 8 -> Mead - Marketplace 500

*/

@tieno = 8                                                          /* No. of tie lines
being monitored        */
```

```
/* tie lines being monitored - internal number */
#tie[0][1] =      13497
#tie[0][2] =      13491
#tie[0][3] =      13494
#tie[0][4] =      13529
#tie[0][5] =      13526
#tie[0][6] =      13503
#tie[0][7] =      13385
#tie[0][8] =      13406


if(dypar[0].time < -0.0041)
     gosub initialize
endif

@counter = (@tcutoff)/(dypar[0].delt)                    /* No. of time steps within the
Timer Threshold        */

/* nominal tie flows */
#tie[1][1] =      mailbox[0].number[11]
#tie[1][2] =      mailbox[0].number[12]
#tie[1][3] =      mailbox[0].number[13]
#tie[1][4] =      mailbox[0].number[14]
#tie[1][5] =      mailbox[0].number[15]
#tie[1][6] =      mailbox[0].number[16]
#tie[1][7] =      mailbox[0].number[17]
#tie[1][8] =      mailbox[0].number[18]

for @t2 = 1 to @tieno
```

```
    /*          Processing                          */
    @indx = #tie[0][@t2]
    @fr = secdd[@indx].ifrom
    @to = secdd[@indx].ito
    $ckt = secdd[@indx].ck
    @realp = flow(0,@fr,@to,$ckt,1)
    @diff = (@realp - #tie[1][@t2])
    @diffpc = @diff/#tie[1][@t2]
    #tie[2][@t2] = @diff

    if(@diffpc>=@overflow)

        mailbox[0].number[@t2] = mailbox[0].number[@t2] + 1

    else

        mailbox[0].number[@t2] = 0    /* reset timer */

    endif
next
/*@ret = setlog($output3)*/

for @t2 = 1 to @tieno
    if(mailbox[0].number[@t2]>= @counter) /* 2 second waiting time        */
        #tie[3][@t2] = 1
    else
        #tie[3][@t2] = 0
    endif
next
```

```
/*  Determine Load Location            */
if(#tie[3][6] = 1)          /* Hassyamp - N.Gila Overload        */
    @lsarea = 22
    gosub shedload
elseif((#tie[3][1] = 1) or (#tie[3][2] = 1) or (#tie[3][3] = 1))     /* California - Oregon Intertie
Overload */
    @lsarea = 30
    gosub shedload
endif

/* Printing Tie Flow Differences        */
@ret = setlog($output1)
logprint($output1,"<",dypar[0].time:6:3)
@ret = close($output1)

for @t2 = 1 to @tieno

    @indx = #tie[0][@t2]
    @fr = secdd[@indx].ifrom
    @to = secdd[@indx].ito
    $ckt = secdd[@indx].ck
    @realp = flow(0,@fr,@to,$ckt,1)
    @diff = (@realp - #tie[1][@t2])
    @diffpc = @diff/#tie[1][@t2]

    @ret = setlog($output1)
    logprint($output1,">",@diff:6:2)
    @ret = close($output1)
```

```
next

/* Printing Area Frequencies */
@ret = setlog($output2)
logprint($output2,"<",dypar[0].time:6:3)
@ret = close($output2)

for @aa = 0 to casepar[0].narea-1
    @swbus = area[@aa].iswng          /* Internal Number of Swing Bus      */

    @ret = setlog($output2)
    logprint($output2,">",60*(1+netw[@swbus].f):6:2)
    @ret = close($output2)
next

/*--------------------------------     Sub Routines   ---------------------------------*/

/* Subroutine 1: initialize */
subroutine initialize
    /* Timers  */
    mailbox[0].number[1]=0
    mailbox[0].number[2]=0
    mailbox[0].number[3]=0
    mailbox[0].number[4]=0
    mailbox[0].number[5]=0
    mailbox[0].number[6]=0
    mailbox[0].number[7]=0
    mailbox[0].number[8]=0

    /*  Nominal Flows          */
```

```
for @t2 = 1 to @tieno
    @indx = #tie[0][@t2]
    @fr = secdd[@indx].ifrom
    @to = secdd[@indx].ito
    $ckt = secdd[@indx].ck
    mailbox[0].number[@t2+10] = flow(0,@fr,@to,$ckt,1)          /* Nominal flows: Index 11 through 18 */
next

/*  Output Files */

@ret = openlog($output1)
logprint($output1,"<", "  Time  ", ">","  Tie1  ","  Tie2  ", ">","  Tie3  ", ">","  Tie4  ", ">","  Tie5  ", ">","  Tie6  ", ">","  Tie7  ", ">","  Tie8  ")
@ret = close($output1)

@ret = openlog($output2)
logprint($output2,"<", "  Time  ")
@ret = close($output2)

for @aa = 0 to casepar[0].narea-1
    @ret = setlog($output2)
    logprint($output2,">", area[@aa].arname)
    @ret = close($output2)
next

@ret = openlog($output3)
logprint($output3, "<", "  Time  ", ">","  Area  ",">","Overflow",">","LoadShed",">"," TotLoad","<"," LdFract")
@ret = close($output3)
```

```
return

/* Subroutine 2: shedload */
subroutine shedload
/* Estimate amount of load to be shed from tie overflows */
@totovrfl = 0
for @t3 = 1 to @tieno
    @totovrfl = @totovrfl + #tie[2][@t3]
next

if(@totovrfl > 3000)
    @ovrflwsh = 0.5
endif

@loadshed = @ovrflwsh * @totovrfl            /* MW to be shed                */

/* Estimate the percent load to be shed                          */
@loadtot = 0
for @l1 = 0 to casepar[0].nloads-1
    if(load[@l1].area = @lsarea)
        if(load[@l1].st = 1)
            @ldbus = load[@l1].lbus
            @consti = load[@l1].ip * volt[@ldbus].vm
            @constz = load[@l1].g * volt[@ldbus].vm * volt[@ldbus].vm
            @loadt = load[@l1].p + load[@l1].pm + @consti + @constz
            @loadtot = @loadtot + @loadt
            /*@loadtot = load[@l1].ip + load[@l1].p+load[@l1].g+load[@l1].pm*/
        endif
    endif
next
```

```
@lsfract = @loadshed/@loadtot                    /* Fraction of load to be shed */

/* Shedding loads      */

for @l1 = 0 to casepar[0].nloads-1
    if(load[@l1].area = @lsarea)
        if(load[@l1].st = 1)
                @ldbus = load[@l1].lbus
                load[@l1].ip = load[@l1].ip * (1 - @lsfract)
                load[@l1].g  = load[@l1].g * (1 - @lsfract)
                load[@l1].p  = load[@l1].p * (1 - @lsfract)
                load[@l1].pm = load[@l1].pm * (1 - @lsfract)
        endif
    endif
next

@ret = setlog($output3)
logprint($output3, "<",dypar[0].time:6:2,">",@lsarea,">",@totovrfl:6:2, ">",@loadshed:6:2,
">",@loadtot:6:2, ">",@lsfract:6:2)
@ret = close($output3)

/* Resetting variables */
for @t2 = 1 to @tieno
    #tie[3][@t2] = 0
    mailbox[0].number[@t2] = 0
next
@lsfract = 0
return
```

Appendix D: GSF in % for loads within California

The eight major 500kV tie lines that connect the five California Utilities with the rest of the WECC network are listed below.

Tie 1 - Capt. Jack - Olinda
Tie 2 - Malin - RoundMt. 1
Tie 3 - Malin - RoundMt. 2
Tie 4 - Paloverde - Devers
Tie 5 - Moenkopi - ElDordo
Tie 6 - Hassyamp - North Gila
Tie 7 - Navajo - Crystal
Tie 8 - Mead – Marketplace

Area	Area No.	Load	Tie 1	Tie 2	Tie 3	Tie 4	Tie 5	Tie 6	Tie 7	Tie 8
Imperial	21	21002	10.88	10.1	10.24	14.01	1.5	9.84	0.63	-1.51
Imperial	21	21004	10.82	10.04	10.18	12.44	1.22	12.27	0.41	-1.95
Imperial	21	21005	10.87	10.09	10.22	13.57	1.38	10.43	0.53	-1.65
Imperial	21	21020	10.57	9.79	9.92	1.48	-0.78	31.03	-1.21	-5.26
Imperial	21	21027	10.55	9.78	9.91	2.18	-0.61	30.17	-1.08	-4.9
Imperial	21	21032	12.2	11.4	11.55	17.76	1.46	1.74	0.6	-0.66
Imperial	21	21033	12.17	11.37	11.53	17.67	1.45	1.7	0.6	-0.66
Imperial	21	21036	10.55	9.78	9.91	2.34	-0.59	30.87	-1.06	-4.75
Imperial	21	21039	12.08	11.29	11.44	17.58	1.44	1.71	0.6	-0.65
Imperial	21	21040	10.6	9.82	9.95	2.04	-0.64	30.35	-1.1	-4.97
Imperial	21	21046	12.54	11.77	11.93	16.68	1.07	-0.39	0.31	-0.84
Imperial	21	21048	10.61	9.83	9.96	5.03	0.04	22.51	-0.51	-4.29
Imperial	21	21050	11.79	10.92	11.07	20.29	2.58	5.08	1.42	-0.28
Imperial	21	21051	-1.45	-1.52	-1.55	6.88	0.99	3.35	0.73	0.63
Imperial	21	21053	11.73	10.87	11.01	20.14	2.57	5.04	1.41	-0.28
Imperial	21	21054	3.96	3.63	3.67	4.45	0.75	2.12	0.62	-0.49
Imperial	21	21056	12	11.13	11.28	19.3	2.11	4.36	1.05	-0.35
Imperial	21	21057	2.08	1.91	1.94	7.05	0.76	0.91	0.63	0.18
Imperial	21	21058	10.56	9.79	9.92	2.13	-0.62	30.34	-1.08	-4.9

Imperial	21	21061	10.46	9.69	9.82	-1.68	-1.27	33.28	-1.55	-6.48
Imperial	21	21064	10.6	9.82	9.96	3.18	-0.41	27.48	-0.89	-4.73
Imperial	21	21065	11.03	10.24	10.38	11.27	1.04	15.28	0.25	-2.38
Imperial	21	21066	12.13	11.33	11.48	17.95	1.41	1.63	0.56	-0.59
Imperial	21	21298	10.31	9.55	9.68	4.26	-0.09	24.19	-0.61	-4.32
Imperial	21	21382	7.42	6.9	6.99	2.11	-0.18	12.1	-0.39	-2.69
LADWP	26	26013	11.43	10.63	10.77	4.82	7.26	0.96	5.37	7.91
LADWP	26	26016	11.32	10.53	10.67	4.58	7.21	0.83	5.36	7.64
LADWP	26	26061	11.46	10.66	10.8	4.97	7.2	1.11	5.3	7.88
LADWP	26	26065	11.22	10.45	10.59	4.75	6.97	0.99	5.15	7.58
LADWP	26	26068	11.44	10.65	10.79	4.75	7.26	0.94	5.37	7.87
LADWP	26	26072	11.37	10.58	10.72	4.68	7.28	0.88	5.4	7.79
LADWP	26	26075	10.95	10.2	10.33	4.43	6.9	0.81	5.14	7.29
LADWP	26	26076	11.09	10.32	10.45	4.67	6.93	0.99	5.12	7.5
LADWP	26	26078	11.33	10.53	10.67	4.74	7.28	0.91	5.38	7.98
LADWP	26	26080	11.34	10.55	10.69	4.73	7.28	0.9	5.39	7.85
LADWP	26	26081	11.42	10.63	10.77	4.77	7.24	0.96	5.35	7.85
LADWP	26	26085	11.27	10.48	10.62	4.72	7.16	0.95	5.3	7.86
LADWP	26	26086	11.49	10.69	10.83	4.99	7.15	1.18	5.26	7.8
LADWP	26	26088	11.22	10.44	10.58	4.8	6.97	1.06	5.15	7.59
LADWP	26	26089	11.2	10.42	10.56	4.7	6.94	1.01	5.13	7.52
LADWP	26	26063	11.39	10.59	10.73	4.76	7.27	0.93	5.38	7.87
LADWP	26	26091	11.26	10.47	10.61	4.57	7.19	0.8	5.35	7.6
LADWP	26	26093	11.46	10.66	10.8	4.96	7.11	1.15	5.23	7.76
LADWP	26	26102	11.37	10.56	10.71	4.84	7.19	1.05	5.31	7.9
LADWP	26	27203	11.31	10.53	10.67	4.7	7.15	0.91	5.29	7.84
LADWP	26	27203	11.28	10.5	10.64	4.72	7.14	0.94	5.28	7.86
LADWP	26	27241	11.51	10.71	10.86	4.79	7.31	0.94	5.4	8
LADWP	26	27241	11.52	10.72	10.86	4.82	7.32	0.98	5.4	8.02

LADWP	26	27244	11.47	10.68	10.82	4.78	7.28	0.94	5.38	7.98
LADWP	26	27302	11.6	10.8	10.94	4.84	7.3	0.95	5.39	7.97
LADWP	26	27326	11.58	10.78	10.92	4.83	7.3	0.95	5.4	7.97
LADWP	26	27330	11.58	10.77	10.91	4.85	7.31	0.98	5.4	7.98
LADWP	26	27330	11.62	10.81	10.96	4.83	7.3	0.96	5.39	7.99
LADWP	26	27332	11.68	10.86	11.01	4.87	7.36	0.95	5.43	8.04
LADWP	26	27332	11.61	10.8	10.94	4.84	7.31	0.96	5.4	7.98
LADWP	26	27334	11.49	10.69	10.83	4.8	7.28	0.94	5.38	7.97
LADWP	26	27336	11.56	10.76	10.9	4.85	7.32	0.97	5.41	7.99
LADWP	26	27498	11.45	10.65	10.79	4.78	7.29	0.93	5.38	7.98
LADWP	26	26039	-3.72	-3.75	-3.81	-2.49	-2.3	-3.48	-0.8	-2.28
LADWP	26	26040	-3.73	-3.75	-3.81	-2.49	-2.27	-3.48	-0.76	-2.28
LADWP	26	27346	11.96	11.14	11.29	4.87	7.38	0.95	5.44	8.08
LADWP	26	27348	11.94	11.12	11.27	4.86	7.38	0.93	5.45	8.05
LADWP	26	27350	11.67	10.86	11.01	4.85	7.34	0.92	5.42	8
LADWP	26	27356	12.14	11.29	11.45	4.91	7.51	0.92	5.53	8.17
LADWP	26	27358	12.14	11.3	11.45	4.92	7.51	0.94	5.53	8.17
LADWP	26	27359	12.24	11.39	11.54	4.95	7.54	0.93	5.56	8.2
PG&E	30	37959	13.54	8.21	8.32	2.68	3.19	0.15	2.36	3.27
PG&E	30	38564	13.88	13.36	13.55	4.51	5.27	0.42	3.89	5.4
PG&E	30	32793	14.13	14.68	14.88	4.59	5.37	0.42	3.97	5.54
PG&E	30	34413	13.92	13.33	13.51	5.09	5.9	0.78	4.3	6.09
PG&E	30	31421	14.06	14.72	14.92	5.53	6.58	1.32	4.92	6.62
PG&E	30	33770	15.13	13.57	13.76	4.53	5.29	0.45	3.9	5.47
PG&E	30	35127	14.12	14.15	14.35	4.6	5.37	0.45	3.97	5.55
PG&E	30	38574	14.38	13.67	13.86	4.81	5.54	0.41	4.1	5.66
PG&E	30	38570	14.49	13.8	13.98	4.79	5.55	0.37	4.09	5.69
PG&E	30	38492	14.46	13.85	14.04	4.71	5.48	0.51	4.04	5.66
PG&E	30	38442	14.44	13.82	14.01	4.69	5.47	0.46	4.03	5.62

PG&E	30	38480	14.3	13.62	13.8	4.67	5.44	0.54	4.01	5.58
PG&E	30	38462	14.39	13.78	13.97	4.69	5.46	0.48	4.01	5.62
PG&E	30	38313	14.11	13.58	13.77	4.69	5.47	0.52	4.04	5.63
PG&E	30	30567	14.1	14.52	14.72	4.56	5.32	0.44	3.93	5.5
PG&E	30	34361	13.86	13.22	13.4	5.11	5.92	0.78	4.32	6.07
PG&E	30	35919	14.49	14.11	14.31	4.89	5.69	0.64	4.18	5.85
PG&E	30	35301	13.81	13.84	14.03	4.48	5.22	0.45	3.85	5.4
PG&E	30	35303	13.82	13.85	14.05	4.48	5.24	0.44	3.87	5.41
PG&E	30	35300	13.78	13.8	14	4.48	5.21	0.43	3.85	5.39
PG&E	30	36866	13.64	13.66	13.85	4.4	5.15	0.41	3.81	5.3
PG&E	30	36869	13.95	13.97	14.17	4.54	5.28	0.43	3.89	5.48
PG&E	30	36869	13.96	13.99	14.18	4.53	5.3	0.41	3.92	5.46
PG&E	30	31471	18.07	10.32	10.44	4.06	4.77	0.09	3.57	5
PG&E	30	31599	20.04	11.83	11.97	4.27	5.02	0.16	3.76	5.25
PG&E	30	35116	14.04	14.07	14.27	4.55	5.31	0.44	3.92	5.46
PG&E	30	34648	6.16	5.94	6.02	2.3	2.53	0.08	1.85	2.65
PG&E	30	31974	14.12	15.83	16.06	4.72	5.53	0.42	4.1	5.74
PG&E	30	31499	4.43	19.29	19.54	4.21	4.95	0.17	3.69	5.15
PG&E	30	36370	14.25	13.37	13.55	5.74	6.58	1.08	4.76	6.8
PG&E	30	36366	13.68	12.97	13.15	5.48	6.17	0.76	4.48	6.34
PG&E	30	36298	13.45	12.62	12.79	5.37	6.16	1.03	4.45	6.34
PG&E	30	30951	12.97	12.06	12.22	5.43	6.28	1.33	4.53	6.45
PG&E	30	34426	13.61	12.67	12.84	5.74	6.6	1.37	4.76	6.77
PG&E	30	34413	13.89	13.3	13.48	5.1	5.9	0.77	4.31	6.07
PG&E	30	33219	13.79	13.86	14.05	4.4	5.13	0.37	3.79	5.31
PG&E	30	33218	13.79	13.85	14.05	4.4	5.13	0.37	3.8	5.28
PG&E	30	34672	13.73	13.07	13.25	5.09	5.89	0.79	4.29	6.03
PG&E	30	34671	13.73	13.07	13.25	5.09	5.89	0.79	4.29	6.03
PG&E	30	34485	5.04	5.14	5.21	1.74	1.96	-0.08	1.49	1.72

PG&E	30	38434	14.45	13.79	13.98	4.71	5.5	0.46	4.06	5.61
PG&E	30	38438	14.44	13.87	14.06	4.67	5.46	0.43	4.03	5.6
PG&E	30	38315	14.32	13.81	14	4.79	5.59	0.52	4.12	5.73
PG&E	30	38307	13.86	13.46	13.65	4.69	5.49	0.46	4.04	5.67
PG&E	30	31010	20.31	11.91	12.05	3.69	4.4	0.09	3.25	4.71
PG&E	30	31090	20.22	11.42	11.55	3.09	3.8	0.11	2.79	4.22
PG&E	30	31090	20.35	11.49	11.62	3.04	3.75	0.09	2.75	4.19
PG&E	30	31158	1.53	1.34	1.36	0.76	0.69	-0.49	0.53	0.7
PG&E	30	32498	5.14	6.52	6.61	1.81	2.07	0.06	1.53	2.2
PG&E	30	32514	4.96	5.61	5.69	1.48	1.7	-0.56	1.21	1.77
PG&E	30	32513	4.96	5.61	5.69	1.48	1.7	-0.56	1.21	1.77
PG&E	30	34590	13.8	13.14	13.32	5.12	5.92	0.84	4.31	6.06
PG&E	30	34366	13.83	13.16	13.34	5.13	5.94	0.83	4.32	6.13
PG&E	30	30464	13.78	14.89	15.1	4.56	5.33	0.41	3.94	5.52
PG&E	30	36886	13.95	13.97	14.17	4.54	5.28	0.43	3.9	5.46
PG&E	30	36886	13.95	13.97	14.16	4.53	5.28	0.42	3.89	5.43
PG&E	30	36871	13.88	13.9	14.1	4.51	5.26	0.42	3.88	5.41
PG&E	30	36871	13.89	13.91	14.11	4.54	5.3	0.46	3.92	5.46
PG&E	30	36880	13.9	13.93	14.12	4.5	5.27	0.42	3.89	5.43
PG&E	30	36879	13.9	13.92	14.12	4.51	5.27	0.43	3.89	5.43
PG&E	30	35038	13.26	12.34	12.51	5.51	6.37	1.26	4.58	6.53
PG&E	30	33917	14.23	13.64	13.82	4.73	5.46	0.18	4.05	5.63
PG&E	30	33529	14.81	14	14.19	4.62	5.37	0.48	3.96	5.56
PG&E	30	34794	13.2	12.26	12.43	5.47	6.35	1.34	4.58	6.5
PG&E	30	34704	13.17	12.24	12.41	5.51	6.4	1.34	4.62	6.56
PG&E	30	34710	13.19	12.26	12.43	5.51	6.37	1.32	4.59	6.54
PG&E	30	36936	5.85	19.29	19.53	4.43	5.02	0.04	3.74	5.32
PG&E	30	36856	12.18	12.19	12.37	3.84	4.47	0.28	3.29	4.59
PG&E	30	36416	13.3	12.47	12.64	5.33	6.11	1.03	4.41	6.29

PG&E	30	36205	12.55	12.28	12.46	4.1	4.76	0.39	3.48	4.85
PG&E	30	35860	14.04	14.08	14.27	4.55	5.34	0.43	3.94	5.47
PG&E	30	35850	13.68	13.68	13.86	4.64	5.41	0.59	3.98	5.46
PG&E	30	35861	13.92	13.95	14.14	4.52	5.26	0.45	3.88	5.44
PG&E	30	34816	13.13	12.21	12.38	5.48	6.34	1.33	4.56	6.5
PG&E	30	35046	13.01	12.1	12.26	5.44	6.31	1.36	4.54	6.44
PG&E	30	35060	13.22	12.3	12.46	5.48	6.36	1.33	4.57	6.55
PG&E	30	30973	13.01	12.09	12.25	5.44	6.3	1.35	4.54	6.48
PG&E	30	35026	12.8	11.94	12.1	5.18	6.17	1.5	4.44	6.07
PG&E	30	35032	13.04	12.18	12.34	5.65	6.47	1.03	4.67	6.63
PG&E	30	35048	13.09	12.19	12.35	5.51	6.34	1.28	4.57	6.52
PG&E	30	35056	2.71	2.53	2.56	0.97	1.18	0.3	0.93	1.02
PG&E	30	35052	13.82	12.87	13.04	5.82	6.72	1.29	4.84	6.88
PG&E	30	35062	13.03	12.14	12.3	5.47	6.32	1.36	4.56	6.43
PG&E	30	35050	7.28	6.82	6.91	3.05	3.36	0.3	2.45	3.52
PG&E	30	35024	13	12.09	12.26	5.45	6.3	1.39	4.54	6.44
PG&E	30	34652	14.06	13.23	13.41	5.33	6.17	0.9	4.48	6.33
PG&E	30	34652	14.08	13.25	13.43	5.33	6.16	0.89	4.48	6.34
PG&E	30	34179	13.78	13.19	13.37	4.96	5.76	0.69	4.22	5.92
PG&E	30	33838	13.88	14.2	14.4	4.5	5.24	0.44	3.87	5.42
PG&E	30	33836	14.39	13.9	14.1	4.53	5.29	0.45	3.91	5.47
PG&E	30	33840	14.05	14.07	14.27	4.53	5.27	0.47	3.89	5.46
PG&E	30	33814	13.86	14.06	14.25	4.68	5.48	0.3	4.05	5.62
PG&E	30	33386	14.28	14.31	14.52	4.59	5.38	0.4	3.97	5.52
PG&E	30	33136	7.24	7.33	7.43	1.79	2.05	-0.01	1.54	2.33
PG&E	30	33139	14.99	15.55	15.77	4.84	5.65	0.36	4.17	5.87
PG&E	30	33145	13.95	14.55	14.75	4.69	5.42	0.33	4.02	5.6
PG&E	30	33150	13.94	14.45	14.65	4.68	5.43	0.38	4.02	5.58
PG&E	30	33141	14.32	14.79	15	4.59	5.4	0.36	3.99	5.55

PG&E	30	33143	14.23	14.72	14.92	4.7	5.46	0.36	4.04	5.63
PG&E	30	33142	14.26	14.75	14.95	4.66	5.44	0.33	4.01	5.58
PG&E	30	33160	13.99	14.42	14.62	4.67	5.46	0.38	4.05	5.62
PG&E	30	33134	15.61	16.07	16.29	4.65	5.18	0.14	3.84	5.6
PG&E	30	33132	14.08	14.48	14.68	4.59	5.38	0.37	3.98	5.54
PG&E	30	33131	14.95	15.54	15.76	4.87	5.66	0.32	4.18	5.83
PG&E	30	33133	15.65	16.14	16.36	4.76	5.34	0.08	3.97	5.7
PG&E	30	33135	7.97	8.13	8.24	2.35	2.64	0.11	1.95	2.83
PG&E	30	32910	14.12	14.66	14.86	4.68	5.44	0.43	4.02	5.62
PG&E	30	32762	14.24	14.77	14.98	4.59	5.37	0.38	3.96	5.55
PG&E	30	32920	14.42	14.97	15.18	4.69	5.45	0.33	4.02	5.67
PG&E	30	32740	14.16	14.7	14.91	4.62	5.39	0.42	3.98	5.57
PG&E	30	32500	10.34	14.9	15.1	4.46	5.21	0.13	3.88	5.38
PG&E	30	32498	5.38	7.28	7.38	1.88	2.12	0.01	1.57	2.3
PG&E	30	32164	13.49	15.11	15.33	4.49	5.23	0.39	3.87	5.45
PG&E	30	32154	16.55	14.85	15.05	4.66	5.52	0.28	4.1	5.74
PG&E	30	32156	8.97	15	15.19	4.33	5.08	0.1	3.78	5.2
PG&E	30	31800	19.33	11.13	11.26	4.11	4.81	0.04	3.6	5.06
PG&E	30	31888	5.63	18.6	18.84	4.36	5.12	0.15	3.83	5.27
PG&E	30	31465	19.41	11.22	11.35	4.1	4.79	0.06	3.57	5.07
PG&E	30	31894	4.52	15.94	16.14	3.91	4.36	0.07	3.27	4.69
PG&E	30	31896	3.93	12.76	12.93	3.57	3.94	-0.31	2.96	4.18
PG&E	30	31874	10.71	16.51	16.72	4.04	4.74	0.08	3.56	4.97
PG&E	30	36877	13.95	13.97	14.17	4.53	5.28	0.45	3.89	5.46
PG&E	30	36877	13.92	13.94	14.14	4.54	5.29	0.45	3.9	5.44
PG&E	30	36891	13.96	13.98	14.18	4.52	5.29	0.45	3.91	5.44
PG&E	30	36891	13.95	13.97	14.17	4.53	5.28	0.43	3.9	5.43
PG&E	30	36887	13.9	13.93	14.12	4.52	5.26	0.45	3.89	5.43
PG&E	30	36874	13.95	13.97	14.17	4.55	5.31	0.42	3.92	5.52

PG&E	30	36890	13.91	13.93	14.13	4.5	5.27	0.43	3.89	5.42
PG&E	30	36890	13.93	13.95	14.15	4.53	5.29	0.43	3.9	5.46
PG&E	30	36889	13.93	13.96	14.15	4.54	5.29	0.44	3.9	5.44
PG&E	30	36889	13.97	14	14.2	4.54	5.3	0.47	3.91	5.45
PG&E	30	36873	13.93	13.96	14.15	4.52	5.29	0.43	3.9	5.49
PG&E	30	36873	13.94	13.97	14.17	4.51	5.27	0.43	3.88	5.45
PG&E	30	36888	13.92	13.95	14.14	4.53	5.3	0.42	3.92	5.43
PG&E	30	36888	13.93	13.96	14.15	4.53	5.28	0.44	3.9	5.46
PG&E	30	36888	13.94	13.97	14.17	4.52	5.28	0.44	3.89	5.45
PG&E	30	36870	13.92	13.95	14.14	4.52	5.29	0.44	3.91	5.45
PG&E	30	36870	13.93	13.96	14.16	4.53	5.27	0.42	3.89	5.46
PG&E	30	36876	13.89	13.92	14.11	4.52	5.26	0.44	3.89	5.45
PG&E	30	36876	13.92	13.94	14.14	4.5	5.27	0.44	3.89	5.45
PG&E	30	36882	13.88	13.9	14.1	4.49	5.27	0.42	3.9	5.41
PG&E	30	36882	13.93	13.96	14.15	4.54	5.28	0.45	3.89	5.45
PG&E	30	36883	13.91	13.93	14.13	4.52	5.29	0.43	3.91	5.44
PG&E	30	31321	1.53	1.49	1.51	0.82	0.93	0.24	0.7	0.92
PG&E	30	31317	1.62	1.58	1.6	0.36	0.39	-0.03	0.29	0.51
PG&E	30	31319	0.94	0.85	0.86	0.23	0.22	0.08	0.16	0.24
PG&E	30	31315	1.64	1.3	1.32	0.15	0.18	0.1	0.12	0.2
PG&E	30	31311	2.85	2.6	2.63	0.72	0.85	0.25	0.63	0.88
PG&E	30	31309	10.39	9.26	9.39	0.08	0.14	-1.09	0.02	1.04
PG&E	30	35857	13.96	13.99	14.19	4.53	5.3	0.42	3.91	5.45
PG&E	30	35856	13.96	13.99	14.19	4.53	5.3	0.42	3.91	5.45
PG&E	30	35855	13.96	13.99	14.19	4.53	5.3	0.42	3.91	5.45
PG&E	30	35854	13.96	13.99	14.19	4.53	5.3	0.42	3.91	5.45
PG&E	30	34418	13.82	13.11	13.29	5.14	5.95	0.86	4.33	6.12
PG&E	30	32185	13.54	15.12	15.34	4.48	5.25	0.39	3.89	5.44
PG&E	30	38305	13.9	13.49	13.67	4.69	5.49	0.46	4.05	5.62

PG&E	30	38311	14.07	13.55	13.73	4.68	5.45	0.5	4.02	5.62
PG&E	30	33178	13.98	14.53	14.73	4.59	5.36	0.42	3.97	5.54
PG&E	30	32494	6.54	17.25	17.47	4.28	5.08	0.09	3.78	5.15
PG&E	30	32496	4.64	11.23	11.38	2.55	3.04	0.01	2.27	3.17
PG&E	30	31976	9.75	15.08	15.27	4.43	5.19	0.13	3.87	5.35
PG&E	30	34722	13.05	12.13	12.29	5.42	6.29	1.37	4.53	6.44
PG&E	30	32994	14.34	14.8	15	4.71	5.49	0.43	4.07	5.68
PG&E	30	35659	14.05	14.07	14.27	4.57	5.32	0.46	3.91	5.5
PG&E	30	30720	14.01	13.93	14.12	4.62	5.39	0.52	3.97	5.56
PG&E	30	35355	13.91	13.85	14.04	4.58	5.36	0.52	3.96	5.5
PG&E	30	30530	14.1	14.41	14.61	4.56	5.33	0.44	3.94	5.51
PG&E	30	30537	14.09	14.37	14.57	4.56	5.34	0.45	3.94	5.52
PG&E	30	33381	14.09	14.13	14.33	4.56	5.32	0.46	3.93	5.49
PG&E	30	32788	14.11	14.66	14.87	4.56	5.34	0.4	3.95	5.51
PG&E	30	31626	19.61	14.47	14.67	4.69	5.51	0.31	4.1	5.73
PG&E	30	32602	14.39	14.93	15.14	4.7	5.49	0.47	4.06	5.68
PG&E	30	31346	2.1	2.06	2.09	1.26	1.41	0.43	1.08	1.39
PG&E	30	32451	7.38	16.25	16.46	4.31	5.07	0.09	3.78	5.22
PG&E	30	35639	13.95	13.87	14.07	4.59	5.36	0.5	3.94	5.54
PG&E	30	35618	13.99	13.97	14.17	4.58	5.35	0.5	3.95	5.52
PG&E	30	35618	14.02	14	14.2	4.59	5.33	0.52	3.93	5.51
PG&E	30	35640	13.98	13.9	14.1	4.62	5.38	0.52	3.96	5.55
PG&E	30	38028	14.05	14.1	14.3	4.55	5.31	0.46	3.91	5.5
PG&E	30	38028	14.01	14.06	14.26	4.54	5.29	0.45	3.9	5.45
PG&E	30	38022	14.17	14.72	14.93	4.59	5.37	0.42	3.98	5.53
PG&E	30	35922	14.05	13.68	13.87	4.78	5.56	0.65	4.08	5.75
PG&E	30	31082	20.59	11.67	11.81	3.25	3.95	0.14	2.91	4.37
PG&E	30	31368	15.76	16.49	16.72	5.19	6.1	0.48	4.52	6.3
PG&E	30	34729	13.03	12.12	12.28	5.45	6.29	1.37	4.52	6.46

PG&E	30	32978	14.05	14.45	14.65	4.62	5.38	0.45	3.98	5.55
PG&E	30	37123	15.47	13.1	13.28	4.47	5.22	0.32	3.88	5.35
PG&E	30	32396	11.39	15.18	15.39	4.65	5.45	0.17	4.05	5.61
PG&E	30	35077	12.93	12.02	12.18	5.43	6.27	1.34	4.51	6.47
PG&E	30	35076	12.93	12.02	12.18	5.43	6.27	1.34	4.51	6.47
PG&E	30	32994	14.35	14.81	15.01	4.71	5.47	0.47	4.04	5.67
PG&E	30	35636	13.93	13.9	14.1	4.56	5.32	0.52	3.92	5.46
PG&E	30	34521	13.72	12.97	13.15	5.15	5.95	0.91	4.33	6.12
PG&E	30	34429	13.77	13.04	13.21	5.16	5.95	0.9	4.33	6.11
PG&E	30	34541	13.41	12.66	12.83	5.11	5.88	0.92	4.26	6.09
PG&E	30	34539	13.41	12.66	12.83	5.11	5.88	0.92	4.26	6.09
PG&E	30	32112	13.36	14.99	15.2	4.47	5.21	0.39	3.85	5.4
PG&E	30	32113	13.36	14.99	15.2	4.47	5.22	0.38	3.86	5.41
PG&E	30	32091	14.1	15.37	15.59	4.73	5.5	0.39	4.06	5.7
PG&E	30	35622	14.01	13.98	14.18	4.59	5.35	0.52	3.94	5.54
PG&E	30	33204	14.1	14.16	14.36	4.55	5.3	0.43	3.92	5.47
PG&E	30	36225	14.01	13.63	13.82	4.77	5.55	0.62	4.07	5.72
PG&E	30	36224	14.01	13.63	13.82	4.77	5.55	0.62	4.07	5.72
PG&E	30	36222	14.06	13.7	13.88	4.82	5.62	0.61	4.12	5.78
PG&E	30	36221	14.06	13.7	13.88	4.82	5.62	0.61	4.12	5.78
PG&E	30	31995	13.83	15.54	15.76	4.62	5.4	0.39	3.99	5.6
PG&E	30	32099	16.12	17.43	17.72	5.17	6.05	0.43	4.47	6.21
PG&E	30	32097	15.97	17.23	17.5	5.09	5.95	0.43	4.39	6.15
PG&E	30	32077	15.01	16.31	16.54	5.02	5.84	0.43	4.32	6.05
PG&E	30	31611	18.23	11.55	11.71	3.92	4.61	0.17	3.43	4.78
PG&E	30	30111	17.16	13.28	13.46	4.28	5.04	0.22	3.76	5.26
PG&E	30	31609	17.08	10.85	11.01	3.66	4.31	0.19	3.2	4.48
PG&E	30	31666	7.9	9.51	9.63	3.03	3.35	0.15	2.52	3.62
PG&E	30	31475	5.48	17.96	18.19	4.22	4.96	0.13	3.7	5.13

PG&E	30	31710	4.5	19.3	19.55	4.23	4.97	0.17	3.72	5.18
PG&E	30	31610	17.59	11.17	11.34	3.76	4.42	0.24	3.29	4.55
PG&E	30	31610	17.58	11.17	11.33	3.76	4.41	0.2	3.27	4.57
PG&E	30	31556	20.28	11.77	11.91	3.98	4.73	0.04	3.5	4.99
PG&E	30	31682	2.89	10.65	10.78	2.45	2.76	0.14	2.07	2.96
PG&E	30	33309	14.11	14.18	14.38	4.56	5.31	0.45	3.92	5.51
PG&E	30	34624	14.15	13.47	13.65	5.39	6.21	0.77	4.53	6.32
PG&E	30	30438	13.97	14.58	14.79	4.63	5.41	0.39	4.02	5.6
PG&E	30	36201	15.07	14.78	14.97	5.37	5.98	0.17	4.37	6.3
PG&E	30	36200	15.04	14.73	14.93	5.33	5.97	0.19	4.37	6.3
PG&E	30	36062	15.11	14.73	14.94	5.1	5.91	0.6	4.33	6.09
PG&E	30	36018	15.59	15.2	15.42	5.25	6.11	0.58	4.48	6.3
PG&E	30	35351	14.02	14.06	14.26	4.56	5.32	0.43	3.92	5.51
PG&E	30	35350	14.04	14.08	14.28	4.56	5.31	0.46	3.9	5.49
PG&E	30	34938	14.44	13.47	13.66	6.05	6.96	1.22	5.02	7.12
PG&E	30	34938	14.43	13.46	13.65	6.04	6.93	1.2	5	7.11
PG&E	30	34938	14.46	13.49	13.67	6.05	6.95	1.22	5.02	7.12
PG&E	30	34947	12.15	11.37	11.53	5.05	5.77	0.87	4.16	5.92
PG&E	30	34947	12.15	11.37	11.53	5.06	5.76	0.92	4.15	5.92
PG&E	30	34703	13.15	12.22	12.39	5.51	6.37	1.34	4.59	6.52
PG&E	30	34432	14.04	13.28	13.46	5.13	5.95	0.82	4.34	6.12
PG&E	30	34432	14.03	13.27	13.45	5.1	5.91	0.82	4.31	6.06
PG&E	30	34182	13.98	13.25	13.43	5.07	5.87	0.86	4.29	6.02
PG&E	30	34164	14.09	13.39	13.58	5.04	5.85	0.8	4.27	5.99
PG&E	30	33306	14.13	14.2	14.4	4.54	5.29	0.43	3.9	5.47
PG&E	30	33207	14.12	14.19	14.39	4.56	5.32	0.42	3.93	5.5
PG&E	30	32974	14.18	14.6	14.8	4.64	5.42	0.44	4.01	5.6
PG&E	30	32786	14.11	14.66	14.87	4.58	5.36	0.42	3.97	5.55
PG&E	30	32786	14.12	14.67	14.88	4.59	5.37	0.42	3.97	5.56

PG&E	30	32766	14.08	14.62	14.82	4.61	5.37	0.46	3.97	5.55
PG&E	30	32766	14.09	14.62	14.83	4.64	5.39	0.47	3.98	5.59
PG&E	30	32490	7.22	16.03	16.23	4.34	5.09	0.09	3.81	5.24
PG&E	30	32492	6.41	17.23	17.45	4.34	5.11	0.07	3.8	5.21
PG&E	30	31584	19.53	11.08	11.21	4.63	5.5	0.11	4.1	5.72
PG&E	30	31736	19.13	13.9	14.09	4.53	5.33	0.27	3.97	5.55
PG&E	30	31576	18.91	10.88	11.01	4.24	5	0.08	3.74	5.25
PG&E	30	31103	22.75	12.02	12.16	3.47	4.38	0.87	3.2	4.64
PG&E	30	35656	14.02	13.97	14.17	4.6	5.37	0.53	3.96	5.55
PG&E	30	35648	13.61	13.58	13.77	4.62	5.38	0.53	3.96	5.53
PG&E	30	35616	13.98	13.97	14.17	4.59	5.35	0.49	3.95	5.51
PG&E	30	35612	14.04	14.05	14.25	4.57	5.35	0.47	3.96	5.53
PG&E	30	35120	14	14.03	14.23	4.56	5.33	0.47	3.94	5.5
PG&E	30	30555	14.12	14.59	14.79	4.6	5.36	0.44	3.97	5.57
PG&E	30	30555	14.15	14.62	14.82	4.59	5.4	0.42	4	5.56
PG&E	30	35225	14.21	14.47	14.67	4.59	5.37	0.41	3.97	5.56
PG&E	30	30635	14.11	14.18	14.38	4.58	5.33	0.47	3.93	5.53
PG&E	30	30635	14.07	14.15	14.35	4.59	5.37	0.48	3.97	5.55
PG&E	30	35219	14.09	14.27	14.47	4.58	5.35	0.44	3.96	5.54
PG&E	30	35120	14.02	14.05	14.25	4.55	5.32	0.49	3.93	5.49
PG&E	30	36260	13.44	12.58	12.75	5.38	6.18	1.09	4.46	6.38
PG&E	30	36254	13.42	12.56	12.73	5.38	6.2	1.12	4.48	6.41
PG&E	30	36378	13.35	12.51	12.68	5.36	6.13	1.08	4.43	6.33
PG&E	30	36266	13.47	12.61	12.78	5.35	6.16	1.1	4.44	6.37
PG&E	30	30905	13.35	12.48	12.65	5.34	6.14	1.14	4.44	6.37
PG&E	30	36252	13.27	12.4	12.57	5.32	6.14	1.1	4.43	6.35
PG&E	30	36254	13.35	12.49	12.66	5.36	6.19	1.1	4.47	6.37
PG&E	30	34774	13	12.08	12.25	5.42	6.28	1.34	4.52	6.47
PG&E	30	34774	12.99	12.08	12.24	5.43	6.29	1.34	4.52	6.48

PG&E	30	30940	13	12.08	12.25	5.44	6.3	1.31	4.54	6.48
PG&E	30	30941	12.99	12.08	12.24	5.43	6.28	1.32	4.51	6.46
PG&E	30	34752	12.99	12.08	12.24	5.43	6.27	1.37	4.51	6.43
PG&E	30	34736	13.11	12.2	12.36	5.47	6.34	1.36	4.57	6.5
PG&E	30	30950	12.99	12.07	12.23	5.43	6.28	1.35	4.53	6.44
PG&E	30	34760	13.32	12.39	12.56	5.56	6.42	1.32	4.63	6.59
PG&E	30	34498	16.29	15.52	15.73	6.04	6.98	0.92	5.08	7.18
PG&E	30	34382	13.87	13.18	13.36	5.14	5.95	0.85	4.34	6.12
PG&E	30	34364	13.84	13.2	13.38	5.14	5.96	0.81	4.35	6.08
PG&E	30	34402	13.75	13.06	13.24	5.09	5.89	0.82	4.3	6.04
PG&E	30	30846	13.87	13.29	13.47	5.06	5.86	0.76	4.28	6.03
PG&E	30	34380	13.94	13.25	13.43	5.16	5.98	0.84	4.36	6.12
PG&E	30	34370	13.79	13.09	13.27	5.12	5.91	0.87	4.3	6.08
PG&E	30	34495	19.8	18.9	19.16	7.3	8.41	1.02	6.11	8.6
PG&E	30	34493	17.07	16.5	16.73	6.32	6.98	0.39	5.09	7.34
PG&E	30	34482	13.76	13.16	13.34	5.01	5.82	0.76	4.26	5.95
PG&E	30	34418	13.85	13.14	13.32	5.16	5.96	0.88	4.34	6.13
PG&E	30	34344	13.86	13.26	13.44	5.15	5.95	0.74	4.34	6.1
PG&E	30	34370	13.8	13.1	13.28	5.12	5.93	0.84	4.32	6.11
PG&E	30	34378	13.54	12.7	12.88	5.17	6	1.02	4.36	6.18
PG&E	30	34493	17.05	16.48	16.71	6.32	6.98	0.38	5.09	7.34
PG&E	30	38208	13.77	13.69	13.87	4.76	5.55	0.52	4.09	5.69
PG&E	30	30805	13.85	13.29	13.47	5.05	5.87	0.74	4.29	6.04
PG&E	30	34134	13.79	13.37	13.55	4.93	5.74	0.71	4.2	5.86
PG&E	30	34000	11.34	10.93	11.09	3.48	3.9	0.23	2.87	4.12
PG&E	30	34150	14.1	13.46	13.65	5.1	5.94	0.74	4.34	6.08
PG&E	30	34248	9.58	9.19	9.31	3.26	3.64	0.38	2.67	3.86
PG&E	30	30795	13.81	13.27	13.45	5.02	5.84	0.73	4.27	5.98
PG&E	30	34144	13.93	13.5	13.68	4.97	5.78	0.68	4.24	5.91

PG&E	30	33564	13.84	14.02	14.21	4.71	5.49	0.36	4.06	5.64
PG&E	30	33555	13.96	14.16	14.35	4.69	5.47	0.33	4.04	5.61
PG&E	30	33520	15.04	14.31	14.51	4.72	5.53	0.4	4.09	5.7
PG&E	30	33678	14.43	14.58	14.78	4.78	5.58	0.41	4.13	5.74
PG&E	30	33553	13.97	14.15	14.34	4.75	5.52	0.37	4.09	5.68
PG&E	30	30505	13.88	14.02	14.21	4.61	5.39	0.4	3.99	5.55
PG&E	30	30622	12.97	14.23	14.42	4.51	5.28	0.4	3.91	5.45
PG&E	30	33676	14.17	14.32	14.51	4.71	5.49	0.42	4.07	5.64
PG&E	30	33650	13.85	14	14.19	4.59	5.37	0.38	3.97	5.52
PG&E	30	33732	13.53	14.75	14.94	4.78	5.58	0.34	4.13	5.75
PG&E	30	33514	14.81	14.06	14.25	4.62	5.41	0.4	3.99	5.58
PG&E	30	33740	13.34	14.11	14.32	4.47	5.21	0.32	3.85	5.38
PG&E	30	33514	14.8	14.06	14.25	4.64	5.43	0.42	4.02	5.59
PG&E	30	33803	12.91	13.72	13.92	4.37	5.1	0.35	3.78	5.27
PG&E	30	33704	13.23	14.06	14.26	4.5	5.28	0.39	3.91	5.45
PG&E	30	33514	14.78	14.04	14.23	4.63	5.41	0.4	4	5.57
PG&E	30	33801	12.92	13.7	13.9	4.36	5.1	0.32	3.77	5.26
PG&E	30	33514	14.81	14.07	14.26	4.63	5.42	0.4	4.01	5.56
PG&E	30	33604	13.59	13.89	14.08	4.57	5.12	0.04	3.79	5.43
PG&E	30	33604	13.56	13.86	14.05	4.57	5.12	0.04	3.79	5.44
PG&E	30	33555	13.99	14.19	14.37	4.68	5.49	0.33	4.06	5.62
PG&E	30	33718	14.46	15.29	15.51	4.86	5.66	0.41	4.17	5.83
PG&E	30	33307	14.07	14.14	14.34	4.54	5.3	0.41	3.91	5.47
PG&E	30	33357	13.99	14.06	14.26	4.54	5.29	0.44	3.9	5.46
PG&E	30	33310	14.02	14.09	14.29	4.55	5.29	0.42	3.9	5.48
PG&E	30	33303	14.06	14.13	14.33	4.55	5.29	0.43	3.9	5.45
PG&E	30	33313	14.08	14.14	14.34	4.57	5.32	0.47	3.93	5.49
PG&E	30	33303	14.06	14.13	14.33	4.54	5.27	0.41	3.89	5.44
PG&E	30	33370	14	14.06	14.26	4.5	5.25	0.44	3.88	5.42

PG&E	30	33387	14.16	14.15	14.36	4.59	5.35	0.42	3.95	5.54
PG&E	30	33307	14.07	14.14	14.34	4.55	5.31	0.44	3.92	5.49
PG&E	30	33020	14.04	14.6	14.8	4.57	5.34	0.42	3.94	5.53
PG&E	30	30523	14.01	14.55	14.75	4.56	5.34	0.42	3.95	5.53
PG&E	30	30565	14.27	14.41	14.61	4.56	5.32	0.46	3.94	5.49
PG&E	30	30523	14.03	14.56	14.76	4.55	5.32	0.43	3.94	5.51
PG&E	30	32970	14.1	14.5	14.7	4.6	5.37	0.43	3.97	5.55
PG&E	30	33010	14.05	14.58	14.79	4.59	5.36	0.43	3.96	5.55
PG&E	30	32973	14.13	14.55	14.76	4.62	5.39	0.45	3.97	5.54
PG&E	30	32973	14.2	14.63	14.83	4.62	5.4	0.45	3.99	5.58
PG&E	30	33000	13.9	14.47	14.67	4.55	5.31	0.37	3.91	5.48
PG&E	30	32990	14.21	14.69	14.9	4.67	5.43	0.41	4.01	5.6
PG&E	30	32810	14.21	14.76	14.96	4.61	5.41	0.38	4	5.58
PG&E	30	32788	14.08	14.64	14.84	4.57	5.35	0.43	3.96	5.51
PG&E	30	32766	14.11	14.64	14.85	4.6	5.36	0.42	3.97	5.54
PG&E	30	32780	14.06	14.62	14.82	4.57	5.33	0.41	3.94	5.53
PG&E	30	32782	14.08	14.63	14.84	4.59	5.37	0.41	3.97	5.54
PG&E	30	32682	14.15	14.95	15.16	4.68	5.48	0.41	4.06	5.67
PG&E	30	32574	13.92	14.77	14.97	4.63	5.42	0.37	4.02	5.61
PG&E	30	32568	13.81	14.66	14.86	4.58	5.37	0.37	3.97	5.56
PG&E	30	32688	15.65	16.47	16.71	5.12	6	0.41	4.44	6.19
PG&E	30	32381	5.61	11.12	11.25	4.36	5.08	-0.69	3.87	5.46
PG&E	30	32365	2.61	7.06	7.13	3.4	4.14	-0.62	3.23	4.37
PG&E	30	32364	9.26	22.69	22.99	5.64	6.6	0.09	4.9	6.87
PG&E	30	32256	10.78	14.52	14.71	4.42	5.18	0.16	3.86	5.35
PG&E	30	32254	10.74	14.49	14.68	4.43	5.2	0.17	3.87	5.33
PG&E	30	32238	8.85	12.95	13.12	4.22	4.97	0.05	3.73	5.14
PG&E	30	32232	7.94	12.16	12.31	4.03	4.77	-0.03	3.59	4.93
PG&E	30	32228	9.11	13.17	13.34	4.21	4.97	0.04	3.73	5.11

PG&E	30	32202	6.95	16.81	17.03	4.34	5.09	0.1	3.8	5.27
PG&E	30	32200	6.78	16.61	16.82	4.26	5.02	0.11	3.76	5.19
PG&E	30	31660	7.92	20.18	20.44	5.08	5.93	0.1	4.41	6.15
PG&E	30	32074	15.27	16.58	16.82	5.09	5.91	0.45	4.38	6.15
PG&E	30	32070	18.77	17.06	17.3	5.04	5.9	0.35	4.37	6.17
PG&E	30	32002	13.28	14.97	15.18	4.47	5.24	0.37	3.88	5.43
PG&E	30	31998	13.26	14.97	15.18	4.45	5.22	0.35	3.87	5.4
PG&E	30	31998	13.25	14.96	15.17	4.44	5.2	0.37	3.85	5.39
PG&E	30	31998	13.24	14.95	15.16	4.44	5.21	0.35	3.86	5.37
PG&E	30	31988	9.84	15.07	15.27	4.44	5.19	0.13	3.87	5.32
PG&E	30	31958	13.97	15.7	15.93	4.66	5.46	0.39	4.04	5.67
SDG&E	22	22004	9.89	9.16	9.28	-1	0.41	31.96	-0.31	-1.44
SDG&E	22	22008	10.5	9.71	9.84	0.56	1.35	29.2	0.4	-0.51
SDG&E	22	22020	10.39	9.61	9.74	1.34	1.75	26.29	0.74	0.08
SDG&E	22	22024	10.57	9.77	9.9	-1.39	0.32	35.53	-0.43	-1.81
SDG&E	22	22040	10.07	9.34	9.46	-0.73	0.46	30.85	-0.27	-1.2
SDG&E	22	22048	10.55	9.75	9.88	-0.22	1	32.45	0.1	-1.04
SDG&E	22	22056	10.2	9.43	9.56	0.03	1.03	30.1	0.17	-0.86
SDG&E	22	22076	10.34	9.57	9.7	-1.7	0.1	35.66	-0.59	-2
SDG&E	22	22088	5.39	5.04	5.1	0.01	0.18	12.4	-0.15	-0.3
SDG&E	22	22092	10.57	9.78	9.91	-1.1	0.47	34.84	-0.31	-1.62
SDG&E	22	22096	10.57	9.77	9.9	-1.12	0.45	34.84	-0.33	-1.65
SDG&E	22	22104	9.31	8.66	8.78	-0.35	0.45	26.38	-0.19	-0.81
SDG&E	22	22108	10.64	9.84	9.97	-0.12	1.08	32.22	0.16	-0.98
SDG&E	22	22112	10.96	10.14	10.27	3.51	2.99	20.31	1.73	1.46
SDG&E	22	22120	10.36	9.57	9.7	-1.06	0.52	34.44	-0.29	-1.64
SDG&E	22	22124	10.5	9.71	9.84	-0.8	0.68	33.9	-0.15	-1.45
SDG&E	22	22132	10.29	9.52	9.64	-1.61	0.14	35.23	-0.57	-1.95
SDG&E	22	22136	10.11	9.35	9.47	-0.7	0.64	32.21	-0.14	-1.32

SDG&E	22	22148	10.86	10.06	10.2	-1.45	0.09	34.41	-0.6	-1.79
SDG&E	22	22152	9.75	9.03	9.15	-0.76	0.52	30.77	-0.22	-1.29
SDG&E	22	22902	6.5	6.06	6.14	-0.08	0.3	17.18	-0.13	-0.39
SDG&E	22	22156	11.05	10.23	10.37	2.4	2.37	25.02	1.2	0.77
SDG&E	22	22160	10.17	9.4	9.53	-0.23	0.9	30.97	0.06	-0.99
SDG&E	22	22168	10.02	9.29	9.42	-0.69	0.52	30.97	-0.22	-1.18
SDG&E	22	22176	9.04	8.45	8.56	-1.13	-0.38	24.22	-0.78	-1.32
SDG&E	22	22196	10.11	9.35	9.48	-0.29	0.86	31.16	0.03	-1.04
SDG&E	22	22204	10.12	9.36	9.48	-0.4	0.81	31.35	0	-1.13
SDG&E	22	22208	9.89	9.16	9.28	-1.23	0.29	32.77	-0.42	-1.63
SDG&E	22	22216	10.15	9.39	9.51	-0.86	0.57	32.95	-0.21	-1.42
SDG&E	22	22252	10.02	9.27	9.39	-0.26	0.85	30.49	0.04	-1.02
SDG&E	22	22256	10.57	9.77	9.9	0.6	1.42	29.51	0.44	-0.48
SDG&E	22	22272	10.91	10.09	10.23	0.47	1.34	30.61	0.37	-0.62
SDG&E	22	22276	10.16	9.39	9.52	-0.84	0.6	33.09	-0.18	-1.41
SDG&E	22	22288	10.49	9.71	9.84	0.46	1.32	29.53	0.39	-0.61
SDG&E	22	22292	10	9.25	9.37	-0.38	0.8	30.82	-0.01	-1.07
SDG&E	22	22300	10.47	9.68	9.81	-0.91	0.64	34.14	-0.18	-1.47
SDG&E	22	22306	9.91	9.17	9.3	-1.11	0.37	32.53	-0.34	-1.55
SDG&E	22	22308	10.08	9.33	9.45	-0.79	0.58	32.47	-0.21	-1.35
SDG&E	22	22316	10.12	9.35	9.48	-0.28	0.88	31.05	0.05	-1.03
SDG&E	22	22324	9.75	9.07	9.19	-0.4	0.5	28.1	-0.19	-0.87
SDG&E	22	22336	9.8	9.07	9.19	-1.22	0.28	32.42	-0.42	-1.57
SDG&E	22	22344	11.47	10.62	10.76	2.12	2.27	27.04	1.1	0.54
SDG&E	22	22352	10.59	9.79	9.92	-1.66	0.13	36.12	-0.59	-2.07
SDG&E	22	22364	10.04	9.29	9.41	-1.55	0.15	34.49	-0.53	-1.91
SDG&E	22	22368	11.32	10.48	10.62	2.21	2.3	26.24	1.13	0.62
SDG&E	22	22372	10.08	9.32	9.45	-0.78	0.6	32.47	-0.18	-1.38
SDG&E	22	22380	10.53	9.74	9.87	-1.32	0.34	35.17	-0.42	-1.76

SDG&E	22	22384	10.06	9.3	9.43	-0.79	0.61	32.41	-0.17	-1.34
SDG&E	22	22392	10.16	9.39	9.52	-0.62	0.69	32.06	-0.11	-1.25
SDG&E	22	22396	10.94	10.11	10.25	3.53	3.01	20.32	1.74	1.48
SDG&E	22	22400	11.12	10.29	10.43	1.99	2.18	26.45	1.04	0.46
SDG&E	22	22404	10.42	9.64	9.77	0.74	1.44	28.37	0.51	-0.37
SDG&E	22	22408	10	9.25	9.37	-1.11	0.38	32.97	-0.35	-1.57
SDG&E	22	22416	9.83	9.1	9.22	-0.97	0.41	31.83	-0.31	-1.41
SDG&E	22	22432	10.92	10.09	10.23	3.51	3	20.28	1.73	1.49
SDG&E	22	22440	10.42	9.64	9.77	1.39	1.81	26.31	0.79	0.06
SDG&E	22	22444	9.94	9.2	9.32	-0.35	0.81	30.43	0	-1.04
SDG&E	22	22448	10.1	9.33	9.46	-0.82	0.58	32.62	-0.2	-1.39
SDG&E	22	22480	9.96	9.21	9.33	-0.4	0.78	30.79	-0.02	-1.09
SDG&E	22	22496	10.21	9.44	9.56	-0.88	0.56	33.15	-0.22	-1.44
SDG&E	22	22512	10.34	9.56	9.69	1.32	1.75	26.33	0.75	0.08
SDG&E	22	22516	10.56	9.76	9.89	-1.62	0.19	36.04	-0.55	-1.97
SDG&E	22	22528	10.48	9.69	9.82	1.42	1.84	26.29	0.81	0.11
SDG&E	22	22532	9.96	9.22	9.35	-1.01	0.46	32.43	-0.27	-1.47
SDG&E	22	22548	10.59	9.8	9.93	-1.56	0.22	35.99	-0.51	-1.93
SDG&E	22	22556	10.58	9.78	9.91	-1.56	0.21	36.04	-0.52	-1.97
SDG&E	22	22576	10.75	9.95	10.08	-1.42	0.29	35.94	-0.47	-1.84
SDG&E	22	22580	10.49	9.69	9.82	-0.31	0.93	32.4	0.05	-1.15
SDG&E	22	22584	10.66	9.86	9.99	1.59	1.95	26.21	0.88	0.22
SDG&E	22	22592	10.39	9.61	9.73	-1.1	0.48	34.39	-0.3	-1.61
SDG&E	22	22602	10.56	9.77	9.9	0.4	1.3	29.81	0.37	-0.58
SDG&E	22	22604	10.53	9.74	9.87	-1.66	0.15	36.04	-0.57	-2.03
SDG&E	22	22612	10.4	9.63	9.75	-1.68	0.13	35.75	-0.56	-2.01
SDG&E	22	22620	10.25	9.48	9.6	-0.92	0.54	33.27	-0.25	-1.48
SDG&E	22	22624	10.39	9.62	9.74	1.07	1.6	27.21	0.64	-0.12
SDG&E	22	22632	10.5	9.7	9.83	-0.2	1.01	32.34	0.1	-1.05

SDG&E	22	22636	10.24	9.47	9.6	-1.68	0.14	35.57	-0.55	-1.97
SCE	24	25655	10.81	10.02	10.16	5.9	3.97	12.92	2.56	3.03
SCE	24	24007	11.05	10.27	10.41	7.22	5.19	5.34	3.58	4.99
SCE	24	24201	10.71	9.95	10.09	7.33	4.84	5.96	3.31	4.5
SCE	24	24017	10.43	9.68	9.81	0.45	0.39	14.58	0.06	-7.12
SCE	24	24203	11.04	10.27	10.41	6.94	5.29	4.65	3.68	5.19
SCE	24	24199	11.44	10.65	10.79	6.91	5.6	4.55	3.91	5.53
SCE	24	24024	10.9	10.13	10.26	8.81	5.14	4.23	3.53	4.79
SCE	24	24722	8.74	8.19	8.29	7.18	9.48	0.03	7.2	9.82
SCE	24	24028	11.08	10.31	10.45	6.73	5.26	5.15	3.66	5.14
SCE	24	24205	11.04	10.28	10.41	5.64	6.08	2.28	4.38	6.44
SCE	24	24039	11.28	10.5	10.64	6.76	5.49	4.4	3.84	5.45
SCE	24	24197	10.78	10.02	10.15	6.45	4.59	8.54	3.1	4.12
SCE	24	24055	11.07	10.29	10.42	10.77	4.98	3.06	3.38	4.48
SCE	24	24032	10.68	9.93	10.07	10.37	4.81	3.01	3.29	4.36
SCE	24	24057	11.21	10.45	10.59	5.08	6.16	1.41	4.49	6.63
SCE	24	25002	11.22	10.45	10.59	6.12	5.94	3.41	4.25	6.12
SCE	24	24206	11.11	10.34	10.48	5.76	6.06	2.83	4.36	6.35
SCE	24	24064	11.37	10.57	10.72	7.02	5.51	4.96	3.83	5.46
SCE	24	24727	12.07	11.22	11.38	5.87	8.28	1.07	6	7.11
SCE	24	24731	10.92	10.2	10.33	5.78	7.85	0.65	5.77	6.75
SCE	24	24207	10.76	10	10.13	6	4.31	9.94	2.86	3.73
SCE	24	24702	11.71	10.88	11.03	5.75	8.06	1.03	5.84	6.97
SCE	24	24073	11.25	10.47	10.61	6.8	5.53	4.42	3.87	5.49
SCE	24	24075	11.18	10.4	10.54	6.51	5.61	4.11	3.95	5.62
SCE	24	24208	11.07	10.3	10.44	6.66	5.4	4.32	3.78	5.36
SCE	24	25202	10.72	9.96	10.1	7.84	4.89	5.51	3.34	4.57
SCE	24	24083	11.22	10.44	10.58	6.91	5.45	4.62	3.8	5.34
SCE	24	24209	11.07	10.3	10.44	6.62	5.53	3.71	3.9	5.52

SCE	24	24210	10.74	9.98	10.11	8.75	5.18	3.66	3.57	4.9
SCE	24	24098	11.24	10.47	10.61	5.12	6.36	1.45	4.65	6.89
SCE	24	24211	10.79	10.04	10.17	7.59	5.21	3.82	3.63	5.04
SCE	24	24111	10.78	10.02	10.16	10.02	4.97	3.13	3.4	4.54
SCE	24	24212	11.08	10.28	10.41	4.72	5.32	-0.53	3.8	6.27
SCE	24	24213	11.09	10.32	10.46	6.29	5.65	3.28	4.01	5.75
SCE	24	24127	11.44	10.65	10.8	5.19	6.35	1.43	4.62	6.8
SCE	24	24214	10.93	10.15	10.28	13.56	4.42	2.64	2.91	3.63
SCE	24	24133	10.8	10.02	10.15	5.54	4.08	12.12	2.65	3.31
SCE	24	24135	11.5	10.72	10.86	5.16	6.55	1.35	4.78	7.16
SCE	24	24215	11.35	10.51	10.65	4.95	5.59	-0.44	3.99	6.59
SCE	24	24759	11.88	11.04	11.19	5.29	8.28	0.67	6.07	6.45
SCE	24	24768	11.21	10.44	10.58	5.79	8.06	0.81	5.89	6.9
SCE	24	24767	12.03	11.18	11.33	5.88	8.23	1	5.97	7.13
SCE	24	24769	13.16	12.23	12.4	6.33	8.93	1.07	6.47	7.69
SCE	24	24770	13.44	12.5	12.66	6.49	9.12	0.98	6.61	7.9
SCE	24	24771	11.81	10.97	11.12	5.13	8.33	0.57	6.11	6.28
SCE	24	24772	10.56	9.86	9.99	7.58	10.06	-0.17	7.58	10.21
SCE	24	24776	10.6	9.84	9.97	8.52	11.02	-0.08	8.34	11.7

Appendix E: System Details

E.1 16-Machine System

The 16-machine, 68-bus system is an equivalent model of the New England-New York interconnected power system. The bus data, line data, transformer data, load data and generator data for this system are summarized below. The Base MVA for this system was 100 MVA.

Bus Data: Bus number is the unique number used to identify the bus, the magnitude of the bus voltage is expressed in p.u., the angle of the bus voltage is expressed in degrees, and the bus type denotes whether the particular bus is the swing bus, a generator bus or a load bus.

Bus Numbers	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
1	1.0600	6.57	Load Bus
2	1.0500	8.35	Load Bus
3	1.0300	5.39	Load Bus
4	1.0000	4.28	Load Bus
5	1.0000	5.22	Load Bus
6	1.0100	5.90	Load Bus
7	1.0000	3.64	Load Bus
8	1.0000	3.10	Load Bus
9	1.0300	2.55	Load Bus
10	1.0100	8.42	Load Bus
11	1.0100	7.56	Load Bus
12	1.0500	7.58	Load Bus
13	1.0100	7.75	Load Bus
14	1.0100	6.20	Load Bus
15	1.0100	6.11	Load Bus
16	1.0300	7.64	Load Bus
17	1.0300	6.55	Load Bus
18	1.0300	5.68	Load Bus
19	1.0500	12.24	Load Bus
20	0.9900	10.80	Load Bus
21	1.0300	10.28	Load Bus
22	1.0500	14.95	Load Bus
23	1.0400	14.67	Load Bus
24	1.0300	7.82	Load Bus
25	1.0600	9.67	Load Bus

Bus Numbers	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
26	1.0500	8.17	Load Bus
27	1.0400	6.29	Load Bus
28	1.0500	11.30	Load Bus
29	1.0500	13.94	Load Bus
30	1.0500	6.03	Load Bus
31	1.0500	8.56	Load Bus
32	1.0500	10.92	Load Bus
33	1.0500	7.44	Load Bus
34	1.0600	2.54	Load Bus
35	1.0100	2.55	Load Bus
36	1.0400	-0.85	Load Bus
37	1.0200	-6.80	Load Bus
38	1.0500	8.57	Load Bus
39	1.0000	-8.40	Load Bus
40	1.0600	15.24	Load Bus
41	0.9900	44.66	Load Bus
42	0.9900	39.19	Load Bus
43	1.0100	-7.58	Load Bus
44	1.0100	-7.61	Load Bus
45	1.0100	2.60	Load Bus
46	1.0200	9.42	Load Bus
47	1.0700	7.34	Load Bus
48	1.0700	9.27	Load Bus
49	1.0200	14.11	Load Bus
50	1.0100	19.56	Load Bus
51	1.0200	6.64	Load Bus
52	0.9900	38.96	Load Bus
53	1.0400	9.55	Gen Bus
54	0.9800	14.37	Gen Bus
55	0.9800	16.40	Gen Bus
56	0.9900	17.45	Gen Bus
57	1.0100	15.98	Gen Bus
58	1.0500	20.29	Gen Bus
59	1.0600	22.52	Gen Bus
60	1.0300	16.41	Gen Bus
61	1.0200	20.75	Gen Bus
62	1.0100	15.84	Gen Bus
63	1.0000	18.31	Gen Bus
64	1.0100	4.85	Gen Bus

Bus Numbers	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
65	1.0100	0.00	Swing Bus
66	1.0000	46.19	Gen Bus
67	1.0000	40.05	Gen Bus
68	1.0000	45.89	Gen Bus
98	1.0200	8.83	Load Bus
99	1.0200	14.71	Load Bus
198	1.0514	5.65	Load Bus
199	1.0553	8.08	Load Bus
298	1.0200	9.20	Load Bus
299	1.0000	8.08	Load Bus

Line Data: Line Number is the unique number used to identify the line, From Bus # represents the number of the From Bus, To Bus # represents the number of the To Bus, the resistance of the line is measured in p.u., the reactance of the line is measured in p.u., and the line charging susceptance is also measured in p.u.

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
1	1	2	0.0035	0.0411	0.6987
2	1	30	0.0008	0.0074	0.4800
3	2	3	0.0013	0.0151	0.2572
4	2	25	0.0070	0.0086	0.1460
5	3	4	0.0013	0.0213	0.2214
6	3	18	0.0011	0.0133	0.2138
7	4	5	0.0008	0.0128	0.1342
8	4	14	0.0008	0.0129	0.1382
9	5	6	0.0002	0.0026	0.0434
10	5	8	0.0008	0.0112	0.1476
11	6	7	0.0006	0.0092	0.1130
12	6	11	0.0007	0.0082	0.1389
13	7	8	0.0004	0.0046	0.0780
14	8	9	0.0023	0.0363	0.3804
15	9	30	0.0019	0.0183	0.2900
16	10	11	0.0004	0.0043	0.0729
17	10	13	0.0004	0.0043	0.0729
18	13	14	0.0009	0.0101	0.1723
19	14	15	0.0018	0.0217	0.3660
20	15	16	0.0009	0.0094	0.1710
21	16	17	0.0007	0.0089	0.1342
22	16	19	0.0016	0.0195	0.3040
23	16	21	0.0008	0.0135	0.2548
24	16	24	0.0003	0.0059	0.0680
25	17	18	0.0007	0.0082	0.1319
26	17	27	0.0013	0.0173	0.3216
27	21	22	0.0008	0.0140	0.2565
28	22	23	0.0006	0.0096	0.1846
29	23	24	0.0022	0.0350	0.3610
30	23	59	0.0005	0.0272	0.0000
31	25	26	0.0032	0.0323	0.5310
32	26	27	0.0014	0.0147	0.2396
33	26	28	0.0043	0.0474	0.7802
34	26	29	0.0057	0.0625	1.0290

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
35	28	29	0.0014	0.0151	0.2490
36	9	30	0.0019	0.0183	0.2900
37	9	36	0.0022	0.0196	0.3400
38	9	36	0.0022	0.0196	0.3400
39	36	37	0.0005	0.0045	0.3200
40	34	36	0.0033	0.0111	1.4500
41	33	34	0.0011	0.0157	0.2020
42	32	33	0.0008	0.0099	0.1680
43	30	31	0.0013	0.0187	0.3330
44	30	32	0.0024	0.0288	0.4880
45	1	31	0.0016	0.0163	0.2500
46	31	38	0.0011	0.0147	0.2470
47	33	38	0.0036	0.0444	0.6930
48	38	46	0.0022	0.0284	0.4300
49	46	49	0.0018	0.0274	0.2700
50	1	47	0.0013	0.0188	1.3100
51	47	48	0.0025	0.0268	0.4000
52	47	48	0.0025	0.0268	0.4000
53	48	40	0.0020	0.0220	1.2800
54	35	45	0.0007	0.0175	1.3900
55	37	43	0.0005	0.0276	0.0000
56	43	44	0.0001	0.0011	0.0000
57	44	45	0.0025	0.0730	0.0000
58	39	44	0.0000	0.0411	0.0000
59	39	45	0.0000	0.0839	0.0000
60	45	51	0.0004	0.0105	0.7200
61	50	52	0.0012	0.0900	2.0600
62	50	51	0.0009	0.0221	1.6200
63	49	52	0.0076	0.0077	1.1600
64	52	42	0.0040	0.0600	2.2500
65	42	41	0.0040	0.0600	2.2500
66	41	40	0.0060	0.0840	3.1500

Transformer Data: Transformer Number is the unique number used to identify the transformer, From Bus # represents the number of the From Bus, To Bus # represents the number of the To Bus, the resistance of the transformer is measured in p.u., the reactance of the transformer is measured in p.u., and the line charging susceptance (if present) is also measured in p.u. The tap-ratio is mentioned in the last column.

Transformer Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)	Tap Ratio
1	1	27	0.0320	0.3200	0.41	1.00
2	2	53	0.0000	0.0091	0.00	1.03
3	6	54	0.0000	0.0250	0.00	1.07
4	10	55	0.0000	0.0200	0.00	1.07
5	12	11	0.0016	0.0435	0.00	1.06
6	12	13	0.0016	0.0435	0.00	1.06
7	19	20	0.0007	0.0138	0.00	1.06
8	19	56	0.0007	0.0142	0.00	1.07
9	20	57	0.0009	0.0180	0.00	1.01
10	22	58	0.0000	0.0143	0.00	1.03
11	25	60	0.0006	0.0232	0.00	1.03
12	29	61	0.0008	0.0156	0.00	1.03
13	31	62	0.0000	0.0260	0.00	1.04
14	32	63	0.0000	0.0130	0.00	1.04
15	35	34	0.0001	0.0074	0.00	0.95
16	36	64	0.0000	0.0075	0.00	1.04
17	37	65	0.0000	0.0033	0.00	1.04
18	41	66	0.0000	0.0015	0.00	1.00
19	41	98	0.0000	0.0100	0.00	1.00
20	42	67	0.0000	0.0015	0.00	1.00
21	42	99	0.0000	0.0100	0.00	1.00
22	42	198	0.0000	0.0100	0.00	1.00
23	46	298	0.0000	0.0100	0.00	1.00
24	49	299	0.0000	0.0100	0.00	1.00
25	52	68	0.0000	0.0030	0.00	1.00
26	52	199	0.0000	0.0100	0.00	1.00

Load Data: Bus Number is the unique number used to identify the bus to which the load is connected, P_load denotes the real component of the load and is measured in p.u., while Q_load denotes the reactive component of the load and is also measured in p.u.

Bus Numbers	P_load (p.u.)	Q_load (p.u.)
1	2.527	1.1856
2	0	0
3	3.22	0.02
4	5	1.84
5	0	0
6	0	0
7	2.34	0.84
8	5.22	1.77
9	1.04	1.25
10	0	0
11	0	0
12	0.09	0.88
13	0	0
14	0	0
15	3.2	1.53
16	3.29	0.32
17	0	0
18	1.58	0.3
19	0	0
20	6.8	1.03
21	2.74	1.15
22	0	0
23	2.48	0.85
24	3.09	-0.92
25	2.24	0.47
26	1.39	0.17
27	2.81	0.76
28	2.06	0.28
29	2.84	0.27
30	0	0
31	0	0
32	0	0
33	1.12	0
34	0	0
35	0	0

Bus Numbers	P_load (p.u.)	Q_load (p.u.)
36	1.02	-0.1946
37	60	3
38	0	0
39	2.67	0.126
40	0.6563	0.2353
41	10	2.5
42	11.5	2.5
43	0	0
44	2.6755	0.0484
45	2.08	0.21
46	1.507	0.285
47	2.0312	0.3259
48	2.412	0.022
49	1.64	0.29
50	1	-1.47
51	3.37	-1.22
52	24.7	1.23
53	0	0
54	0	0
55	0	0
56	0	0
57	0	0
58	0	0
59	0	0
60	0	0
61	0	0
62	0	0
63	0	0
64	0	0
65	0	0
66	0	0
67	0	0
68	0	0
98	1.09	0.36
99	-1.1	0.609
198	1.09	0.36
199	-1.1	0.609
298	1.09	0.36
299	-1.1	0.609

Generator Data: Bus Number is the unique number used to identify the bus to which the generator is connected, MVA_base denotes the base MVA of the individual generators, P_gen denotes the real component of the power generated by the generator and is measured in p.u., Q_gen denotes the reactive component of the power generated by the generator and is also measured in p.u., X_l denotes the leakage reactance in p.u., X'_d denotes the unsaturated direct-axis transient reactance of the generator, H denotes the inertia constant of the turbine-governor set and is measured in seconds, and Qgen_max and Qgen_min denote the maximum and the minimum reactive power limits respectively.

Bus Numbers	MVA_base	P_gen (p.u.)	Q_gen (p.u.)	X_l (p.u.)	X'_d (p.u.)	H (sec)	Qgen_max (p.u.)	Qgen_min (p.u.)
53	300	2.500	0.000	0.003	0.248	3.400	999	-999
54	800	5.450	0.000	0.035	0.425	4.949	999	-999
55	800	6.500	0.000	0.030	0.383	4.962	999	-999
56	800	6.320	0.000	0.030	0.300	4.163	999	-999
57	700	5.052	0.000	0.027	0.360	4.767	999	-999
58	900	7.000	0.000	0.022	0.354	4.911	999	-999
59	800	5.600	0.000	0.032	0.299	4.327	999	-999
60	800	5.400	0.000	0.028	0.354	3.915	999	-999
61	1000	8.000	0.000	0.030	0.487	4.037	999	-999
62	1200	5.000	0.000	0.020	0.487	2.911	999	-999
63	1600	10.000	0.000	0.010	0.253	2.005	999	-999
64	1900	13.500	0.000	0.022	0.552	5.179	999	-999
65	12000	35.910	0.000	0.003	0.334	4.078	0	0
66	10000	17.850	0.000	0.002	0.285	3.000	999	-999
67	10000	10.000	0.000	0.002	0.285	3.000	999	-999
68	11000	40.000	0.000	0.004	0.359	4.450	999	-999

D.2 29-Machine System

The 29-machine, 127-bus system is an equivalent model of the WECC system. The bus data, line data, transformer data, load data, generator data and shunt data for this system are summarized below. The Base MVA for this system was 100 MVA.

Bus Data: Bus number is the unique number used to identify the bus, the bus name is the unique name used to identify the bus, the base kV denotes the base voltage of the bus in kV, the magnitude of the bus voltage is expressed in p.u., the angle of the bus voltage is expressed in degrees, and the bus type denotes whether the particular bus is the swing bus, a generator bus or a load bus.

Bus Numbers	Bus Names	Base kV	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
1	CMAIN GM	20	1.0200	67.80	Gen Bus
2	CA230	230	1.0011	62.87	Load Bus
3	CA230TO	230	0.9786	53.83	Load Bus
4	CANALB	500	1.0786	49.24	Load Bus
5	CANAD G1	20	1.0000	24.74	Gen Bus
6	CANADA	500	1.0363	20.95	Load Bus
7	NORTH	500	1.0499	12.11	Load Bus
8	NORTH G3	20	1.0000	26.59	Gen Bus
9	HANFORD	500	1.0495	0.23	Load Bus
10	COULEE	500	1.0700	0.16	Load Bus
11	GARRISON	500	1.0371	-12.16	Load Bus
12	JOHN DAY	500	1.0828	-11.12	Load Bus
13	JOHN DAY	13.8	1.0000	0.00	Swing Bus
14	BIG EDDY	500	1.0892	-13.31	Load Bus
15	GRIZZLY	500	1.0674	-17.15	Load Bus
16	CELILOCA	500	1.0897	-13.42	Load Bus
17	BIG EDDY	230	1.0659	-14.57	Load Bus
18	CELILO	230	1.0616	-15.08	Load Bus
19	DALLES21	13.8	1.0550	-7.94	Gen Bus
20	BIG EDDY	115	1.0686	-16.93	Load Bus
21	SUMMER L	500	1.0582	-18.23	Load Bus
22	BURNS2	500	0.9844	-6.69	Load Bus
23	MALIN	500	1.0543	-23.34	Load Bus
24	MONTANA	500	1.0493	48.20	Load Bus
25	COLSTRP	500	1.0784	-1.36	Load Bus
26	MONTA G1	20	1.0000	56.59	Gen Bus
27	MIDPOINT	500	1.0619	-5.20	Load Bus
28	BRIDGER2	22	1.0090	2.46	Gen Bus

Bus Numbers	Bus Names	Base kV	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
29	MIDPOINT	345	0.9984	-1.57	Load Bus
30	BENLOMND	345	1.0446	-3.40	Load Bus
31	BENLOMND	230	1.0462	-3.96	Load Bus
32	NAUGHTON	230	1.0445	0.61	Load Bus
33	NAUGHT	20	1.0000	3.41	Gen Bus
34	TERMINAL	345	1.0391	-3.42	Load Bus
35	CAMP WIL	345	1.0429	-2.42	Load Bus
36	SPAN FRK	345	1.0351	-1.09	Load Bus
37	EMERY	345	1.0371	4.89	Load Bus
38	EMERY	20	1.0500	9.60	Gen Bus
39	SIGURD	345	1.0519	-0.55	Load Bus
40	PINTO	345	1.0404	-1.41	Load Bus
41	PINTO PS	345	1.0368	-2.44	Load Bus
42	MONA	345	1.0560	-2.01	Load Bus
43	INTERMT	345	1.0526	-4.37	Load Bus
44	INTERM1G	26	1.0500	0.28	Gen Bus
45	CRAIG	345	0.9752	16.27	Load Bus
46	CRAIG	22	0.9500	23.55	Gen Bus
47	HAYDEN	20	1.0000	33.73	Gen Bus
48	SAN JUAN	345	1.0356	-3.88	Load Bus
49	SJUAN G4	22	1.0000	-0.89	Gen Bus
50	FOURCORN	345	1.0091	-4.69	Load Bus
51	FOURCORN	500	1.0681	-7.91	Load Bus
52	FOURCORN	230	1.0073	-5.23	Load Bus
53	FCNGN4CC	22	1.0000	2.23	Gen Bus
54	CHOLLA	345	0.9774	-16.96	Load Bus
55	CORONADO	500	0.9795	-26.18	Load Bus
56	CORONADO	20	1.0400	-19.66	Gen Bus
57	MOENKOPI	500	1.0673	-24.86	Load Bus
58	WESTWING	500	1.0559	-29.59	Load Bus
59	PALOVRDE	500	1.0486	-29.64	Load Bus
60	PALOVRD2	24	0.9600	-21.72	Gen Bus
61	NAVAJO	500	1.0720	-23.94	Load Bus
62	NAVAJO 2	26	1.0000	-17.81	Gen Bus
63	ELDORADO	500	1.0512	-33.10	Load Bus
64	DEVERS	500	1.0354	-43.52	Load Bus
65	ELDORADO	20	1.0200	-25.98	Gen Bus
66	MOHAVE	500	1.0700	-29.36	Load Bus
67	MOHAV1CC	22	1.0500	-21.04	Gen Bus

Bus Numbers	Bus Names	Base kV	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
68	LUGO	500	1.0550	-46.09	Load Bus
69	SERRANO	500	1.0413	-50.08	Load Bus
70	VALLEY	500	1.0369	-47.76	Load Bus
71	MIRALOMA	500	1.0409	-49.68	Load Bus
72	MIRALOMA	20	1.0500	-45.44	Gen Bus
73	MIRALOMA	230	1.0382	-50.13	Load Bus
74	MESA CAL	230	1.0071	-55.06	Load Bus
75	LITEHIPE	230	1.0119	-55.78	Load Bus
76	LITEHIPE	20	1.0200	-49.63	Gen Bus
77	VINCENT	500	1.0612	-48.95	Load Bus
78	VINCENT	230	0.9949	-51.64	Load Bus
79	EAGLROCK	230	1.0101	-52.76	Load Bus
80	PARDEE	230	1.0060	-51.68	Load Bus
81	PARDEE	20	1.0100	-39.60	Gen Bus
82	SYLMAR S	230	1.0207	-48.26	Load Bus
83	MIDWAY	200	1.1670	-51.45	Load Bus
84	MIDWAY	500	1.0593	-48.61	Load Bus
85	LOSBANOS	500	1.0493	-49.53	Load Bus
86	MOSSLAND	500	1.0464	-49.80	Load Bus
87	DIABLO	500	1.0530	-46.13	Load Bus
88	DIABLO1	25	0.9800	-42.33	Gen Bus
89	GATES	500	1.0471	-47.68	Load Bus
90	TEVATR	500	0.9982	-39.00	Load Bus
91	TEVATR2	20	1.0000	-30.78	Gen Bus
92	OLINDA	500	1.0372	-31.07	Load Bus
93	ROUND MT	500	1.0346	-27.93	Load Bus
94	TABLE MT	500	1.0134	-32.07	Load Bus
95	ROUND MT	200	1.1239	-25.14	Load Bus
96	ROUND MT	20	1.0200	-15.08	Gen Bus
97	COTWDPGE	200	1.1361	-30.49	Load Bus
98	LOGAN CR	200	1.1402	-34.59	Load Bus
99	GLENN	200	1.1409	-34.20	Load Bus
100	CORTINA	200	1.1310	-34.98	Load Bus
101	TEVATR	200	1.1274	-39.64	Load Bus
102	TEVATR	20	1.0500	-35.69	Gen Bus
103	SYLMARLA	230	1.0383	-47.15	Load Bus
104	VICTORVL	500	1.0587	-42.48	Load Bus
105	VICTORVL	287	1.0521	-44.50	Load Bus
106	STA B2	287	1.0366	-50.72	Load Bus

Bus Numbers	Bus Names	Base kV	Voltage Magnitude (p.u.)	Voltage Angle (degree)	Bus Type
107	STA B1	287	1.0366	-50.72	Load Bus
108	STA B	138	1.0326	-51.90	Load Bus
109	STA BLD	230	1.0273	-52.11	Load Bus
110	STA F	230	1.0248	-51.88	Load Bus
111	RIVER	230	1.0236	-51.85	Load Bus
112	HAYNES	230	1.0313	-50.65	Load Bus
113	HAYNES3G	18	1.0000	-47.35	Gen Bus
114	STA G	230	1.0239	-51.18	Load Bus
115	GLENDAL	230	1.0234	-50.93	Load Bus
116	STA E	230	1.0252	-50.06	Load Bus
117	VALLEY	230	1.0293	-49.03	Load Bus
118	RINALDI	230	1.0340	-47.84	Load Bus
119	OWENS G	11.5	1.0200	-47.27	Gen Bus
120	STA E	500	1.0430	-47.67	Load Bus
121	ADELANTO	500	1.0603	-42.16	Load Bus
122	ADELAN&1	500	1.0809	-46.23	Load Bus
123	RINALDI	500	1.0721	-45.48	Load Bus
124	STA J	230	1.0311	-48.92	Load Bus
125	CASTAIC	230	1.0319	-47.29	Load Bus
126	CASTAI4G	18	1.0200	-45.98	Gen Bus
127	OLIVE	230	1.0348	-47.63	Load Bus

Line Data: Line Number is the unique number used to identify the line, From Bus # represents the number of the From Bus, To Bus # represents the number of the To Bus, the resistance of the line is measured in p.u., the reactance of the line is measured in p.u., and the line charging susceptance is also measured in p.u.

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
1	2	3	0.0020	0.0200	0.8000
2	4	6	0.0035	0.0700	4.6060
3	6	7	0.0008	0.0239	3.3000
4	7	9	0.0002	0.0082	1.3000
5	7	9	0.0002	0.0082	1.3000
6	9	10	0.0011	0.0207	1.8553
7	9	11	0.0014	0.0226	1.8800
8	9	12	0.0012	0.0232	1.7152
9	9	12	0.0003	0.0200	3.6000
10	9	24	0.0007	0.0740	4.8700
11	11	12	0.0020	0.0330	1.8800
12	11	25	0.0018	0.0141	3.6800
13	12	14	0.0002	0.0045	0.3332
14	12	14	0.0002	0.0045	0.3050
15	12	15	0.0006	0.0141	1.0976
16	12	15	0.0011	0.0241	1.5554
17	12	15	0.0011	0.0241	1.5535
18	14	16	0.0000	0.0003	0.0143
19	14	16	0.0000	0.0003	0.0184
20	15	21	0.0010	0.0051	1.0513
21	15	23	0.0021	0.0166	2.9358
22	15	23	0.0021	0.0158	2.9538
23	17	18	0.0001	0.0013	0.0038
24	17	18	0.0001	0.0012	0.0033
25	21	22	0.0012	0.0237	2.2071
26	21	23	0.0008	0.0077	0.3273
27	22	27	0.0029	0.0025	23.9151
28	23	92	0.0011	0.0129	2.7575
29	23	93	0.0011	0.0091	1.2808
30	23	93	0.0010	0.0092	1.5715
31	29	30	0.0062	0.0673	1.1156
32	30	34	0.0016	0.0226	0.3810
33	30	35	0.0024	0.0332	0.5849
34	31	32	0.0108	0.0965	0.3296

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
35	34	35	0.0008	0.0106	0.2039
36	35	36	0.0012	0.0172	0.2987
37	35	37	0.0052	0.0602	1.0100
38	35	37	0.0049	0.0537	0.8843
39	35	42	0.0017	0.0225	0.3992
40	35	42	0.0021	0.0238	0.3845
41	36	37	0.0034	0.0392	0.6524
42	37	39	0.0034	0.0374	0.6208
43	37	39	0.0034	0.0372	0.6182
44	37	40	0.0096	0.0878	1.4265
45	39	42	0.0038	0.0340	0.5824
46	39	42	0.0032	0.0349	0.5722
47	41	50	0.0048	0.0436	0.7078
48	42	43	0.0018	0.0245	0.4392
49	42	43	0.0018	0.0245	0.4392
50	42	45	0.0081	0.1369	2.4348
51	45	48	0.0098	0.1100	2.0000
52	48	50	0.0005	0.0053	0.0882
53	50	54	0.0018	0.0199	2.5760
54	51	57	0.0018	0.0323	3.1129
55	57	58	0.0018	0.0269	3.3453
56	57	61	0.0008	0.0055	1.3922
57	57	63	0.0022	0.0160	3.8163
58	58	59	0.0004	0.0096	0.9038
59	58	59	0.0004	0.0096	0.9038
60	58	61	0.0026	0.0376	4.7289
61	59	64	0.0026	0.0297	2.1530
62	59	64	0.0026	0.0297	2.1530
63	61	63	0.0028	0.0211	1.0194
64	63	66	0.0006	0.0142	1.0429
65	63	68	0.0019	0.0278	4.6712
66	63	104	0.0018	0.0252	0.5355
67	63	104	0.0018	0.0252	0.5355
68	64	70	0.0004	0.0091	0.6679
69	66	68	0.0019	0.0310	4.1402
70	68	69	0.0006	0.0128	0.9462
71	68	71	0.0003	0.0075	0.5174
72	68	71	0.0004	0.0075	0.5536
73	68	77	0.0004	0.0113	0.8292

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
74	68	77	0.0004	0.0113	0.8292
75	68	104	0.0002	0.0041	0.2962
76	69	70	0.0004	0.0093	0.6856
77	69	71	0.0002	0.0046	0.3234
78	73	74	0.0014	0.0540	0.1525
79	74	75	0.0011	0.0127	0.0480
80	74	78	0.0032	0.0395	0.1440
81	74	79	0.0019	0.0258	0.0984
82	77	84	0.0013	0.0082	1.9687
83	77	84	0.0013	0.0082	1.9492
84	77	84	0.0011	0.0077	1.6015
85	78	80	0.0029	0.0365	0.1266
86	78	80	0.0014	0.0340	0.1125
87	79	80	0.0085	0.0703	0.1595
88	79	82	0.0014	0.0264	0.1020
89	80	82	0.0007	0.0119	0.0467
90	80	82	0.0007	0.0119	0.0467
91	84	85	0.0015	0.0147	0.0000
92	84	87	0.0009	0.0209	1.4571
93	84	87	0.0009	0.0209	1.4571
94	84	89	0.0007	0.0061	2.8240
95	84	90	0.0017	0.0376	2.0789
96	85	86	0.0005	0.0130	0.0000
97	85	89	0.0008	0.0199	0.0000
98	87	89	0.0008	0.0194	1.3285
99	89	90	0.0010	0.0257	0.7976
100	90	92	0.0016	0.0111	3.6348
101	90	94	0.0010	0.0104	0.9312
102	90	94	0.0016	0.0123	2.2819
103	93	94	0.0015	0.0069	0.7944
104	93	94	0.0015	0.0069	0.7944
105	95	97	0.0111	0.0668	0.0729
106	95	97	0.0105	0.0654	0.0686
107	95	97	0.0111	0.0664	0.0716
108	97	98	0.0167	0.1138	0.1361
109	97	99	0.0138	0.0927	0.1106
110	97	100	0.0248	0.1694	0.2023
111	97	101	0.0390	0.2740	0.3107
112	98	101	0.0224	0.1611	0.1834

Line Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Line Charging (p.u.)
113	99	101	0.0306	0.2046	0.2447
114	100	101	0.0148	0.1010	0.1207
115	103	118	0.0003	0.0039	0.0092
116	103	118	0.0003	0.0039	0.0092
117	103	118	0.0003	0.0039	0.0092
118	103	125	0.0023	0.0342	0.0751
119	104	121	0.0000	0.0016	0.1200
120	104	121	0.0000	0.0016	0.1200
121	104	123	0.0008	0.0188	1.6667
122	105	106	0.0107	0.0791	0.3667
123	105	107	0.0107	0.0791	0.3667
124	109	110	0.0007	0.0103	0.0256
125	109	110	0.0007	0.0103	0.0256
126	110	111	0.0004	0.0037	0.0083
127	110	112	0.0020	0.0307	0.0689
128	110	114	0.0011	0.0119	0.0251
129	111	112	0.0022	0.0342	0.0772
130	111	112	0.0024	0.0367	0.0828
131	111	114	0.0006	0.0059	0.0125
132	112	114	0.0028	0.0430	0.0965
133	114	115	0.0004	0.0054	0.0120
134	114	116	0.0012	0.0124	0.0280
135	114	116	0.0012	0.0124	0.0280
136	115	116	0.0005	0.0072	0.0162
137	116	117	0.0013	0.0098	0.0212
138	116	118	0.0023	0.0158	0.0306
139	116	118	0.0023	0.0158	0.0306
140	117	118	0.0014	0.0112	0.0247
141	117	118	0.0014	0.0112	0.0247
142	118	124	0.0014	0.0097	0.0194
143	118	124	0.0014	0.0097	0.0194
144	118	124	0.0016	0.0097	0.0193
145	118	124	0.0016	0.0097	0.0193
146	118	125	0.0029	0.0380	0.0824
147	118	127	0.0003	0.0043	0.0095
148	120	121	0.0008	0.0167	1.1880
149	121	122	0.0007	0.0186	1.4026
150	124	125	0.0031	0.0468	0.1008
151	125	127	0.0022	0.0335	0.0734

Transformer Data: Transformer Number is the unique number used to identify the transformer, From Bus # represents the number of the From Bus, To Bus # represents the number of the To Bus, the resistance of the transformer is measured in p.u. and the reactance of the transformer is also measured in p.u. The tap-ratio is mentioned in the last column.

Transformer Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Tap Ratio
1	1	2	0.0000	0.0020	1.0000
2	3	4	0.0000	0.0100	1.1000
3	5	6	0.0000	0.0015	1.0500
4	7	8	0.0000	0.0025	1.0660
5	12	13	0.0000	0.0038	1.0977
6	14	17	0.0002	0.0118	1.0238
7	14	17	0.0001	0.0074	1.0238
8	16	18	0.0000	0.0022	1.0234
9	17	19	0.0000	0.0103	1.0455
10	17	20	0.0009	0.0299	0.9873
11	24	26	0.0000	0.0050	1.0900
12	27	29	0.0000	0.0072	1.0500
13	28	29	0.0000	0.0046	1.0000
14	30	31	0.0003	0.0181	1.0000
15	32	33	0.0005	0.0141	1.0588
16	37	38	0.0002	0.0058	0.9855
17	40	41	0.0000	0.0195	1.0000
18	43	44	0.0000	0.0052	1.0250
19	45	46	0.0000	0.0124	1.0000
20	45	47	0.0000	0.0150	1.0000
21	48	49	0.0000	0.0060	1.0435
22	50	51	0.0000	0.0110	1.0630
23	50	51	0.0000	0.0110	1.0630
24	50	52	0.0003	0.0138	1.0000
25	50	52	0.0003	0.0139	1.0000
26	50	53	0.0000	0.0059	1.0000
27	54	55	0.0000	0.0146	1.0000
28	55	56	0.0000	0.0173	0.9545
29	59	60	0.0001	0.0050	1.1061
30	61	62	0.0000	0.0067	1.0800
31	63	65	0.0000	0.0151	0.9960
32	66	67	0.0000	0.0098	1.0500
33	71	72	0.0000	0.0052	0.9843
34	71	73	0.0000	0.0050	1.0000

Transformer Numbers	From Bus #	To Bus #	Resistance (p.u.)	Reactance (p.u.)	Tap Ratio
35	75	76	0.0000	0.0037	0.9787
36	77	78	0.0000	0.0115	1.0631
37	77	78	0.0000	0.0115	1.0631
38	77	78	0.0000	0.0115	1.0631
39	80	81	0.0000	0.0103	0.9871
40	82	103	0.0000	0.0012	1.0133
41	83	84	0.0003	0.0174	1.1190
42	83	84	0.0002	0.0119	1.1190
43	87	88	0.0000	0.0098	1.0500
44	90	91	0.0000	0.0045	0.9452
45	90	101	0.0002	0.0125	1.1190
46	93	95	0.0001	0.0174	1.1190
47	95	96	0.0000	0.0228	0.9174
48	101	102	0.0000	0.0182	0.9091
49	104	105	0.0002	0.0234	0.9789
50	106	108	0.0006	0.0149	1.0017
51	107	108	0.0006	0.0149	1.0017
52	108	109	0.0003	0.0133	1.0000
53	108	109	0.0003	0.0134	1.0000
54	112	113	0.0006	0.0254	1.0491
55	116	120	0.0001	0.0139	1.0106
56	116	120	0.0001	0.0139	1.0106
57	118	119	0.0050	0.1147	1.0478
58	118	122	0.0001	0.0069	1.0500
59	118	123	0.0003	0.0139	1.0500
60	125	126	0.0005	0.0238	1.0000

Load Data: Bus Number is the unique number used to identify the bus to which the load is connected, the bus name is the unique name used to identify the bus to which the load is connected, the base kV denotes the base voltage of the bus in kV, P_load denotes the real component of the load and is measured in p.u., while Q_load denotes the reactive component of the load and is also measured in p.u.

Bus Numbers	Bus Names	Base kV	P_load (p.u.)	Q_load (p.u.)
1	CMAIN GM	20	1.000	0.000
2	CA230	230	36.000	7.000
5	CANAD G1	20	1.000	0.000
6	CANADA	500	44.000	10.000
7	NORTH	500	50.000	4.000
8	NORTH G3	20	1.000	0.000
9	HANFORD	500	35.000	5.000
11	GARRISON	500	25.840	3.940
12	JOHN DAY	500	32.000	11.000
13	JOHN DAY	13.8	1.000	0.000
14	BIG EDDY	500	-0.442	0.220
15	GRIZZLY	500	-0.666	-0.970
17	BIG EDDY	230	-0.675	1.600
18	CELILO	230	31.370	16.810
19	DALLES21	13.8	1.000	0.000
20	BIG EDDY	115	1.600	0.313
23	MALIN	500	-3.390	-1.190
24	MONTANA	500	17.000	3.000
25	COLSTRP	500	-15.250	-0.500
26	MONTA G1	20	1.000	0.000
28	BRIDGER2	22	1.000	0.000
29	MIDPOINT	345	6.100	-4.140
30	BENLOMND	345	0.339	0.119
31	BENLOMND	230	1.480	-0.079
32	NAUGHTON	230	2.550	1.000
33	NAUGHT	20	1.000	0.000
34	TERMINAL	345	1.850	0.785
35	CAMP WIL	345	4.577	0.817
36	SPAN FRK	345	1.412	0.714
37	EMERY	345	1.161	0.384
38	EMERY	20	1.000	0.000
39	SIGURD	345	3.790	-0.430
40	PINTO	345	0.316	0.115
42	MONA	345	-0.620	0.128

Bus Numbers	Bus Names	Base kV	P_load (p.u.)	Q_load (p.u.)
43	INTERMT	345	20.530	9.071
44	INTERM1G	26	1.000	0.000
45	CRAIG	345	23.500	-1.270
46	CRAIG	22	1.000	0.000
47	HAYDEN	20	1.000	0.000
48	SAN JUAN	345	8.400	0.050
49	SJUAN G4	22	1.000	0.000
50	FOURCORN	345	2.390	-0.560
52	FOURCORN	230	1.397	0.238
53	FCNGN4CC	22	1.000	0.000
55	CORONADO	500	17.500	-0.560
56	CORONADO	20	**1.000**	**0.000**
58	WESTWING	500	6.170	-0.690
59	PALOVRDE	500	7.934	2.070
60	PALOVRD2	24	1.000	0.000
61	NAVAJO	500	0.900	0.700
62	NAVAJO 2	26	1.000	0.000
63	ELDORADO	500	9.023	-0.114
64	DEVERS	500	8.560	0.196
65	ELDORADO	20	1.000	0.000
67	MOHAV1CC	22	1.000	0.000
68	LUGO	500	2.042	-0.282
69	SERRANO	500	12.300	0.728
70	VALLEY	500	4.060	0.410
71	MIRALOMA	500	30.980	11.890
72	MIRALOMA	20	1.000	0.000
74	MESA CAL	230	3.774	0.645
75	LITEHIPE	230	31.910	6.300
76	LITEHIPE	20	1.000	0.000
78	VINCENT	230	10.660	-0.108
79	EAGLROCK	230	1.750	0.180
80	PARDEE	230	31.180	0.780
81	PARDEE	20	1.000	0.000
82	SYLMAR S	230	4.010	0.806
83	MIDWAY	200	7.776	0.326
84	MIDWAY	500	0.556	-3.290
85	LOSBANOS	500	2.650	0.140
86	MOSSLAND	500	0.400	0.215
87	DIABLO	500	0.500	0.250

Bus Numbers	Bus Names	Base kV	P_load (p.u.)	Q_load (p.u.)
88	DIABLO1	25	1.000	0.000
89	GATES	500	3.050	-0.076
90	TEVATR	500	56.610	34.910
91	TEVATR2	20	1.000	0.000
92	OLINDA	500	-1.890	0.615
94	TABLE MT	500	-0.007	1.185
95	ROUND MT	200	1.480	0.000
96	ROUND MT	20	1.000	0.000
97	COTWDPGE	200	2.104	-0.770
98	LOGAN CR	200	0.080	0.000
99	GLENN	200	0.275	-0.001
100	CORTINA	200	-0.433	0.200
101	TEVATR	200	8.840	0.548
102	TEVATR	20	1.000	0.000
103	SYLMARLA	230	-27.710	16.540
105	VICTORVL	287	-1.290	0.322
108	STA B	138	2.372	-0.632
109	STA BLD	230	1.380	0.280
110	STA F	230	1.170	0.240
111	RIVER	230	3.200	0.650
113	HAYNES3G	18	1.000	0.000
114	STA G	230	1.210	0.250
115	GLENDAL	230	1.350	0.270
116	STA E	230	8.078	1.321
117	VALLEY	230	2.052	0.176
118	RINALDI	230	1.210	0.250
119	OWENS G	11.5	1.000	0.000
121	ADELANTO	500	-18.620	9.710
124	STA J	230	8.877	-0.062
126	CASTAI4G	230	1.000	0.000
127	OLIVE	20	-0.728	-0.170

Generator Data: Bus Number is the unique number used to identify the bus to which the generator is connected, the bus name is the unique name used to identify the bus to which the generator is connected, MVA_base denotes the base MVA of the individual generators, P_gen denotes the real component of the power generated by the generator and is measured in p.u., Q_gen denotes the reactive component of the power generated by the generator and is also measured in p.u., X_l denotes the leakage reactance in p.u., X′_d denotes the unsaturated direct-axis transient reactance of the generator, X′_q denotes the unsaturated quadrature-axis transient reactance of the generator, and H denotes the inertia constant of the turbine-governor set and is measured in seconds.

Bus Numbers	Bus Names	MVA_base	P_gen (p.u.)	Q_gen (p.u.)	X_l (p.u.)	X'_d (p.u.)	X'_q (p.u.)	H (sec)
1	CMAIN GM	6100	44.800	11.502	0.250	0.291	0.440	2.950
5	CANAD G1	9004	44.500	10.111	0.150	0.250	0.600	4.340
8	NORTH G3	13000	99.500	18.540	0.161	0.228	0.424	3.460
13	JOHN DAY	5421	51.748	8.552	0.248	0.357	0.651	3.670
19	DALLES21	1199	13.010	4.315	0.287	0.370	0.500	3.000
26	MONTA G1	3085	29.100	9.533	0.178	0.220	0.348	3.380
28	BRIDGER2	1770	16.400	2.857	0.215	0.280	0.490	2.320
33	NAUGHT	832	4.450	0.917	0.260	0.324	0.450	3.010
38	EMERY	2229	16.650	-0.314	0.185	0.240	0.430	2.820
44	INTERM1G	1982	17.800	5.346	0.200	0.245	0.420	2.880
46	CRAIG	1488	10.480	-1.329	0.190	0.245	0.510	2.610
47	HAYDEN	3000	20.500	4.648	0.190	0.250	0.500	2.450
49	SJUAN G4	2054	9.620	1.488	0.205	0.260	0.453	2.630
53	FCNGN4CC	2458	21.600	-0.305	0.205	0.285	0.485	3.420
56	CORONADO	914	8.000	1.230	0.195	0.250	0.453	2.640
60	PALOVRD2	3117	26.400	3.781	0.285	0.375	0.567	3.830
62	NAVAJO 2	3540	16.900	1.955	0.175	0.220	0.400	3.590
65	ELDORADO	2104	9.827	-1.288	0.300	0.320	0.530	6.070
67	MOHAV1CC	1818	16.800	4.466	0.205	0.285	0.485	3.490
72	MIRALOMA	3000	16.900	5.938	0.290	0.340	1.000	2.750
76	LITEHIPE	9000	31.950	10.325	0.175	0.245	0.376	2.820
81	PARDEE	2500	22.000	3.937	0.180	0.220	0.440	3.030
88	DIABLO1	1685	7.650	-2.062	0.311	0.467	1.270	3.460
91	TEVATR2	6840	34.670	16.546	0.190	0.250	0.500	3.820
96	ROUND MT	1022	10.570	0.256	0.263	0.320	0.670	4.390
102	TEVATR	895	5.940	1.924	0.300	0.320	0.530	4.160
113	HAYNES3G	540	3.250	0.683	0.185	0.256	0.410	4.130
119	OWENS G	113	1.100	0.291	0.150	0.238	0.365	3.800
126	CASTAI4G	500	2.000	-0.522	0.155	0.195	0.568	6.410

Shunt Data: Bus Number is the unique number used to identify the bus to which the shunt element is connected, the bus name is the unique name used to identify the bus to which the shunt element is connected, the base kV denotes the base voltage of the bus in kV, G_shunt represents the conductance of the shunt element in p.u., and B_shunt represents the susceptance of the shunt element also in p.u.

Bus Numbers	Bus Names	Base kV	G_shunt (p.u.)	B_shunt (p.u.)
7	NORTH	500	0.0000	12.0000
9	HANFORD	500	0.0000	5.5000
12	JOHN DAY	500	0.0000	10.1935
15	GRIZZLY	500	-0.0929	-5.6029
16	CELILOCA	500	0.0000	4.6200
17	BIG EDDY	230	0.0000	5.7685
18	CELILO	230	0.0000	7.9200
21	SUMMER L	500	0.0028	1.1638
22	BURNS2	500	11.5674	-23.7541
23	MALIN	500	0.0799	-0.8631
27	MIDPOINT	500	-10.9334	-2.2000
29	MIDPOINT	345	0.0000	-8.7000
35	CAMP WIL	345	0.0000	-0.6000
37	EMERY	345	0.0000	-2.2000
39	SIGURD	345	0.0000	-0.5000
40	PINTO	345	0.0000	-0.1800
43	INTERMT	345	0.0000	4.3000
48	SAN JUAN	345	0.0000	3.9000
50	FOURCORN	345	0.0000	-1.5500
51	FOURCORN	500	0.0058	-1.1300
57	MOENKOPI	500	-0.0058	-3.7070
58	WESTWING	500	0.0000	-4.2700
59	PALOVRDE	500	0.0000	-1.4600
61	NAVAJO	500	0.0000	-1.9000
63	ELDORADO	500	0.0000	-3.1900
66	MOHAVE	500	0.0000	-1.9600
71	MIRALOMA	500	0.0000	4.0000
77	VINCENT	500	0.0179	0.0000
78	VINCENT	230	0.0000	-1.9000
83	MIDWAY	200	0.0000	-1.3000
84	MIDWAY	500	-0.1346	-2.6639
89	GATES	500	0.1196	-2.6538
90	TEVATR	500	0.0321	15.5844
92	OLINDA	500	-0.0096	0.1388

Bus Numbers	Bus Names	Base kV	G_shunt (p.u.)	B_shunt (p.u.)
93	ROUND MT	500	-0.1282	0.4316
94	TABLE MT	500	0.1197	-0.4221
95	ROUND MT	200	0.0000	-1.2800
101	TEVATR	200	0.0000	-0.3200
103	SYLMARLA	230	0.0000	21.4600
105	VICTORVL	287	0.0000	-1.0800
121	ADELANTO	500	0.0000	9.1200
123	RINALDI	500	0.0000	-0.8000

Appendix F: Program Codes

F.1 MATLAB Programs

The Matlab programs for performing LMI and SMA computations are divided into three parts. The first program called "Postpro" does post-processing on the system matrices obtained out of PST. It reorders the matrices in the desired format required for performing iterations of SMA. The second program called "SMA" performs the actual SMA iterations and to check for its convergence in accordance with the proposed algorithm. The third program "Simplepp" does the polytopic formulation and comes up with a single *gain* matrix capable of optimizing all cases lying inside the polytope in accordance with the LMI concept. The programs summarized below are for the 29 machine, 127 bus equivalent model of the WECC system having six controls.

Program 1: Postpro

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                            %
% Program Name: Postpro                                                      %
%                                                                            %
% Description: Performs post-processing on the matrices obtained out of PST %
%                                                                            %
% Author: Anamitra Pal                                                       %
%         Virginia Tech.                                                     %
%                                                                            %
% Last Modified: 10/13/2011                                                  %
%                                                                            %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% a_mat is the system matrix obtained out of PST
nn = size(a_mat)*[1 0]'; % nn = Size of System
nc = 12; % Number of original Controls; four for each DC line, one each for
SVC and ESD
n4 = nn - nc;
r1 = find(mac_state(:,2)==1); % Corresponds to the generator angles
r2 = find(mac_state(:,2)==2); % Corresponds to the generator speeds
r3 = find(mac_state(:,2)>2); % Corresponds to the remaining machine states
r4 = n4+1:nn; % Corresponds to the states associated with the Controls
r = [r1' r2' r3' r4];
A = 0*eye(nn); % Initializing the A-matrix
BB = 0*ones(nn,nc); % Initializing the B-matrix
A(1:nn,1:nn) = a_mat(r,r);

% Corresponds to the control action performed by the SVC
BB(:,1) = b_svc(r,1);

% Corresponds to the control action performed by the ESDs
BB(:,2:4) = b_lmod(r,5:7);

% Corresponds to the control action performed by the DC lines
BB(:,5:8) = b_lmod(r,1:4);
BB(:,9:12) = b_rlmod(r,1:4);
```

```
C1S = c_ang(1,r); % Corresponding to the H_inf optimization
C2S = c_spd(1:28,r); % Corresponding to the H_2 optimization

% Transformation matrix to reduce the number of controls
gamma = [ 1 0 0 0 0 0 0 0 0 0 0 0 ;
          0 1 0 0 0 0 0 0 0 0 0 0 ;
          0 0 1 0 0 0 0 0 0 0 0 0 ;
          0 0 0 1 0 0 0 0 0 0 0 0 ;
          0 0 0 0 1 -1 0 0 .3 .3 0 0;
          0 0 0 0 0 0 1 -1 0 0 .3 .3; ];

nnc = size(gamma)*[1 0]'; % Number of reduced controls

% Transforming the A-matrix
An(1:n4,1:n4) = A(1:n4,1:n4);
An(1:n4,n4+1:n4+nnc) = A(1:n4,n4+1:n4+nc)*gamma';
An(n4+1:n4+nnc,1:n4) = gamma*A(n4+1:n4+nc,1:n4);
An(n4+1:n4+nnc,n4+1:n4+nnc) = gamma*A(n4+1:n4+nc,n4+1:n4+nc)*gamma';
AA = An;

% Transforming the B-matrix
Bnn = gamma*BB(n4+1:nn,1:nc)*gamma';
Bn = [ 0*ones(nnc,n4) Bnn ]';
BB = [ Bn Bn ];

% Transforming the C-matrix
C1 = C1S(:,1:n4+nnc);
C2 = C2S(1:28,1:n4+nnc);
CC = [ C1 ; C2 ];

% Initializing the D-matrix in accordance with the size of the other matrices
DD = 0*ones(29,nnc*2);
DD(1,1) = 1;
DD(2:7,7:12) = eye(nnc);

% Creating the LTI system
S127_6controls = ltisys(AA,BB,CC,DD,eye(n4+nnc));
save num127_6controls S127_6controls % Storing the LTI system in a .MAT file
for future use
```

In accordance with the proposed algorithm, the system matrix obtained as the output of "Postpro" is re-ordered so that the relevant dynamics of the system is governed by its top-left portion (A_1 matrix). The following program reads this file and tests the convergence of SMA on

it. It also performs the rudimentary control check in the form of an LQR optimization as suggested in Step 4 of the proposed technique.

Program 2: SMA

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                        %
% Program Name: SMA                                                      %
%                                                                        %
% Description: Performs iterations of SMA to check for its convergence %
%                                                                        %
% Author: Anamitra Pal                                                   %
%         Virginia Tech.                                                 %
%                                                                        %
% Last Modified: 10/13/2011                                              %
%                                                                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc
clear

m = 21; % Size of the system to be tested
n = 2*m;

% Reading system matrix from the Excel File
[NUMERIC,TXT,RAW]=XLSREAD('21Gen.xlsx');

% Storing the relevant partitions of the system matrix
for i=1:174
    for j=1:174
        A(i,j) = NUMERIC(i,j);
    end
end
for i=1:n
    for j=1:n
        A1(i,j) = NUMERIC(i,j);
    end
end
for i=1:n
    for j=n+1:174
        A2(i,j-n) = NUMERIC(i,j);
    end
end
for i=n+1:174
    for j=1:n
        A3(i-n,j) = NUMERIC(i,j);
    end
end
for i=n+1:174
    for j=n+1:174
        A4(i-n,j-n) = NUMERIC(i,j);
    end
end
for i=1:n
    for j=175:180
        B1(i,j-174) = NUMERIC(i,j);
```

```
    end
end
for i=n+1:174
    for j=175:180
        B2(i-n,j-174) = NUMERIC(i,j);
    end
end

% The new Control Matrix
B = [ B1 ; B2 ];

N0 = zeros(174-n,6);

% First Iteration of SMA
[V,D] = eig(A1);
W = 0*eye(n);
WW = 0*ones(n,6);
s = ones(n,1);
U = inv(V);
for i=1:n
    s = D(i,i);
    v = V(:,i);
    u = U(i,:);
    W(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M = real(W/V);
N = real(V*WW);

% Second Iteration of SMA
[V1,D1] = eig(A1+M);
U1 = inv(V1);
for i=1:n
    s = D1(i,i);
    v = V1(:,i);
    u = U1(i,:);
    W1(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW1(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M1 = real(W1/V1);
N1 = real(V1*WW1);

% Third Iteration of SMA
[V2,D2] = eig(A1+M1);
U2 = inv(V2);
for i=1:n
    s = D2(i,i);
    v = V2(:,i);
    u = U2(i,:);
    W2(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW2(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M2 = real(W2/V2);
N2 = real(V2*WW2);

% Fourth Iteration of SMA
```

```
[V3,D3] = eig(A1+M2);
U3 = inv(V3);
for i=1:n
    s = D3(i,i);
    v = V3(:,i);
    u = U3(i,:);
    W3(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW3(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M3 = real(W3/V3);
N3 = real(V3*WW3);

% SMA was found to converge at the end of the fourth iteration, the next
% two iterations were done to ensure that the system did not digress from
% the converged points

% Fifth Iteration of SMA
[V4,D4] = eig(A1+M3);
U4 = inv(V4);
for i=1:n
    s = D4(i,i);
    v = V4(:,i);
    u = U4(i,:);
    W4(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW4(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M4 = real(W4/V4);
N4 = real(V4*WW4);

% Sixth Iteration of SMA
[V5,D5] = eig(A1+M4);
U5 = inv(V5);
for i=1:n
    s = D5(i,i);
    v = V5(:,i);
    u = U5(i,:);
    W5(:,i) = A2/(s*eye(174-n)-A4)*A3*v;
    WW5(i,:) = (u*A2/(s*eye(174-n)-A4))*B2;
end
M5 = real(W5/V5);
N5 = real(V5*WW5);

% Generates the plots showing the convergence of SMA by the fourth iteration
plot(eig(A1),'go')
hold on
plot(eig(A1+M),'co')
plot(eig(A1+M1),'bo')
plot(eig(A1+M2),'mo')
plot(eig(A1+M3),'ro')
plot(eig(A),'k.')
axis([-2 0.1 -15 15])

% Generates the plots showing the transition of the eigenvalues with increase
in gain
figure
plot(eig(A),'ks')
```

```
hold on
plot(eig(A1+M5),'bs')
Anew = A1 + M5;
[K,S,E] = lqr(Anew,N5,eye(n),eye(6)); % LQR optimization
Nnew5 = [ K' ; N0 ];
for i=1:11
    g1 = 1*(i-1)*.1;
    plot(eig(A1+M5-g1*N5*K),'r.')
    plot(eig(A-g1*B*Nnew5'),'go')
end
axis([-2 0.1 -15 15])

% Storing the reduced system as an input for the LMI control program
AA = real(A1+M5);
BS = 0*eye(n,6);
BS(:,1:6) = N5;
BB = real([BS BS]);
for i=175:175+m
    for j=1:n
        CC(i-174,j) = real(NUMERIC(i,j));
    end
end
DD = 0*ones(m+1,12);
DD(1,1) = 1;
DD(2:7,7:12) = eye(6);
SS1_21_6controls = ltisys(AA,BB,CC,DD,eye(n));
save num1_21_6controls SS1_21_6controls
```

The set of reduced systems obtained through "SMA" in the previous program are combined together to form the polytope. A suitable LMI region is specified to perform the optimization. The output of "Simplepp" is the desired gain of the state feedback, denoted by the matrix K.

Program 3: Simplepp

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                                                     %
% Program Name: Simplepp                                              %
%                                                                     %
% Description: Performs LMI optimization of the reduced-order systems %
%                                                                     %
% Author: Anamitra Pal                                                %
%         Virginia Tech.                                              %
%                                                                     %
% Last Modified: 10/13/2011                                           %
%                                                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc
clear

tic

% Loads the reduced-order system obtained as an output of SMA
```

```
load num1_21_6controls
load num2_21_6controls
load num3_21_6controls
load num4_21_6controls
load num5_21_6controls
load num6_21_6controls
load num7_21_6controls
load num8_21_6controls

% Defining individual cases of the polytopic system
SS1 = SS1_21_6controls;
SS2 = SS2_21_6controls;
SS3 = SS3_21_6controls;
SS4 = SS4_21_6controls;
SS5 = SS5_21_6controls;
SS6 = SS6_21_6controls;
SS7 = SS7_21_6controls;
SS8 = SS8_21_6controls;

% Defining the polytopic system
Pols = psys([SS1,SS2,SS3,SS4,SS5,SS6,SS7,SS8]);

% Defining the LMI region
region = [ 0.6000 + 1.0000i         0                    0              1.0000
0                  0
                 0                   0 + 2.0000i         0                    0
0.9986            -0.0523
                 0                   0                    0                    0
0.0523             0.9986 ]; % 7.5% Damping with Half Plane at -0.30

% Computing the multi-objective state feedback control
[gopt,h2opt,K,Pcl] = msfsyn(Pols,[21 6],[0 0 .5 .5],region);

% Defining the closed loop system
SP1 = psinfo(Pcl,'sys',1);
SP2 = psinfo(Pcl,'sys',2);
SP3 = psinfo(Pcl,'sys',3);
SP4 = psinfo(Pcl,'sys',4);
SP5 = psinfo(Pcl,'sys',5);
SP6 = psinfo(Pcl,'sys',6);
SP7 = psinfo(Pcl,'sys',7);
SP8 = psinfo(Pcl,'sys',8);

% Plots the eigenvalues of the closed loop system
plot(eig(SP1(1:42,1:42)),'ko')
hold on
plot(eig(SP2(1:42,1:42)),'ko')
plot(eig(SP3(1:42,1:42)),'ko')
plot(eig(SP4(1:42,1:42)),'ko')
plot(eig(SP5(1:42,1:42)),'ko')
plot(eig(SP6(1:42,1:42)),'ko')
plot(eig(SP7(1:42,1:42)),'ko')
plot(eig(SP8(1:42,1:42)),'ko')

% For plotting the line denoting 7.5% Damping and Half-plane at -0.30
```

```
x = -9:1:0;
y1 = -16.3499*x;
y2 = 16.3499*x;
plot(x,y1,'k')
hold on
plot(x,y2,'k')
y = -15:0.1:15;
x0 = -0.30;
plot(x0,y,'k')
axis([-2 0 -15 15])

% Stores the gain matrix in a .MAT File
save K_opt21_6controls K

toc
```

F.2 EPCL Programs

The EPCL programs for performing the dynamic simulations in PSLF are divided into two parts. The first program called “Sample_main” states all the initial quantities. It specifies the details of the contingency to be tested and calls for an in-run program at every time-step to apply the control and generate the output. The second program called “Sample_in” specifies the control actions to be performed and creates a text file containing the values of the desired output at every time-step. The programs summarized below are for the 29 machine, 127 bus equivalent model of the WECC system having six controls.

Program 1: Sample_main

```
/*%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%*/
/*                                                      */
/* Program Name: Sample_main                            */
/*                                                      */
/* Description: Performing Dynamic Simulations in PSLF */
/*                                                      */
/* Author: Anamitra Pal                                 */
/*         Virginia Tech.                               */
/*                                                      */
/* Last Modified: 10/13/2011                            */
/*                                                      */
/*%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%*/

/*------------------------------------*/
/* Initializing and loading base case */
/*------------------------------------*/

$base = "127bus.sav"        /* Load-Flow Data in PSLF format */
$basedy = "127bus.dyd"      /* Dynamic Data in PSLF format   */
$outchan = "pslf.chf"       /* Output Channel                */
$initrep = "pslf.rep"       /* Init Report                   */
```

```
$dynrep = "pslf2.rep"       /* Dynamic Report                */
$inrun = "Sample_in.p"      /* Inrun EPCL to output data     */

/*----------------------------------------*/
/* Specifying Dynamic Simulation Variables */
/*----------------------------------------*/
@tinit = 1          /* Time at which contingency starts */
@tstep = 1.16       /* Time at which contingency ends   */
@tend = 40          /* Time to end simulation           */

/* Retrieving Saved Case */
@ret = getf($base)
dispar[0].noprint = 0

/* Retrieving Dynamic Data */
@ret = psds()                               /* MUST be included to setup
modlib */
@ret = rdyd($basedy,$dynrep,1,1,1)          /* All flags 1
*/

/* Setting In-RUN -> MUST BE BEFORE INIT */
dypar[0].run_epcl = $inrun                  /* Name of the EPCL to In-Run */

/* Initialize Dynamic Simulation */
@ret = init($outchan,$initrep,"1","0")      /* Output Channel: pslf.chf */
                                            /* "1" Fix Bad Data, "0" don't
turn off unused models */

/* Setting Parameters for Run */            /* Run to @tinit, apply
contingency, run to @tstep, remove contingency, run to @tend */
dypar[0].tpause = @tinit
dypar[0].nscreen = 999999                   /* Don't Print to Screen (makes
simulation run faster) */
@ret = run()

/* 20% increase in load across Celilo-Sylmar HVDC Line */
load[13].p = load[13].p + 2*320
load[87].p = load[87].p - 2*280

dypar[0].tpause = @tstep
dypar[0].nscreen = 999999                   /* Don't Print to Screen (makes
simulation run faster) */
@ret = run()

load[13].p = load[13].p - 2*320
load[87].p = load[87].p + 2*280

dypar[0].tpause = @tend
dypar[0].nscreen = 1                        /* Don't Print to Screen (makes
simulation run faster) */
@ret = run()

@ret = dsst()                               /* Stop dynamic simulation */
end
```

Program 2: Sample_in

```
/*%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%*/
/*                                             */
/* Program Name: Sample_in                     */
/*                                             */
/* Description: Outputs results to a text file */
/*                                             */
/* Author: Anamitra Pal                        */
/*         Virginia Tech.                      */
/*                                             */
/* Last Modified: 10/13/2011                   */
/*                                             */
/*%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%*/

/*--------------------------------------*/
/* In-RUN EPCL                          */
/*--------------------------------------*/
@onetime = -0.008                         /* Time before initialization */
dim #delta[50]                            /* Specifying an array of size 50
*/

/*-------------------------------------------------*/
/*Monitoring the Supervisory Boundary (in-run EPCL)*/
/*-------------------------------------------------*/

$output = "127bus.txt"                    /* Output file*/

@ret = setlog($output)
logprint($output, "<",dypar[0].time, ">")   /* Prints the time step */

if(dypar[0].time < @onetime)

/* Initializing global variables */
mailbox[0].number[1] = genbc[0].angle      /* genbc[x].angle denotes the
angle of the generator whose internal number is x */
mailbox[0].number[2] = genbc[4].angle
mailbox[0].number[3] = genbc[5].angle
mailbox[0].number[4] = genbc[8].angle
mailbox[0].number[5] = genbc[9].angle
mailbox[0].number[6] = genbc[12].angle
mailbox[0].number[7] = genbc[13].angle
mailbox[0].number[8] = genbc[14].angle
mailbox[0].number[9] = genbc[15].angle
mailbox[0].number[10] = genbc[16].angle
mailbox[0].number[11] = genbc[17].angle
mailbox[0].number[12] = genbc[18].angle
mailbox[0].number[13] = genbc[20].angle
mailbox[0].number[14] = genbc[23].angle
mailbox[0].number[15] = genbc[25].angle
mailbox[0].number[16] = genbc[27].angle
mailbox[0].number[17] = genbc[28].angle
mailbox[0].number[18] = genbc[29].angle
mailbox[0].number[19] = genbc[30].angle
```

```
mailbox[0].number[20] = genbc[31].angle
mailbox[0].number[21] = genbc[32].angle
mailbox[0].number[22] = genbc[0].speed      /* genbc[x].speed denotes the
speed of the generator whose internal number is x */
mailbox[0].number[23] = genbc[4].speed
mailbox[0].number[24] = genbc[5].speed
mailbox[0].number[25] = genbc[8].speed
mailbox[0].number[26] = genbc[9].speed
mailbox[0].number[27] = genbc[12].speed
mailbox[0].number[28] = genbc[13].speed
mailbox[0].number[29] = genbc[14].speed
mailbox[0].number[30] = genbc[15].speed
mailbox[0].number[31] = genbc[16].speed
mailbox[0].number[32] = genbc[17].speed
mailbox[0].number[33] = genbc[18].speed
mailbox[0].number[34] = genbc[20].speed
mailbox[0].number[35] = genbc[23].speed
mailbox[0].number[36] = genbc[25].speed
mailbox[0].number[37] = genbc[27].speed
mailbox[0].number[38] = genbc[28].speed
mailbox[0].number[39] = genbc[29].speed
mailbox[0].number[40] = genbc[30].speed
mailbox[0].number[41] = genbc[31].speed
mailbox[0].number[42] = genbc[32].speed
else

/* Computing increment in respective generator angles and speeds */
@delta1 = genbc[0].angle - mailbox[0].number[1]
@delta2 = genbc[4].angle - mailbox[0].number[2]
@delta3 = genbc[5].angle - mailbox[0].number[3]
@delta4 = genbc[8].angle - mailbox[0].number[4]
@delta5 = genbc[9].angle - mailbox[0].number[5]
@delta6 = genbc[12].angle - mailbox[0].number[6]
@delta7 = genbc[13].angle - mailbox[0].number[7]
@delta8 = genbc[14].angle - mailbox[0].number[8]
@delta9 = genbc[15].angle - mailbox[0].number[9]
@delta10 = genbc[16].angle - mailbox[0].number[10]
@delta11 = genbc[17].angle - mailbox[0].number[11]
@delta12 = genbc[18].angle - mailbox[0].number[12]
@delta13 = genbc[20].angle - mailbox[0].number[13]
@delta14 = genbc[23].angle - mailbox[0].number[14]
@delta15 = genbc[25].angle - mailbox[0].number[15]
@delta16 = genbc[27].angle - mailbox[0].number[16]
@delta17 = genbc[28].angle - mailbox[0].number[17]
@delta18 = genbc[29].angle - mailbox[0].number[18]
@delta19 = genbc[30].angle - mailbox[0].number[19]
@delta20 = genbc[31].angle - mailbox[0].number[20]
@delta21 = genbc[32].angle - mailbox[0].number[21]
@delta22 = genbc[0].speed - mailbox[0].number[22]
@delta23 = genbc[4].speed - mailbox[0].number[23]
@delta24 = genbc[5].speed - mailbox[0].number[24]
@delta25 = genbc[8].speed - mailbox[0].number[25]
@delta26 = genbc[9].speed - mailbox[0].number[26]
@delta27 = genbc[12].speed - mailbox[0].number[27]
@delta28 = genbc[13].speed - mailbox[0].number[28]
@delta29 = genbc[14].speed - mailbox[0].number[29]
@delta30 = genbc[15].speed - mailbox[0].number[30]
```

```
@delta31 = genbc[16].speed - mailbox[0].number[31]
@delta32 = genbc[17].speed - mailbox[0].number[32]
@delta33 = genbc[18].speed - mailbox[0].number[33]
@delta34 = genbc[20].speed - mailbox[0].number[34]
@delta35 = genbc[23].speed - mailbox[0].number[35]
@delta36 = genbc[25].speed - mailbox[0].number[36]
@delta37 = genbc[27].speed - mailbox[0].number[37]
@delta38 = genbc[28].speed - mailbox[0].number[38]
@delta39 = genbc[29].speed - mailbox[0].number[39]
@delta40 = genbc[30].speed - mailbox[0].number[40]
@delta41 = genbc[31].speed - mailbox[0].number[41]
@delta42 = genbc[32].speed - mailbox[0].number[42]

/* Providing State-feedback obtained out of the LMI control */
@temp1a = @delta1 * 0.8267 - @delta2 * 0.8521 + @delta3 * 1.6231 - @delta4 *
0.2039 + @delta5 * 0.4158 - @delta6 * 0.2483 - @delta7 * 0.2079 + @delta8 *
0.1874 + @delta9 * 0.2809 + @delta10 * 0.4229 + 0.6478 * @delta11
@temp1b = 0.6665 * @delta12 + 1.5459 * @delta13 - 0.3800 * @delta14 - 0.5064
* @delta15 - 1.6067 * @delta16 - 1.9393 * @delta17 - 2.9317 * @delta18 -
1.3006 * @delta19 + 1.0875 * @delta20 + 0.5389 * @delta21
@temp1 = @temp1a + @temp1b
@temp2a = - 1.0184*(@delta1) + 0.7170*(@delta2) - 0.9408*(@delta3) -
0.0803*(@delta4) + 0.0405*(@delta5) + 0.1490*(@delta6) + 0.1306*(@delta7) +
0.0174*(@delta8) + 0.0286*(@delta9) - 0.0018*(@delta10) - 0.0106*(@delta11)
@temp2b = - 0.0389*(@delta12) - 0.0270*(@delta13) + 0.0608*(@delta14) +
0.0842*(@delta15) + 0.1299*(@delta16) - 0.0749*(@delta17) + 0.2152*(@delta18)
+ 0.1239*(@delta19) - 0.0308*(@delta20) - 0.0036*(@delta21)
@temp2 = @temp2a + @temp2b
@temp3a = 1.0184*(@delta1) - 0.7170*(@delta2) + 0.9408*(@delta3) +
0.0803*(@delta4) - 0.0405*(@delta5) - 0.1490*(@delta6) - 0.1306*(@delta7) -
0.0174*(@delta8) - 0.0286*(@delta9) + 0.0018*(@delta10)
@temp3b = 0.0106*(@delta11) + 0.0389*(@delta12) + 0.0270*(@delta13) -
0.0608*(@delta14) - 0.0842*(@delta15) - 0.1299*(@delta16) + 0.0749*(@delta17)
- 0.2152*(@delta18) - 0.1239*(@delta19) + 0.0308*(@delta20) +
0.0036*(@delta21)
@temp3 = @temp3a + @temp3b
@temp4a = 0.7514*(@delta1) + 1.8209*(@delta2) - 1.7085*(@delta3) +
0.2423*(@delta4) + 0.0721*(@delta5) + 0.0374*(@delta6) - 0.0240*(@delta7) +
0.0708*(@delta8) + 0.1441*(@delta9) + 0.0641*(@delta10)
@temp4b = 0.1181*(@delta11) + 0.0313*(@delta12) + 0.0201*(@delta13) -
0.0705*(@delta14) - 0.4859*(@delta15) - 0.1817*(@delta16) - 0.9893*(@delta17)
- 0.1686*(@delta18) - 0.0376*(@delta19) + 0.2244*(@delta20) +
0.2289*(@delta21)
@temp4 = @temp4a + @temp4b
@temp5a = -1.0478*(@delta1) - 1.7400*(@delta2) + 3.0994*(@delta3) -
0.1844*(@delta4) - 0.1208*(@delta5) - 0.1148*(@delta6) - 0.0585*(@delta7) -
0.0537*(@delta8) - 0.1018*(@delta9) - 0.0261*(@delta10)
@temp5b = -0.0621*(@delta11) + 0.0641*(@delta12) + 0.2619*(@delta13) +
0.0083*(@delta14) + 0.2126*(@delta15) - 0.0590*(@delta16) + 0.8992*(@delta17)
+ 0.0003*(@delta18) - 0.0794*(@delta19) - 0.6233*(@delta20) -
0.1166*(@delta21)
@temp5 = @temp5a + @temp5b
@temp6a = -0.4747*(@delta1) + 0.3217*(@delta2) + 0.8256*(@delta3) +
0.3174*(@delta4) - 0.1441*(@delta5) - 0.1958*(@delta6) + 0.0630*(@delta7) -
0.0898*(@delta8) - 0.1766*(@delta9) - 0.0849*(@delta10)
@temp6b = -0.1609*(@delta11) - 0.0154*(@delta12) - 1.0588*(@delta13) -
0.0044*(@delta14) + 0.7507*(@delta15) + 0.0633*(@delta16) + 0.6286*(@delta17)
```

```
- 0.1744*(@delta18) - 0.2595*(@delta19) + 0.4607*(@delta20) -
0.3837*(@delta21)
@temp6 = @temp6a+@temp6b

@temp7a = -130.7776*(@delta22) - 180.4285*(@delta23) + 342.1774*(@delta24) +
3.3141*(@delta25) - 31.6656*(@delta26) - 87.6744*(@delta27) -
85.6134*(@delta28) - 15.5447*(@delta29) - 24.7519*(@delta30) -
33.3579*(@delta31) - 47.7442*(@delta32)
@temp7b = -33.6183*(@delta33) - 348.7562*(@delta34) - 139.0175*(@delta35) -
280.7580*(@delta36) - 251.2506*(@delta37) - 391.7090*(@delta38) -
196.8194*(@delta39) - 186.0879*(@delta40) - 489.2731*(@delta41) +
11.9309*(@delta42)
@temp7 = @temp7a + @temp7b
@temp8a = -1269.0066*(@delta22) + 126.4543*(@delta23) + 187.1619*(@delta24) +
130.1404*(@delta25) + 15.2010*(@delta26) + 19.1882*(@delta27) +
18.2794*(@delta28) + 4.6150*(@delta29) + 7.7950*(@delta30) +
8.5408*(@delta31) + 13.3665*(@delta32)
@temp8b = 8.1613*(@delta33) + 32.3788*(@delta34) + 15.1990*(@delta35) +
28.3337*(@delta36) + 14.5469*(@delta37) + 12.0087*(@delta38) +
10.7103*(@delta39) + 10.2886*(@delta40) + 30.3945*(@delta41) +
1.2851*(@delta42)
@temp8 = @temp8a + @temp8b
@temp9a = 1269.0066*(@delta22) - 127.4543*(@delta23) - 188.1619*(@delta24) -
130.1404*(@delta25) - 15.2010*(@delta26) - 19.1882*(@delta27) -
18.2794*(@delta28) - 4.6150*(@delta29) - 7.7950*(@delta30) -
8.5408*(@delta31) - 13.3665*(@delta32)
@temp9b = -8.1613*(@delta33) - 32.3788*(@delta34) - 15.1990*(@delta35) -
28.3337*(@delta36) - 14.5469*(@delta37) - 12.0087*(@delta38) -
10.7103*(@delta39) - 10.2886*(@delta40) - 30.3945*(@delta41) -
1.2851*(@delta42)
@temp9 = @temp9a + @temp9b
@temp10a = -122.4764*(@delta22) + 1185.5276*(@delta23) + 200.5925*(@delta24)
+ 224.3504*(@delta25) + 28.0838*(@delta26) + 45.4993*(@delta27) +
46.7550*(@delta28) - 0.5357*(@delta29) - 2.7838*(@delta30) -
11.7476*(@delta31) - 18.4768*(@delta32)
@temp10b = -22.3124*(@delta33) - 61.6172*(@delta34) - 6.3438*(@delta35) +
26.3427*(@delta36) - 3.1481*(@delta37) - 121.7168*(@delta38) -
0.9221*(@delta39) + 7.4908*(@delta40) + 20.9023*(@delta41) -
0.2698*(@delta42)
@temp10 = @temp10a + @temp10b
@temp11a = -118.9276*(@delta22) - 1245.7470*(@delta23) - 223.7195*(@delta24)
- 171.8230*(@delta25) - 40.5872*(@delta26) - 45.3658*(@delta27) -
46.3880*(@delta28) + 0.5908*(@delta29) + 3.2032*(@delta30) +
8.9754*(@delta31) + 14.2057*(@delta32)
@temp11b = 14.1506*(@delta33) + 46.9547*(@delta34) + 7.0600*(@delta35) -
16.5136*(@delta36) - 1.4113*(@delta37) + 111.0152*(@delta38) -
1.1990*(@delta39) - 12.3790*(@delta40) - 121.1228*(@delta41) -
18.0024*(@delta42)
@temp11 = @temp11a + @temp11b
@temp12a = 66.7455*(@delta22) + 43.0315*(@delta23) - 150.5899*(@delta24) -
30.9669*(@delta25) - 45.7038*(@delta26) - 130.7615*(@delta27) -
137.9946*(@delta28) - 15.0034*(@delta29) - 24.6488*(@delta30) +
12.7803*(@delta31) + 21.1476*(@delta32)
@temp12b = 43.9640*(@delta33) + 84.7148*(@delta34) - 12.9572*(@delta35) -
112.0149*(@delta36) - 24.3929*(@delta37) + 61.4606*(@delta38) -
19.4907*(@delta39) - 25.5700*(@delta40) + 105.8469*(@delta41) +
45.0020*(@delta42)
```

```
@temp12 = @temp12a + @temp12b

/* Provision for adjusting the gain of the control */
@temp11 = 2*(@temp1)
@temp21 = 2*(@temp2)
@temp31 = 2*(@temp3)
@temp41 = 2*(@temp4)
@temp51 = 2*(@temp5)
@temp61 = 2*(@temp6)
@temp71 = 2*(@temp7)
@temp81 = 2*(@temp8)
@temp91 = 2*(@temp9)
@temp101 = 2*(@temp10)
@temp111 = 2*(@temp11)
@temp121 = 2*(@temp12)

/* Computing new loads in accordance with the control */

/* Corresponding to the SVC */
load[100].q = load[100].q - @temp11 - @temp71           /* load[x].q denotes
reactive power of the load having internal number x */

/* Corresponding to the ESD */
load[0].p = load[0].p - @temp21 - @temp81               /* load[x].p denotes
real power of the load having internal number x */
load[2].p = load[2].p - @temp31 - @temp91
load[62].p = load[62].p - @temp41 - @temp101

/* Corresponding to the DC lines */
load[13].p = load[13].p - @temp51 - @temp111
load[13].q = load[13].q - 0.3*(@temp51) - 0.3*(@temp111)
load[87].p = load[87].p + @temp51 + @temp111
load[87].q = load[87].q - 0.3*(@temp51) - 0.3*(@temp111)
load[34].p = load[34].p - @temp61 - @temp121
load[34].q = load[34].q - 0.3*(@temp61) - 0.3*(@temp121)
load[100].p = load[100].p + @temp61 + @temp121
load[100].q = load[100].q - 0.3*(@temp61) - 0.3*(@temp121)

/* Updating the global variables */
mailbox[0].number[1] = genbc[0].angle
mailbox[0].number[2] = genbc[4].angle
mailbox[0].number[3] = genbc[5].angle
mailbox[0].number[4] = genbc[8].angle
mailbox[0].number[5] = genbc[9].angle
mailbox[0].number[6] = genbc[12].angle
mailbox[0].number[7] = genbc[13].angle
mailbox[0].number[8] = genbc[14].angle
mailbox[0].number[9] = genbc[15].angle
mailbox[0].number[10] = genbc[16].angle
mailbox[0].number[11] = genbc[17].angle
mailbox[0].number[12] = genbc[18].angle
mailbox[0].number[13] = genbc[20].angle
mailbox[0].number[14] = genbc[23].angle
mailbox[0].number[15] = genbc[25].angle
mailbox[0].number[16] = genbc[27].angle
mailbox[0].number[17] = genbc[28].angle
```

```
mailbox[0].number[18] = genbc[29].angle
mailbox[0].number[19] = genbc[30].angle
mailbox[0].number[20] = genbc[31].angle
mailbox[0].number[21] = genbc[32].angle
mailbox[0].number[22] = genbc[0].speed
mailbox[0].number[23] = genbc[4].speed
mailbox[0].number[24] = genbc[5].speed
mailbox[0].number[25] = genbc[8].speed
mailbox[0].number[26] = genbc[9].speed
mailbox[0].number[27] = genbc[12].speed
mailbox[0].number[28] = genbc[13].speed
mailbox[0].number[29] = genbc[14].speed
mailbox[0].number[30] = genbc[15].speed
mailbox[0].number[31] = genbc[16].speed
mailbox[0].number[32] = genbc[17].speed
mailbox[0].number[33] = genbc[18].speed
mailbox[0].number[34] = genbc[20].speed
mailbox[0].number[35] = genbc[23].speed
mailbox[0].number[36] = genbc[25].speed
mailbox[0].number[37] = genbc[27].speed
mailbox[0].number[38] = genbc[28].speed
mailbox[0].number[39] = genbc[29].speed
mailbox[0].number[40] = genbc[30].speed
mailbox[0].number[41] = genbc[31].speed
mailbox[0].number[42] = genbc[32].speed
endif

/* Printing the Generator angles */
for @i=0 to casepar[0].ngen - 1
     @x = genbc[@i].angle                                /* Retrieving the
Generator angle at bus i */
     logprint($output, @x,">")
next

@ret = close ( $output )
```

APPENDIX J:
Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation Final Report

Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

Online Analysis of Wind and Solar Part I: Ramping Tool

Final Report

Prepared for: California Energy Commission and the California Institute for Energy and Environment

Prepared by: Pacific Northwest National Laboratory

JANUARY 2012

PNNL-21112

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Prepared by:

Pacific Northwest National Laboratory
Krishnappa Subbarao, Project Manager
Yuri V. Makarov, Principal Investigator:

Authors:

PNNL: Yuri V. Makarov, Pavel V. Etingov,
Krishnappa Subbarao, Jian Ma
CAISO: Clyde Loutan

Contract Number: 500-07-537
Work Authorization No.: POTPO1-X11

Prepared for:

California Energy Commission

Cathy Turner
Contract Manager

Jamie Patterson
Project Manager

Mike Gravely
Office Manager, Energy Systems Research

Laurie ten Hope
Deputy Director, Energy Research & Development Division

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

This work was funded by the **Public Interest Energy Research (PIER) program** in renewable energy at the **California Energy Commission** and managed by the California Institute for Energy and Environment. This report was prepared with substantial support from California Independent System Operator personnel.

The authors would like to thank Mike Gravely, Pedro Gomez, and Jamie Patterson, California Energy Commission; Merwin Brown, Larry Miller, and Jim Cole, California Institute for Energy and Environment; and Sirajul Chowdhury, Zhijun (June) Xie, and Ajay Mannepalli, California Independent System Operator, for providing the project team with consultations, day-by-day support, and discussions essential to this work.

The authors would also like to thank Managers Carl H. Imhoff, Dale King, Evan O. Jones, Mark P. Morgan, Ron Melton, and Landis Kannberg, Staff Scientists Dr. Ryan Hafen, Michael T. Batdorf, John C. Bower (retired), Contracting Officer Sheena Kanyid, Project Specialist Susan Arey, and Administrative Assistant Nikki Stringer, Pacific Northwest National Laboratory, for supporting this work.

Many thanks go to Technical Writers Maura K. Zimmerschied and Kathy Neiderhiser, Pacific Northwest National Laboratory, for editing the final manuscript.

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

This report is the final report for the "Online Analysis of Wind and Solar" project (contract number: 500-07-537, work authorization number: POTPO1-X11) conducted by the Pacific Northwest National Laboratory. The information from this project contributes to PIER's Energy Systems Integration program area.

For more information about the PIER Program, please visit the Energy Commission's website at http://www.energy.ca.gov/research/, or contact the Energy Commission at 916-654-4878.

ABSTRACT

To improve the system control performance characteristics, maintain system reliability, and minimize expenses related to the system balancing functions, it becomes necessary to incorporate the uncertainty information into the scheduling, load following, and, to some extent, into the regulation processes. It is also important to address the uncertainty problem comprehensively by considering all sources of uncertainty (load, intermittent generation, generators' forced outages, etc.) in consideration.

Currently, uncertainties associated with wind and load forecasts, as well as uncertainties associated with random generator outages and unexpected disconnection of supply lines, are not taken into account in power grid operation. Thus, operators have few resources to weigh the likelihood and magnitude of upcoming events of power imbalance. In this project, funded by the California Energy Commission, a framework has been developed for incorporating uncertainties associated with wind, solar and load forecast errors, unpredicted ramps, and forced generation disconnections into the energy management system as well as generation dispatch and commitment applications.

A new approach to evaluating the uncertainty ranges for the required generation performance envelope, including balancing capacity, ramping capability, and ramp duration, is proposed and implemented. Assessment of the capacity and ramping requirements is performed using a specially developed probabilistic algorithm based on a histogram analysis. A new method called the "flying brick" technique has been developed to evaluate the look-ahead required generation performance envelope for the worst-case scenario within a user-specified confidence level.

The software tool has been developed and was installed at the California Independent System Operator (CAISO) control room in May 2011 for testing and benchmarking. The tool received very positive feedback from the CAISO specialists.

Keywords: Load following, ancillary services, load forecast, wind generation forecast, probability density function, swinging door algorithm.

Please use the following citation for this report:

Makarov, Yuri V., Pavel V. Etingov, Krishnappa Subbarao, Jian Ma (Pacific Northwest National Laboratory), and Clyde Loutan (CAISO). 2011. *Online Analysis of Wind and Solar, Final Project Report*. California Energy Commission.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ..... **i**

PREFACE ..... **iii**

ABSTRACT ..... **v**

TABLE OF CONTENTS ..... **vi**

LIST OF FIGURES ..... **viii**

LIST OF TABLES ..... **x**

EXECUTIVE SUMMARY **1**

CHAPTER 1: Introduction **9**

Background 9

Goals of This Project 11

Report Organization 13

CHAPTER 2: Load and Wind/Solar Generation Uncertainty Evaluation **14**

Generation Reserves 14

Load Forecast Uncertainty 16

Net Load Uncertainty 17

Statistical Methods to Evaluate the Forecast Uncertainty 17

Distribution Fitting Approach 17

Empirical Probability Approach 18

Assessment of the Generation Capacity Uncertainty 19

Assessment of Ramping Uncertainties 22

"Flying Brick" Method 24

Evaluation of Generation Requirements 26

Uncertainty Range Validation Approach 28

Framework of Probabilistic Tool Integration 30

Real-Time Forecast Errors 32

Wind and Solar Generation Forecast Errors 32

Load Forecast Errors 33

CHAPTER 3: Review of Current Operating Practices at CAISO **34**

CHAPTER 4: Software Tool **41**

User Interface Conceptual Design 41

Capacity Requirements Screen 41

Ramping Requirements Screen 42

Conceptual Design of Probabilistic Tool Integration 43

Data Processing 45

Sudden-Change Detection 45

Outlier Detection 46

Straight-Line Detection Algorithm 46

Software Tool Design and User Interface 47

Main User Interface Screen 47

Test Plan for the Ramp Tool Prototype 50

CHAPTER 5 Simulation Results **53**

Self-Validation Results 55

Real-Time Mode 56

Hour-Ahead Mode 56

Day-Ahead Mode 57

Prediction of Real-Time Market Price Spikes 57

Real-Time Ramping Requirements 58

CHAPTER 6: Conclusions **60**

Next Steps (Technical Area) 60

Next Steps (Commercialization) 61

CHAPTER 7: References **62**

CHAPTER 8: Glossary **64**

APPENDIX A : Generation Fleet Ramping Capability 66

APPENDIX B : Generator Forced Outage Model 70

LIST OF FIGURES

Figure 1: Probabilistic Display Concept 3

Figure 2: Probabilistic Assessment Methodology Concept 4

Figure 3: "Flying Brick" Method 4

Figure 4: Software Tool GUI 5

Figure 5: Real-Time Capacity Requirements Prediction (6/24/11 16:15) 7

Figure 6: CAISO Real-Time Price (6/24/11) 7

Figure 7: "Active" and "Proactive" Integration Approaches 8

Figure 8: Methodology Concept 12

Figure 9: Allocation of Generation Unit Capacity 15

Figure 10: Load Fluctuation and Uncertainty: a) Day-Ahead Load Forecast vs. Actual Load; b) Load Forecast Error 16

Figure 11: Load Forecast Error Histogram 18

Figure 12: Net Load Forecast Error Distribution: a) Histogram; b) Empirical CDF 19

Figure 13: Statistical Characteristics of Wind Generation Forecast for Different Look-Ahead Periods: a) PDF; b) Empirical CDF 20

Figure 14: Wind Generation Forecast Inverse CDFs for Different Look-Ahead Intervals and 95% Uncertainty Ranges 22

Figure 15: Concept of the "Swinging Door" Algorithm 23

Figure 16: "Swinging Door" Algorithm – Obtaining Capacity, Ramp, and Ramp Duration 23

Figure 17: Concurrent Consideration of the Capacity, Ramping and Duration Requirements 24

Figure 18. Concept of the "Flying Brick" Method 25

Figure 19: Ramping Requirement PDFs for Different Ramp Durations 26

Figure 20: Ramping Requirement Inverse CDFs for Different Ramp Durations and 95% Confidence Intervals 26

Figure 21: Evaluation of Capacity Requirements 28

Figure 22: Validation Procedure 29

Figure 23: Flowchart of EMS Integration for the Uncertainty Model 31

Figure 24: Flowchart of Proactive Integration 32

Figure 25. Simple Persistence Model Illustration 32
Figure 26: Real-Time Wind Generation Forecast 33
Figure 27: Real-Time Solar Generation Forecast 33
Figure 28. Real-Time Load Forecast Error 33
Figure 29: An illustration of CAISO Operating Timelines (not to scale) 35
Figure 30: A detailed illustration of CAISO Operating Timelines 37
Figure 31: RTUC/STUC Timeline 38
Figure 32: RTED Timeline 39
Figure 33: Generation Dispatch Components 40
Figure 34: Capacity Requirements Display Concept 42
Figure 35: Ramping Requirements Display Concept 43
Figure 36: CAISO Capacity Requirements Uncertainty Evaluation Concept 44
Figure 37: Example of Wind/Load/Solar Forecast Structure 45
Figure 38: Sudden-Change Detection 45
Figure 39: Outlier Detection 46
Figure 40. Straight-Line Detection 46
Figure 41: Screenshot of Day-Ahead Capacity Requirements Display 48
Figure 42: Screenshot of Real-Time Requirements Display 48
Figure 43: Screenshot of Day-Ahead Ramping Requirements Display 49
Figure 44: Screenshot of Statistical Analysis Display 49
Figure 45: Day-Ahead Capacity Prediction 53
Figure 46: Day-Ahead Ramping Requirements Prediction 54
Figure 47: Hour-Ahead Capacity Requirements Prediction 55
Figure 48: Hour-Ahead Ramping Requirements Prediction 55
Figure 49: Real-Time Mode Self-Validation Results 56
Figure 50: Hour-Ahead Mode Self-Validation Results 56
Figure 51: Day-Ahead Mode Self-Validation Results 57
Figure 52: Real-Time Capacity Requirements Prediction 58

Figure 53: CAISO Real-Time Price* 58

Figure 54: Real-Time Ramping Requirements 59

LIST OF TABLES

Table 1: Example of Validation Table (1-Hour Ahead Forecast) 30

Table 2: Time Characteristics of the Scheduling Process at CAISO 35

EXECUTIVE SUMMARY

This research was conducted by Pacific Northwest National Laboratory (PNNL) for the California Energy Commission and the California Institute for Energy and Environment.

Because conventional generators need time to be committed and dispatched to a desired megawatt level, scheduling and load following processes use load and wind power production forecasts to achieve future balance between conventional generation and energy storage on the one side and system load, intermittent resources (such as wind and solar generation), and scheduled interchange on the other side. The power system balancing process, which includes scheduling, real-time dispatch (load following), and regulation processes, is traditionally based on deterministic models.

Uncertainties in forecasting the output of intermittent resources such as wind and solar generation, as well as system loads, are not reflected in an existing energy management system (EMS) or tools for generation commitment, dispatch, and market operation. With the growing penetration of intermittent resources, these uncertainties could result in significant unexpected load-following and dispatch problems, and pose serious risks to control and operation performance characteristics as well as the reliability of a power grid. Without knowing the risks posed by the uncertainties, system operators have limited means to weigh the likelihood of occurrence and the magnitude of problems to mitigate adverse impacts caused by them. Some important questions need to be addressed in counteracting the impact of uncertainties; for instance, whether and when one should start more units to balance against possible fast ramps in the future over a given time horizon.

Furthermore, these uncertainties could require procuring additional costly balancing services. Major unexpected variations in wind power, unfavorably combined with load forecast errors and forced generator outages could cause significant power mismatches, which could be essentially unmanageable without knowing these variations in advance.

Because the actual load and intermittent generation can deviate from forecasts, it becomes increasingly unclear (especially with the increasing penetration of renewable resources) whether the system would be actually able to meet the conventional generation requirements within the look-ahead horizon, what additional balancing efforts would be needed as we approach real time, and what additional costs would be incurred by those needs.

In order to improve the system control performance characteristics, maintain system reliability, and minimize expenses related to the system balancing functions, it becomes necessary to incorporate the projected uncertainty ranges into the scheduling, load following, and, to some extent, into the regulation processes. This need has been realized already, and some wind forecast service providers offer uncertainty information for their forecasts. Various researchers are developing methodologies and tools to incorporate these uncertainties into power system operations. Unfortunately, in many cases, these efforts are limited to wind generation uncertainties only and ignore the fact that there are additional sources of uncertainty such as system loads and forced generation outages. Most of these efforts consider only the uncertainty ranges for the megawatt imbalances and do not address additional essential characteristics such

as ramps and ramp duration uncertainties. This limited consideration could be misleading to power system operators responsible for system reliability and control performance characteristics.

It is very important to address the uncertainty problem comprehensively by including all sources of uncertainty (load, intermittent generation, generators' forced outages, etc.) into consideration. All aspects of uncertainty, such as the imbalance size (which is the same as the capacity needed to mitigate the imbalance) and generation ramping requirement, must be taken into account. The latter unique features make this work a significant step forward toward the objective of incorporating wind, solar, load, and other uncertainties into power system operations.

In this project, all uncertainties associated with wind power generation forecasting, load demand forecasting, and generation supply interruptions caused by forced outages are taken into account in the evaluation of uncertainty ranges for the required generation performance envelope including balancing capacity, ramping capability, and ramp duration. A probabilistic algorithm, based on a histogram analysis to assess the capacity and ramping requirements, is presented. Simulation was performed using California Independent System Operator (ISO)'s system model and data. This report also presents these simulation results confirming the validity and efficiency of the proposed solutions.

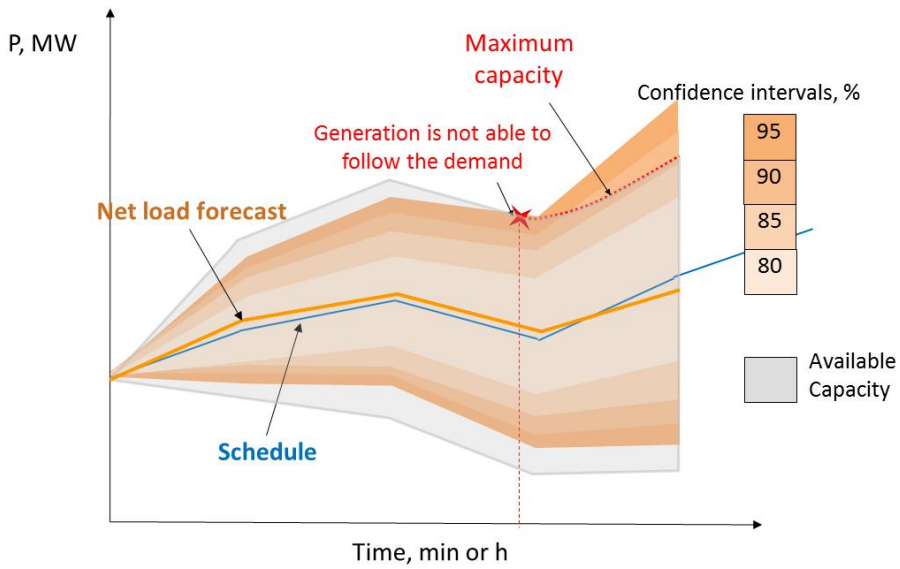
The work pursues the following objectives:

- Develop a probabilistic model to evaluate uncertainties of wind and load forecast errors and to provide rapid (every 5 minutes) look-ahead (up to 5-8 hours ahead) assessments of their uncertainty ranges.

  Figure 1 shows the conceptual picture of the probabilistic capacity requirements display. The light and dark orange areas represent the evaluated capacity ranges for different confidence levels. The blue curve is the generation schedule. The gray area is the available balancing reserve, which is calculated from the unloaded capacity and ramp rates of online generators. The system would have adequate balancing reserve with a specified confidence level if the available balancing reserve (the gray area) covers the entire net load uncertainty range (the dark or light orange area). Otherwise, deficiency of balancing reserve occurs. This means that there is a certain probability that the online generation will not be able to follow the net load requirement. In this case it is necessary to commit or de-commit additional generators to achieve the desired confidence level for the balancing reserve.

- Elaborate similar models to evaluate uncertainties caused by generator random forced outages, failures to start up, and contingency reserve activation processes.

Figure 1: Probabilistic Display Concept



- Create an integrated tool that consolidates the above-mentioned continuous and discrete random factors, contributing to the overall uncertainty, to evaluate look-ahead, worst-case balancing generation requirements (performance envelopes) in terms of the required capacity, ramping capability, and ramp duration.
- Build a methodology and procedures for self-validation of the predicted performance envelope for each look-ahead interval.
- Develop visualization displays to communicate information about the expected ramps and their uncertainty ranges.
- Develop a framework of the tool integration into the California Independent System Operator's (CAISO's) market systems
- Use actual CAISO data to perform simulation.

The following results have been achieved in this work:

Innovative methodology and software tools have been developed that are capable of evaluating future generation requirements, including the required capacity, ramping capability, and ramp duration capability (performance envelope) in view of uncertainties caused by wind and solar generation and load forecast errors. The approach includes three stages: 1) forecast and actual data acquisition, 2) statistical analysis of retrospective information, and 3) prediction of future grid balancing requirements for specified time horizons and confidence intervals
Assessment of the capacity and ramping requirements is performed using a specially developed probabilistic algorithm based on a histogram analysis incorporating all sources of uncertainty and parameters of a continuous and discrete nature (Figure 2).

- A "flying brick" method has been developed to assess the look-ahead worst-case performance envelope requirement to enable the system to accommodate the uncertainties with certain specified degree of confidence (Figure 3). The "flying brick"

concept is to simultaneously include the ramp rate, ramp duration, and capacity requirements directly in the balancing process.

Figure 2: Probabilistic Assessment Methodology Concept

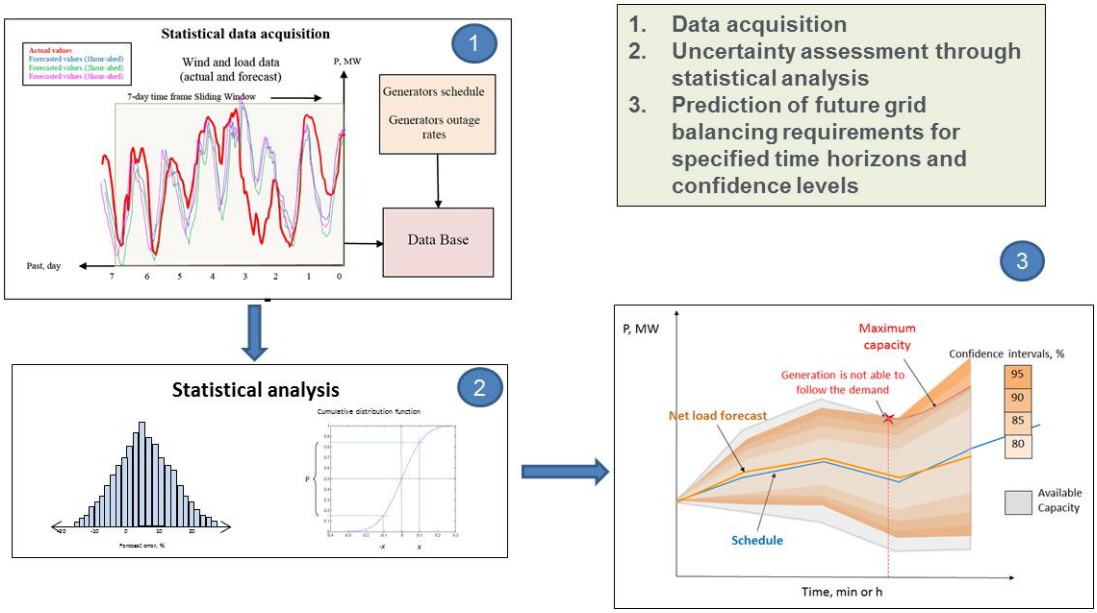
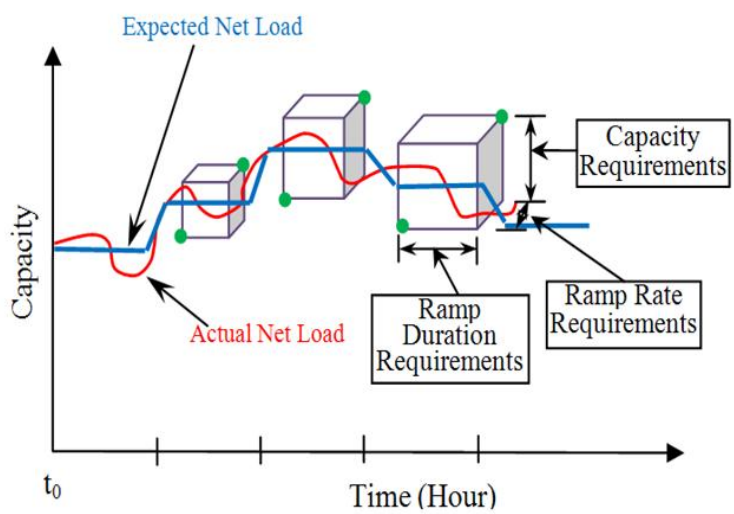


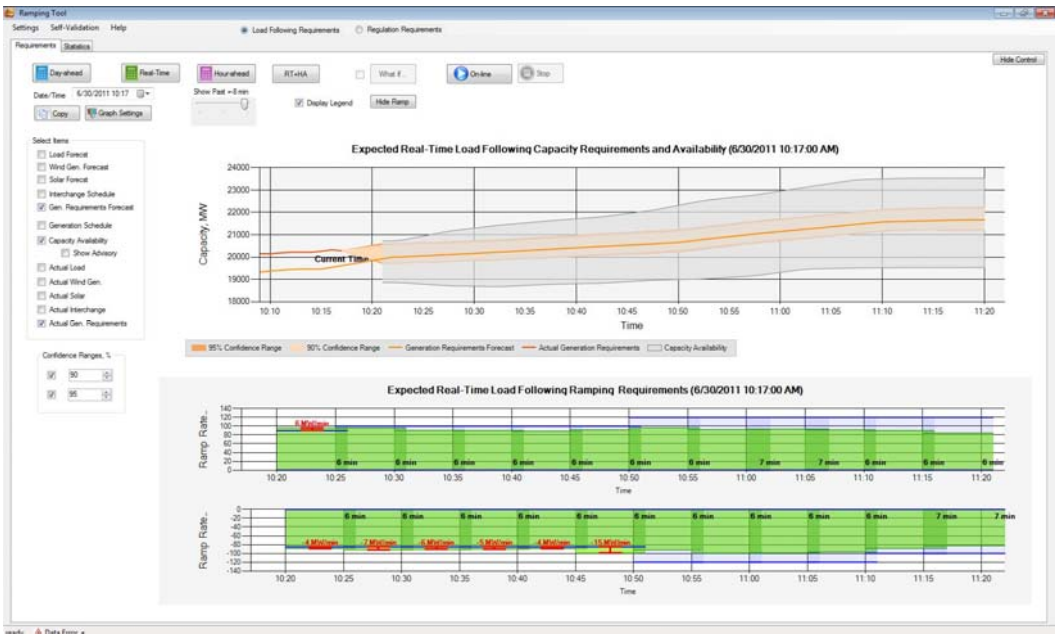
Figure 3: "Flying Brick" Method



- A self-validation approach has been proposed. The purpose of the self-validation algorithm is to verify that the uncertainty ranges predicted based on retrospective information are valid for the future dispatch intervals.

- An industrial software tool has been developed and tested. An example of software tool graphical user interface (GUI) is presented in Figure 4.
- Simulations using actual data provided by this project's CAISO engineering support team have been carried out. Simulation results have shown that the proposed methodology is quite accurate and efficient.

Figure 4: Software Tool GUI



It has been found that the tool is capable of predicting intra-hour deficiency in generation capability. This deficiency of balancing resources can cause price spikes in the real-time market. As an example, one can see in

Figure 5 that a deficiency in the system generation capability greater than 300 MW is predicted in the 10- to 25-min look-ahead period (red error bars). Figure 6 shows the CAISO's real-time market price information. Price spikes occurred in the CAISO market at the same time at which generation capability deficiency was predicted by the tool.

- The concept of probabilistic tool integration into the CAISO's Real Time Pre-dispatch (RTPD) market software applications has been developed. The concept includes three levels of integration: a passive level, an active level, and a proactive level. The passive integration level implies integration of wind and solar forecast information and its visualization without introducing any changes to the RTPD applications. On the active level, the unit commitment (UC) and RTPD procedures are repeated several times for every dispatch interval to determine whether the system can meet the generation requirements caused by uncertainties for a certain confidence level (Figure 7). The

system “breaking points” are communicated to the user. The proactive level requires some modifications of the UC and RTPD algorithms in order to directly

incorporate uncertainties into these procedures (Figure 7). In this case, the generation units will be committed and dispatched, so that these uncertainties would not create system capacity and ramping deficiencies.

Figure 5: Real-Time Capacity Requirements Prediction (6/24/11 16:15)

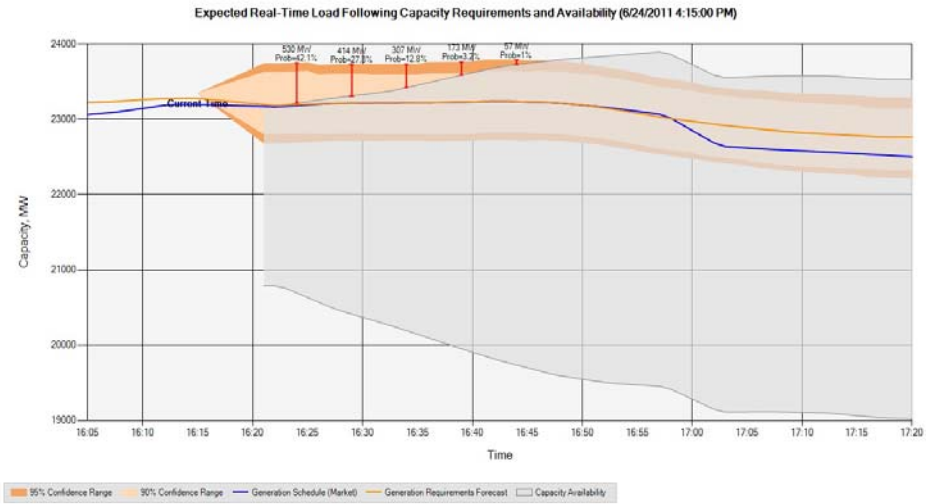
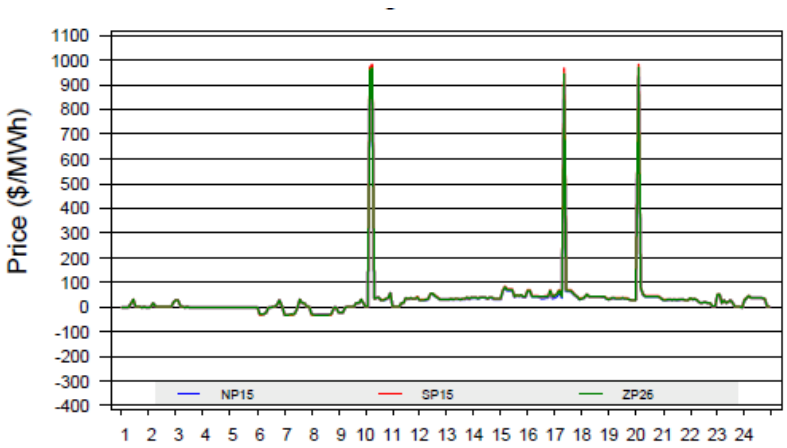
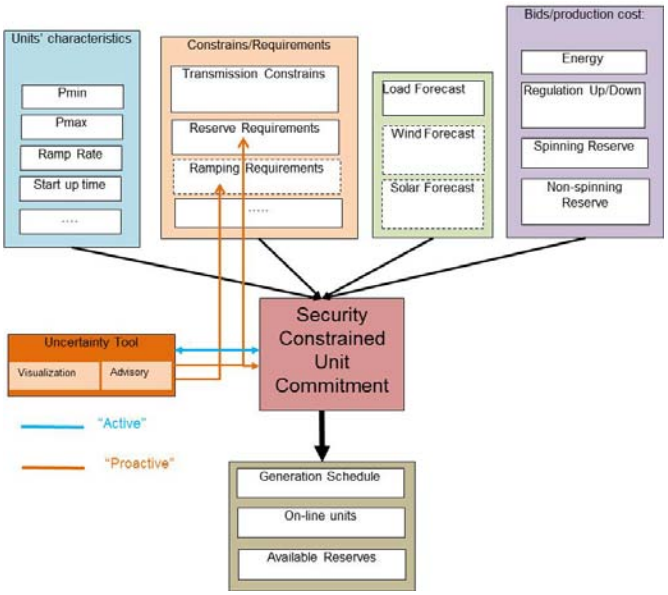


Figure 6: CAISO Real-Time Price (6/24/11)[1]



[1] Available at http://www.caiso.com/Documents/June%202011/DailyMarketWatch_Real-Time_Jun_24_2011.pdf

Figure 7: "Active" and "Proactive" Integration Approaches



The following recommendations for the next phase have been made:

- Integrate the wind and solar forecast service providers' data in the tool to improve the accuracy of the balancing requirements prediction.
- Continue development and implementation of proactive integration methodology to incorporate the tool into CAISO market and unit commitment procedures.
- Develop and implement a new generation of statistical methods to address non-stationary characteristics of forecast errors to further improve the accuracy and robustness of the tool.
- Develop a decision support system using the PNNL tool to help dispatchers address potential deficiencies.
- Incorporate the new Balancing Authority ACE (Area Control Error) Limit (BAAL) proposed standard into the balancing requirements assessment methodology.

The planned commercialization activities include a wide dissemination and technology transfer effort with the ultimate objective to install the tool in several Balancing Authorities (BAs) in California. Among these activities, the highest priority tasks will include a proactive integration of the software tool in the CAISO control room with comprehensive testing and final refinements. It is expected that several more organizations will become interested in installing the tool in their control rooms. In parallel with the California activities, the results of this project will be widely distributed via Web seminars organized for the industry and by presenting them at the industry forums, including Utility Wind Integration Group, Western Electricity Coordinating Council groups, North American Electric Reliability Corporation subcommittees, and other conferences. It is expected that through these activities (supported by the U.S. Department of Energy), the impact of this project will be extended from the statewide level to the nationwide level.

CHAPTER 1: Introduction

Background

The work described in this report was performed by Pacific Northwest National Laboratory (PNNL) and funded by the California Energy Commission (CEC).

Because conventional generators need time to be committed and dispatched to a desired megawatt (MW) level, the scheduling and load following processes use load and wind power production forecasts to achieve future balance between the conventional generation and energy storage on the one side, and system load, intermittent resources (such as wind and solar generation) and scheduled interchange on the other side. The power system balancing process, which includes the scheduling, real-time dispatch (load following) and regulation processes, is traditionally based on deterministic models.

Uncertainties in forecasting the output of intermittent resources, such as wind and solar generation, as well as system loads are not reflected in existing energy management systems (EMS) and tools for generation commitment, dispatch and market operation. With the growing penetration of intermittent resources, these uncertainties could result in significant unexpected load-following and dispatch problems, and pose serious risks to control and operation performance characteristics as well as the reliability of a power grid. Without knowing the risks posed by the uncertainties, the system operators have limited means to weigh the likelihood of occurrence and the magnitude of potential problems and mitigate any adverse impacts caused by them. Some important questions need to be addressed in counteracting the impact of uncertainties; for instance, whether and when additional resources should be started to balance against possible fast ramps in the future over a given time horizon.

Furthermore, these uncertainties could require procuring additional costly balancing services. Major unexpected variations in wind power that are unfavorably combined with load forecast errors and forced generator outages could cause significant power mismatches, which could be essentially unmanageable without knowing these variations in advance.

Because the actual load and intermittent generation can deviate from the forecasts, it becomes increasingly important to assess with increasing penetration of renewable resources whether the system would actually be able to meet the conventional generation requirements within the look-ahead horizon, what additional balancing efforts would be needed as we approach real time, and what additional costs would be incurred by those needs.

In order to improve the system control performance characteristics, maintain system reliability, and minimize expenses related to the system balancing functions, it becomes necessary to incorporate the projected uncertainty ranges into the scheduling, load following, and, to some extent, into the regulation processes. This need has been realized already, and some wind

forecast service providers offer the uncertainty information for their forecasts. Additional work needs to be done to develop methodologies and tools to incorporate these uncertainties into power system operations.

Some wind forecast service providers offer uncertainty information for their forecasts. For instance, AWS Truepower (Zack 2006) and 3TIER (Lerner et al. 2009) companies developed wind power generation forecasting tools with built-in capability to assess wind generation uncertainty. Similar tools have been developed in Europe. In the context of a European Union project, ANEMOS, a tool for on-line wind generation uncertainty estimation based on adaptive re-sampling or quantile regression has been developed (Kariniotakis 2008). A German company, Energy and Meteo Systems, developed a tool for wind generation forecasting, assessing the uncertainty ranges associated with wind forecast, and predicting extreme ramping events (Energy & Meteo Systems 2007). Pinson et al. (2006) discusses a wind generation interval forecast approach using the quantile method. Luig et al. (2001) used statistical analysis based on standard deviation to predict wind generation forecast errors. Work is underway to incorporate these uncertainties into power system operations (Kehler et al. 2010; Maggio et al. 2010). In Constantinescu et al. (2011), Wang et al. (2008), and Ummels et al. (2007), wind power generation is taken into account in the unit commitment problem.

Unfortunately, in many cases, these efforts are limited to wind generation uncertainties only, and ignore the fact that there are additional sources of uncertainty such as system loads and forced generation outages. Most of the works are considering only the uncertainty ranges for the MW imbalances, and do not address additional essential characteristics such as ramps and ramp duration uncertainties.

It is very important to address the uncertainty problem comprehensively, by including all sources of uncertainty (load, variable generation, generators' forced outages, etc.) into consideration. All aspects of uncertainty such as the imbalance size (which is the same as capacity needed to mitigate the imbalance) and generation ramping requirement must be taken into account. The latter unique features make this work a significant step forward toward the objective of incorporating of wind, solar, load, and other uncertainties into power system operations.

In this project, the uncertainties associated with wind power generation forecasting, load demand forecasting, and generation supply interruptions caused by forced outages are taken into account in the evaluation of uncertainty ranges for the required generation performance envelope, including balancing capacity, ramping capability and ramp duration. A probabilistic algorithm, based on the proposed histogram analysis to assess the capacity and ramping requirements, is presented. Simulation was performed using CAISO's system model and data. This report presents these simulation results confirming the validity and efficiency of the proposed solutions.

A probabilistic software tool capable of determining the impact of wind, solar, load and generation uncertainties on the power grid is currently under development. In the research, an

assessment of generation capacity requirements means evaluation of uncertainty ranges of conventional generation requirements in order to meet the power system balance.

Goals of This Project

The objective of this project is to develop a tool to estimate CAISO's upward and downward balancing requirements in terms of its capacity, ramp rate and ramp duration for a user-specified time horizon (several hours ahead or the next day). Based on a scientific approach that uses a specified level of confidence, the estimate will indicate balancing requirements without compromising reliability or compliance with mandatory control performance standards.

This report discusses the following developments:

- a probabilistic model to evaluate uncertainties of the wind and load forecast errors and to provide rapid (every 5 minutes) look-ahead (up to 5-8 hours ahead) assessments of their uncertainty ranges
- similar models to evaluate uncertainties caused by random generator forced outages
- an integrated tool that consolidates the abovementioned continuous and discrete random factors contributing to the overall uncertainty to evaluate look-ahead worst-case balancing generation requirements (performance envelopes) in terms of the required capacity, ramping capability, and ramp duration
- a methodology and procedures for self-validation of the predicted performance envelope for each look-ahead interval
- visualization displays to communicate information about the expected ramps and their uncertainty ranges
- use of the actual CAISO data to perform simulation
- review of the actual dispatch scheduling processes of the CAISO

The proposed approach to evaluate the uncertainty ranges for a required generation performance envelope, including the balancing capacity, ramping capability and ramp duration, consists of the following three stages (Figure 8):

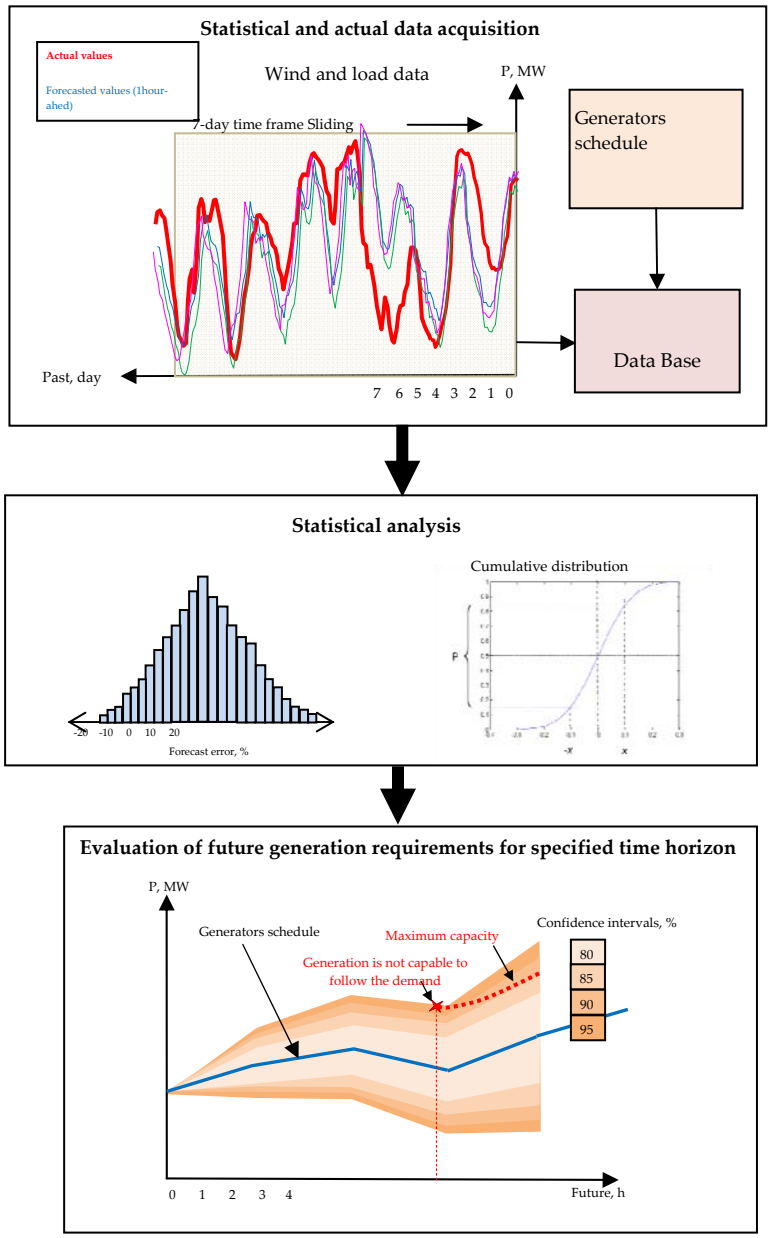
1. The first stage deals with acquiring statistical data. Retrospective information for a user-specified moving window (e.g., for one month), such as forecasted system load and its actual values, wind and solar generation forecasts and their actual values, as well as generation and interchange schedules, are needed to perform the proposed statistical analysis and to build a projection of the balancing requirements into the future.

2. The second stage is a statistical analysis of the retrospective information acquired at the first stage. It consists of the following:

    - capacity requirements analysis based on an empirical statistical analysis of forecast errors

- ramping requirements analysis based on the "swinging door" algorithm (Makarov et al. 2009).
- generation forced outage analysis based on the Markov chain reliability model

Figure 8: Methodology Concept



3. The third stage is an evaluation of future generation requirements for specified time horizons, e.g., 5 or 8 hours ahead. Examples of generation requirements that can be evaluated are regulation and load-following capacity requirements, ramping requirements,

contingency reserve requirements, etc., for different confidence levels such as 80, 85, 90, and 95% (as shown in Figure 8).These requirements can be compared against the actual generation capability of conventional generators that are currently or will be online within the look-ahead horizon. If the actual generation capability is insufficient to meet the requirements, a warning will be issued to the system operators. This would constitute a "passive" integration of wind-related uncertainties into the system operations. In a proactive approach, the look-ahead generation requirement information will be fed back into the generation commitment and dispatch procedures in order to modify them and to make sure that the generators are committed on time and dispatched in a manner to be able to meet the capacity, ramping and ramp duration requirements with a certain level of confidence for the entire look-ahead period.

Report Organization

The report is organized as follows. Chapter 2 discusses evaluation of uncertainties associated with the system load forecast and wind generation forecast using different statistical methods. Chapter 3 reviews the current operating processes and schedules followed by the CAISO. Chapter 4 presents software prototype design. Chapter 5 provides testing and simulation results. Chapter 6 provides conclusions and future work;. a list of references is provided in Chapter 7 and a glossary in Chapter 8.

Appendices are also included to provide additional information on the ramping capability analysis methodology and forced-outage model.

CHAPTER 2:
Load and Wind/Solar Generation Uncertainty Evaluation

This section describes an innovative methodology that is capable of evaluating future generation requirements including the required capacity, ramping capability, and ramp duration capability (these characteristics form the so-called performance envelope). The methodology incorporates uncertainties caused by wind and solar generation and load forecast errors as well as (potentially) uninstructed generation deviations of conventional generation. These tools meet the industry need in a more robust (that is, more reliable for a range of possible future operating conditions) assessment of the balancing reserves required in a BA.

The previous works discussed in the introduction (Zack 2006; Lerner et al. 2009; Kariniotakis 2008; Energy & Meteo Systems 2007; Pinson et al. 2006; Luig et al. 2001; Kehler et al. 2010; Maggio et al. 2010; Constantinescu et al. 2011; Wang et al. 2008; Ummels et al. 2007) address only a single source of uncertainty: the one related to wind generation. Because the influence of the other sources of uncertainty is not reflected in the assessment, the resulting confidence intervals are of limited value to the system operators. Unlike these existing approaches, the methodology developed in this report addresses all sources of uncertainty, including the uncertainties surrounding the load forecasts, uncertainties associated with the forced generator outages, and uncertainties caused by forced generation outages (see Appendix B).

A "flying brick" method was developed in this study to assess the look-ahead worst-case performance envelope requirements and to be able to make sure the system has the capability to balance against the uncertainties with a certain specified degree of confidence. The "flying brick" concept is to include the ramp rate, ramp duration, and capacity requirements simultaneously and directly in the balancing process, and then look for the worst combinations of these parameters located along the vertices' trajectories of the "flying brick."

Generation Reserves

According to the Western Electricity Coordinating Council (WECC), standard power systems are required to maintain the following types of reserves (WECC 2007):

Operating Reserve: the generation capacity above the amount needed to supply firm system demand that is required to provide for regulation, to balance against the load forecasting error and equipment forced and scheduled outages, and to maintain local area reliability. It consists of spinning reserve and non-spinning reserve.

Spinning Reserve: unloaded generation that is synchronized, automatically responsive to frequency deviations, and ready to serve an additional demand. It consists of regulating reserve and contingency reserve.

Non-spinning Reserve: 1. The generating reserve that is not connected to the system but capable of serving the demand within a specified time from its activation. 2. Loads or exports that can be removed from the system in a specified time.

Regulating Reserve: an amount of reserve responsive to automatic generation control (AGC), which is sufficient to provide normal regulating margin.

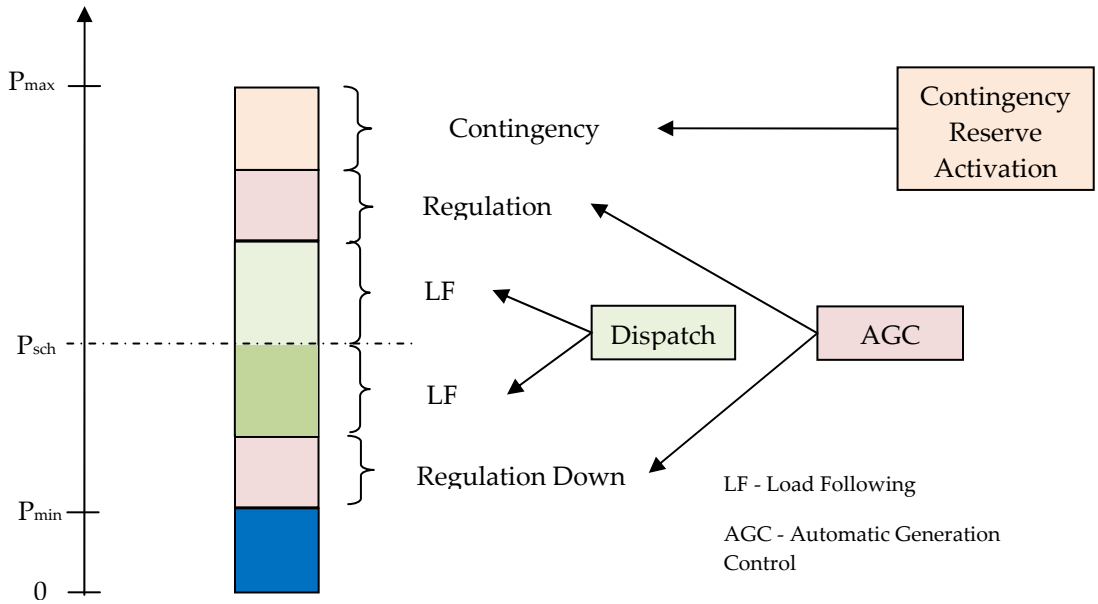
Contingency Reserve – The capacity available to be deployed by a BA to meet the North American Electric Reliability Corporation (NERC) and WECC contingency reserve requirements. Increasing penetration of wind and solar generation leads to growing uncertainties in the reserve requirements.

In the study, the term "assessment of generation capacity requirements" refers to the evaluation of uncertainty ranges for generation requirements needed to achieve power system balance. These uncertainty ranges define intervals within which the future generation requirement is expected to lie with a specified level of confidence.

Uncertainties associated with wind and solar intermittency, electrical load variability, and unexpected generation outages are considered in this report. These uncertainties affect the load following needs as well as regulating and contingency reserve requirements. Details regarding the load and wind/solar generation uncertainties are given in this section; description of the generation forced outage model is presented in Appendix B. In general, the generation capacity allocation is performed by the unit commitment (UC) process, as shown in Figure 9 (WSCC 1998).

To integrate the probabilistic tool into an EMS, it is necessary to take into account the operating practices of the given power system. In Chapter 3, details of the operating practices of the CAISO are presented.

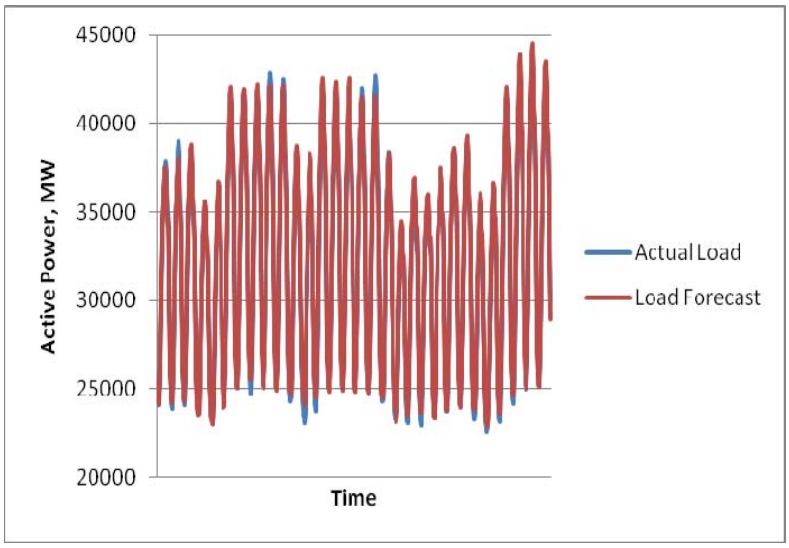
Figure 9: Allocation of Generation Unit Capacity



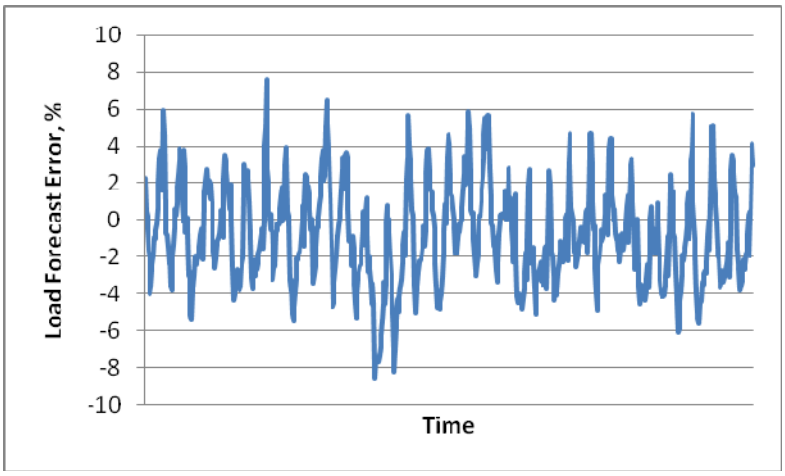
Load Forecast Uncertainty

The uncertainty associated with the load forecast is one of the most influential factors influencing the overall uncertainty. In Figure 10, the load forecast uncertainty for one of the BA is shown. The solid blue curve in Figure 10 (a) shows the hourly average demand over one month, while the red curve shows the day-ahead load forecast for the same time period. The load forecast error is presented in Figure 10 (b). One can see that day-ahead load forecast has an error of about ±8%. What is also important is the fact that the system load is normally more significant than wind or solar generation, so that even if the load forecast is more accurate than the forecast for the intermittent resources (in terms of the percentage error), the MW values of the errors can be quite comparable.

Figure 10: Load Fluctuation and Uncertainty: a) Day-Ahead Load Forecast vs. Actual Load; b) Load Forecast Error



a)



b)

Net Load Uncertainty

Wind and solar generation and power system load demand have a number of similar features:

- Wind/solar generation and most of the load are non-dispatchable resources.
- They both have cycling behavior.
- They both depend on the weather conditions.
- They deviate from the forecast, etc.

Actually, wind generation has more in common with electrical load than with traditional (dispatchable) generation; therefore, wind generation can be considered as a negative load. At the same time, electrical load and wind/solar generation cannot be considered as independent statistical variables. The correlation between load and wind generation forecast errors is shown in (Constantinescu et al. 2011; Wang et al. 2008). To address this issue, the net load concept is commonly used in wind integration studies to assess the impact of load and wind generation variability on the power system operation. The net load has the following definition: net load is total electrical load minus total wind generation output, minus total solar generation output, plus the interchange.

Statistical Methods to Evaluate the Forecast Uncertainty

There are different approaches that can be used for the uncertainty analysis of the forecast errors. In this work, we analyzed two methods in terms of their applicability for the purpose of this project: distribution fitting and empirical probability.

Distribution Fitting Approach

Probability distributions are based on assumptions about a specific standard form of random variables; for example, normal, uniform or Poisson distributions. Based on the standard distributions and selected set of its parameters, they assign probability to the event that the random variable takes on a specific, discrete value, or falls within a specified range of continuous values (MathWorks® 2010).

Selecting a distribution model means choosing a standard probability distribution and then adjusting its parameters to fit the data (MathWorks® 2010). For example, in (CAISO 2007) it is assumed that the load and wind forecast errors are described by the truncated normal distribution (TND).

The probability density function (PDF) of the truncated normal distribution is:

$$PDF_{TND}(x;\mu,\sigma,a,b) = \frac{\frac{1}{\sigma} PDF_N\left(\frac{x-\mu}{\sigma}\right)}{CDF_N\left(\frac{b-\mu}{\sigma}\right) - CDF_N\left(\frac{a-\mu}{\sigma}\right)} \tag{1}$$

where μ = the mean value of the non-truncated normal distribution;

σ = the standard deviation of the non-truncated normal distribution;

a, b = upper and lower limits of the non-truncated normal distribution;

$x \in (a,b), -\infty \le a < b \le \infty$;

$PDF_N\left(x;\mu,\sigma\right) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ = the probability density function of the standard normal distribution, and

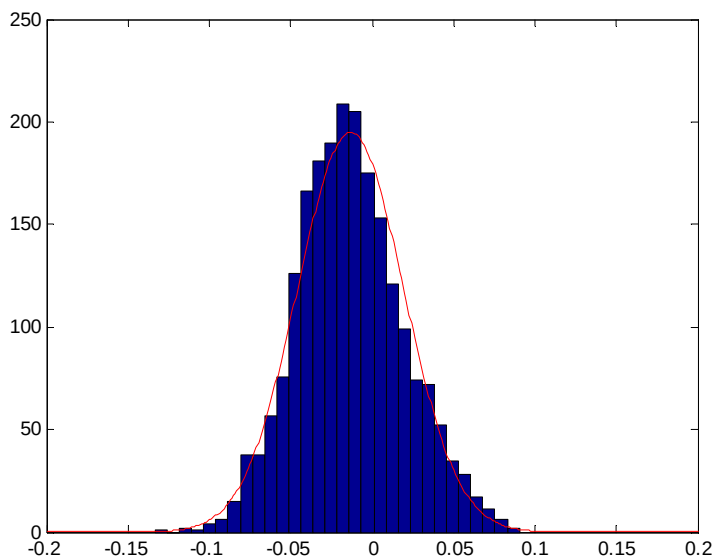
$CDF_N(\cdot)$ = the cumulative distribution function (CDF) of the standard normal distribution.

The cumulative distribution function of the truncated normal distribution is:

$$CDF_{TND}(x;\mu,\sigma,a,b) = \frac{CDF_N\left(\frac{x-\mu}{\sigma}\right) - CDF_N\left(\frac{a-\mu}{\sigma}\right)}{CDF_N\left(\frac{b-\mu}{\sigma}\right) - CDF_N\left(\frac{a-\mu}{\sigma}\right)}, \quad a \le x \le b \tag{2}$$

An example of the load forecast error distribution is presented in Figure 11. The blue bars represent the histogram of the real load forecast error. The red curve depicts the TND of the load forecast error.

Figure 11: Load Forecast Error Histogram

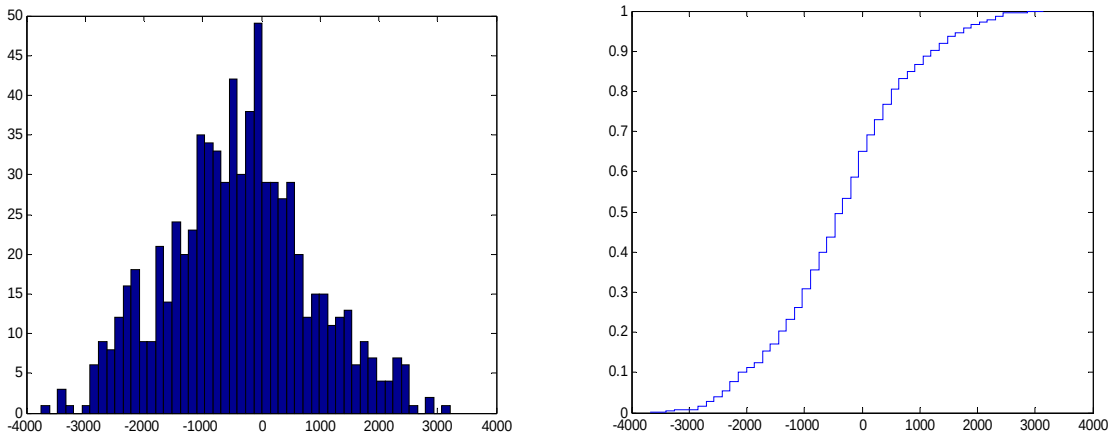


Empirical Probability Approach

When data do not follow a standard probability distribution, nonparametric models based on empirical probability distributions are more appropriate. These models have the advantage of

making no assumptions about the form of the underlying distribution, so no parameter estimates are needed (MathWorks® 2010). The idea behind building the empirical Cumulative Distribution Function (CDF) is relatively simple. This is a function that assigns probability $1/n$ to each of n observations in the analyzed dataset. The CDF for a given value x of a parameter is calculated by adding all probabilities for the samples that have values smaller than x. Its graph has a stair-like appearance. An example of an empirical distribution (net load forecast error distribution and empirical CDF) are presented in Figure 12.

Figure 12: Net Load Forecast Error Distribution: a) Histogram; b) Empirical CDF



a) **b)**

Assessment of the Generation Capacity Uncertainty

A statistical approach based on the time-varying empirical probability density function (PDF) is used in the study to determine the combined uncertainty ranges of the wind/solar and load forecast errors, as well as the effect of the forced generation outages. In this section, we only consider the wind and load forecast error uncertainties. The solar forecast error can be included into the consideration in the same way as the wind forecast error. The methodology to incorporate the generator forced-outages uncertainty will be given in the following sections.

In our approach, wind and load forecast errors are summed together for each dispatch interval in the past within a sliding window. The sliding window size is selected to collect sufficient statistical information regarding the forecast errors. The information can be accumulated separately for each forecast horizon; for instance, for the hour-ahead forecast, two hours ahead forecast, and so on. Based on the collected statistics, the approach evaluates the percentile intervals (also called confidence intervals or uncertainty ranges) for each forecast horizon and different level of confidence. These intervals are assumed to be the same in the future dispatch interval; that is, for the next hour, the hour after that, and so on.

An example, based on data from a real power system, of the statistical characteristics of wind generation forecast for different look-ahead dispatch intervals (1, 2, 3, 4, and 5 hours ahead) is

presented in Figure 13. Figure 13 (a) shows the empirical PDF and Figure 13 (b) shows the empirical CDF.

The uncertainty range defines an interval within which a random parameter is expected to lie with a specified level of confidence. To determine an uncertainty range, it is necessary to find two solutions of the inverse CDF function corresponding to the desired percentiles on both ends of the distribution. The definition of the inverse CDF is the following:

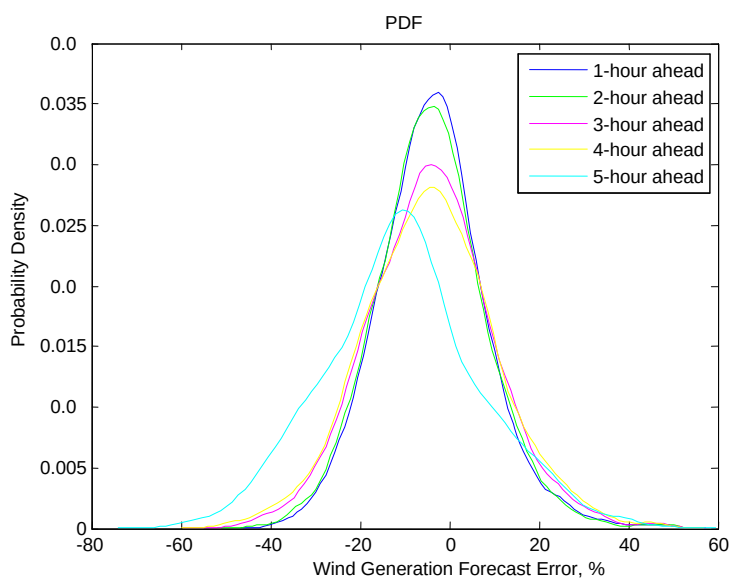
For a strictly increasing and continuous CDF, for a given value p of the probability, the inverse CDF function $CDF^{-1}(p)$, $p \in [0,1]$ is the unique real number x such that $CDF(x) = p$. The inverse of the CDF is called the quantile function. An evaluation of the quantile functions often involves special numerical methods.

Our task is to find the forecast error range $x_1 \ldots x_2$ to the given level of confidence p

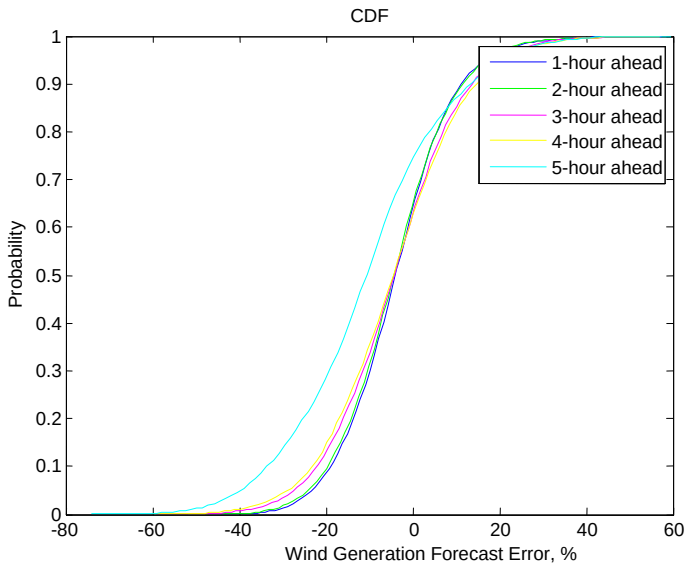
$$CDF(x_2) - CDF(x_1) = p(x_1 \le X \le x_2) = \int_{x_1}^{x_2} PDF(x)dx \tag{3}$$

Inverse CDF functions for wind generation forecast errors for different look-ahead periods are presented in Figure 14. The uncertainty ranges are evaluated at a 95% confidence level. The 95% uncertainty range corresponds to the 2.5 to 97.5 percentile range of the distribution reflecting the uncertainty (Figure 14). It is clear that the size of uncertainty ranges depends on the look-ahead time. It can be seen from Figure 14 that for the longer look-ahead periods, the uncertainty range becomes larger.

Figure 13: Statistical Characteristics of Wind Generation Forecast for Different Look-Ahead Periods: a) PDF; b) Empirical CDF

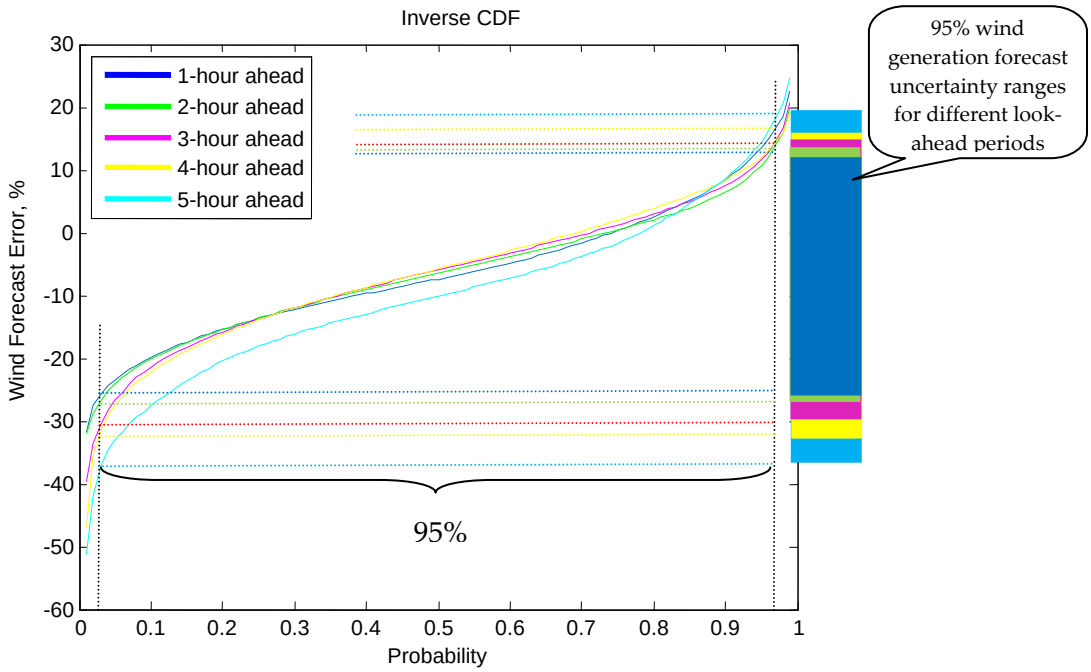


a)


CDF
Probability
Wind Generation Forecast Error, %
1-hour ahead
2-hour ahead
3-hour ahead
4-hour ahead
5-hour ahead
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-80
-60
-40
-20
0
20
40
60

b)

Figure 14: Wind Generation Forecast Inverse CDFs for Different Look-Ahead Intervals and 95% Uncertainty Ranges



Assessment of Ramping Uncertainties

Assessment of ramping requirements is very important with high penetration of wind and solar generation into a power system. Sudden wind generation ramps can happen frequently and cause additional need for fast responsive generation units available on-line.

The required ramping capability needed to follow the net load curve, which covers all system imbalances, can be derived from the shape of the regulation and load following curves – see details in Makarov et al. (2009). The "swinging door" algorithm is proposed for this purpose (Makarov et al. 2009).

Figure 15 demonstrates the idea of the "swinging door" approach. A point is classified as a "turning point" whenever the next point in the sequence causes any intermediate point to fall outside a parallelogram defined by the admissible accuracy range $\pm\varepsilon\Delta G$. For instance, for point 3, one can see that point 2 stays inside the window *abcd*. For point 4, both points 2 and 3 stay within the window *abef*. But for point 5, point 4 lies outside the window defined between points 1 and 5, and therefore point 4 is marked as a turning point.

Based on this analysis, we conclude that points 1, 2, and 3 correspond to the different magnitudes of the regulation signal, π_1, π_2 and π_3, whereas the ramping requirement at all of these points is the same, $\rho_{1\text{-}3}$ (see Figure 16) The swinging door algorithm also determines the ramp duration δ.

Figure 15: Concept of the "Swinging Door" Algorithm

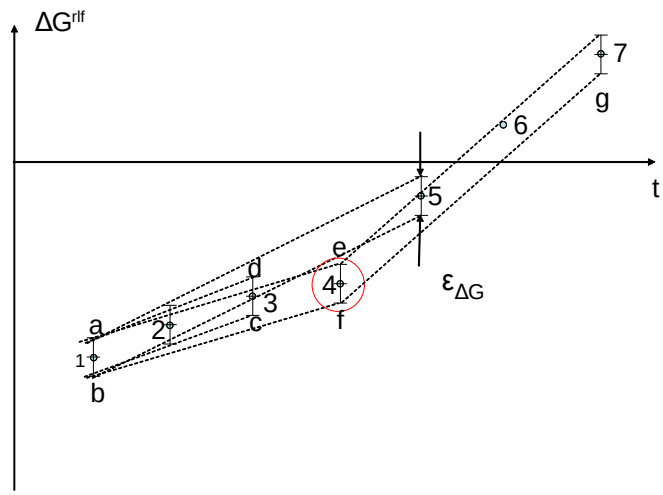
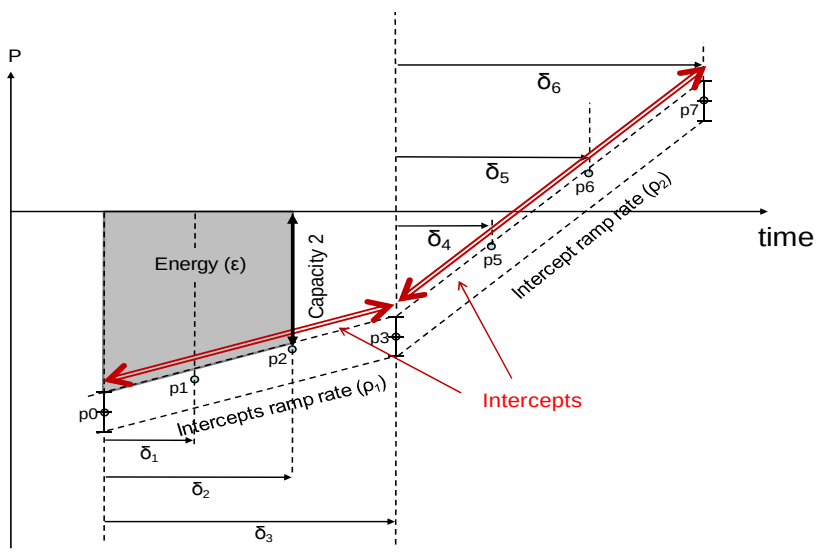


Figure 16: "Swinging Door" Algorithm – Obtaining Capacity, Ramp, and Ramp Duration



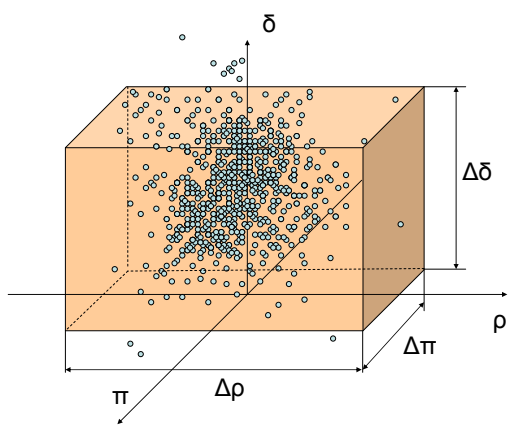
The regulation capacity and ramping requirements are inherently related. Insufficient ramping capability could cause additional capacity requirements. A multivariable statistical analysis can be applied to provide a concurrent consideration of the regulation and load following capacity, ramping, and ramp duration requirements. For the regulation/load following requirement curve, the "swinging door" algorithm is applied to determine the sequences of its magnitudes and ramps, $\pi_1, \pi_2, \ldots$, $\rho_1, \rho_2, \ldots$, and $\delta_1, \delta_2, \ldots$. The triads $(\pi_i, \rho_i, \delta_i)$ can be used to populate the three-dimensional space of these parameters (Figure 17). Let us define a rectangular box in the space that contains a certain percentage of the points. If a point lies outside the box, the regulation/load following requirements are not met at this point. We will require that this

probability must be below a certain minimum probability, P_{min}. Our task is to find a position of the walls of the probability box that corresponds to a given P_{min}. For given ranges of these three parameters, $\Delta\pi, \Delta\rho$ and $\Delta\delta$, a box can be plotted in this space, so that some triads are inside the box (N_{in}), and some are outside (N_{out}). This approach helps determine the probability of being outside the box,

$$p_{out} = \frac{N_{out}}{N_{out} + N_{in}} \tag{4}$$

For example, assume that the confidence level for the analysis is established at 94%. Then for each dimension of the box, we can assign equal probability for finding a point outside the box due to any of the three possible reasons: insufficient generation capacity (incremental or decremental), insufficient ramping capability (upward and downward), or insufficient ramp duration capability. This results in a requirement that only 1% of the points should be left outside the two sides of the box along any of the analyzed coordinates while adjusting its walls. Of course, we should be careful not to double or triple count points that are found outside of the box due to more than one reason. The resulting size of the box determines the ranges of the generation requirements for the capacity, ramp, and ramp duration characteristics that are sufficient to meet the system needs in 94% of the cases.

Figure 17: Concurrent Consideration of the Capacity, Ramping and Duration Requirements



"Flying Brick" Method

Figure 18 illustrates the idea of the flying brick method (Makarov et al. 2011). Three uncertainty ranges, i.e., capacity, ramp rate and ramp duration requirements, are represented as a three-dimensional probability box, i.e. the flying brick. The blue curve shows the generation requirements that meet the expected net load. The red curve refers to actual net load, which can deviate from its expected values. Suppose t_0 is the current moment. At this point, the multivariable statistical analysis is applied to forecast errors for different look-ahead intervals.

The worst combinations of the three requirements shown by vertices of the probability box provide generation characteristics needed to meet system requirements with a certain level of confidence. For each subsequent time interval, the probability box is built based on three-dimensional CDFs.

Figure 18. Concept of the "Flying Brick" Method

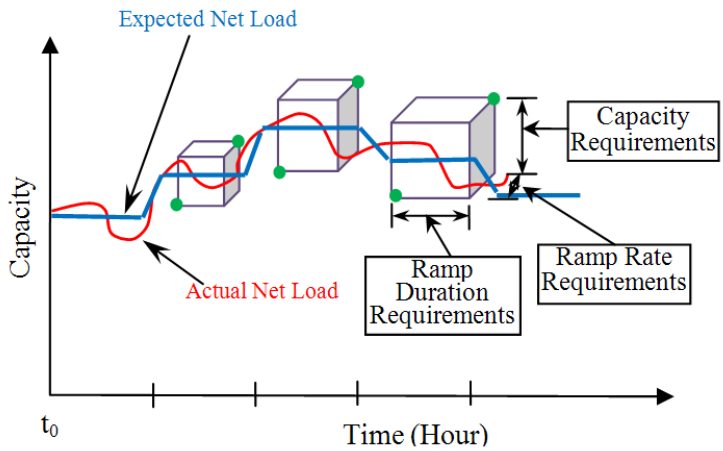


Figure 19 presents the ramping requirement PDFs for different ramp durations. Inverse CDF functions of the ramp-rate distribution for different ramp durations, obtained using the "flying brick" approach, are presented in Figure 20. Evaluation of uncertainty ranges for ramping requirements is similar to evaluating capacity requirement. Ramping requirement uncertainty ranges evaluated at the 95% confidence level are shown in Figure 20. It can be observed that the ramping ranges depend on ramp durations, and ramping requirements become lower for longer ramp durations.

Figure 19: Ramping Requirement PDFs for Different Ramp Durations

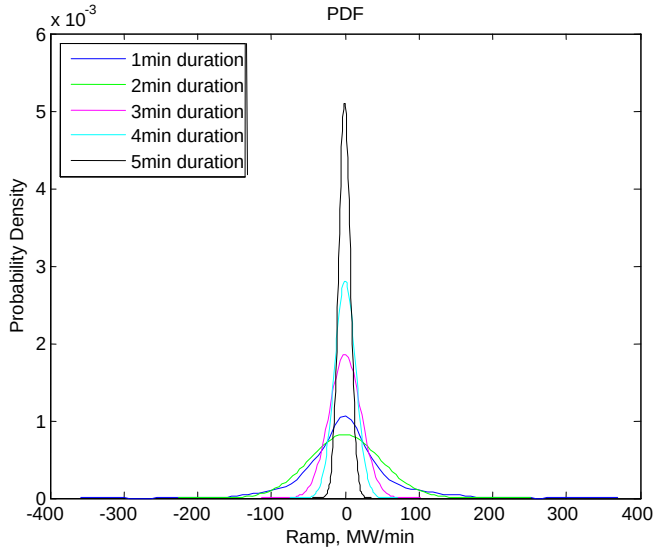
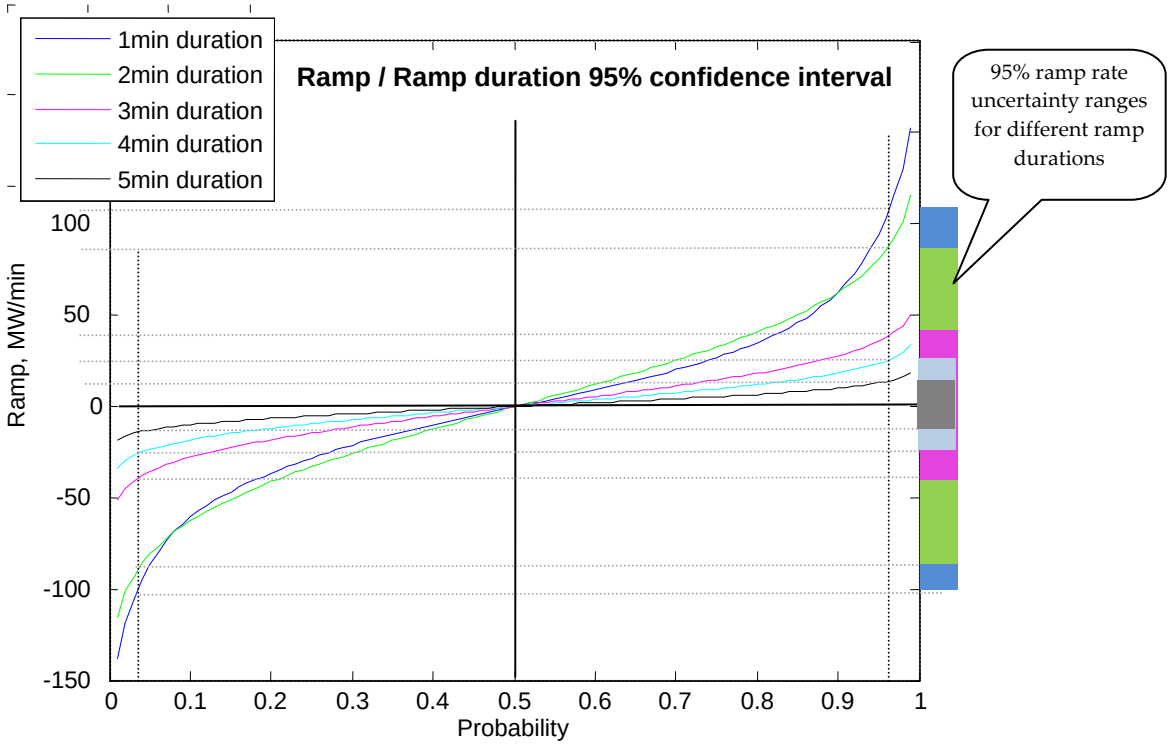


Figure 20: Ramping Requirement Inverse CDFs for Different Ramp Durations and 95% Confidence Intervals



Evaluation of Generation Requirements

Evaluation of generation requirements includes an assessment of generation capacity requirements and generation ramping requirements. Evaluation of balancing capacity

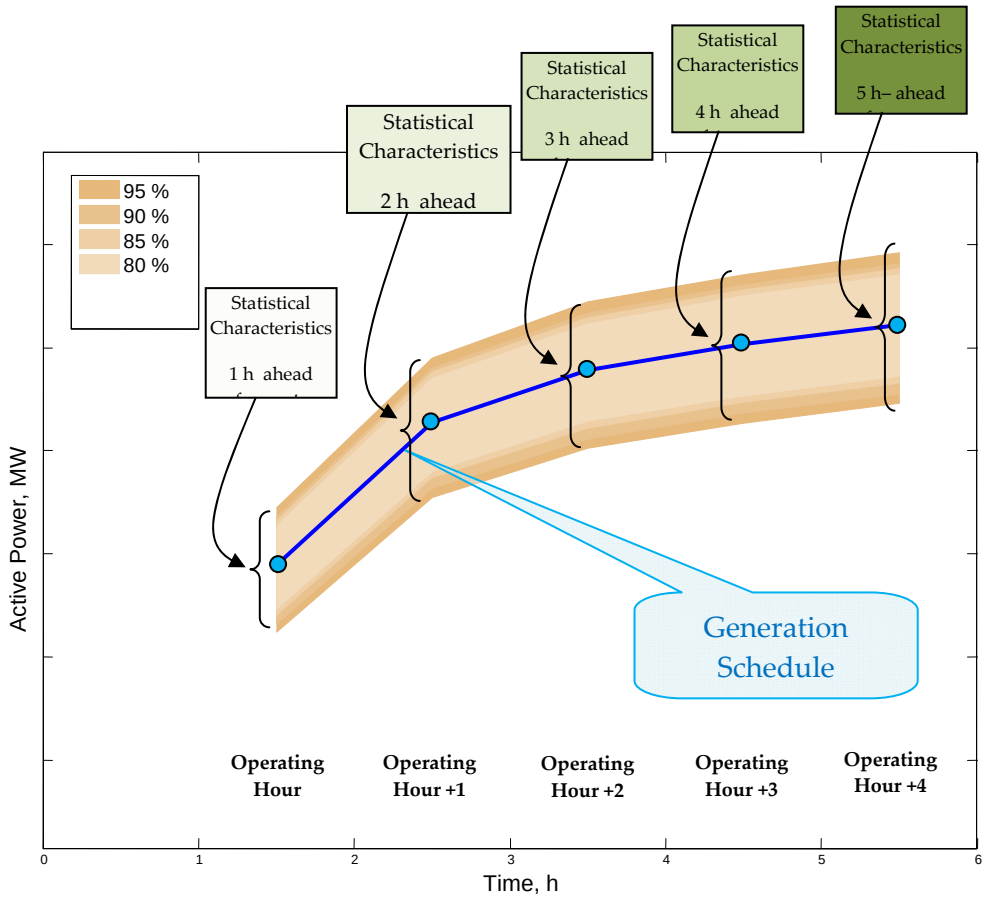
requirements is shown in Figure 21. The blue line corresponds to the generation schedule. The hour-ahead schedule with 1-hour resolution is considered in this example. Uncertainty ranges are calculated for each scheduling (dispatch) interval using individual statistical characteristics for a specified look-ahead horizon and taking into account the level of predicted wind generation, as it is obtained by the statistical analysis of retrospective information.

The following information is used:

- Load
  - Actual load
  - 1 (2, 3, 4, 5)-hour-ahead load forecast
- Wind generation
  - Actual wind generation
  - 1 (2, 3, 4, 5)-hour-ahead wind generation forecast
- Solar generation
  - Actual wind generation
  - 1(2,3,4,5)-hour-ahead wind generation forecast
- Interchange schedule
- Generation schedule.

Building the resulting uncertainty characteristics is a repetitive process. The generation schedule, load and wind/solar generation forecasts, and statistical characteristics of the retrospective data are continuously updated. A sliding window with a user-specified refreshment rate is used to acquire continuously updated statistical information. The uncertainty ranges are also updated, taking into account changing generation schedules, load forecast, and wind generation forecast and their statistical characteristics.

Figure 21: Evaluation of Capacity Requirements



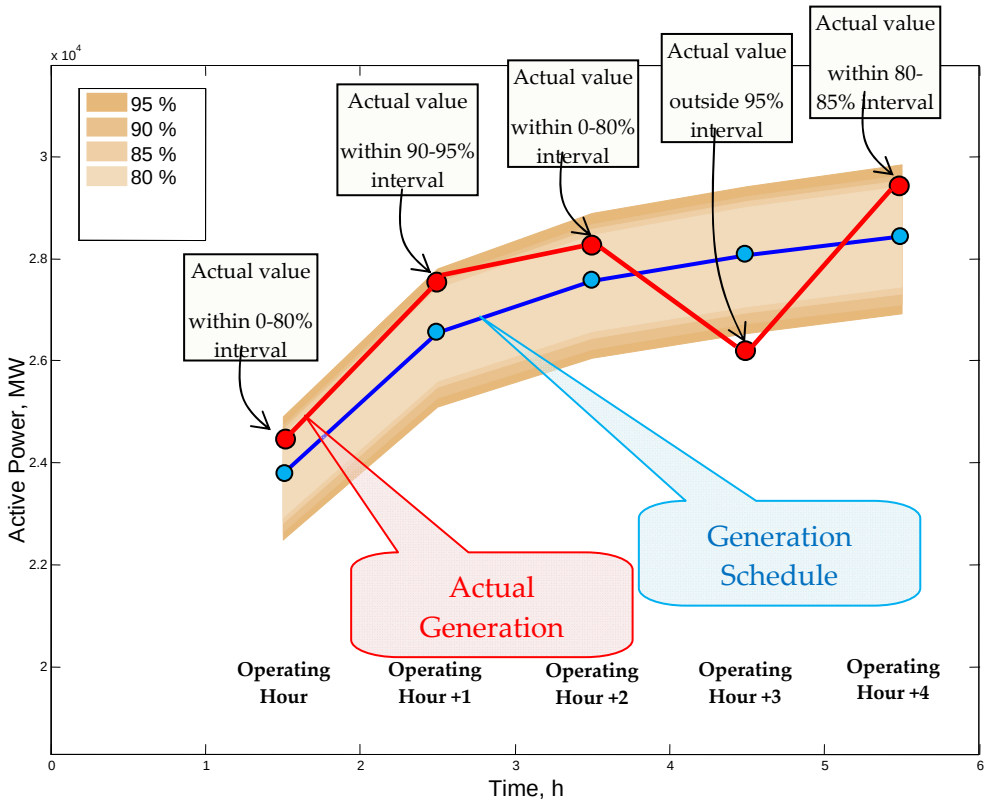
Uncertainty Range Validation Approach

To validate the accuracy of the uncertainty model of generation requirements, a validation approach has been developed.. It is based on comparing the predicted uncertainty ranges against the actually observed ranges for the same dispatch intervals. The algorithm includes the following steps.

1. Acquire retrospective statistical information using the sliding window technique. The sliding window is updated hourly (or according to some other specified refreshment rate).
2. Perform a statistical analysis of the data acquired in Step 1. The derived statistical characteristics are also updated hourly (or according to a user-specified refreshment rate).
3. Evaluate uncertainty intervals for the future generation requirements using the statistical characteristics obtained in Step 2. Uncertainty intervals are also updated according to a specified refreshment rate.
4. Overlay the actual generation values over the previously forecasted uncertainty intervals, as shown in Figure 22, and determine which predicted uncertainty interval the actual

generation value belongs to. Put this information into the validation table (Table 1). Note that for different look-ahead forecasted intervals, different tables should be used.

Figure 22: Validation Procedure



At the end of simulation, the following calculations are made:

1. Count how many points belong to a predicted interval with a specified confidence level, and calculate the percentage of points found within the interval (Table 1).
2. Compare the obtained percentages with targeted percentage values. The targeted percentages correspond to the confidence level of the interval. For example, for the 0 to 80% confidence interval, the targeted value is equal to 80%, and for 80 to 85% uncertainty interval, the targeted value is equal to 5%, etc. (see Table 1).

The uncertainty algorithm is validated if the calculated percentages and the targeted percentages are close.

Table 1: Example of Validation Table (1-Hour Ahead Forecast)

	Day 1						…			Day N							Objective
Interval	1h	2h	3h	4h	….	24h	…	…	…	1h	2h	3h	…	24h	Total Points	Percentage, %	Values, %
0-80%	✓	✓					✓		✓	✓	✓			✓	803	80.3	80
80-85%			✓			✓						✓			46	4.6	5
85-90%				✓									✓		51	5.1	5
90-95%					✓										49	4.9	5
95-100%								✓							51	5.1	5
Total															**1000**	**100%**	

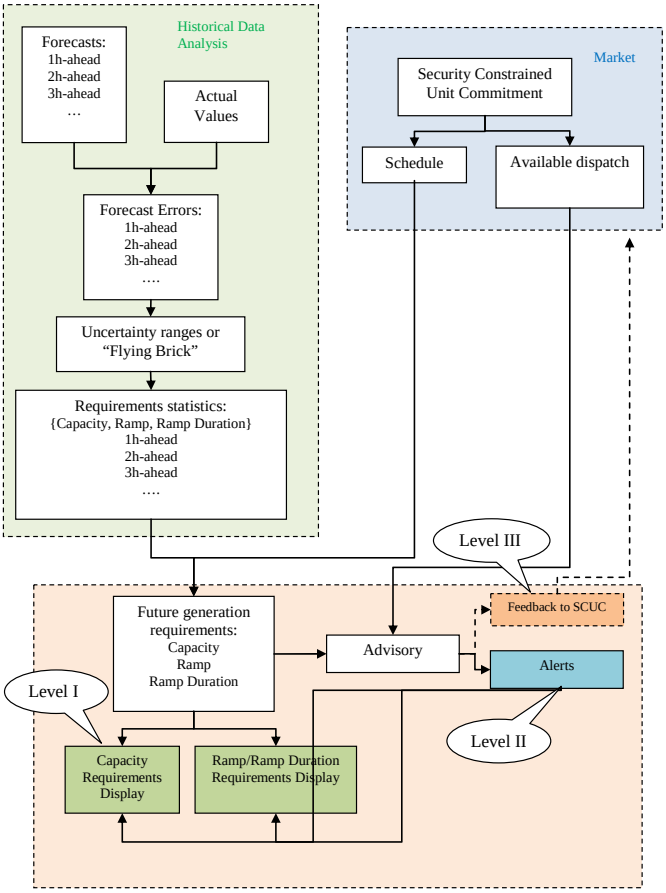
Framework of Probabilistic Tool Integration

Figure 23 shows the concepts of the three levels of integration, namely passive integration, active integration, and proactive integration.

1. Passive Integration (Level I)

Passive integration is the initial step and the simplest way of integration to bring awareness of wind, solar and load forecast uncertainties into a control center through visualization and alarms. In passive integration, displays with look-ahead capacity and ramping requirements are provided to the real-time operators for better situational awareness. They help operators assess balancing needs and take preventive actions to mitigate potential balancing energy deficiencies.

Figure 23: Flowchart of EMS Integration for the Uncertainty Model



2. Active Integration (Level II)

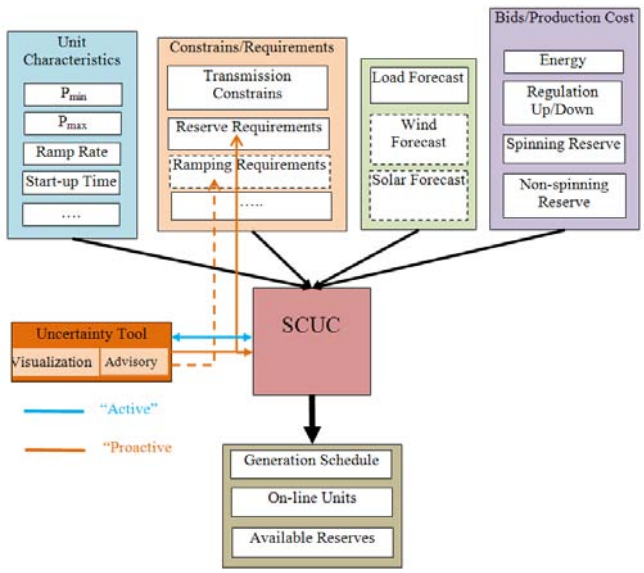
The active integration is more comprehensive than passive integration. The active integration uses uncertainty information to re-run existing grid operation functions such as UC and economic dispatch (ED) processes for the worst-case combination of uncertainties within the specified confidence level. The tool displays warning messages about potential threats to the power system if the UC or ED procedures cannot find solutions for the worst cases. It also provides operators with advisory information regarding the actions that could be taken to avoid potential problems. The active integration does not modify the UC and ED procedures. Instead, it uses existing processes in the RTPD systems to check the sufficiency of balancing resources within the range of uncertain system requirements.

3. Proactive Integration (Level III)

Proactive integration is the most comprehensive level of market system integration, because it not only interacts with UC, ED, and other applications in the systems, but also modifies the algorithms. New constraints based on uncertainty range evaluations are incorporated into the UC and ED processes. For example, the uncertainty ranges of the capacity and ramping

requirements can be incorporated in the UC process as a part of reserve requirements as shown in Figure 24.

Figure 24: Flowchart of Proactive Integration



Real-Time Forecast Errors

Wind and Solar Generation Forecast Errors

Currently, the real-time wind and solar generation forecasts are not provided or included in the CAISO real-time dispatch process. Instead, the simple persistence model is implicitly used (Figure 25). Practically this means that, for example, for a 5-minute dispatch interval [t + 5, t + 10], the implicit real-time wind (or solar) generation forecast is assumed to be equal to the average actual wind (or solar) generation in the interval [t – 5, t].

Figure 25. Simple Persistence Model Illustration

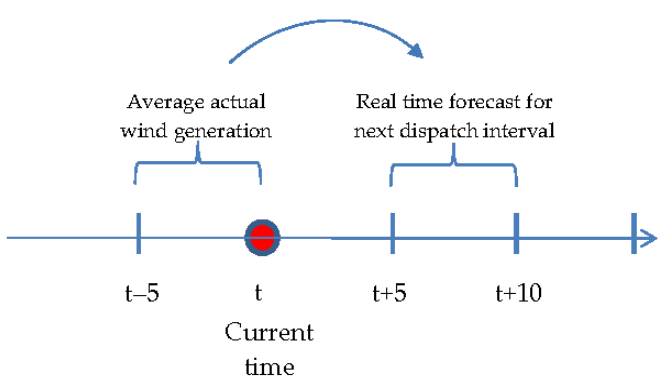


Figure 26 and Figure 27 show CAISO's real-time wind and solar generation forecast errors calculated using the persistence model.

Figure 26: Real-Time Wind Generation Forecast

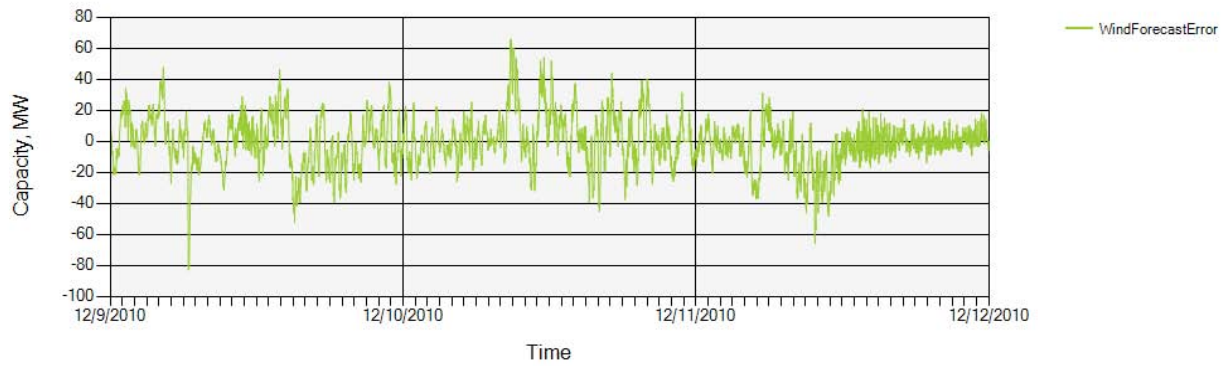
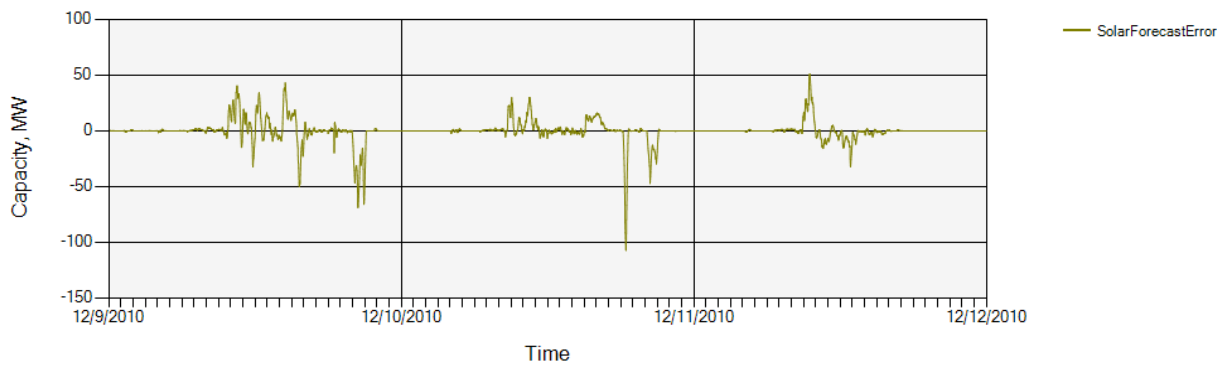


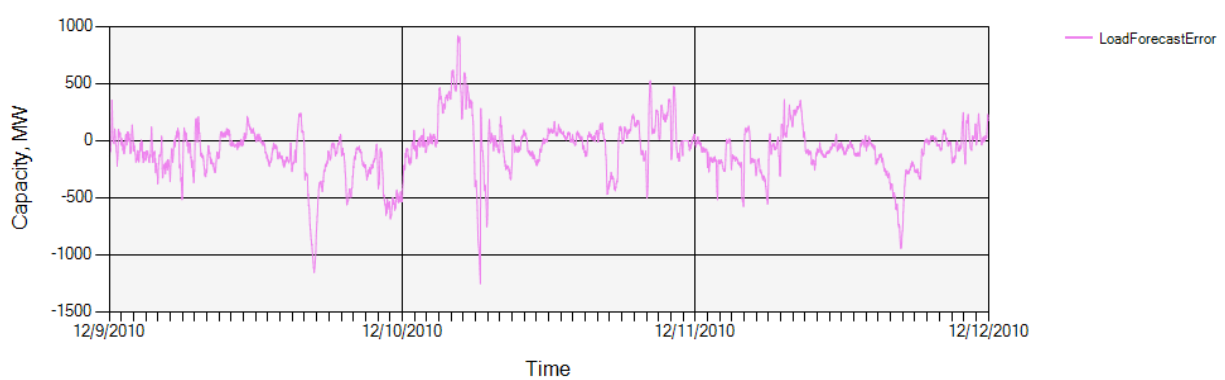
Figure 27: Real-Time Solar Generation Forecast



Load Forecast Errors

CAISO uses an adaptive load forecasting system (ALFS) to predict load in real time. The forecast is updated every 5 minutes up to 65 min ahead. Figure 28 presents the observed CAISO real-time load forecast errors for 12/9/2010 – 12/12/2010.

Figure 28. Real-Time Load Forecast Error



CHAPTER 3:
Review of Current Operating Practices at CAISO

To incorporate the proposed probabilistic tool into the CAISO's Real-Time Market (RTM) systems, we need to understand the actual procedures for generation scheduling and dispatch. In this section, the operating practices at the CAISO are briefly reviewed.

CAISO runs different generation schedules in the day-ahead market and real-time market to make sure that the energy and reserve requirements including regulation up, regulation down, and ramping requirements are ultimately met in real-time operation.

Figure 29 shows the CAISO market timeline. The RTM applications include two sequence of processes, Real Time Pre-dispatch (RTPD) and Real Time Economic Dispatch (RTED). Under normal operating conditions, the RTPD and RTED processes work together to ensure enough capacity is on-line to meet real time load demand.

The RTPD process runs every 15 minutes. It contains the Hour-Ahead Scheduling Process (HASP), the Short-Term Unit Commitment (STUC) process, and the Real Time Unit Commitment (RTUC) process. The STUC process runs once in an hour to look out four and half hours to commit resources that have time constraints more than 90 minutes. The RTUC process runs every 15 minutes and looks out between four and seven 15-minute intervals to ensure there is sufficient capacity to meet demand. In the real time dispatch horizon, the RTED runs every 5-minute to meet the imbalance between supply and demand (CAISO 2006).

The CAISO does not dispatch Regulation Reserve through its market systems but automatically dispatches regulation through its Automatic Generation Control (AGC) system every four-seconds to meet moment-to-moment fluctuations in customer load demand and to correct for the unintended fluctuations in generation.

The regulation capacity is procured day-ahead for each operating hour of the next operating day. The additional ancillary services (AS) also can be procured in the real-time market (RTM) to meet additional AS requirements. The AS include: regulation-up reserve, regulation-down reserve, spinning reserve and non-spinning reserve. Time characteristics of the scheduling and dispatch processes are given in Table 2. A detailed picture of the CAISO market timeline is presented in Figure 30.

Figure 29: An illustration of CAISO Operating Timelines (not to scale)

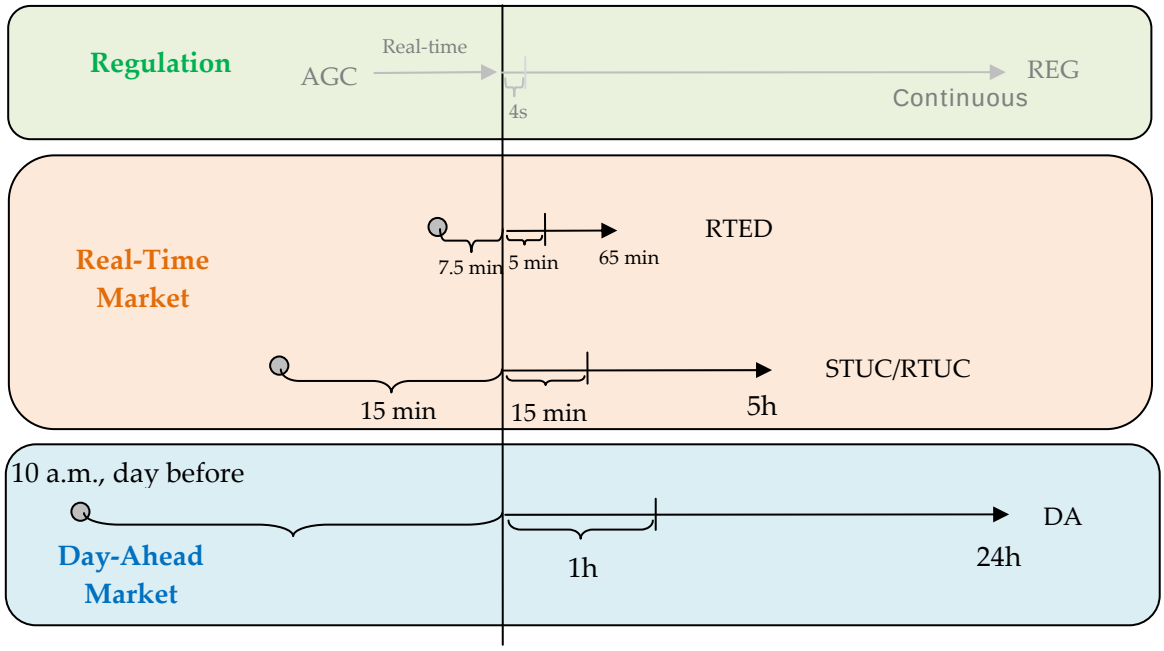


Table 2: Time Characteristics of the Scheduling Process at CAISO

Element	Acronym	Start time	Interval	Frequency	Time horizon
Day-Ahead Market	DAM	Closes at 10:00 on the day before	1 h	Every day	24 h
Short-Term Unit commitment	STUC	~75 min before	15 min	hourly	up to 5 hours
Real-Time Unit commitment	RTUC	-	15 min	15 min	4–7 x 15 min interval
Real-Time Economic Dispatch	RTED	7.5 min before	5 min	Every 5 min	65 min
Regulation	REG	-	4 s	4 s	-

The CAISO RTM consists of several applications, three of which, including STUC, RTUC, and RTED, work together. The STUC and RTUC applications ensure there is enough on-line

capacity to meet a 5-minute demand (Figure 31). The STUC is performed in the RTM to commit units and balance the system resources and demand while enforcing transmission constraints. STUC is run once an hour and looks out 5 hours to commit resources that have start-up times greater than 90 minutes.

The RTUC application runs every 15 minutes and looks out between four and seven 15-minute intervals to determine whether short-start and fast-start units need to be committed or de-committed.

The RTED process runs every 5 minutes to meet the imbalance energy requirements of the CAISO (Figure 32). This process looks ahead 65 minutes to ensure that enough capacity is on line to meet real-time demand. It is expected that wind variability and the lack of accurate wind forecasts could create challenges for the RTED application. RTED is the lowest granularity of dispatch in the CAISO market. Between the RTED runs, any imbalance on the system is met with regulating reserves, which is dispatched through the Energy Management System AGC system every 4 seconds.

Figure 30: A detailed illustration of CAISO Operating Timelines

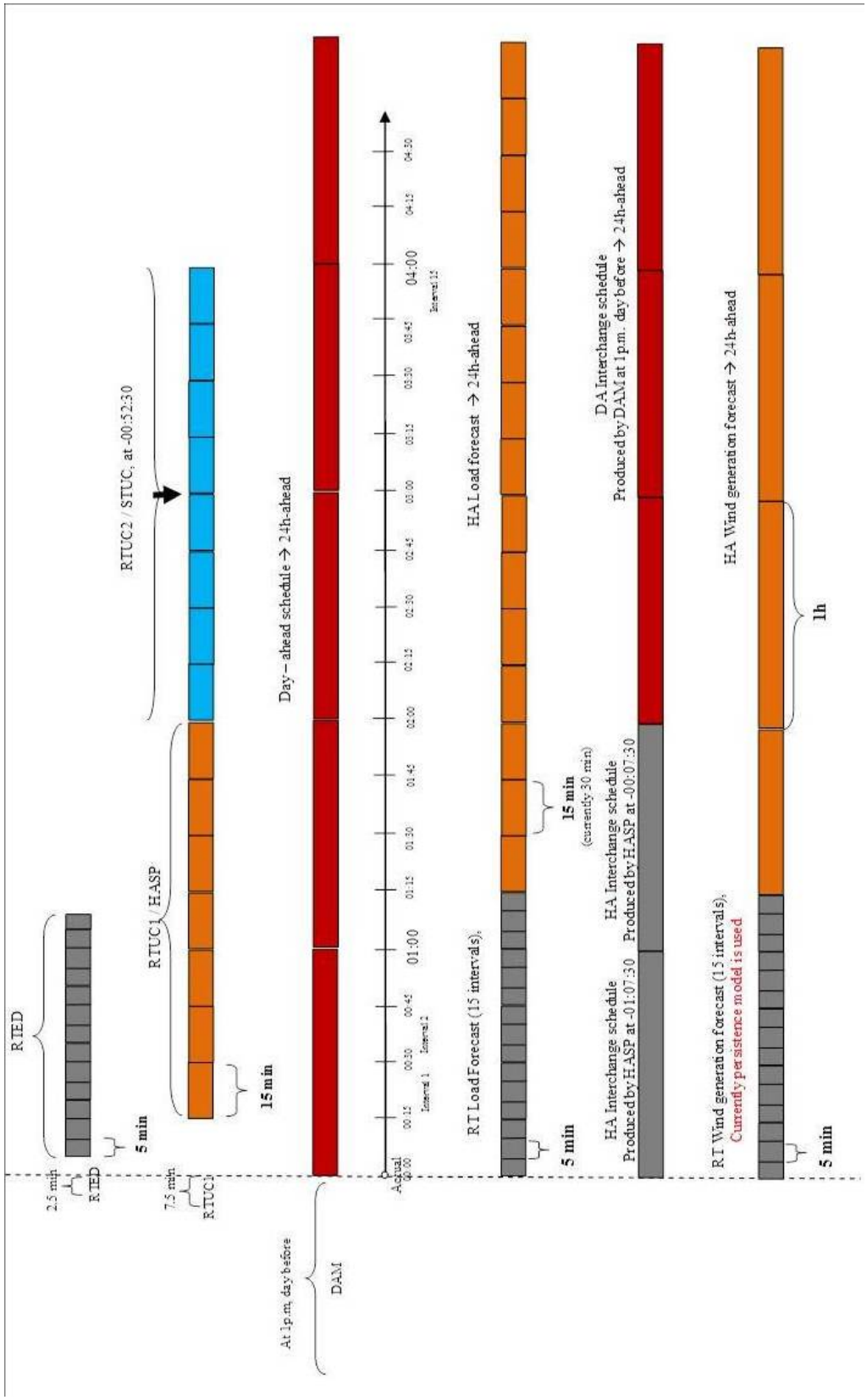


Figure 31: RTUC/STUC Timeline

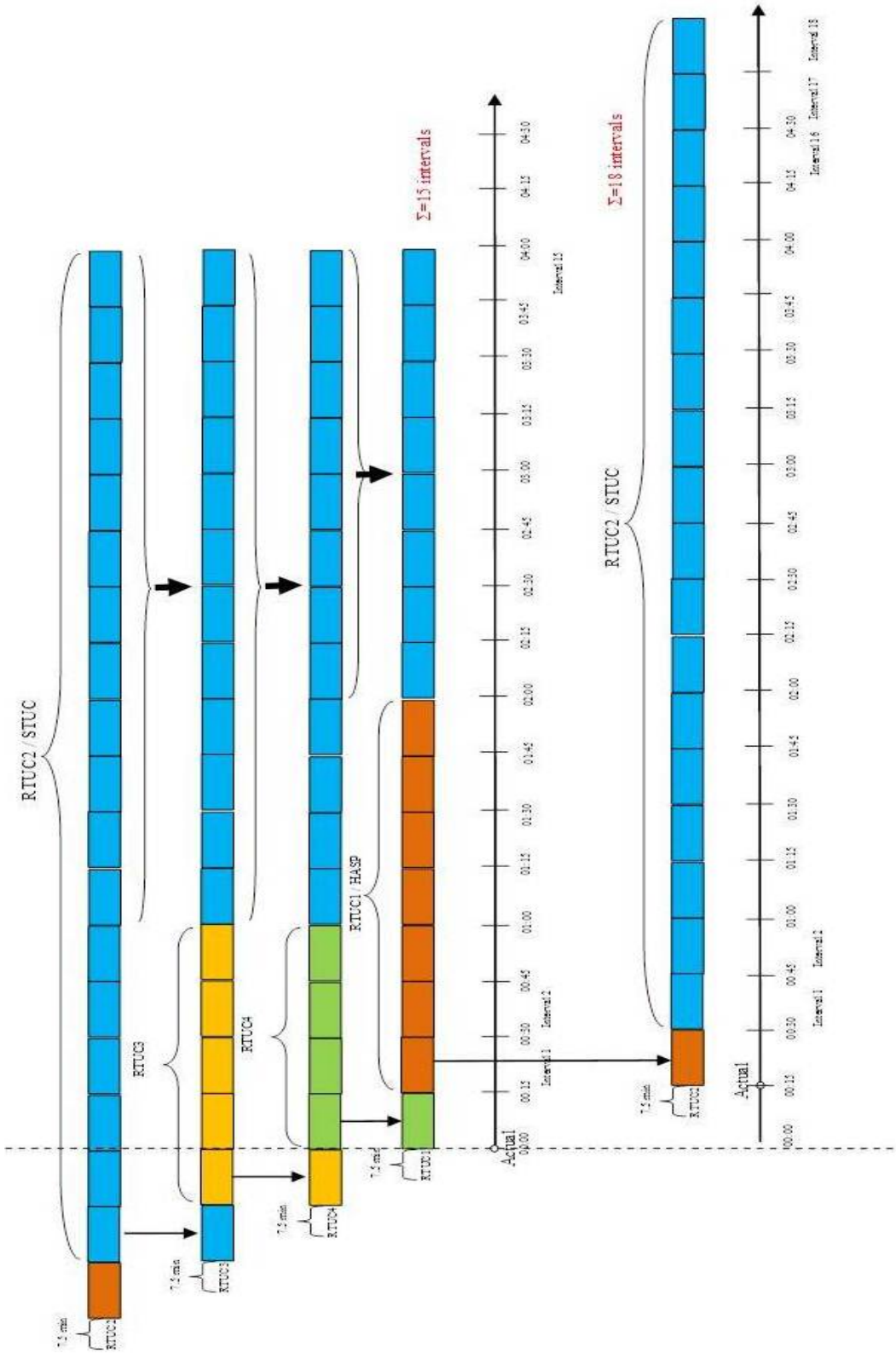


Figure 32: RTED Timeline

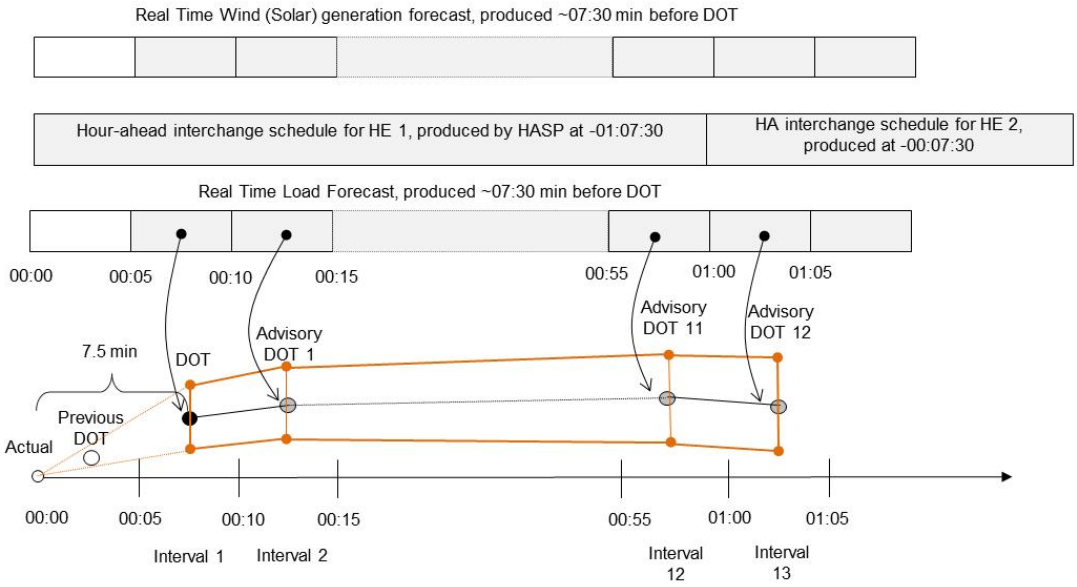
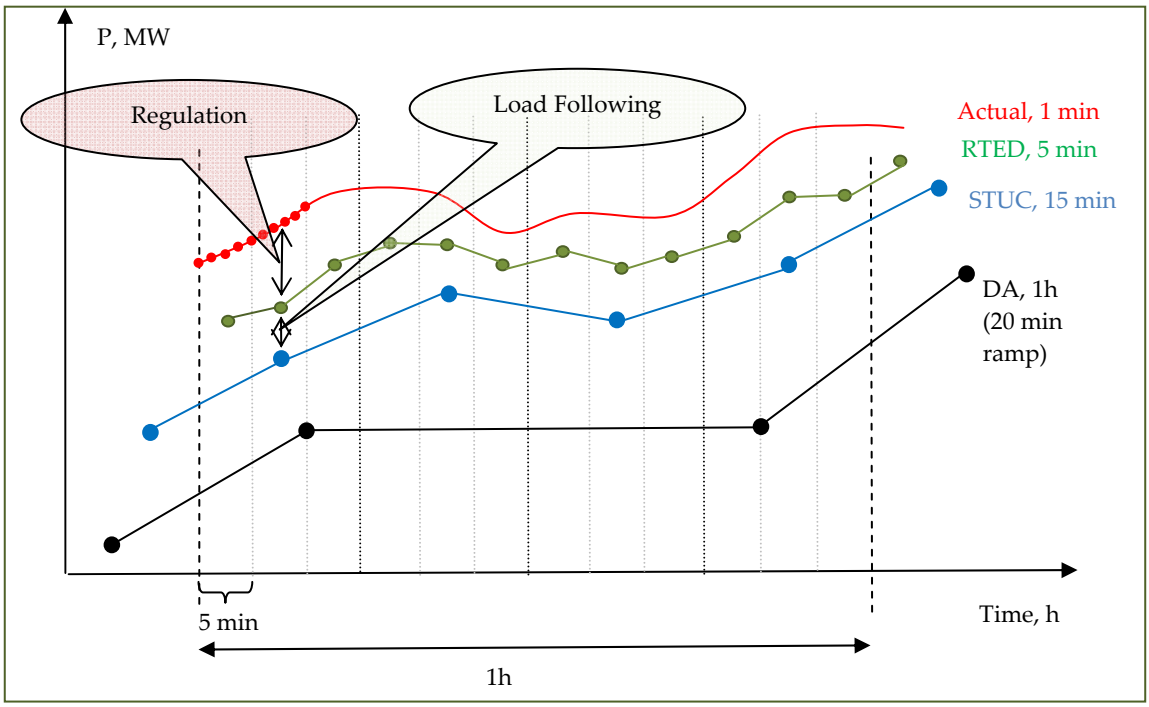


Figure 33 represents the CAISO market design generation schedules. In the day-ahead (DA) timeframe, wind and solar resources are not required to bid directly into the CAISO markets. This fact can significantly impact the unit commitment process in the DA timeframe because the CAISO must forecast the expected hourly production in the DA to ensure that enough resources are committed for the next day's operation. Similarly, the CAISO load forecast is done in the DA and real time (RT) timeframes. In the DAM, the forecast of the CAISO's hourly demand is done for three days in advance. The DA schedule is an hourly block energy schedule that includes 20-minute ramps between hours. It is provided at 10:00 a.m. the day prior to the operating day. The real-time schedule is based on STUC/RTUC timelines. RTED is provided 7.5 minutes before the dispatch operating target (DOT) and is based on real-time forecasts (Figure 32). Symmetrical ramping is used, which means that by dispatching for the average, the DOT ends in the center of the interval. In the RTM, the CAISO ALFS provides a load forecast for each 15-minute and 5-minute interval. Load and wind forecasting errors can cause the RTM application to dispatch incorrect amounts of imbalance energy needs. RTED results are 5-minute dispatch instructions and advisory notices for the look-ahead timeframe.

Thus, the load-following or supplemental energy dispatches are the difference between RTED and STUC/RTUC curves. This is an instructed deviation caused by real-time dispatches. Regulation is the difference between the actual demand and the RTED curves (see Figure 33).

Figure 33: Generation Dispatch Components



CHAPTER 4:
Software Tool

A software tool for generation requirements uncertainty has been developed and is based on the methodology outlined in this report . The initial version of the tool was installed at the CAISO control room for testing in May 2011.

In the first phase, the plan is to operate the tool in the testing mode as a stand-alone tool. It corresponds to the passive level of integration (see Chapter 2 for details). During the testing period, the CAISO specialists will evaluate the efficiency and the usefulness of the tool. Testing will be based on analysis of retrospective data collected from different sources of information, such as CAISO's supervisory control and data acquisition/energy management system (SCADA/EMS), CAISO's market system, CAISO's master file, CAISO's wind forecast provider, etc. The prototype can help CAISO to evaluate the balancing capacity needed to mitigate negative impacts caused by unpredicted deviations of wind generation, as well as those due to inaccurate load forecast. Assuming the tool is successful in the testing phase, CAISO can decide on active or proactive integration of the tool into the CAISO's Real-Time market systems.

User Interface Conceptual Design

Information representation is an important aspect in the integration, in order to provide easy-to-understand, real-time information to dispatchers. The design of several displays is presented in this section.

Capacity Requirements Screen

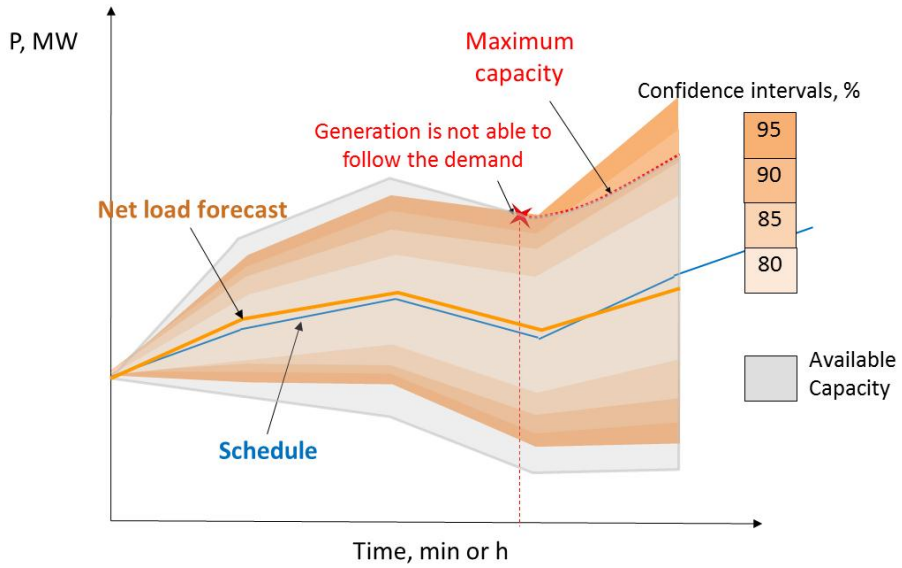
A conceptual view of the capacity requirement screen is shown in Figure 34. The capacity requirement screen contains the following information:

- generation requirements forecast (orange line)
- generation schedule to a specified time horizon (blue line)
- capacity requirements uncertainty ranges with different confidence levels associated with the generation schedule (orange ranges)
- available balancing capacity reserve in the system (gray areas)
- alerts and advisories.

The system would have adequate balancing reserve with a specified confidence level if the available balancing reserve (the gray area) covers the entire net load uncertainty range (the dark or light orange area). Otherwise, deficiency of balancing needs occurs. This means that there is a certain probability that the online generation will not be able to follow the net load requirement. In this case it is necessary to commit or de-commit additional conventional generators to achieve the desired confidence level for the balancing needs.

The screen is updated at a specified interval (every five minutes in real-time mode). As the screen is updated, the confidence intervals, as well as any alerts or advisories, will also be updated.

Figure 34: Capacity Requirements Display Concept



Ramping Requirements Screen

A conceptual view of the ramping requirements screen is shown in Figure 35. The ramping requirements screen contains the following information:

- Uncertainty range of ramping requirements at each operating interval for a specific time horizon (green bars).

The length of each green bar indicates the ramp rate requirements (MW/min). The width of a bar indicates the ramp duration requirements (minutes);

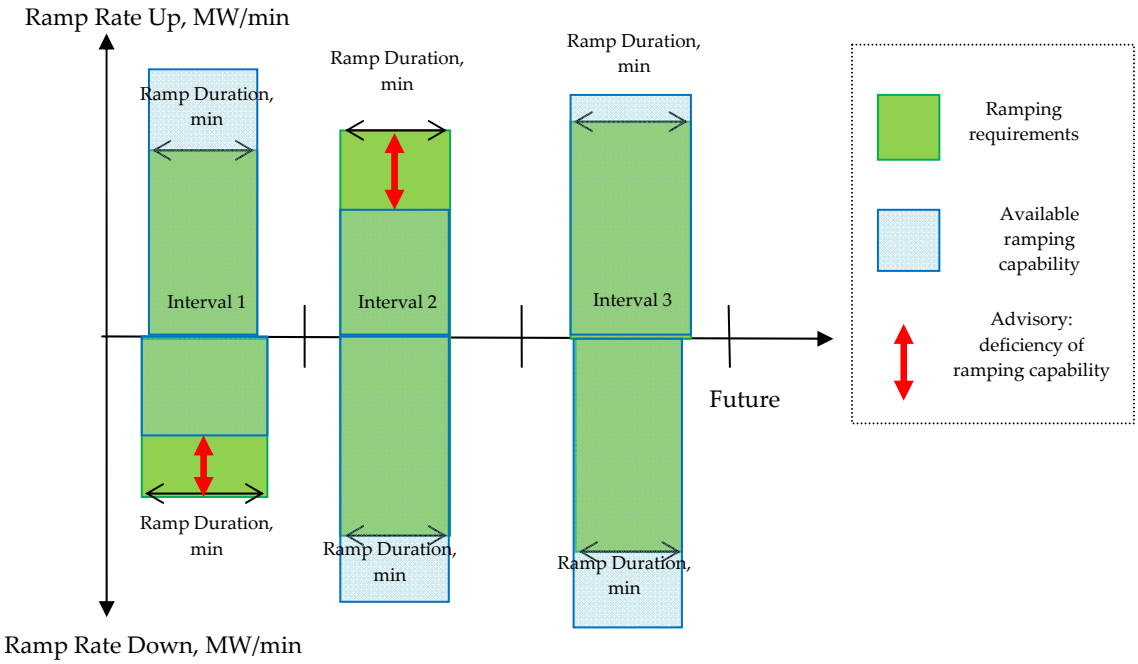
- Available generation ramping capability at each operating interval for a specific time horizon (blue bars).

The length of each blue bar indicates the maximum ramp rate capability (MW/min) for a given ramp duration (the width of the bar);

- Alerts and advisories (red vertical error bars).

The length of each red bar indicates the deficiency of system ramping capability in terms of ramp rate (MW/min).

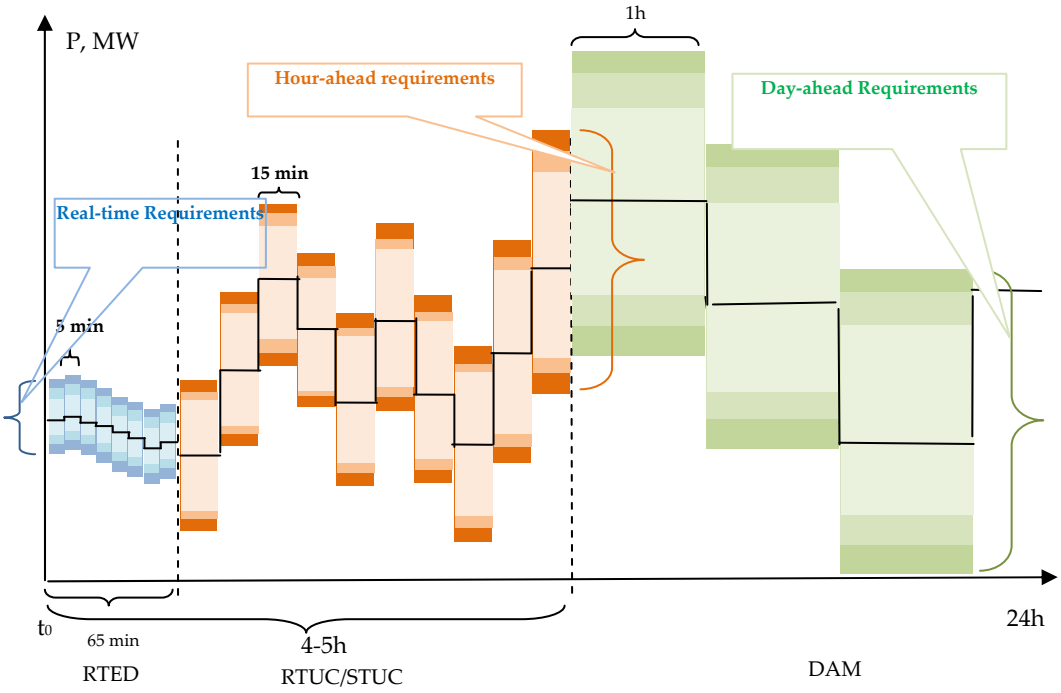
Figure 35: Ramping Requirements Display Concept



Conceptual Design of Probabilistic Tool Integration

Integration of probabilistic tools into an RTM software should take into account operating practices of specific applications and their timelines. Figure 36 shows a conceptual view of the capacity requirements uncertainty evaluation based on the CAISO scheduling process. The RTED, STUC, and DAM scheduling tools (described in Chapter 3) use various forecasts, such as those that provide forecasts with different dispatch intervals for different time horizons, and those with different resolutions. Therefore, these forecasts have different accuracies, statistical characteristics, and uncertainty ranges associated with them. Figure 36 shows the uncertainty ranges as color bars for different time horizons. Different shades of each color indicate different levels of confidence. For the first 65-minute time horizon, when the scheduling is done by RTED, the uncertainty range is smaller because the forecast is more accurate compared to longer-term forecasts such as those for the 5-hour horizon and the 24-hour horizon, when the scheduling is done by STUC and DAM, respectively. RTED runs every 5 minutes, so the uncertainty needs to be evaluated at a 5-minute interval. For the 5-hour STUC and the 24-hour DAM, uncertainty can be evaluated for look-ahead intervals of 15 minutes up to hours.

Figure 36: CAISO Capacity Requirements Uncertainty Evaluation Concept



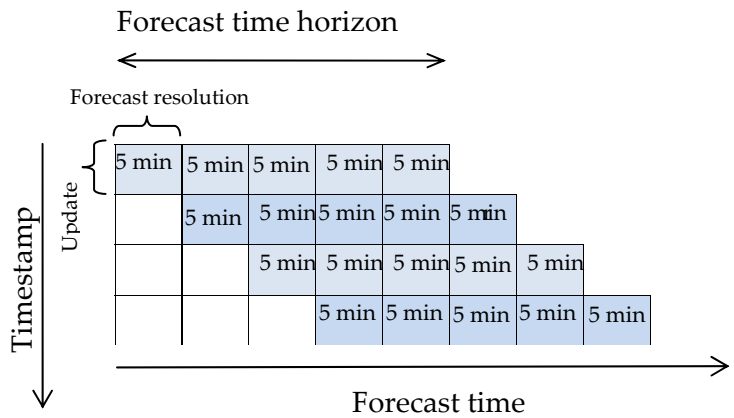
Data Acquisition

In order to model the statistical uncertainty information, large volumes of historical and real-time data are needed. As shown in Figure 37, a sliding window is used for acquiring continuous statistical information on quantities such as system load, wind and solar power generation, and generation schedules.

Data needed for the uncertainty evaluation process is stored in a database. The time-frame size and refreshment rates of sliding windows are tuned for different systems depending on their individual characteristics. This study uses a one- to two-month time frame and a 15 min refreshment rate for hour-ahead data and 5 min refreshment rate for real-time data.

Figure 37 represents a typical structure of the load or wind generation forecasts. The forecast resolution is the time interval between two consecutive data records. The time horizon is the length of the look-ahead interval, and the forecast update interval is the time interval between updates of the forecast. Besides the statistical information, actual measurements are also acquired.

Figure 37: Example of Wind/Load/Solar Forecast Structure



Data Processing

A visual inspection of the provided data revealed that the data sets contain instances of bad data, such as outliers, spikes and missing points. Two approaches are used to detect and eliminate bad data. The first approach identifies the bad data by detecting sudden changes. The second approach is based on a standard outlier-detection algorithm, such as the *k*-sigma criterion (sigma is the standard deviation of the examined data set).

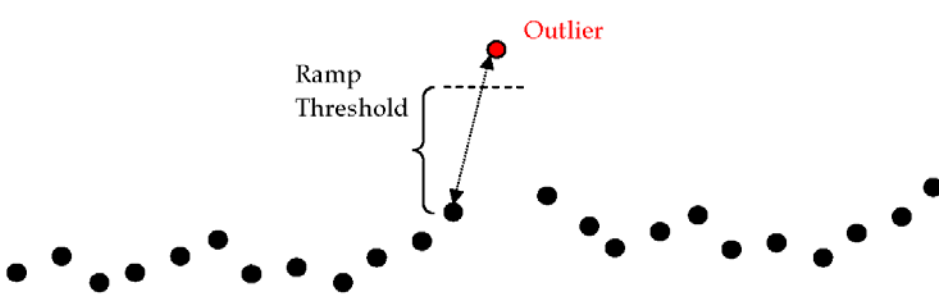
Sudden-Change Detection

Point x_t does not belong to time series X if

$$\Delta_t = \left| x_t - x_{t-1} \right| > \Delta_{\max} \quad , \tag{5}$$

where Δmax is a threshold ramp value (Figure 38).

Figure 38: Sudden-Change Detection



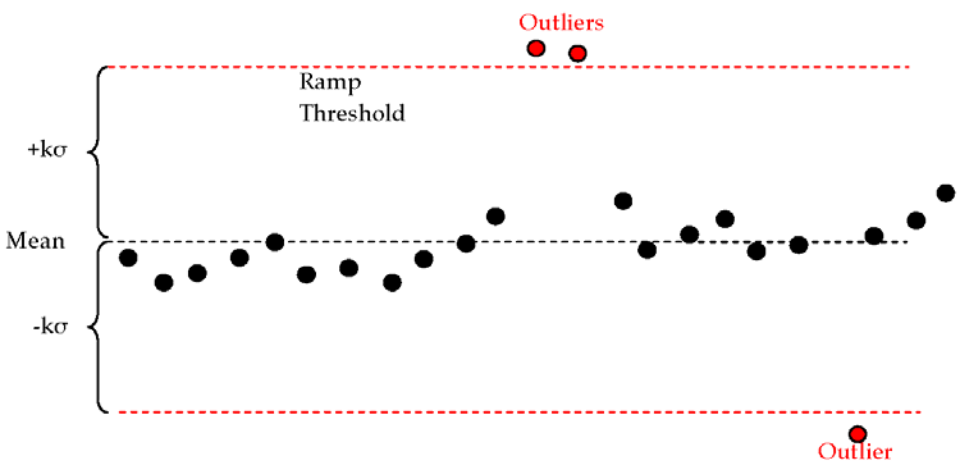
Outlier Detection

Point x_t does not belong to time series X if

$$\begin{cases} x_t > \mu + k\sigma \\ x_t < \mu - k\sigma \end{cases}, \tag{6}$$

where σ = standard deviation;
μ = mean value;
k = the deviation factor (Figure 39).

Figure 39: Outlier Detection



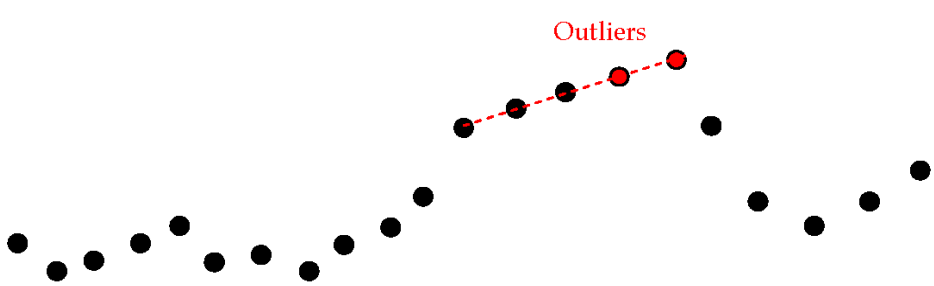
Straight-Line Detection Algorithm

To replace the missing points, the OSISoft® PI database uses an interpolation (connecting the beginning and the end of the region with missing data by a line). These points should be excluded from the statistical analysis (Figure 40).

Point x_t does not belong to time series X, if

$$x_t - x_{t-1} = x_{t-1} - x_{t-2} = x_{t-2} - x_{t-3}$$

Figure 40. Straight-Line Detection



Software Tool Design and User Interface

Microsoft Visual Studio® 2008 was used to develop the regulation prediction tool, which is deployed on the Microsoft Windows® platform and Microsoft® .NET Framework. The prototype consists of three main modules: the database, the uncertainty evaluation module and the display for results and alerts. The database is implemented in Oracle® 10g. Examples of the software user interface are presented in Figure 41 – Figure 44.

Main User Interface Screen

The user can select any required date and time to display information on the forecasted and actual parameters in tabular or graphical form. This information includes:

- load forecast
- wind Generation forecast
- solar generation forecast
- interchange schedule
- generation requirements forecast (Load forecast minus wind & solar generation forecasts and minus interchange schedule)
- generation schedule
- actual load
- actual wind generation
- actual solar generation
- actual interchange
- actual generation requirements
- available generation ramping capability.

The user can select the desired uncertainty ranges with any required level of confidence. The ranges reflect the uncertainty in generation requirements caused by different sources: wind, load, etc.

Screenshots shown in Figure 41–Figure 42 are examples of the capacity requirements displays. Figure 43 shows an example of ramping requirements display.

The software tool can display capacity and ramping requirements for three look-ahead horizons (modes):

1. Day-ahead mode (next day, 24-h, 1-h resolution). Figure 41 shows a screen shot of the day-ahead display.
2. Real-time mode (65 min ahead, 5-min resolution). Figure 42 shows a screen shot of the real-time display.
3. Hour-ahead mode (up to 4 and half hours ahead, 15-min resolution).

Figure 41: Screenshot of Day-Ahead Capacity Requirements Display

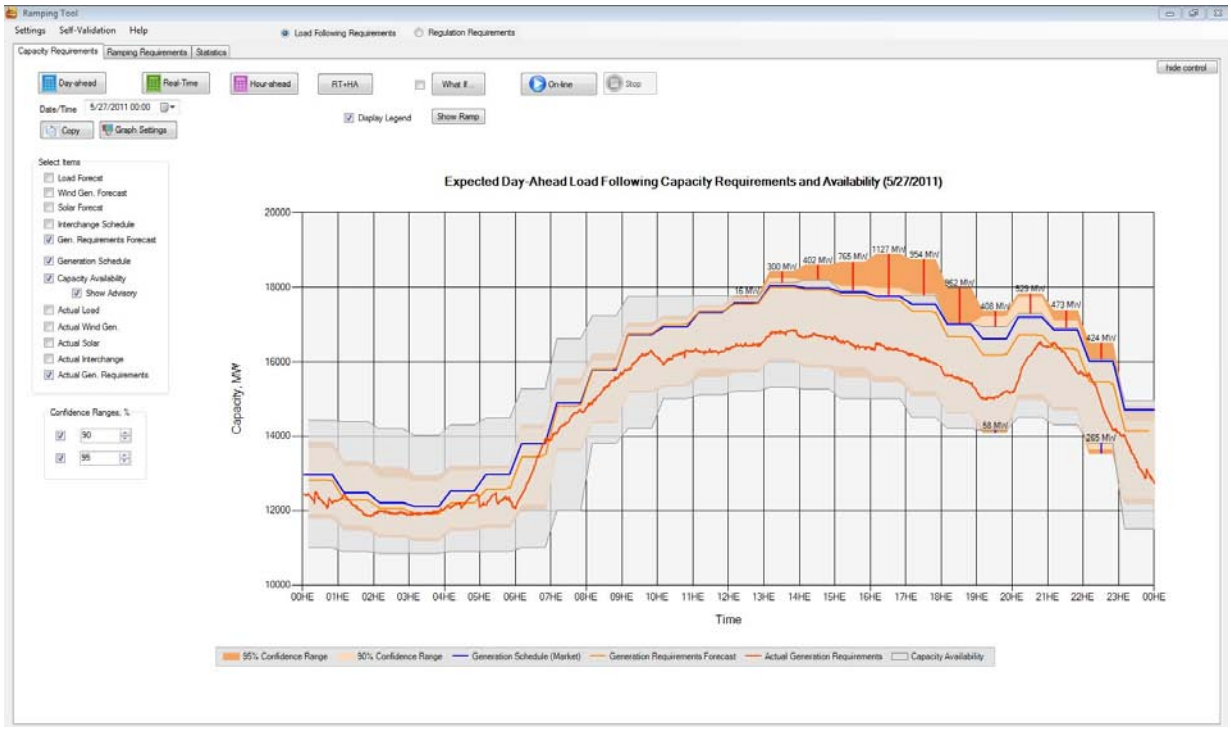


Figure 42: Screenshot of Real-Time Requirements Display

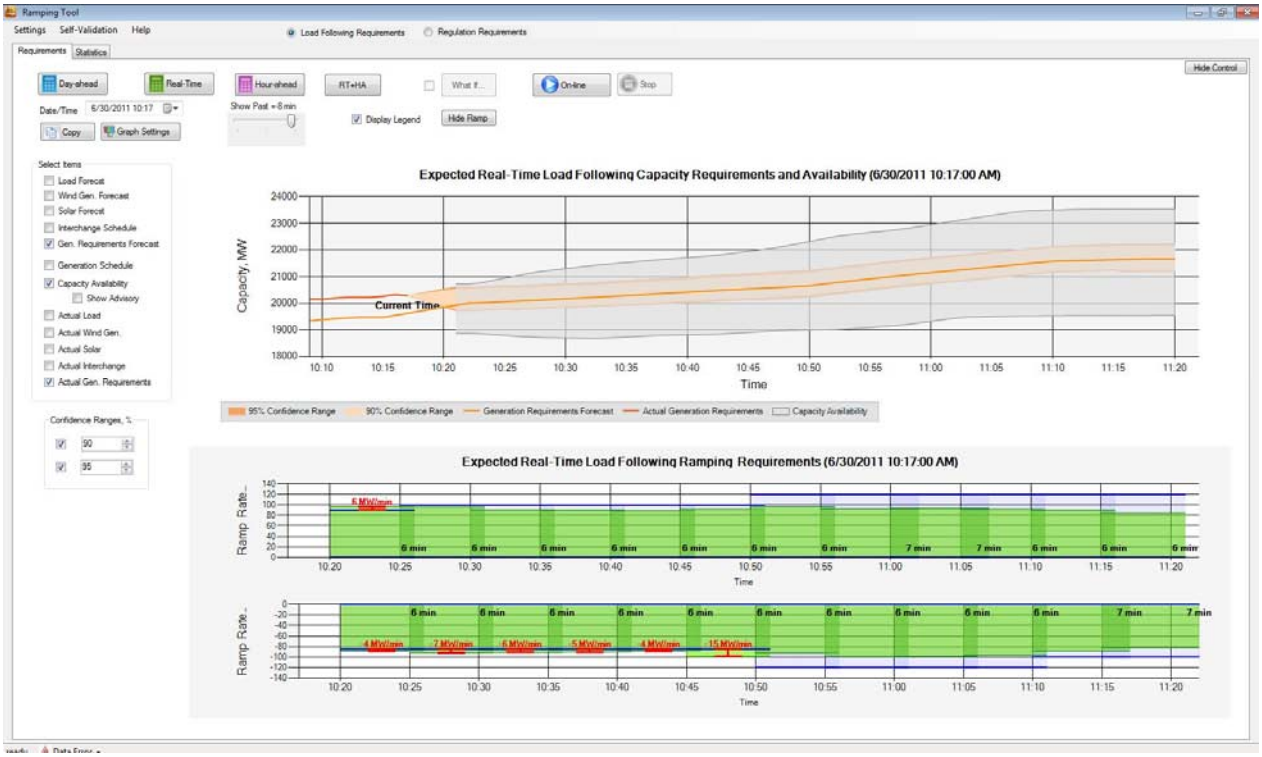
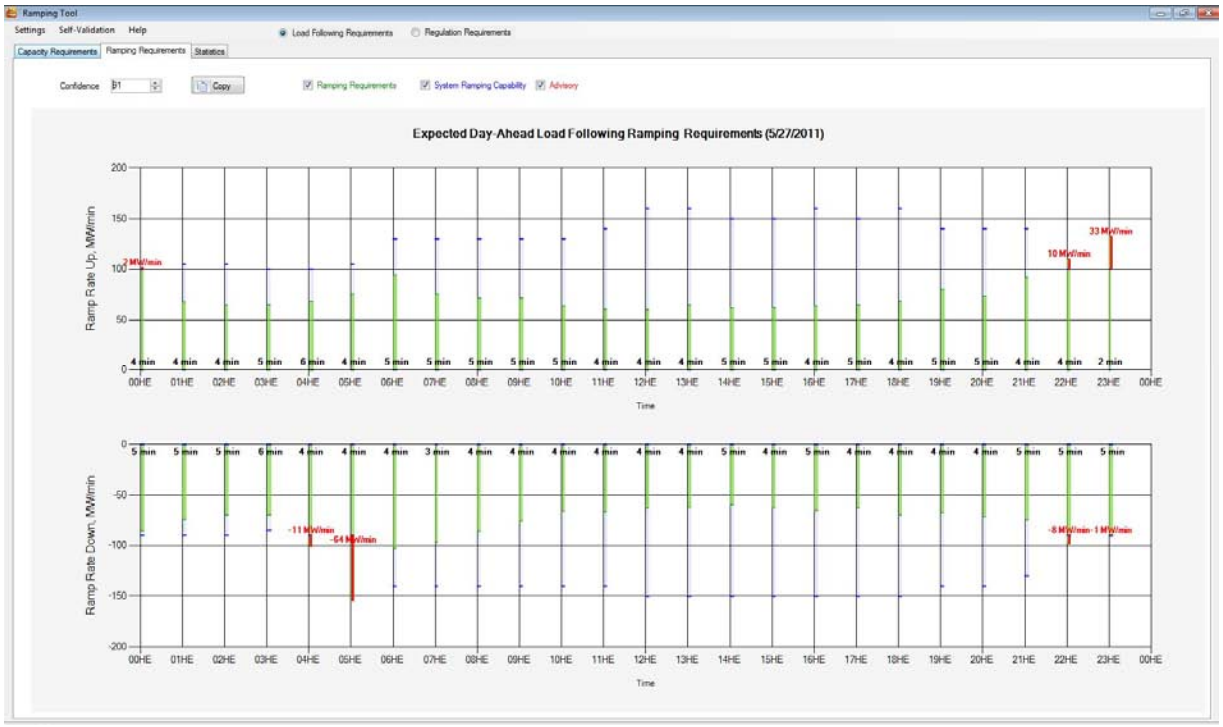
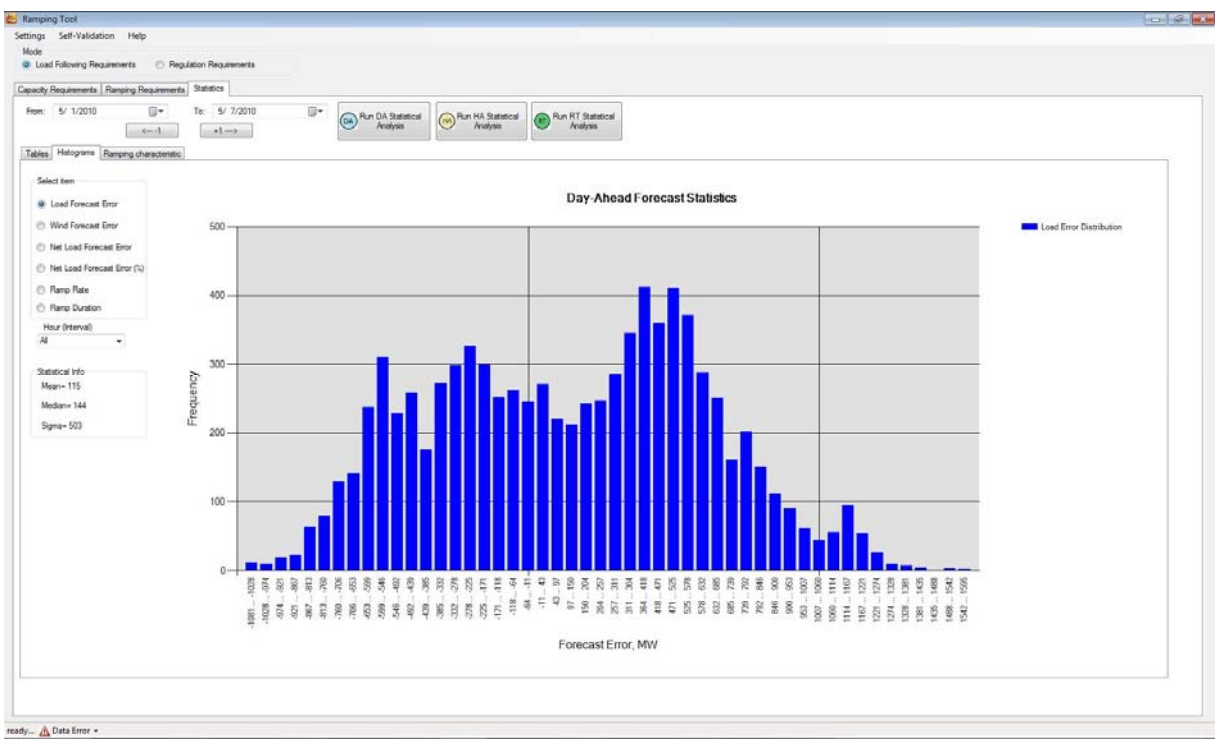


Figure 43: Screenshot of Day-Ahead Ramping Requirements Display



The statistical analysis display is shown in Figure 44. Using this tool, one can analyze statistical characteristics of forecast errors and plot different histograms and CDF functions.

Figure 44: Screenshot of Statistical Analysis Display



Test Plan for the Ramp Tool Prototype

A comprehensive plan to test the tool prior to release has been developed. It includes functional, requirements and performance testing of the database, database loading, analytical, and graphical user interface (GUI).

A server will be initialized by installing the test database with no data. It will then be updated using the data loading software and examined for correct loading. One or more standard personal computer workstations, configured with needed supporting software, in accordance with the Prototype Hardware and Software Requirements and Prototype Data Specification, will then be loaded and tested using procedures in the test tool.

Testing is performed using the database running on a separate workstation as a server and with the database running on the local workstation.

Items and features to be tested:

- Tool analytics test
- Tool GUI.
  - Display graphical information

    Verify that the GUI provides an analysis screen for selected data sets for a specified duration, and that this analysis screen includes a line graph of selected data. The user must be able to select any required date and time for which to display information in the graphical form on the forecasted and actual parameters.

  - Uncertainty prediction (confidence bands) display test

    Verify that the user is able to select the desired uncertainty ranges with any required level of confidence. The uncertainty ranges reflect the uncertainty in generation requirements caused by different sources such as wind, load, etc. The uncertainty prediction screen includes:

    - capacity requirements
    - ramping requirements.
  - Advisory display test

    The tool should display available generation capability in the system and notify system operators of potential deficiency of balancing resources in the system. The following advisories must be provided:

    - deficiency of capacity
    - deficiency of ramping capability.

- Oracle database performance testing.
  - Connection to the Oracle server

    Confirm that the software tool connects to the database server through the local network. The user should be able to specify the database internet protocol (IP) address, user name and password.
  - Reading data from the Oracle server

    Confirm that the software tool can read information from, and save information to, the database.
- Computational test

  The purpose of these computation tests is to 1) verify that all calculations performed by the Wind Uncertainty Prediction Tool are consistent with published algorithms and 2) validate that the tool predicts system balancing requirements for the following look-ahead horizons:
  - 65 min ahead (Real-Time mode)
  - 4–7 h ahead (Real-Time + Hour-Ahead mode)
  - next day (Day-Ahead mode)
- All user controls

  Validate functionality of miscellaneous user controls:
  - graph settings screen
  - "Copy to clipboard" feature
  - "What-If" screen
  - on/off control for display of legend on graph
- Statistical analysis module test

  To validate the statistical analysis module developed by PNNL using Visual Studio® 2008 Integrated Development Environment (IDE), results produced by this module should be compared with standard (etalon) results obtained from a professional statistical package. The MATLAB® statistical toolbox is used as the standard statistical package.
- On-line mode test

  In on-line mode, the tool should use the current date and time. The tool updates the predicted capacity and ramping requirements every minute automatically. The tool also updates displayed actual and forecasted information every minute. Thus, the user will always see the latest available information in the system.
- Acceptance test (based on self-validation procedure)

  To validate the accuracy of the uncertainty prediction model, a self-validation algorithm is used. The self-validation algorithm is based on comparing the predicted uncertainty

ranges against the actual observed values for the same dispatch intervals. The algorithm counts how many points belong to the predicted intervals with a specified confidence level, and calculates the percentage of points found within the intervals. The uncertainty algorithm is validated if the calculated percentages are close to the targeted percentages.

Self-validation tests must be performed for:

- Real-time mode
- Hour-ahead mode
- Day-ahead mode.

CHAPTER 5
Simulation Results

Using the prototype tool, case studies have been run to test the uncertainty assessment approach and to demonstrate the capabilities of the tool. CAISO's actual data were used in the simulation and the tool development. The actual data used include total load, total wind generation, load forecast (day-ahead, hour-ahead and real-time forecast), and wind generation forecast.

Figure 45 shows the day-ahead uncertainty ranges for the system net load. The light and dark orange areas represent the evaluated capacity ranges for the 90% and 95% confidence levels. The blue curve is the day-ahead generation schedule. The gray area is the available balancing reserve, which is calculated from the margin of online generators. The system would have adequate balancing reserve with a specified confidence level if the available balancing reserve (the gray area) covers the entire net load uncertainty range (the dark or light orange area). Otherwise, deficiency of balancing reserve occurs; in this case, there is a certain probability that the online generation will not be able to follow the net load requirement. The deficiency of the balancing reserve is shown using the red (generation up) and blue (generation down) bars in Figure 45. It gives an indication that it is necessary to commit or de-commit additional generators to achieve the desired confidence level for the balancing needs.

Figure 45: Day-Ahead Capacity Prediction

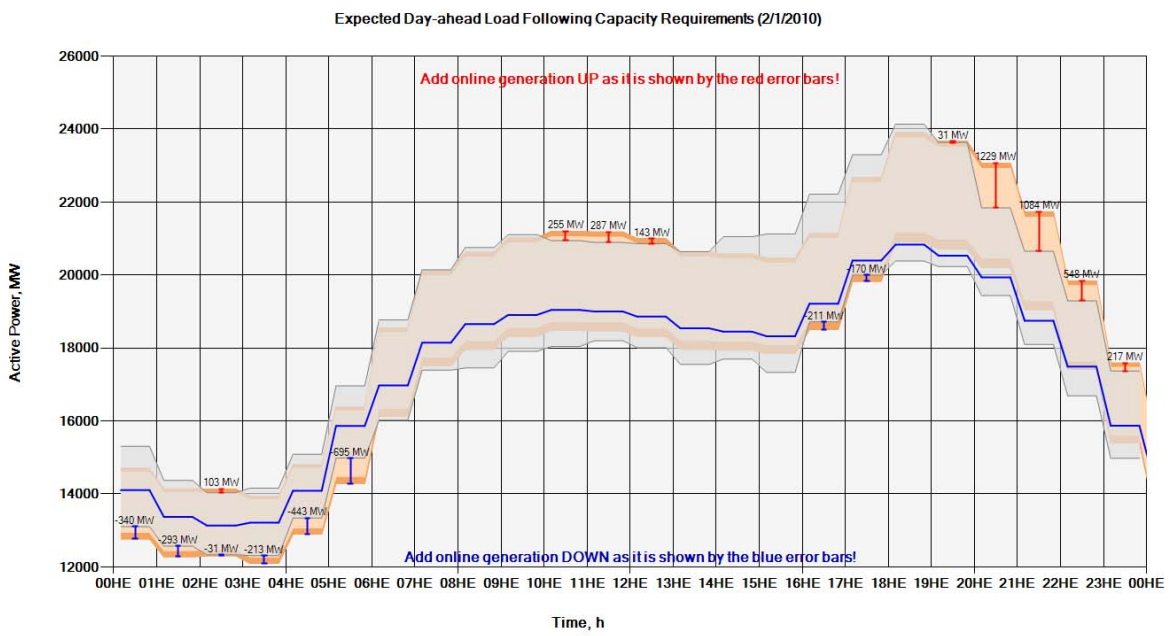


Figure 46 shows the results of the evaluation of hourly day-ahead ramping requirements. The length of each green bar indicates the ramp rate requirements (MW/min). The width of each bar indicates the ramp duration requirements (minutes). From this figure, operators can compare the ramping requirements against available system ramping capacity to see whether the system has sufficient resources to meet the ramp rate requirements. Details of the methodology for estimating system ramping capability are given in Appendix A.

Figure 46: Day-Ahead Ramping Requirements Prediction

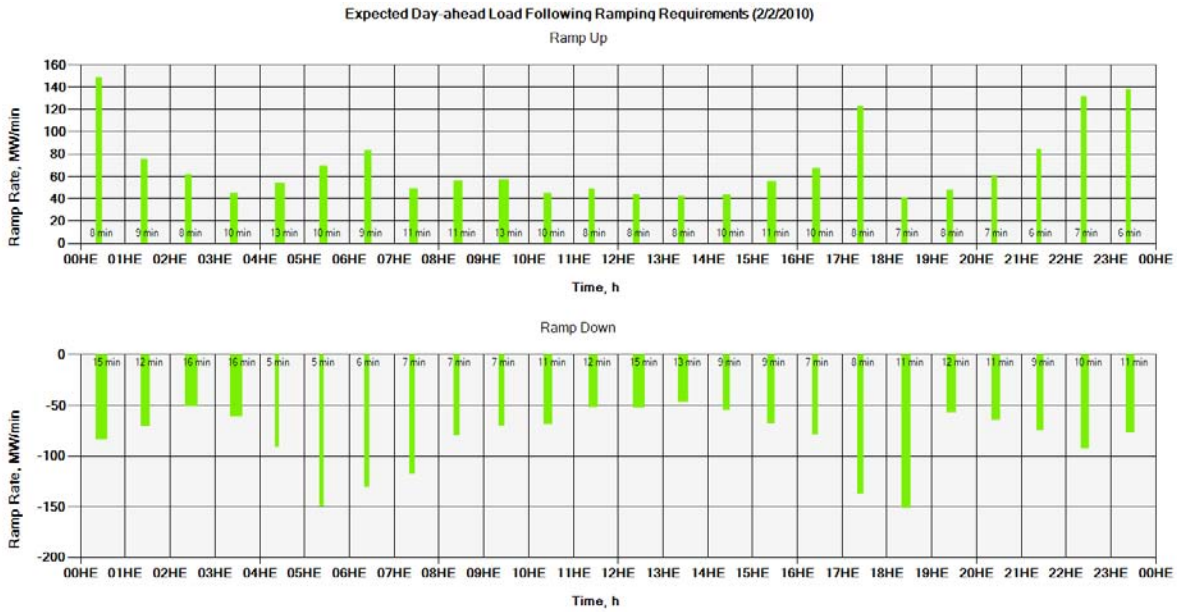


Figure 47 presents a snapshot of the hour-ahead capacity requirements for a 7-hour time horizon. Similar to Figure 45, the light and dark orange areas represent the evaluated capacity ranges for the 90% and 95% confidence levels. The blue curve is the hour-ahead generation schedule. Also similar to Figure 45, the deficiency of the balancing reserve, shown as red (generation up) and blue (generation down) bars, provides guidance to operators for committing or de-committing additional generators to achieve the desired confidence level for the balancing reserve.

Figure 48 presents the hour-ahead ramping requirements for a 7-hour time horizon. This evaluation is based on statistical analysis of hour-ahead forecast uncertainty. The length of each green bar indicates the ramp rate requirements (MW/min). The width of a bar indicates the ramp duration requirements (minutes). This information can be used to determine whether the system would be able to meet the ramp rate requirements.

Figure 47: Hour-Ahead Capacity Requirements Prediction

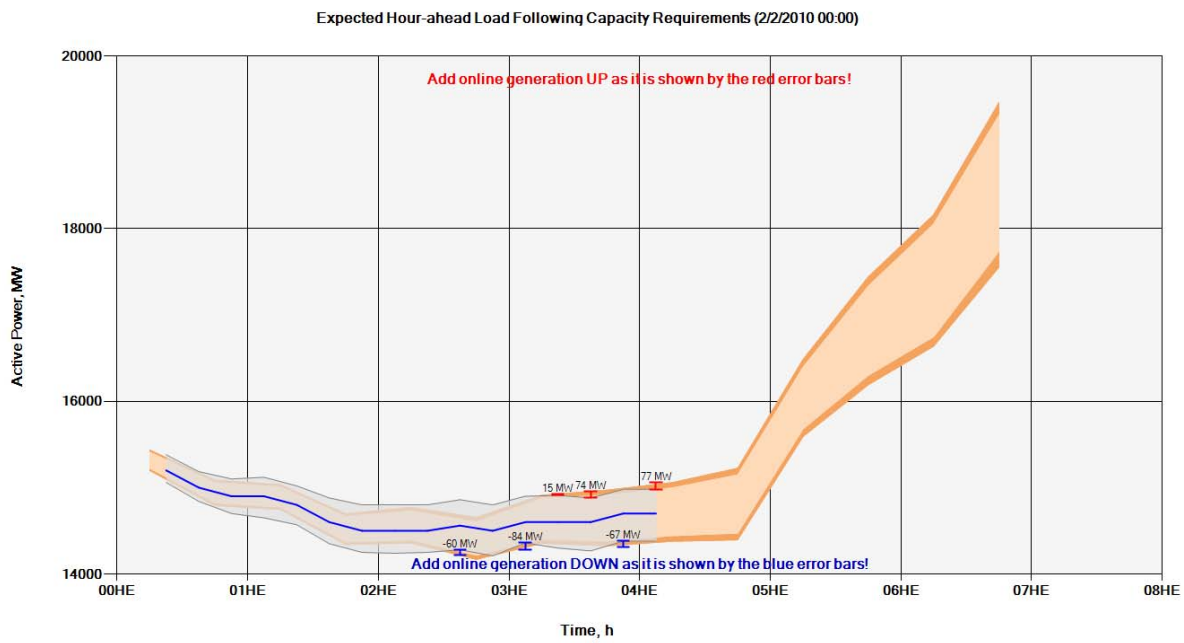
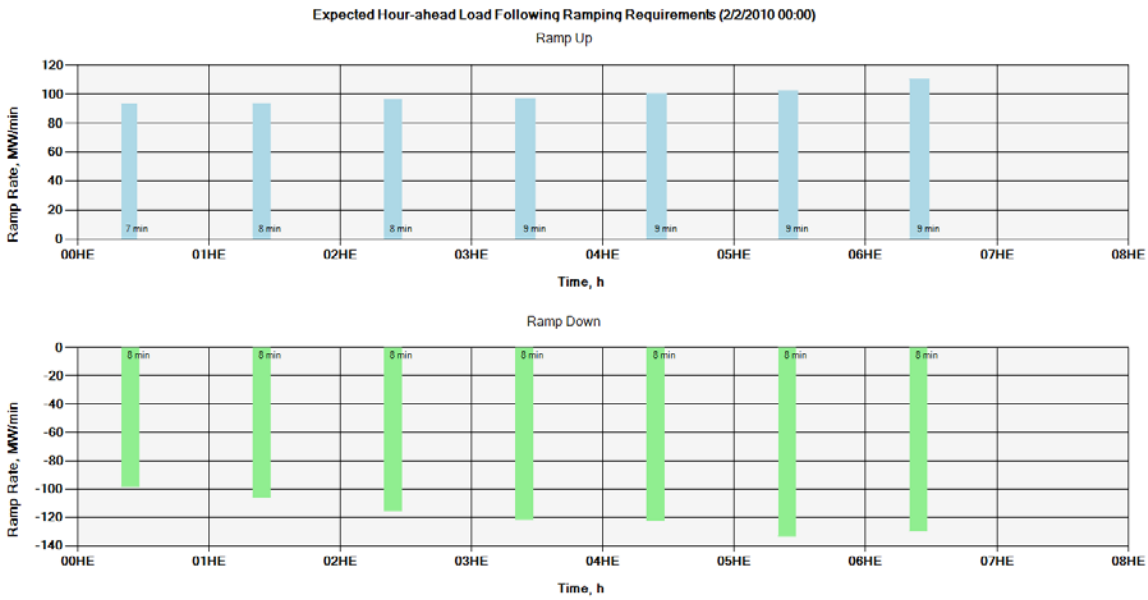


Figure 48: Hour-Ahead Ramping Requirements Prediction



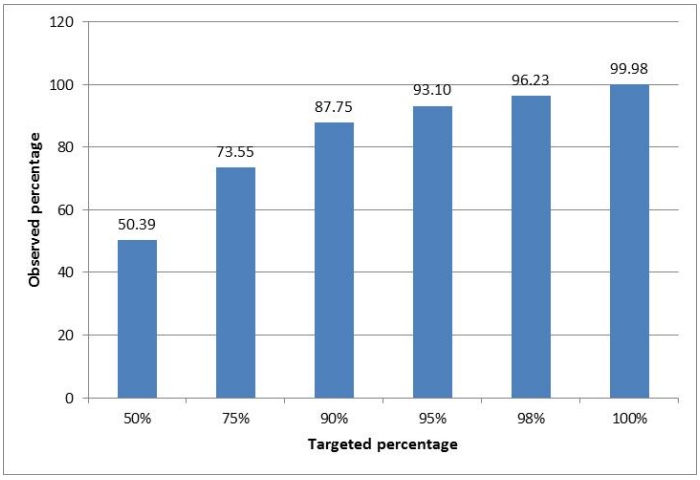
Self-Validation Results

To validate the accuracy of the uncertainty evaluation model, a self-validation test was performed. CAISO's actual statistical information for years 2010–2011 was used in this test.

Real-Time Mode

Results of real-time mode self-validation for May–June 2011 are presented in Figure 49. One can see that the observed percentage values are very close to the targeted percentage values. For example, the percentage of the actual generation requirements points found within the 98% confidence interval is about 96.23%, and the percentage within the 95% confidence interval is about 93.1%. Thus the uncertainty evaluation model tests have confirmed the adequacy of the proposed uncertainty evaluation algorithm as well as the proper operation of the developed prototype tool.

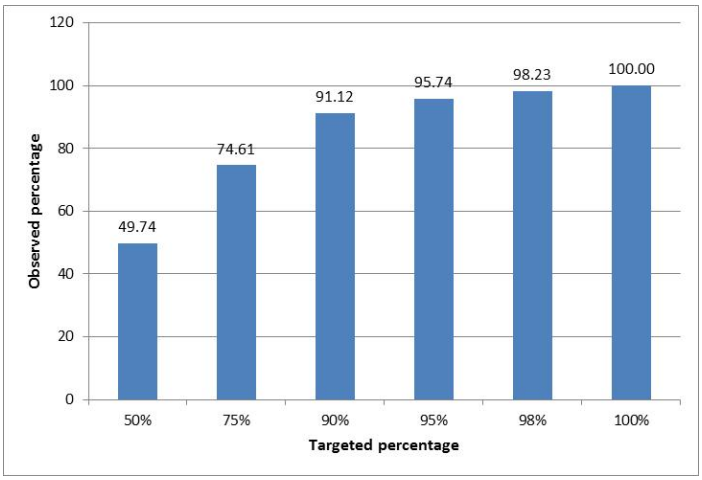
Figure 49: Real-Time Mode Self-Validation Results



Hour-Ahead Mode

Results of hour-ahead mode self-validation for May–June 2011 are presented in Figure 50. Similar to real-time mode testing results, we can see that the percentages of observed actual values are very close to the targeted percentage values.

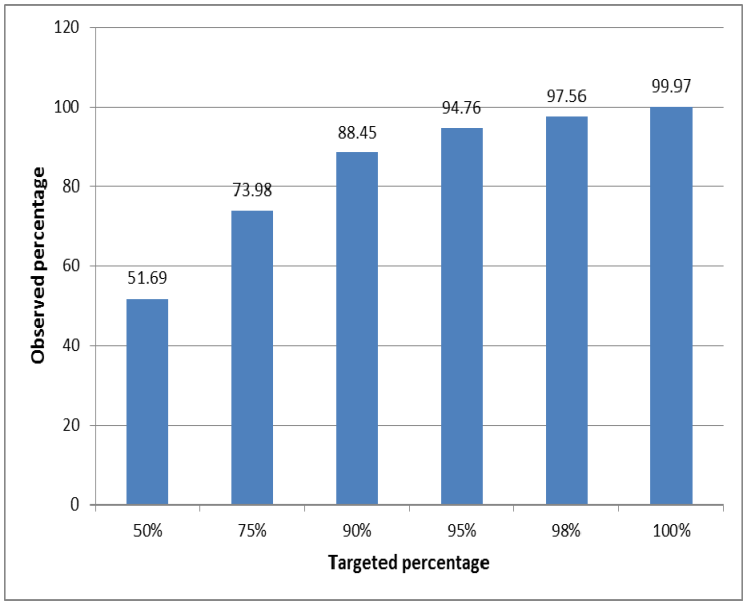
Figure 50: Hour-Ahead Mode Self-Validation Results



Day-Ahead Mode

Results of day-ahead mode self-validation for May–June 2011 are presented in Figure 51. One can see that the observed percentage values are very close to the targeted percentage values. Thus, the tests performed have validated the accuracy of the predictions produced by the tool.

Figure 51: Day-Ahead Mode Self-Validation Results



Prediction of Real-Time Market Price Spikes

Figure 52 presents a snapshot of the real-time capacity requirements for the next operating hour. The light and dark orange areas represent the evaluated capacity ranges for the 90% and 95% confidence levels. The blue curve is the real-time generation schedule (economic dispatch). The gray area is the available balancing reserve, which is calculated from the margin of online generators. The system would have adequate balancing reserve with a specified confidence level if the available balancing reserve (the gray area) covers the entire net load uncertainty range (the dark or light orange area). Otherwise, deficiency of balancing reserve occurs. This means that there is a certain probability that the online generation will not be able to follow the net load requirement.

The deficiency of the balancing reserve, shown as red bars, provides guidance to operators for committing or de-committing additional generators to achieve the desired confidence level for the balancing reserve.

It has been found that the tool is capable of predicting intra-hour deficiency in generation capability. This deficiency of balancing resources can cause price spikes in the real-time market. One can see in Figure 52 that a more than 300 MW deficiency in the system generation capability is predicted in the 10- to 25-min look-ahead period (red error bars). Figure 53 shows

the CAISO's real-time market price information. Price spikes occurred in the CAISO market at the same time at which generation capability deficiency was predicted by the tool.

Figure 52: Real-Time Capacity Requirements Prediction

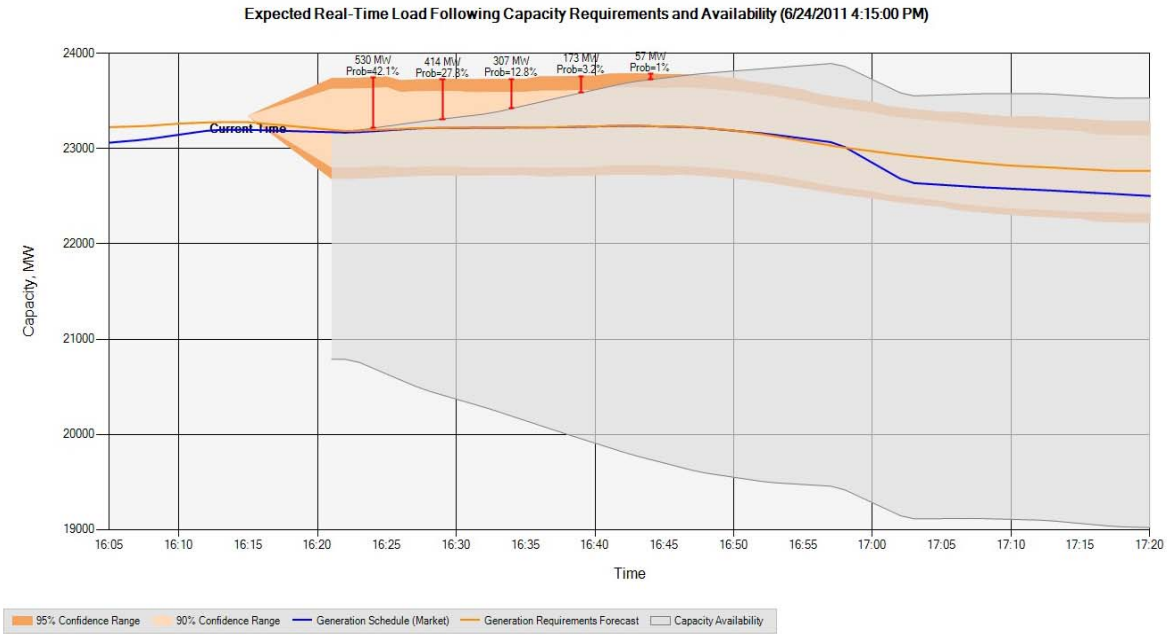
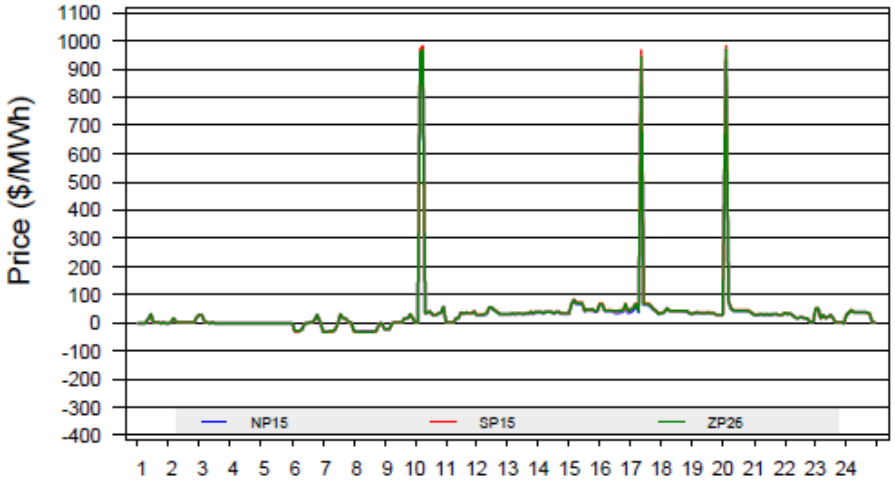


Figure 53: CAISO Real-Time Price*



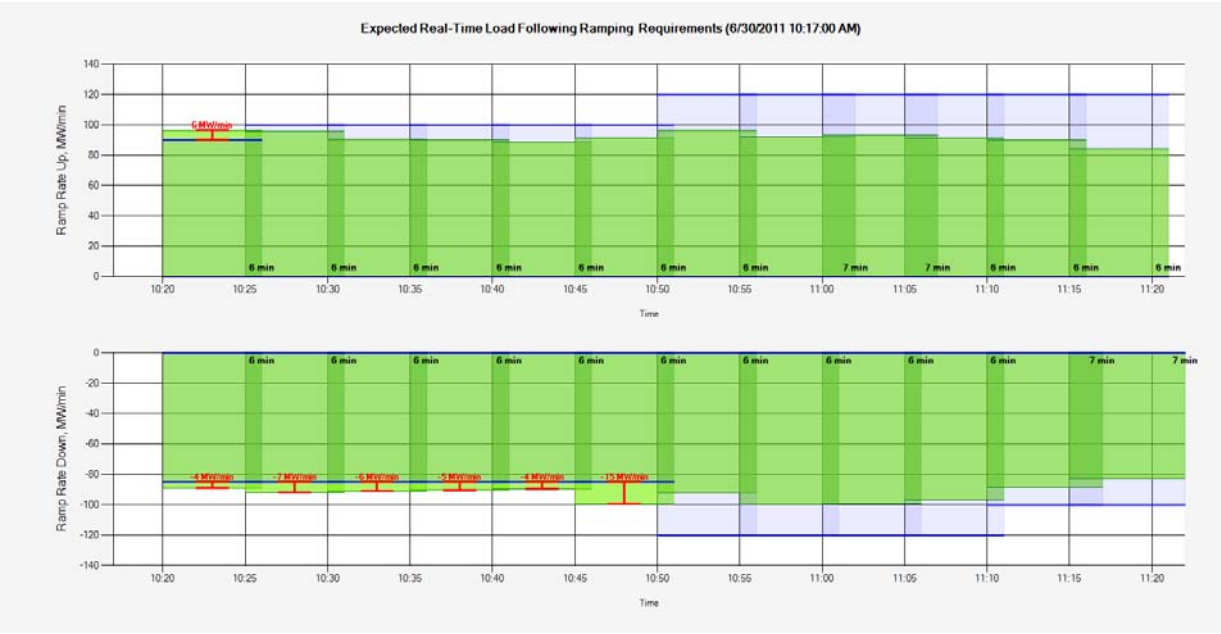
*Available at http://www.caiso.com/Documents/June%202011/DailyMarketWatch_Real-Time_Jun_24_2011.pdf

Real-Time Ramping Requirements

Figure 54 presents the real-time ramping requirements prediction display. This evaluation is based on statistical analysis of real-time forecast uncertainty. The length of each green bar

indicates the ramp rate requirements (MW/min). The width of each green bar indicates the ramp duration requirements (minutes). This information can be used to determine whether the system would be able to meet the ramp rate requirements. From this display, operators can compare the ramping requirements against available system ramping capacity (blue bars) to see whether the system has sufficient resources to meet the ramp rate requirements. Methodology to estimate system ramping capability is given in Appendix A. Insufficient ramping capability is indicated using red error bars (Figure 54).

Figure 54: Real-Time Ramping Requirements



CHAPTER 6: Conclusions

A methodology capable of evaluating the impact of wind generation and load uncertainties, as well as unexpected generation outages, on balancing resource requirements has been developed, implemented in a software tool and deployed in the operating environment at the CAISO. The tool enables evaluation of the uncertainty ranges for the required generation performance envelope for a look-ahead period. The generation performance envelope includes the required balancing capacity, ramping capability and ramp duration capability.

The development, implementation and deployment include the following elements:

- Evaluation of the capacity and ramping requirements using a specially developed probabilistic algorithm based on histogram analysis, and incorporating various sources of uncertainties, both continuous (wind and load forecast errors) and discrete (forced generator outages and start-up failures).
- Evaluation of the look-ahead generation performance requirements envelope using a "flying brick" technique for the worst-case scenario within a user-specified confidence level.
- A self-validation algorithm to assess the accuracy of the predicted uncertainty ranges
- A software tool based on the methodology has been developed. The operating practices at CAISO have also been incorporated. The concept of integrating the probabilistic tool into CAISO RTM environments has been developed taking into account current operating practices.
- Simulation studies using actual CAISO data have been performed. The developed software tool passed all tests performed in accordance with the tool testing specification. Study results have shown that the methodology of the generation-requirements evaluation for uncertainty management is quite accurate and efficient.

  The tool is installed at a CAISO control center and has been tested by CAISO specialists. The tool received very positive feedback from CAISO. Testing of the tool performed by CAISO specialists has shown that the tool is also capable of predicting price spikes in the real-time market caused by deficiency of available on-line balancing resources in the system. CAISO expressed its interest in incorporating the tool into CAISO market and scheduling procedures.

Next Steps (Technical Area)

The proposed steps in the technical area will increase the robustness and performance of the tool while handling the information typically available in control centers, improving the probabilistic models to further reduce predicting range requirements, and adding additional model components reflecting new sources of uncertainty.

The following specific steps are suggested:

- Integrate the tool with the wind/solar forecast service providers' information to improve the accuracy of the balancing requirements prediction.
- Develop proactive integration methodology to incorporate the tool into CAISO market and unit commitment procedures.
- Develop and implement a new generation of statistical methods to address non-stationary characteristics of forecast errors. Further improve the accuracy and robustness of the tool.
- Perform probabilistic modeling of uninstructed deviation of generating units.
- Develop a decision support system using the tool to help dispatchers addressing potential issues of the system balancing process.
- Incorporate consideration of the new BAAL guidlines into balancing requirements assessment methodology.
- Address data interpretation and quality issues to enhance robustness of the tool.

Next Steps (Commercialization)

The purposes of the planned commercialization activities include a wide dissemination and technology transfer effort with the ultimate objective to install the tool in several Balancing Authorities in California. Among these activities the highest priority tasks will include a proactive integration of the software tool at the CAISO, including comprehensive testing and final adjustments. The results of this effort will create a platform for a wider reach in California by serving as an example for other Balancing Authorities and utilities in the state. In parallel with the California activities, the results of this project will be widely distributed via Web seminars organized for the industry and by presenting them at the industry forums, including Utility Wind Integration Group , WECC groups, NERC subcommittees, and conferences. It is expected that through these activities (supported by DOE), the impact of this project will be extended from the statewide level to the nationwide level.

CHAPTER 7: References

CAISO – California Independent System Operator. 2006. "Market Redesign and Technology Update Tutorial for Market Participants," CAISO, Folsom California.

CAISO – California Independent System Operator. 2007. "Integration of Renewable Resources Report," CAISO, November 2007. [Online.] Available: http://www.caiso.com/1ca5/1ca5a7a026270.pdf.

Constantinescu, E. M., V. M. Zavala, M. Rocklin, S. Lee, and M. Anitescu. 2011. "A computational framework for uncertainty quantification and stochastic optimization in unit commitment with wind power generation." *IEEE Trans. Power Syst.* 26(1):431-441.

Energy & Meteo Systems. 2007. "Wind power prediction Previento," Energy & Meteo Systems. [Available online]: http://energymeteo.de/media/PrevientoENG.pdf .

Kariniotakis, G. 2008. "ANEMOS, leading European Union research on wind power forecasting." In *Proc. International Wind Forecast Techniques and Methodologies Workshop*, July 24-25, 2008. [Available online]: http://www.bpa.gov/corporate/business/innovation/docs/2008/BPA_California%20ISO%20ANEMOS%20Presentation.pdf.

Kehler, J., M. Hu, M. McMullen, and J. Blatchford. 2010. "ISO perspective and experience with integrating wind power forecasts into operations." In *Proc. IEEE General Meeting,* July 25-29, 2010, Minneapolis, Minnesota.

Lerner, J., M. Grundmeyer, and M. Garvert. 2009. "The role of wind forecasting in the successful integration and management of an intermittent energy source." *Energy Central, Wind Power*, vol. 3, no. 8, July 2009.

Luig, A., S. Bofinger, and H. G. Beyer. 2001. "Analysis of confidence intervals for the prediction of the regional wind power output." In *Proc. 2001 European Wind Energy Conference*, July 2-6, 2001, Copenhagen, Denmark.

Maggio, D., C. D'Annunzio, S.-H. Huang, and C. Thompson. 2010. "Utilization of forecasts for wind-powered generation resources in ERCOT operations." In *Proc. IEEE PES General Meeting,* July 25-29, 2010, Minneapolis, Minnesota.

Makarov, Y. V., C. Loutan, J. Ma, and P. De Mello. 2009. "Operational Impacts of Wind Generation on California Power Systems." *IEEE Trans. on Power Syst.* 24:1039-1050.

Makarov, Y., P. Etingov, J. Ma, Z. Huang, and K. Subbarao. 2011. "Incorporating Uncertainty of Wind Power Generation Forecast into Power System Operation, Dispatch, and Unit Commitment Procedures." *IEEE Transactions on Sustainable Energy* 2(4):433-442.

MathWorks®. 2010. "MATLAB Statistical toolbox," User's Guide. The MathWorks, Inc, Natick, Massachusetts.

Pinson, P., G. Kariniotakis, H. A. Nielsen, T. S. Nielsen, and H. Madsen. 2006. "Properties of quantile and interval forecasts of wind generation and their evaluation." In *Proc. European Wind Energy Conference & Exhibition,* February 2-March 2, 2006, Athens, Greece.

Ummels, B. C., M. Gibescu, E. Pelgrum, W. L. Kling, and A. J. Brand. 2007. "Impacts of Wind Power on Thermal Generation Unit Commitment and Dispatch." *IEEE Trans. Energy Conversion* 22(1):44-51.

Wang, J., M. Shahidehpour, and Z. Li. 2008. "Security-constrained unit commitment with volatile wind power generation." *IEEE Trans. Power Syst.* 23(3):1319-1327.

WECC – Western Electricity Coordinating Council. 2007. "WECC Standard BAL-STD-002-0 – Operating Reserves." [Online.] Available: http://www.nerc.com/files/BAL-STD-002-0.pdf.

WSCC – Western Systems Coordinating Council. 1988. "WSCC Operating Reserve White Paper." [Online.] Available: http://www.wecc.biz/library/Library/White%20Papers/Operating%20Reserves.pdf.

Zack, J. 2006. "An analysis of the errors and uncertainty in wind power production forecasts." In *Proc. WINDPOWER Conference and Exhibition 2006*, June 4-7, 2006, Pittsburgh, Pennsylvania.

CHAPTER 8: Glossary

AGC	automatic generation control
ALFS	adaptive load forecasting system
AS	ancillary services
BA	balancing authority
BAAL	Balancing Authority ACE Limit
CAISO	California Independent System Operator
CDF	cumulative distribution function
CEC	California Energy Commission
COPT	capacity outage probability table
DA	day ahead
DAM	day-ahead market
DOT	dispatch operating target
ED	economic dispatch
EFDH	equivalent forced derating hours
EFORd	equivalent forced outage rate demand
EMS	energy management system
FOH	forced outage duration within a year, (hours)
FOP	full outage probability
FOR	forced outage rate
FORd	forced outage rate demand
GADS	Generating Availability Data System
GUI	graphical user interface
HASP	hour-ahead scheduling process
ISO	Independent System Operator
MTTF	mean time to failure
MTTR	mean time to repair
MW	megawatt
NERC	North American Electric Reliability Corporation
PDF	probability density function
PIER	Public Interest Energy Research

PNNL	Pacific Northwest National Laboratory
RD&D	research, development, and demonstration
REG	regulation
RT	real time
RTED	real-time economic dispatch
RTM	real-time market
RTUC	real-time unit commitment
SCADA	supervisory control and data acquisition
SCUC	security-constrained unit commitment
SH	service hours
STUC	short-term unit commitment
TND	truncated normal distribution
UC	unit commitment
UWIG	Utility Wind Integration Group
WECC	Western Electricity Coordinating Council

APPENDIX A:
Generation Fleet Ramping Capability

Each generating unit has specific physical characteristics:

- Minimum generation – P_{min} (MW)
- Maximum generation – P_{max} (MW)
- Maximum ramp rate – R (MW/min)

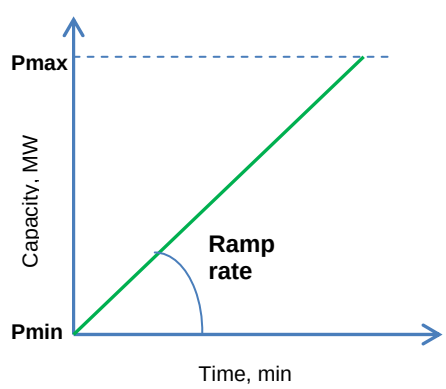
Those characteristics can be segmented depending on incremental blocks of power output provided by them.

Other characteristics are:

- Scheduled operating point - P_{sched} (MW)
- Regulation reserve (upward and downward) – P_{REG_UP}, P_{REG_DN} (MW)
- Contingency reserve – P_{cont} (MW)

A simplified ramping characteristic of a generation unit is shown in Figure A.1. Some units can have segments with different maximum ramp rates, but for simplicity the linearized ramping characteristic is used in Figure A.1.

Figure A.1: Generation Unit Ramping Characteristic



The ramping capability characteristic of unit i at time t starting from an operating point $P_{sched,\,i}$ is as follows:

$$
\begin{aligned}
&P^{i}_{UP,t} = P_{sched,i} + R_i \cdot t, \\
&P^{i}_{DN,t} = P_{sched,i} - R_i \cdot t, \\
&t = 0...T,
\end{aligned}
\tag{A.1}
$$

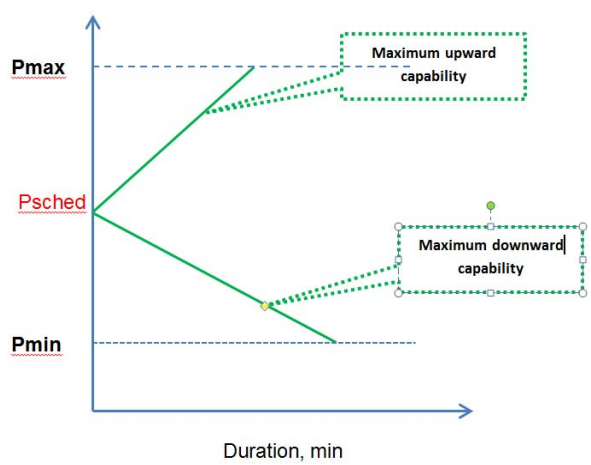
where $P^i_{UP,t}$ is the maximum available upward capacity of the unit *i* at time *t*; $P^i_{DN,t}$ is the maximum available downward capacity of the unit *i* at time *t*, and *T* is the duration of the ramping characteristic.

The upward and downward capacity is also limited by the following constraints:

$$P^i_{UP,t} \le P_{\max,i},$$
$$P^i_{DN,t} \ge P_{\min,i} \tag{A.2}$$

Figure A.2 shows an illustration of the simplified unit ramping capability characteristic. Assume that initially the unit is operated at the scheduled generation point P_{sched}. The unit cannot change the generation with the ramp rate faster than its maximum ramp rate, *R*. The maximum upward and downward capability of the generation unit is shown using green lines in Figure A.2. The maximum and minimum generation of the unit is also limited by the P_{min} and P_{max} constraints (dotted lines in Figure A.2).

Figure A.2: Generation Unit Ramping Capability



Ramping Capability of the Generation Fleet

The individual ramping capabilities of generation units should be combined to calculate the total system ramping capability of the online units:

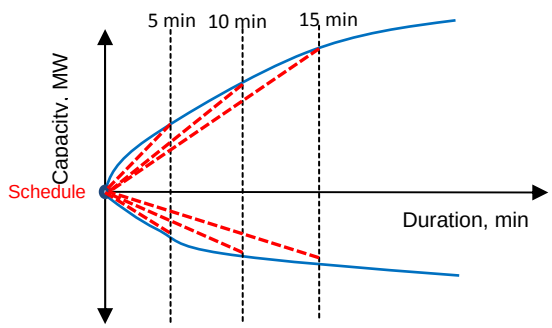
$$P_{UP_\Sigma,t} = \sum_{i=1}^{N} P^i_{UP,t},$$
$$P_{DN_\Sigma,t} = \sum_{i=1}^{N} P^i_{DN,t}, \tag{A.3}$$

where N is the number of online units available in the system.

Figure A.3 shows an illustration of generation fleet ramping capability in terms of its changing capacity. To calculate the maximum available system capability in terms of time and ramp rate, the following equation can be used:

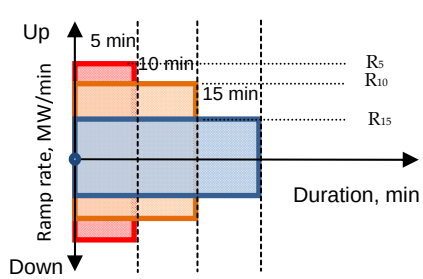
$$R_{UP_{\Sigma},t} = \frac{P_{UP_{\Sigma},t}}{t},$$
$$R_{DN_{\Sigma},t} = \frac{P_{DN_{\Sigma},t}}{t},$$
$$t = 1...T \qquad \text{(A.4)}$$

Figure A.3: Illustration of Generation Fleet Ramping Capability (capacity vs. duration)



An illustration of the relationship between generation fleet ramp rate capability and maximum ramp duration capability is presented in Figure A.4. Five-minute intervals for the ramp duration are used in this example. During first 5-minute interval, the maximum generation fleet ramp rate capability cannot be higher than R_5 (Figure A.4). After 5 minutes, the fastest units achieve their maximum capacity limit and maximum system ramp rate capability starts decreasing. Thus, for 10- and 15-minute ramp duration intervals, the generation fleet ramping capability is limited by R_{10} and R_{15}, correspondently (Figure A.4).

Figure A.4: Illustration of Generation Fleet Ramping Capability (ramp rate vs. duration)



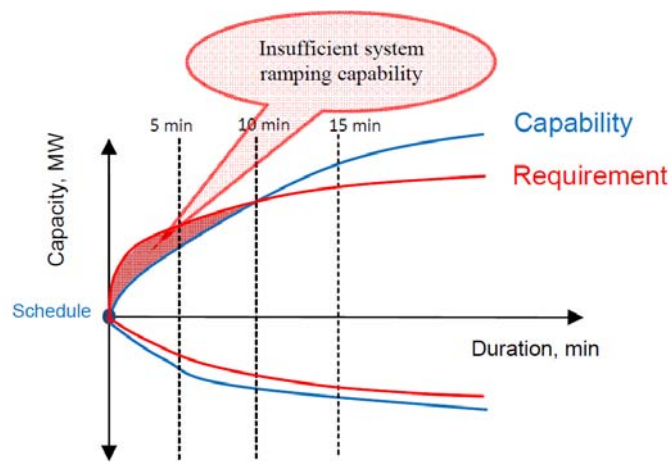
Adequacy of Ramping Capability

Generation fleet ramping capability is compared against the ramping requirements.

Figure A.5 illustrates a comparison of system ramping capability (blue curve) against ramping requirements (red curve) for some operating hours. System ramping capability is calculated using (3). Ramping requirements are calculated using the swinging door algorithm.

An area with insufficient system ramping capability is highlighted in red (Figure A.5); in other words, there is certain probability that the generation fleet does not have sufficient ramping up capability to meet the demand.

Figure A.5: Ramping Requirements vs. System Capability



APPENDIX B:
Generator Forced Outage Model

The term "generator forced outage" usually refers to the shutdown of a generating unit for emergency reasons or a condition in which the generator unit is unavailable for supplying the load because of an unanticipated breakdown. Generator outage is a discrete event and may or may not happen in any given dispatch interval. This characteristic contrasts with the continuous nature of wind and load variations. Also, the size of the power mismatch caused by a forced outage depends on the generator that is disconnected and the generators' load at the moment of the event. Any of the generators that are online within a dispatch interval could be forced out. The main challenge that has been overcome in this development was to combine the uncertainty information on continuous parameters (such as the generation capacity requirement) with discrete information (such as forced generation outages). This challenge has been successfully met in this project.

Forced outages of system generators cause temporary imbalances that must be eliminated within 10 minutes of notification by activating contingency reserve. Within this 10-minute interval, the system is exposed to an imbalance that can be as much as 1140 MW (the size of the largest generation unit in the system). The system inertia, governor response, and automatic generation control act to minimize the system power mismatch during the first seconds and minutes after the disturbance. Therefore, the generation controls and generation characteristics needed to balance the system must be sufficient to mitigate these possible mismatches. Again, there is an uncertainty associated with this process because the timing and the size of the forced outages are not known ahead of time and the contingency reserve activation process is not a deterministic process (for example, it depends on the characteristics of activated generators and type of activated reserve – spinning or non-spinning).

A methodology has been developed that evaluates additional uncertainty caused by forced generator outages and incorporates this information into the overall framework. This advanced feature constitutes a significant step forward in handling the uncertainty information in real-time operation. As a result, the system reliability and control performance can be additionally improved.

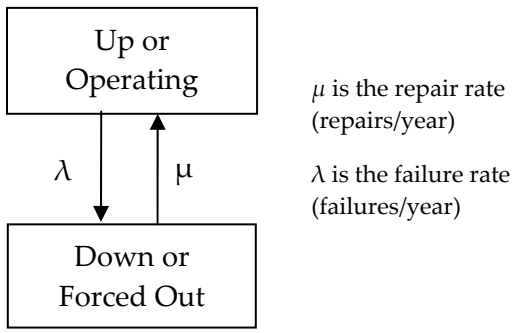
Generator forced outages are stochastic events. Modeling statistical characteristics of generator forced outages is important for a correct evaluation of the future generation requirement. In the following sections, two types of generator forced outage models, i.e., the two-state Markov model and four-state Markov model, are described. The capacity outage probability table (COPT) and an example of COPT calculation are provided. Simulation results on forced outage model are also provided.

Forced Outage Rate Calculation

A generator outage is a discrete event and may or may not happen in any given hour. This feature contrasts with the continuous nature of the wind and load variations (Doherty and O'Malley 2005).

The simplest type of the generation unit model is a two-state Markov model as shown in Figure B.1. Here the unit is assumed to always be in one of the two states: "up" – fully available, running, and subject to a possible failure; or "down" – totally unavailable, not running, and undergoing repair (Billinton and Allan 1996; Billinton and Ge 2004).

Figure B.1: Two-State Markov Model



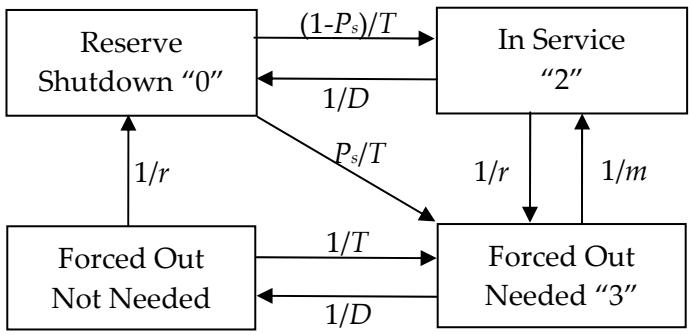
Here, μ (repairs/year) is the repair rate, r=1/ μ (years) is the mean downtime due to a forced outage (mean time to repair - MTTR), λ is the failure rate, (failures/year), and m=1/ λ is the mean up time between failure events (mean time to failure - MTTF). The unit's forced outage rate (FOR) is the probability that the unit is down:

$$FOR = \frac{\lambda}{\lambda + \mu} = \frac{r}{m + r} = \frac{FOH}{SH + FOH} \tag{B.1}$$

where FOH is the forced outage duration within a year, (hours), and SH is the service hours within a year.

The two-state model is a valid representation for base load units but does not adequately represent intermittent operating units used to meet peak load conditions. The two-state model for a base load unit has been extended to the four-state peaking unit model shown in Figure B.2, which is widely used in practice (Billinton and Ge 2004; Patton 1993). The model assumes that the generating unit is either fully available or totally unavailable, but also considers that the unit may be either needed or not needed (Billinton and Ge 2004).

Figure B.2: IEEE Four-State Markov Model



D is the average in-service time per occasion of demand;
T is the average reserve shutdown time between periods of need;
r is the average repair time per forced outage occurrence;
m is the average in-service time between occasions of forced outage when needed;
P_s is the probability of a starting failure resulting in inability to serve load during all or part of a demand period.

The frequency balance equations for the four-state model shown in Figure B.2 are as follows (Billinton and Allan 1996; Billinton and Ge 2004):

$$\begin{cases} P_2 \times \left(\frac{1}{D} + \frac{1}{m}\right) = P_0 \times \frac{1-P_s}{T} + P_3 \times \frac{1}{r} \\ P_3 \times \left(\frac{1}{r} + \frac{1}{D}\right) = P_2 \times \frac{1}{m} + P_1 \times \frac{1}{T} + P_0 \times \frac{P_S}{T} \\ P_1 \times \left(\frac{1}{T} + \frac{1}{r}\right) = P_3 \times \frac{1}{D} \\ P_0 + P_1 + P_2 + P_3 = 1 \end{cases} \tag{B.2}$$

where P_i is the probability of the state i, $i = 0 \ldots 3$.

According to Billinton and Allan (1996), P_1 and P_3 can be calculated using the following equations:

$$P_1 = \frac{r^2 T (D + mP_s)}{M} \tag{B.3}$$

$$P_3 = \frac{rD(D + r)(D + mP_s)}{M} \tag{B.4}$$

Demand factor f can be expressed as the function of the parameters given in Figure B.2 as follows (Billinton and Ge 2004):

$$f = \frac{P_3}{P_3 + P_1} = \frac{\frac{1}{r} + \frac{1}{T}}{\frac{1}{D} + \frac{1}{r} + \frac{1}{T}} \tag{B.5}$$

The factor f serves to weight the FOH to reflect the time the unit was actually on forced outage when in demand by the system (Billinton and Allan 1996).

Forced outage rate demand (FORd) can be evaluated as follows:

$$FORd = \frac{f \times FOH}{f \times FOH + SH} \tag{B.6}$$

FORd is the probability that a generating unit will not be available when required.

Equivalent forced outage rate demand (EFORd) (Billinton and Allan 1996):

$$EFORd = \frac{f \times FOH + f_p \times EFDH}{f \times FOH + SH} \tag{B.7}$$

where f_p is the partial outage factor and EFDH is the equivalent forced derating hours.

EFORd can be found in the NERC Generating Availability Data System (GADS) (NERC 2007; Curley 2006). The difference between EFORd and FORd is that EFORd also includes derated states of the generator.

The full outage probability (FOP) of a unit is the probability that the unit will stop providing all of its current output in an hour period. Here, it is assumed that the trip causes the unit's output to be instantaneously unavailable. The hourly FOP of a unit can be related to the FOR and MTTR as follows (Doherty and O'Malley 2005):

$$FOP_i = \frac{FOR_i}{MTTR_i} \tag{B.8}$$

In the case of peaking units, EFORd can be used instead of FOR in (B.8).

Capacity Outage Probability Table

The capacity adequacy evaluation of generation systems requires the creation of a generation capacity model, known as the capacity outage probability table (COPT). COPT gives the probability of occurrence for each possible outage capacity level (Billinton and Allan 1996).

Let us assume that the system has n independent generating units and that unit i has m_i discrete states with outage capacity C_{ij} and individual probability $p_{ij} = p(X_i = C_{ij})$, where $j = 1 \ldots m_i$ (Morrow and Gan 1993). Outage states of unit i are arranged in ascending order. The COPT contains $N + 1$ discrete states, where $N = C_{max}/\Delta$, C_{max} is the installed capacity of the system and Δ is the resolution of the COPT. The new individual state probabilities, after unit i is added to the system, can be calculated using the following recursive algorithm (Morrow and Gan 1993):

$$p(k) = \sum_{j=1}^{m_i} p_{ij}\, p'(k - \frac{c_{ij}}{\Delta}), \quad k = 0,1,2,\ldots,N \tag{B.9}$$

where $p(\cdot)$ is individual state probabilities after unit i is added; $p'(\cdot)$ is individual state probabilities before unit i is added; and k is an index of discrete state.

The recursive convolution process starts with the initial values: $p(0) = 1$ and $p(k) = 0$, $k = 1,2 ,... N$. Note that $p(k) = 0$ if $k < 0$.

In summary, the recursive convolution procedure for building a COPT has the following basic steps (Morrow and Gan 1993):

- Read unit data, determine Δ and $N = C_{max}/\Delta$;
- Set initial values: $p(0) = 1$ and $p(k) = 0$, $k = 1,2 ,... N$;
- Add unit i to the system, calculate $p(k)$, $k = 0,1,2 ,... ,N$ using (B.8);
- Repeat Step 3 for all the units.

Usually, the table obtained by (B.8) is simplified by rounding the COPT to selected discrete capacity levels. The size of the round-off increment depends on the desired accuracy.

The cumulative probability of having $k\Delta$ MW to be forced out can be calculated using the following equation:

$$P(k) = \sum_{s=0}^{k} p(s) \tag{B.10}$$

Example of COPT Calculation

Let the system consist of two generators. The first generator has a capacity of 100 MW and outage probability 10%, and the second generator has a capacity of 50 MW and outage probability 20%. Assume that generating units has only two states: operating state and forced out state.

Then, the capacity matrix is:

$$C = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} = \begin{bmatrix} 0 & 100 \\ 0 & 50 \end{bmatrix}$$

where $c_{11} = 0$ and $c_{21} = 0$ – correspond to operating states of generators one and two (no forced outage) and $c_{12} = 100$ and $c_{22} = 50$ – correspond to forced out states (nominal generator capacity).

Individual probability matrix is defined as:

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} = \begin{bmatrix} 0.9 & 0.1 \\ 0.8 & 0.2 \end{bmatrix},$$

where $p_{11} = 0.9$ and $p_{21} = 0.8$ are probabilities of operating state of generators one and two; and $p_{12} = 0.1$ and $p_{22} = 0.2$ are probabilities of the forced out state.

The installed system capacity is $C_{max} = 150$ MW, and the COPT resolution is $\Delta = 50$ MW. Therefore, COPT contains four discrete states.

Let us set initial probability values $p(k)$in the COPT (Table B.1).

Table B.1. COPT (Initial Values)

State, *k*	Capacity, *c(k)* (MW)	Probability, *p(k)*
0	0	1
1	50	0
2	100	0
3	150	0

Now we will add unit one to the system and calculate new capacity outage probabilities using (B.8) - see Table B.2

$$k=0: \quad p(0)=p_{11}\cdot p'(k-\frac{c_{11}}{\Delta})+p_{12}\cdot p'(k-\frac{c_{12}}{\Delta})=0.9\cdot p'(0-\frac{0}{50})+0.1\cdot p'(0-\frac{100}{50})=$$
$$=0.9\cdot p'(0)+0.1\cdot p'(-2)=0.9\cdot 1+0.1\cdot 0=0.9$$

$$k=1: \quad p(1)=p_{11}\cdot p'(k-\frac{c_{11}}{\Delta})+p_{12}\cdot p'(k-\frac{c_{12}}{\Delta})=0.9\cdot p'(1-\frac{0}{50})+0.1\cdot p'(1-\frac{100}{50})=$$
$$=0.9\cdot p'(1)+0.1\cdot p'(-1)=0.9\cdot 0+0.1\cdot 0=0$$

$$k=2: \quad p(2)=p_{11}\cdot p'(k-\frac{c_{11}}{\Delta})+p_{12}\cdot p'(k-\frac{c_{12}}{\Delta})=0.9\cdot p'(2-\frac{0}{50})+0.1\cdot p'(2-\frac{100}{50})=$$
$$=0.9\cdot p'(2)+0.1\cdot p'(0)=0.9\cdot 0+0.1\cdot 1=0.1$$

$$k=3: \quad p(3)=p_{11}\cdot p'(k-\frac{c_{11}}{\Delta})+p_{12}\cdot p'(k-\frac{c_{12}}{\Delta})=0.9\cdot p'(3-\frac{0}{50})+0.1\cdot p'(3-\frac{100}{50})=$$
$$=0.9\cdot p'(3)+0.1\cdot p'(1)=0.9\cdot 0+0.1\cdot 0=0$$

Table B.2: COPT (Unit One Added)

State, *k*	Capacity, *c(k)* (MW)	Probability, *p(k)*
0	0	0.9
1	50	0
2	100	0.1
3	150	0

The next step is adding the unit two and update values of COPT (Table B.3):

$$k=0: \quad p(0)=p_{21}\cdot p'(k-\frac{c_{21}}{\Delta})+p_{22}\cdot p'(k-\frac{c_{22}}{\Delta})=0.8\cdot p'(0-\frac{0}{50})+0.2\cdot p'(0-\frac{50}{50})=$$
$$=0.8\cdot p'(0)+0.2\cdot p'(-1)=0.8\cdot 0.9+0.2\cdot 0=0.72$$

$$k=1: \quad p(1)=p_{21}\cdot p'(k-\frac{c_{21}}{\Delta})+p_{22}\cdot p'(k-\frac{c_{22}}{\Delta})=0.8\cdot p'(1-\frac{0}{50})+0.2\cdot p'(1-\frac{50}{50})=$$
$$=0.8\cdot p'(1)+0.2\cdot p'(0)=0.8\cdot 0+0.2\cdot 0.9=0.18$$

$$k=2: \quad p(2)=p_{21}\cdot p'(k-\frac{c_{21}}{\Delta})+p_{22}\cdot p'(k-\frac{c_{22}}{\Delta})=0.8\cdot p'(2-\frac{0}{50})+0.2\cdot p'(2-\frac{50}{50})=$$
$$=0.8\cdot p'(2)+0.2\cdot p'(1)=0.8\cdot 0.1+0.2\cdot 0=0.08$$

$$k=3: \quad p(3)=p_{21}\cdot p'(k-\frac{c_{21}}{\Delta})+p_{22}\cdot p'(k-\frac{c_{22}}{\Delta})=0.8\cdot p'(3-\frac{0}{50})+0.2\cdot p'(3-\frac{50}{50})=$$
$$=0.8\cdot p'(3)+0.2\cdot p'(2)=0.8\cdot 0+0.2\cdot 0.1=0.02$$

Table B.3: COPT (Unit Two Added)

State, *k*	Capacity, *c(k)* (MW)	Probability, *p(k)*
0	0	0.72
1	50	0.18
2	100	0.08
3	150	0.02

Figures B.3–B.4 show the capacity discrete outage probability density function (PDF) and cumulative distribution function (CDF) based on the calculated COPT.

Figure B.3: Discrete Probability Density Function

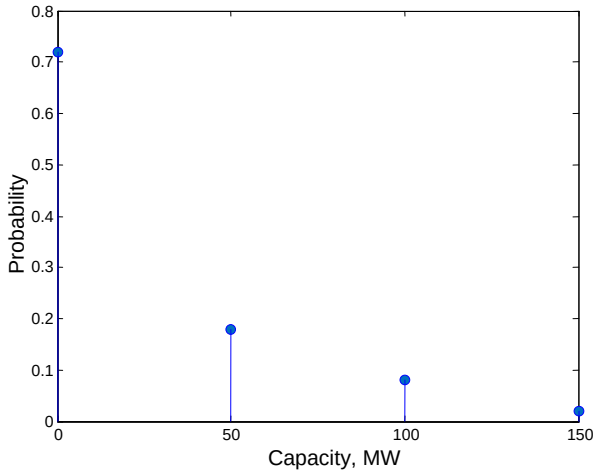
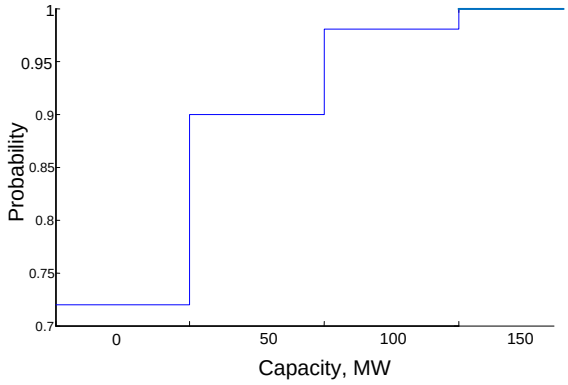


Figure B.4: Cumulative Distribution Function



Simulation Results (Forced Outage Model)

An example of a California Independent System Operator (CAISO) generation schedule is presented in Table B.4, and generation unit performance statistical characteristics taken from GADS (NERC 2007) are presented in Table B.5.

COPTs are calculated to each hour, taking into account the generators' schedule. Figures B.5-B.6 show the capacity outage PDF and CDF functions for a 1-hour look-ahead period.

Table B.4: Generation Schedule

Number	UNIT_ID	Unit Type	1h	2h	3h	4h	5h
1	Unit1	STUR	16	16	16	16	16
2	Unit2	STUR	20	20	20	20	20
3	Unit3	HYDR	16	16	16	16	16
4	Unit4	GTUR	0	0	0	0	0
…..	…	……	…	…	…	…	…
516	Unit516	STUR	3	3	3	3	3
517	Unit517	WIND	10	10	10	10	10
	Total Generation		17792.9	16512.06	16113.22	15813.15	15811.15
	Wind		1344	1310.28	1313.55	1299.14	1256.3

GTUR = Gas turbine
HYDR = Hydro
STUR = Stem turbine
WIND = Wind

Table B.5: Annual Unit Performance Statistic

GEN_TYPE	GEN_TECH	FUEL_TYPE	FOR	Service Hours	Number of Occurrences
T	STUR	GEOT	0.5	8500	3.6
T	GTUR	GAS	46.33	270	3
T	STUR	GAS	8.29	2750	4
H	HYDR	WATR	4.92	4981	3
T	WIND	WIND	-	-	-
T	CCYC	GAS	7.33	3673	9
H	PTUR	WATR	3.71	2634	3.86

CCYC = Combined cycle
GAS = Gas
GEOT = Geothermal
GTUR = Gas turbine
HYDR = Hydro
STUR = Steam turbine
WATR = Water
WIND = wind

Figure B.5: Capacity Outage Discrete PDF

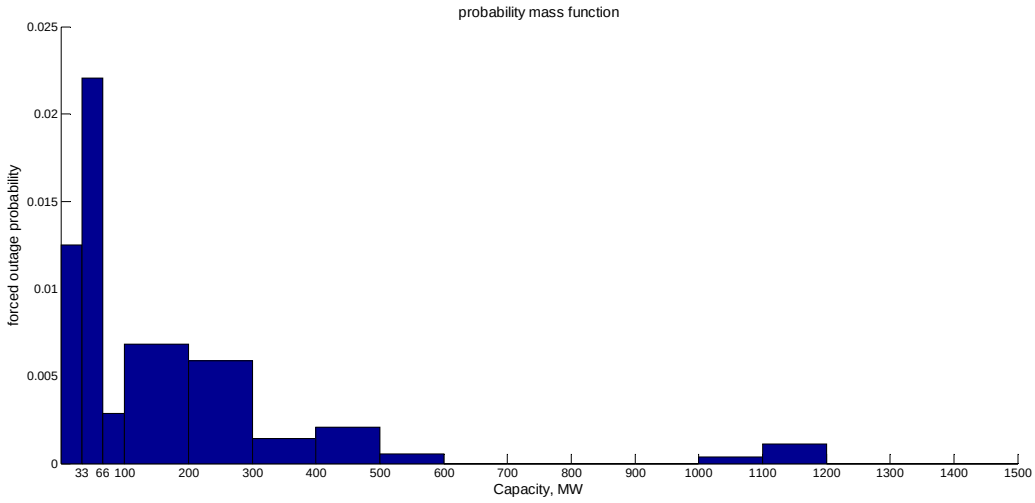
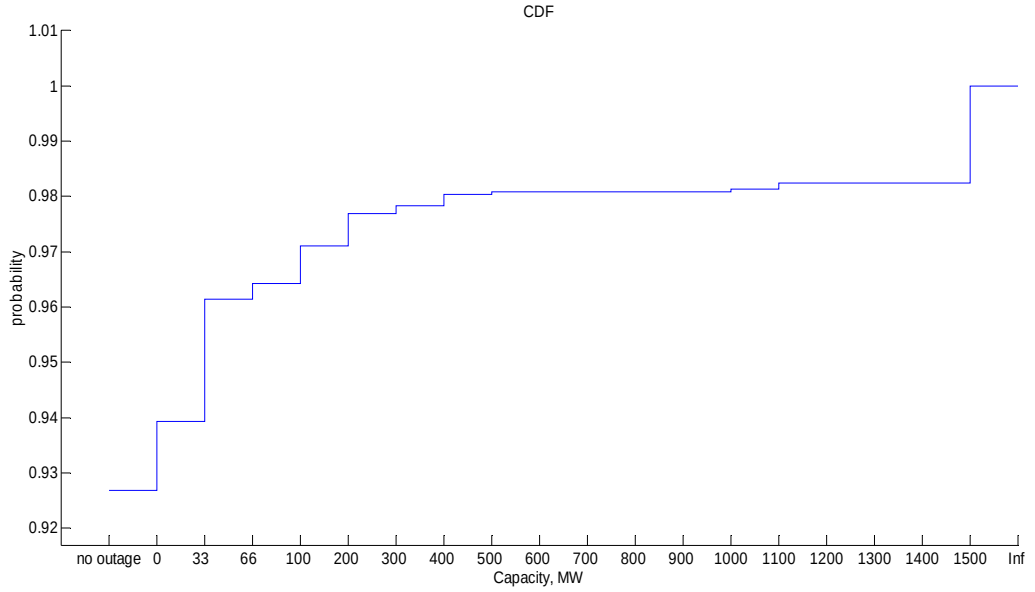


Figure B.6: Capacity Outage CDF



References

Billinton R., and J. Ge. 2004. "A Comparison of Four-state Generating Unit Reliability Models for Peaking Units." *IEEE Trans. on Power Syst.* 19:763–768.

Billinton, R., and R. Allan. 1996. *Reliability Evaluation of Power System*, Plenum Press, New York.

Curley, G. M. 2006. "Power Plant Performance Indices in New Market Environment." IEEE Standard 762 Working Group Activities and GADS Database. *Proc. IEEE Power Engineering Society General Meeting*, p. 5.

Doherty, R., and M. O'Malley. 2005. "A new approach to quantify reserve demand in systems with significant installed wind capacity." *IEEE Trans. on Power Syst.* 20:587–595.

Morrow, D., and L. Gan. 1993. "Comparison of Methods for Building a Capacity Model in Generation Capacity Adequacy Studies." *Proc. IEEE WESCANEX'93, Communications, Computers and Power in the Modern Environment*, pp. 143–149.

NERC – North American Electric Reliability Corporation. 2007. "Generating Availability Data System Report." North American Electric Reliability Corporation. [Online.] Available: http://www.nerc.com/files/gar2007.zip.

Patton, A. D. 1993. "Duty Cycle Effects on Generating Unit Availability." *IEEE Trans. on Industry Applications* 29:1018–1021.

Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

Online Analysis of Wind and Solar Part II: Transmission Tool

Final Report

Prepared for: California Energy Commission and the California Institute for Energy and Environment

Prepared by: Pacific Northwest National Laboratory

JANUARY 2012

PNNL-21105

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Prepared by:

Pacific Northwest National Laboratory

Krishnappa Subbarao, Project Manager

Yuri V. Makarov, Principal Investigator:

Authors:

PNNL: Yuri V. Makarov, Pavel V. Etingov, Krishnappa Subbarao, Jian Ma

CAISO: Clyde Loutan

Contract Number: 500-07-537

Work Authorization No.: POTPO1-X11

Prepared for:

California Energy Commission

Cathy Turner

Contract Manager

Jamie Patterson

Project Manager

Mike Gravely

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

This work was funded by the **Public Interest Energy Research (PIER) program** in renewable energy at the **California Energy Commission** and managed by the California Institute for Energy and Environment. This report was prepared with substantial support from California Independent System Operator personnel.

The authors would like to thank Gil Bindewald and Stan Calvert, U.S. Department of Energy; Mike Gravely, Pedro Gomez, and Jamie Patterson, California Energy Commission; Merwin Brown, Larry Miller, and Jim Cole, California Institute for Energy and Environment; and Mark Rothleder, William Bonnell, Hani Alarian, Jim McIntosh, Sirajul Chowdhury, Zhijun (June) Xie, and Ajay Mannepalli, California Independent System Operator, for providing the project team with consultations, day-by-day support, and discussions essential to this work.

The authors would also like to thank Managers Carl H. Imhoff, Dale King, Evan O. Jones, Mark P. Morgan, Ron Melton, and Landis Kannberg, Staff Tony Nguyen, John C. Bower (retired), Contracting Officer Sheena Kanyid, Project Specialist Susan Arey, and Administrative Assistant Nikki Stringer, Pacific Northwest National Laboratory, for supporting this work.

Many thanks go to Document Production Specialist Kathy Neiderhiser, Pacific Northwest National Laboratory, for formatting the final manuscript.

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

This report is the final report for the "Online Analysis of Wind and Solar" project (contract number: 500-07-537, work authorization number: POTPO1-X11) conducted by the Pacific Northwest National Laboratory. The information from this project contributes to PIER's Energy Systems Integration program area.

For more information about the PIER Program, please visit the Energy Commission's website at http://www.energy.ca.gov/research/, or contact the Energy Commission at 916-654-4878.

ABSTRACT

Interacting wind, solar, and load forecast errors can create significant unpredictable impacts on the transmission system, congestion, voltage and reactive power stability margins. These impacts will be increasing with the increasing penetration levels of variable renewable generation in the Western Interconnection and California power systems. To maintain a secure system reliability level, the probability and the magnitude of the impacts should be evaluated and communicated to the system operators. Based on this information, the system power flow limits, dispatches, voltage levels, and available reactive power margins could be adjusted to minimize the risk of system problems and failures to an acceptable level whenever it is required.

To facilitate wider penetration of renewable resources without compromising system reliability, two tools intended for use by California Independent System Operator (CAISO) power grid operators have been developed for predicting and displaying the operational impacts of uncertainties in forecasts of loads and renewable generation. The first tool (so-called "ramping tool") addresses real-time (load following) capacity and ramping requirements, and the second ("transmission tool") addresses voltage, stability and transmission congestion caused by renewables resources (mainly wind power and solar power generation). The first tool is an industry-grade product connected to the California ISO systems and operated in real time in the California ISO Control Center. This tool is described in a separate report prepared and submitted by Pacific Northwest National Laboratory (PNNL).

Based on a contract with the California Energy Commission (CEC) and California Institute for Energy and Environment (CIEE), PNNL is developing a second tool for predicting transmission uncertainties and related impacts ("transmission tool" - TT). The present report addresses this second tool –"transmission tool".

TABLE OF CONTENTS

PREFACE ..... **iii**

Abstract ..... **v**

EXECUTIVE SUMMARY **1**

CHAPTER 1: Introduction **5**

Business Need 5

Objectives 6

CHAPTER 2: Real-Time Voltage Stability Analysis Software Description and Connectivity Issues **8**

Description of the RTVSA Methodology 8

Some Algorithmic Details 8

Continuation Power Flow 9

Contingency Analysis 9

CAISO RTVSA Architecture and Information Flow (Varghese et al. 2008) 9

Network Model and Supplemental Data (Varghese et al. 2008) 9

Dynamic Input Data and Interface (Varghese et al. 2008) 9

Results Overview (Varghese et al. 2008) 10

Output Data Interface (Varghese et al. 2008) 10

Definitions and Output Parameters 11

Generation Dispatch 11

Stress Patterns 11

Load Margin 11

P-V and Q-V Curves 12

Critical Interface and Deterministic Transmission Limits 14

Selected TT-RTVSA Integration Approach and its Implications 14

CHAPTER 3: Transmission Tool Outputs and Their Utilization **17**

Probability Distribution of Transmission Flows 17

Probability of Violation of Transmission Limits 18

Probability Distribution of Voltage Levels and Reactive Power Margins 21
CHAPTER 4: Connectivity with Visualization Software 23
CHAPTER 5: Methodology 25
Power System Congestion Model 25
Linearized Incremental Power Flow Model and PTDF 27
Mathematical Definition of the Incremental Model 28
Incremental Model Development Using Power World Simulator 30
CHAPTER 6: High Level Transmission Tool Description 32
Connectivity Diagram with Real-Time Voltage Stability Analysis Tool and CAISO Visualization Software 32
Internal System Architecture 32
Platform 33
System Features and Benefits for CAISO 33
Module 1: Power Flow Module 34
Module 2: PTDF Module 35
Module 3: Uncertainty Module 36
Module 4: Probabilistic Analysis 36
CHAPTER 7: User Interface Prototype 37
Graphic User Interface (GUI) 37
Presenting Simulation Results 38
Database Structure 42
CHAPTER 8: Conclusions 45
CHAPTER 9: References 46
CHAPTER 10: Glossary 48

LIST OF FIGURES

Figure 1: Probabilistic Analysis of Transmission Interface Power Flow 3

Figure 2: Conceptual Design of the Visualization Display Based on Google Earth Technology ... 4

Figure 3: The Current Transmission Paths Used by RTVSA Tool and Their Status Monitors (Salem-Natarajan et al. 2008) 10

Figure 4: RTVSA Architecture (Varghese et al. 2008) 11

Figure 5: P-V Curves and Derived System Characteristics (Varghese et al. 2008) 12

Figure 6: P-V and Q-V Curves Produced by VSA&E Tool (Li et al. 2004) 13

Figure 7: Critical Interface and Deterministic Transmission Limits 14

Figure 8: Example Part of a Power System 18

Figure 9: Probabilistic Limits for Base Case Conditions and Contingencies 19

Figure 10: Advisory Information for Probabilistic Assessment of Congested Transmission Paths 20

Figure 11: Mean and the Maximum Overloads 21

Figure 12: The Idea of Using P-V and Q-V Curves to Obtain Probability Distributions of Voltages and Reactive Power 22

Figure 13: A Conceptual Screen for Visual Presentation of Transmission Tool Results on a Conventional Map 23

Figure 14: A Google Earth Design of the TT Screen 24

Figure 15: Active Congestion Zones and Branch Groups (Department of Market Monitoring 2007) 25

Figure 16. Interfaces Between Two Areas 26

Figure 17. Multi-Line Interfaces Between Areas 26

Figure 18: Zonal Structure of the WECC System 28

Figure 19. WECC System Transmission Lines And Paths (WECC 2005) 29

Figure 20: Connections and Type of Information to be Exchanged PNNL's TT and RTVSA and Visualization Software 32

Figure 21: Architecture of the Transmission Tool 33

Figure 22: Power Flow Module 35

Figure 23: PTDF Module 35

Figure 24: Uncertainty Module 36
Figure 25: Main GUI of the Transmission Tool 37
Figure 26: Interfaces Active Power Flow 38
Figure 27: Transmission Load Margin 38
Figure 28: Simulation Results – Incremental Power Flow 39
Figure 29: Interfaces' Information 40
Figure 30: Zonal Information 40
Figure 31: Probability of Power Flow for Base Case 41
Figure 32. Probability of Power Flow for Contingency Case – 1 41
Figure 33. Probability of Power Flow for Contingency Case – 2 41
Figure 34: Probability Distribution of a Power Flow 42

LIST OF TABLES

Table 1: P-V Curves and Derived System Characteristics (Varghese et al. 2008) 13
Table 2: Interface Description 26
Table 3. Zonal Information 27
Table 4: Interface PTDFs (%) 30
Table 5: Interface Power Flow Validation 31
Table 6: Contingency Cases 42
Table 7: Transmission Limits and Margin for Base Case 42
Table 8: Transmission Limits and Margin for a Contingency Case 43
Table 9: Zonal Information 43
Table 10: Tie Line Information 44

EXECUTIVE SUMMARY

Interacting wind, solar, and load forecast errors can create significant unpredictable impacts on the transmission system, congestion, voltage and reactive power stability margins. These impacts will be increasing with the increasing penetration levels of variable renewable generation in the Western Interconnection and California power systems. To maintain a secure system reliability level, the probability and the magnitude of the impacts should be evaluated and communicated to the system operators. Based on this information, the system power flow limits, dispatches, voltage levels, and available reactive power margins could be adjusted to minimize the risk of system problems and failures to an acceptable level whenever it is required.

To facilitate wider penetration of renewable resources without compromising system reliability, two tools intended for use by California Independent System Operator (CAISO) power grid operators have been developed for predicting and displaying the operational impacts of uncertainties in forecasts of loads and renewable generation. The first tool (so-called "ramping tool") addresses real-time (load following) capacity and ramping requirements, and the second ("transmission tool") addresses voltage, stability and transmission congestion caused by renewables resources (mainly wind power and solar power generation). The first tool is an industry-grade product connected to the California ISO systems and operated in real time in the California ISO Control Center. This tool is described in a separate report prepared and submitted by Pacific Northwest National Laboratory (PNNL).

Based on a contract with the California Energy Commission (CEC) and California Institute for Energy and Environment (CIEE), PNNL is developing a second tool for predicting transmission uncertainties and related impacts ("transmission tool" - TT). The present report addresses this second tool –"transmission tool".

The TT analyzes impacts on:

1. Congestion;
2. Voltage and transient stability margins, and
3. Voltage reductions and reactive power margins.

The TT analyzes the impact on the base case and under user-specified contingencies, so that the most limiting contingency is determined and addressed.

Information provided to the real-time dispatchers by the transmission tool includes:

1. The *probability of violation of transmission constraints*: this probability can be compared against the corresponding threshold risk levels specified by the users. If the violation probability exceeds the threshold, the TT issues advisory information suggesting an increase of the security margin helping to lower the probability of violation to an acceptable level.
2. The *average and the maximum size of violation*s: the average size of violations is compared against their user-specified thresholds. If the average expected violation exceeds a

user-specified threshold, the TT issues advisory information suggesting an increase of the security margin helping to lower the average size of violation to an acceptable level.

3. The available *probability-based security margin* (a distance to violation) and recommendations on its increase whenever is required, and

4. Visualization of the transmission impacts, real time dispatcher alerts and advisory information on a Western Electricity Coordinating Council (WECC) or California system map.

The proposed transmission tool has several very important advantages and opportunities for the California system operators:

1. *Better quantification of available security margins*. Because the analyzed transmission impacts are caused by random variations of forecast errors in different parts of the system, they are not predictable in a deterministic sense. Based on a statistical analysis of multiple forecast errors, the tool provides a unique opportunity to adjust security margins depending on the risk (expected size and probability) of potential transmission violations.

2. *Better reliability level*. By adjusting the system security margins on critical paths in the system, the tool helps to prevent potential violations caused by random variations of system load and variable generation around their forecasted values.

3. *Better utilization of transmission assets*. In cases when the deterministic security margin is excessive, the tool will provide recommendations to reduce this margin based on the actual variability of the flows in the analyzed critical paths.

4. *Better situation awareness and predictive system monitoring*. The TT algorithm is run for multiple look-ahead dispatch intervals and possible contingencies. Based on this information, system dispatchers will be informed about potential violations and associated risks on all critical paths in the system, and on the most critical contingencies as well as the expected time to violations.

5. *Preventive control*. As a result of its look-ahead feature, the TT algorithm leaves some time for mitigation measures, helping to reduce the expected size and probability of violations to an acceptable level.

The transmission tool is a standalone working prototype product[2] that demonstrates the key features and advantages of the methodology developed by PNNL. The initial design incorporates all required essential informational, analytical, and visualization functions. Further development and integration with vendor-supported software at California ISO are necessary for deployment.

---

[2] Based on previous input by California ISO in meetings organized by CEC, the ramping tool was given higher priority and therefore a higher share of the project resources. This necessitated a reduction in the resources for the transmission tool, and the scope is therefore limited to developing a prototype of the tool that demonstrates the main capabilities.

Since the beginning of the project, the California ISO has implemented a real-time voltage stability analysis (RTVSA) tool (voltage stability analysis and enhancement (VSA&E) tool developed by Bigwood Systems Company), and advanced visualization and data processing tools (developed by Space Time Insight Company). In this situation, the project priorities and scope has changed by California ISO. Developing of a stand-alone fully- functional transmission tool would be redundant. Based on recommendation of the California ISO project support team, a decision was made to develop a TT prototype and its integration approach with the tools already installed and used by California ISO. The connectivity issues are addressed in this report from the methodology and system model perspective to provide future connectivity of the future industry-grade applications with the California ISO systems generally, and with the Bigwood real-time stability analysis applications, as well as with the Space Time Insight visualization tools.

Developed methodology is based on the Monte-Carlo simulations and statistical analysis of different sources of uncertainty that can impact on the transmission network. The developed methodology also includes linearized power flow model to calculate incremental active power flows in the transmission network caused by forecasting errors.

Figure 1 shows a screenshot of the probabilistic analysis display. The user can select any monitored transmission interface to check the probability of power flow distribution via interface at specific look-ahead operating intervals. The user is also advised if the interface transmission limit potentially can be violated, and what the probability and size of this violation might be.

Figure 55: Probabilistic Analysis of Transmission Interface Power Flow

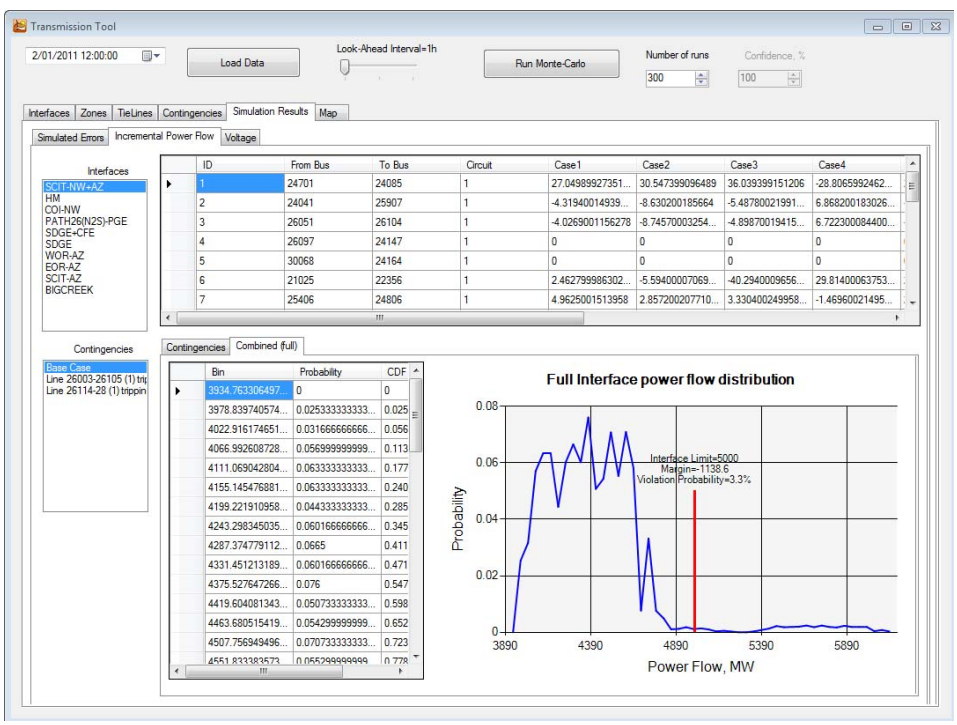
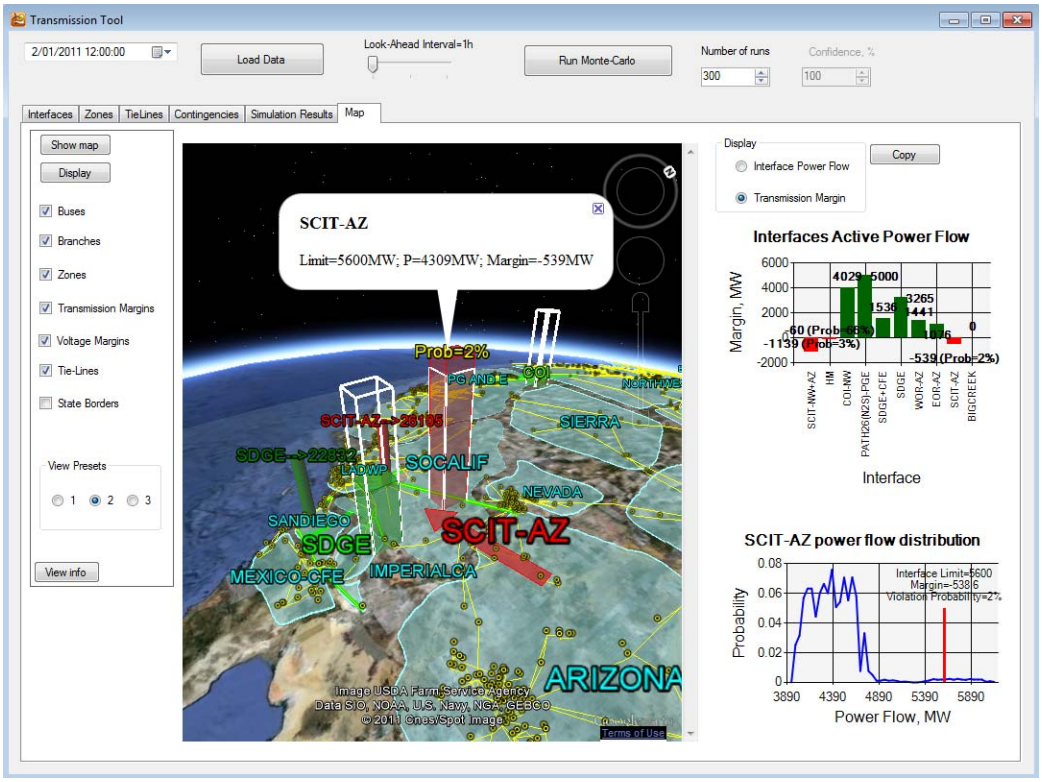


Figure 2 shows a conceptual design of visualization display based on Google Earth technology. Congested transmission interfaces and buses with potential voltage problems can be highlighted on the Google Earth display. Depending on probability of transmission and voltage limits violation, different colors can be used. Three-dimensional bars and cylinders can be used to show the size and probability of transmission congestions or voltage stability problems.

Figure 56: Conceptual Design of the Visualization Display Based on Google Earth Technology



To summarize this work, in this report, the development of a transmission tool on the prototype level is presented. The methodology, design consideration, system architecture, simulation results, and graphical user interface (GUI) are described. The power system model and the methodology to determine and probabilistic thermal congestion limits based on power transfer distribution factor are presented. The five key system modules, e.g., power flow module, power transfer distribution factors (PTDF) module, forecast error module, probability congestion module and interface module are also discussed in the report. Currently, the developed transmission tool is in a prototype level based on a simplified model and data. Future work could be to install and test the tool in a real control center using actual system model and data.

The use of specific vendors or equipment in this document is for research purposes only, and does not constitute an endorsement.

CHAPTER 1: Introduction

Business Need

The "CAISO Integration of Renewable Resources: Operational Requirements and Generation Fleet Capability at 20% RPS" report published in August 2010 noted that the "integration of variable energy resources will require increased operational flexibility— notably capability to provide load-following and regulation in wider operating ranges and at ramp rates that are faster and of longer sustained duration than are currently experienced." Uncertainties in forecasts of intermittent generation and load make this integration considerably more complex.

Interacting wind, solar, and load forecast errors can create significant unpredictable impacts on the transmission system, congestion, voltage and reactive power stability margins. For instance, the worst case can be a combination of the significant positive errors in one area of the power system interconnection with the significant negative errors in another area. This event can lead to the significant deviation of power flow from the scheduled values, and thus create the congestion and voltage stability problems. These impacts will be increasing with the increasing penetration levels of variable renewable generation in the Western Interconnection and California power systems. To maintain a secure system reliability level, the probability and the magnitude of the impacts should be evaluated and communicated to the system operators. Based on this information, the system power flow limits, dispatches, voltage levels, and available reactive power margins could be adjusted to minimize the risk of system problems and failures to an acceptable level whenever it is required.

Currently California Independent System Operator's (ISO's) vendor software determines thermal congestion and voltage stability margins for a number of selected transmission paths and contingencies. However, this analysis is based on a deterministic model and does not take into account the probabilistic nature of the variable generation. This analysis does not show the probability and magnitude of possible transmission violations caused by random deviations of system parameters from their forecasted values. To assist California ISO in making operational decisions that minimize reliability concerns arising from the lack of predictability of renewable intermittent resources, Pacific Northwest National Laboratory (PNNL), in conjunction with California ISO, developed a tool for predicting and displaying the operational transmission impact of forecast uncertainties.

Based on recommendation of the California ISO project support team, a decision was made to ensure connectivity to the analytical tool being developed by PNNL with the tools already installed and used by the California ISO. In the course of this project, the California ISO has implemented a real-time voltage stability analysis (RTVSA) tool, and advanced visualization and data processing tools. In this situation, the project priorities and scope have been changed by California ISO. Developing a standalone fully- functional transmission tool (TT) would be redundant. Based on recommendation of the California ISO project support team, a decision was made to develop a TT prototype and its integration approach with the tools already installed and used by California ISO.

The software tool is expected to utilize the results of real-time voltage stability analysis tool. The output of the PNNL tool is expected to be displayed in a control room by California Independent System Operator (CAISO) visualization software.

Objectives

The objective of this work is to develop a prototype tool to identify transmission problems, posed by the intermittency and variability of wind and solar generation, 1 to 3 hours ahead of time, and inform operators on potential risks for the purposes of early warning and preventive control. As noted before, the scope is limited to developing a prototype tool that implements and demonstrates the main developed methods and models, and fully illustrates the advantages of PNNL's methodology.

The analyzed system impacts include:

1. Impacts on congestion;
2. Impacts on voltage and transient stability margins, and
3. Impacts on voltage reductions and reactive power margins.

The impacts are analyzed in the base case and under all user-specified contingencies, so that the most limiting contingency is determined and addressed.

The developed methodology and prototype software should provide the following features:

1. *Better quantification of available security margins*. Based on a statistical analysis of multiple forecast errors, the tool should provide an opportunity to adjust security margins depending on the risk (expected size and probability) of potential transmission violations.
2. *Better reliability*. By adjusting the system security margins on critical paths in the system, the tool should help to prevent potential violations caused by random variations of system load and variable generation around their forecasted values.
3. *Better utilization of transmission assets*. In cases when the deterministic security margin is excessive, the tool should provide recommendations to reduce this margin based on the actual variability of the flows in the analyzed critical paths.
4. *Better situation awareness and predictive system monitoring*. System dispatchers should be informed about potential violations and associated risks on all critical paths in the system, and on the most critical contingencies as well as the expected time to violations.
5. *Preventive control*. The TT algorithm should provide time for decision-making and selection of mitigation measures to reduce the expected size and probability of violations to an acceptable level.

This report focuses on probabilistic assessment and visualization of stability margin, voltage levels, reactive power reserves, and transmission congestion caused by random factors including renewable generation. This is one of the two tools developed in this project. The other

tool – the "ramping tool" – focuses on probabilistic assessment of generation and ramping requirements needed for intra-hour balancing purposes and is described in a separate report.

Based on California ISO input, the ramping tool was given a higher priority and therefore a higher share of the project resources. The transmission tool scope is therefore limited to developing a prototype of the tool that demonstrates the main capabilities. Further development and integration with vendor-supported software (such as real-time voltage stability analysis software and CAISO visualization software for displaying purposes) at California ISO are necessary for a practical deployment, and they are not addressed in this document.

This report enables the California ISO technical staff and management to evaluate the need for a fully developed tool. It is, therefore, important to note the capabilities of the prototype that has been developed in relation to the capabilities of the fully developed system.

CHAPTER 2:
Real-Time Voltage Stability Analysis Software Description and Connectivity Issues

Since the beginning of the project, the California ISO has implemented a RTVSA tool, and advanced visualization and data processing tools. In this situation, the project priorities and scope have been changed by California ISO. Developing of a standalone fully functional transmission tool would be redundant. Based on recommendation of the California ISO project support team, a decision was made to develop a TT prototype and its integration approach with the tools already installed and used by California ISO. The connectivity issues are addressed in this report from the methodology and system model perspective to provide future connectivity of the future industry-grade applications with the California ISO systems generally, and with the real-time stability analysis applications, as well as with the CAISO visualization tools.

Description of the RTVSA Methodology

CAISO real-time operations have implemented a RTVSA tool and corresponding wide-area visual displays to manage the voltage and reactive power resources on the transmission system and to identify the following related characteristics (Varghese et al. 2008):

- Voltage security margin calculation;
- Worst-case contingencies leading to voltage collapse;
- Abnormal reductions of nodal voltages;
- Contingency ranking by margin to voltage collapse;
- System conditions with insufficient stability margin;
- Weakest elements within the grid, and
- Two-dimensional nomograms.

Some Algorithmic Details

The RTVSA algorithmic details include the following (Varghese et al. 2008):

- Continuation power flow(CPF);
- Voltage stability indices;
- Routes to voltage collapse;
- Preventive and enhancement control;
- Detection of insecure contingencies;
- Identification of critical contingencies;
- Preventive control against insecure contingencies;
- Enhancement control for critical contingencies, and
- Nomogram computation algorithm.

Continuation Power Flow

CPF is a powerful tool to simulate power system steady-state stationary behaviors with respect to a given power injection variation scenario. Power injection variations include both load variation and real generation scheduling in power systems. This tool has been implemented in several commercial packages for generating P-V curves. CPFLOW methods have been studied extensively in power system (Varghese et al. 2008).

Contingency Analysis

CAISO developed inputs to RTVSA to define interfaces and other flows to monitor, three severe N-2 contingencies and their associated RAS scripts, a N-1 contingency list and voltage limit and thermal limit monitoring lists (Varghese et al. 2008).

More details about the RTVSA methodology can be found in Chiang et al. (2009).

CAISO RTVSA Architecture and Information Flow (Varghese et al. 2008)

The CAISO RTVSA project can be broken down into several components as specified below.

1. Network model and supplemental data
2. Dynamic input data and interface
3. Modules and results overview
4. Output data interface.

Network Model and Supplemental Data (Varghese et al. 2008)

The RTVSA application uses the same operational model that is used for the power system applications in the energy management system (EMS). This operational model is of node-breaker CIM/XML format and contains a detailed system configuration and a simplified bulk system (161 kV and above) representation for the Western Electricity Coordinating Council (WECC) region. On a periodic basis, changes to system configurations are updated into this model. For every periodic update (several in a given year), the new model, in CIM/XML format, is imported into the RTVSA application.

The supplemental data files include data related to stress patterns, interfaces, contingencies, remedial action scheme models, tuning parameters for control/corrective actions, and monitored equipment list.

Dynamic Input Data and Interface (Varghese et al. 2008)

This section describes the data associated with changes in the system conditions and requirements. The dynamic data used are

1. Real-time system condition
2. Study base cases (user setup)
3. Load forecast
4. Outage schedules.

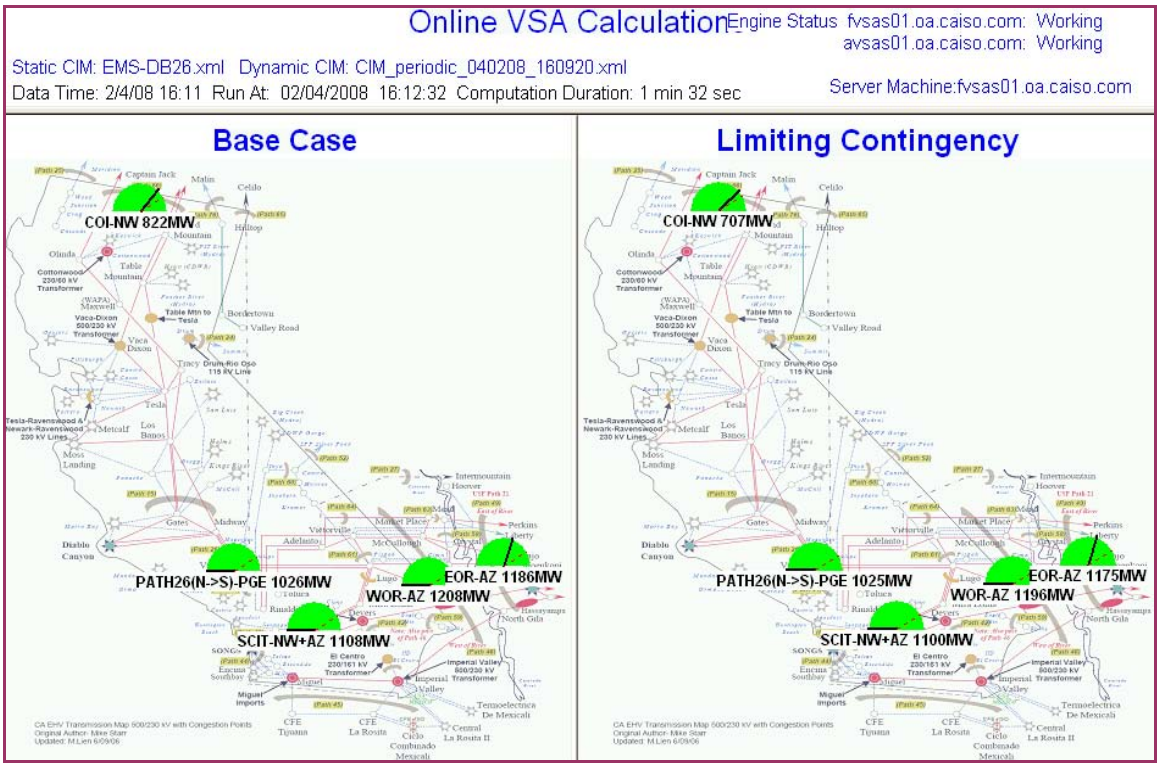
In the EMS system, the State Estimation executes every minute followed by an automated power flow execution prior to the dynamic CIM/XML export.

The load forecast data for the different sub-control areas are obtained from a neural network-based forecasting tool that will publish the hourly load forecast.

Results Overview (Varghese et al. 2008)

The results of the RTVSA are presented to the control room personnel through two overview displays, respectively – see Figure 57. It is proposed to have a geographic layout of the control area over which the color-coded results of RTVSA modules are presented. The users have the ability to drill down -to displays with more granularities from the overview displays.

Figure 57: The Current Transmission Paths Used by RTVSA Tool and Their Status Monitors (Salem-Natarajan et al. 2008)



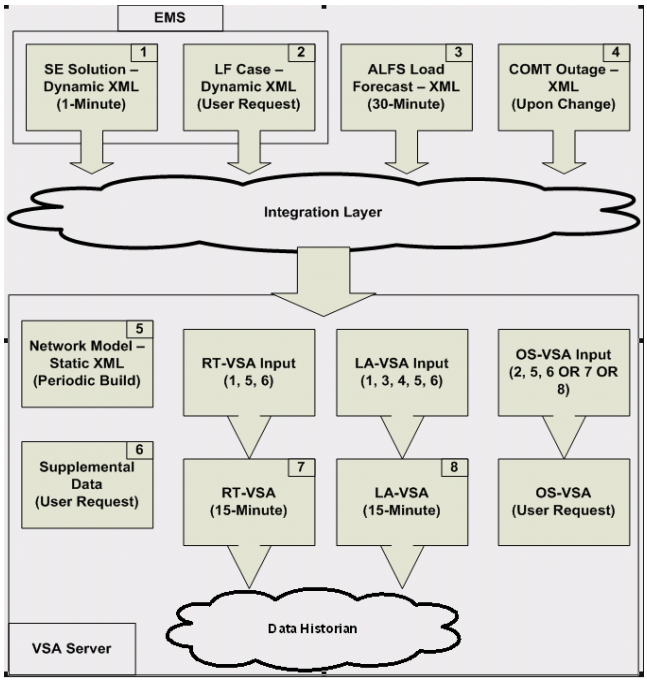
Output Data Interface (Varghese et al. 2008)

In the initial implementation, the results from the RTVSA system are made available for transfer to a data historian system.

The RTVSA implementation at CAISO involves implementing the RTVSA system and specific interfaces for input and output data. The schematic of the different systems involved is presented in Figure 58, where the boxes numbered 1 through 8 refer to the various data pieces

that can be used as input for the different RTVSA modules and, for these items, the value in parenthesis represents the update frequency for the data.

Figure 58: RTVSA Architecture (Varghese et al. 2008)



Definitions and Output Parameters

This section outlines definitions used in the RTVSA tool. These definitions are reproduced in this report because they are adopted without change in the transmission tool as a result of connectivity issues.

Generation Dispatch

The RTVSA tool implements its own generation redispatch under contingency conditions and to simulate system stress. Details of these algorithms are not known.

Stress Patterns

To stress each interface, the RTVSA algorithm determines certain stress patterns, which is an approach to change load and generation to increase the power flow in this interface. Details of the algorithm are not known, and apparently have not been published yet.

Load Margin

Import (Load Margin) is the maximum total real power transferred from source to sink before the system hits the voltage collapse point under a proposed stress pattern. In this regard, import is the same as load margin. In the voltage stability analysis (VSA) viewer and study mode VSA, import always means load margin. Note that P_{import} along the x-axis of the P-V curves shown

below denotes the value of the real power imported from source to sink as the system is being stressed. The nose point of this "import" curve is the system load margin to voltage collapse (Varghese et al. 2008).

Load margin corresponds to the maximum total real power transferred from source to sink before the system hits the voltage collapse point under a proposed stress pattern (Salem-Natarajan et al. 2008). The voltage stability analysis and enhancement (VSA&E) load margin calculation determines the voltage stability margin in megawatts (MW) and megaVAr, between the voltage collapse point and the current power system operation point (Bigwood Systems, Inc. 2012).

P-V and Q-V Curves

P-V curves, Q-V curves, or P-Q-V curves are used to analyze power system behavior under varying loading conditions. The nose point of these curves provides information for various power system analysis such as voltage stability analysis and loadability analysis (Varghese et al. 2008). Figure 59 and Table 3 taken from Varghese et al. (2008) explain how system conditions are analyzed using these curves, and which system characteristics are derived from these curves by the VSA&E tool under normal and contingency conditions.

Figure 59: P-V Curves and Derived System Characteristics (Varghese et al. 2008)

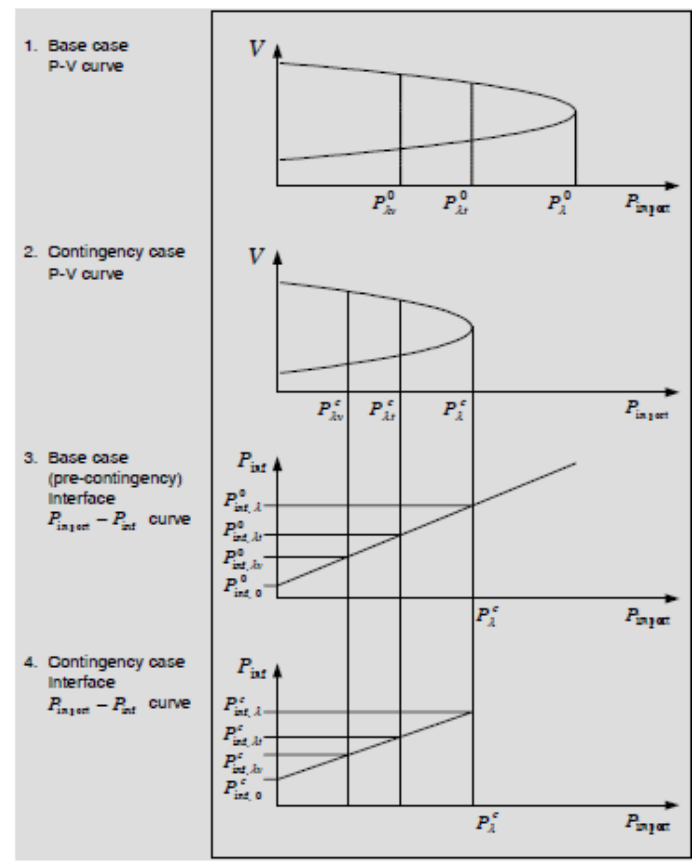
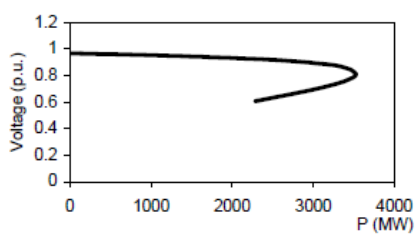


Table 3: P-V Curves and Derived System Characteristics (Varghese et al. 2008)

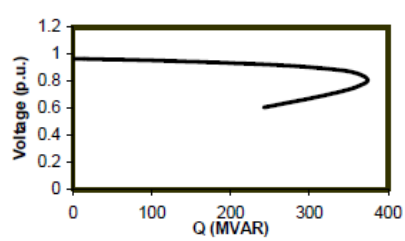
P_{import}	System import value
P_{inf}	Power flow across the interface
P^0_{λ}	Base case Load Margin.
$P^0_{\lambda v}$	Base case voltage limit load margin.
$P^0_{\lambda t}$	Base case thermal limit load margin.
P^c_{λ}	Contingency case Load Margin.
$P^c_{\lambda v}$	Contingency case voltage limit load margin.
$P^c_{\lambda t}$	Contingency case thermal limit load margin.
$P^0_{inf,0}$	Base case (pre-contingency) interface flow
$P^c_{inf,0}$	Contingency case interface flow without stress.
$P^c_{inf,\lambda}$	Contingency case interface flow at P^c_{λ}
$P^c_{inf,\lambda v}$	Contingency case interface flow at $P^c_{\lambda v}$
$P^c_{inf,\lambda t}$	Contingency case interface flow at $P^c_{\lambda t}$

Figure 60 shows examples of real P-V and Q-V curves (Li et al. 2004).

Figure 60: P-V and Q-V Curves Produced by VSA&E Tool (Li et al. 2004)



(a) P-V curve



(b) Q-V Curve

Critical Interface and Deterministic Transmission Limits

Generally, deterministic transmission limits can be induced by thermal, voltage, voltage stability, and transient stability constraints. A transmission constraint (TC) on a transmission path i-j is denoted as TC_{ij}. The usual conditions that are set and monitored for the TCs are as follows:

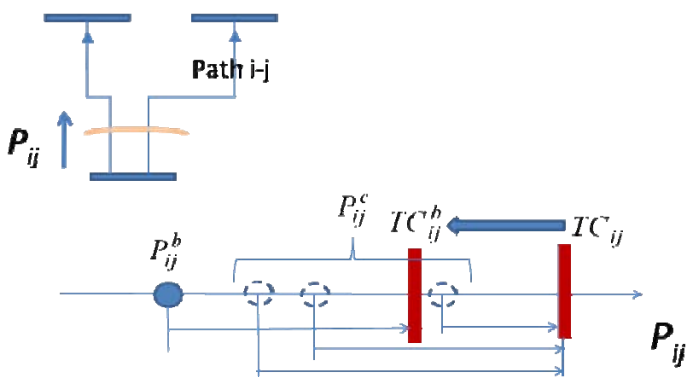
$$\begin{aligned} &P_{ij}^{b} \le TC_{ij} \\ &\max P_{ij}^{c} \le TC_{ij} \end{aligned} \tag{1}$$

where P_{ij}^{b} and P_{ij}^{c} are power flows through the path i-j in the normal (base case) and contingency situations, respectively. Because the flow in the base case P_{ij}^{b} influences the contingency flows P_{ij}^{c}, that is $P_{ij}^{c} = f\left(P_{ij}^{b}\right)$, conditions (1) could be reduced to

$$P_{ij}^{b} \le TC_{ij}^{b} \tag{2}$$

where $TC_{ij}^{b} \le TC_{ij}$ is an adjusted base case deterministic limit for the base case conditions, selected to eliminate thermal violations on the path i-j for all analyzed contingencies. Figure 61 explains the idea of the adjusted base case deterministic limit TC_{ij}^{b} for the base case condition. If (2) is satisfied, then all contingency conditions (1) will be satisfied as well.

Figure 61: Critical Interface and Deterministic Transmission Limits



Selected TT-RTVSA Integration Approach and its Implications

The TT prototype is designed to minimize incremental efforts by taking maximum advantage of existing tools already deployed at the California ISO Control Center, mostly the real-time

voltage stability analysis and enhancement (VSA&E) tool and the mapping and visualization tool. This approach, supported by the California ISO, implies the following important consequences to the TT:

(a) The analysis is limited to several critical transmission paths (interfaces), so that all transmission constraints are represented as limits applied to power transfers along these paths. Mutual dependences between power transfers, as well as the limits on different paths, are ignored.

(b) The limits are determined based on certain stress patterns applied to system generation and load. Possible deviations from these patterns, resulting in changing transmission limits, are ignored.

(c) Generation redispatch algorithms are limited to the ones embedded into the RTVSA tool.

(d) Voltage and reactive power changes are reflected using P-V and Q-V curves. Variations of these curves resulting from changing stress patterns are ignored.

(e) The TT has no access to the internal algorithms and information processed by the VSA&E tool, so the TT algorithm has been designed to process only the input and output VSA&E information.

CHAPTER 3:
Transmission Tool Outputs and Their Utilization

The output parameters of our Transmission Tool (TT) are designed to enhance the RTVSA tool by adding the probability dimension to the analysis. Thus, instead of the deterministic *load margin*, which "is the maximum total real power transferred from source to sink before the system hits the voltage collapse point under a proposed stress pattern," a probabilistic value is calculated. This value is based on the acceptable probability of violations (can be set to zero) and their average and maximum size (can also be zero). If the probabilistic margin is found to be below its deterministic assessment, this indicates that random variations of power in the analyzed interface need to be addressed by an appropriate additional increase of the security margin and by applying additional controls helping to stay away from violations. Similarly, probabilistic *voltage reductions* and *reactive power margins* can be evaluated. Details of the proposed probability-based methodology are provided below in the following sections.

The main factor considered in this analysis is the impact of random variations of system load, wind and solar generation from their forecasted values on power transfers in the analyzed transmission paths. These impacts can be revealed by simulating *forecasting errors* (of different kinds) distributed over a large geographical area. The *state space model* developed for this purpose presented in Makarov et al. (2010). Errors caused by *variability* (deviations from flat energy schedules) are also simulated. Based on this model and an incremental linearized model reflecting the impacts of system imbalances on power transfers, by repeating simulations of random forecast errors and the corresponding increments of monitored flows, we determine the *probability distributions* of the flows. These distributions are used to find the *probabilistic load margin*. Also, these distributions and P-V and Q-V curves computed by VSA&E – RTVSA tool are used to determine probability distributions of the voltage magnitudes and reactive power margins.

Probability Distribution of Transmission Flows

In this project, a probabilistic approach is applied, where the probability of violating the preset transmission limit, as well as the average and maximum size of violation will be evaluated. Random factors contributing to this possible violation include random unpredicted variations of wind, solar generation and system load. Their model will be described below. Similar to a deterministic approach, the analysis will be conducted for a specified set of contingencies.

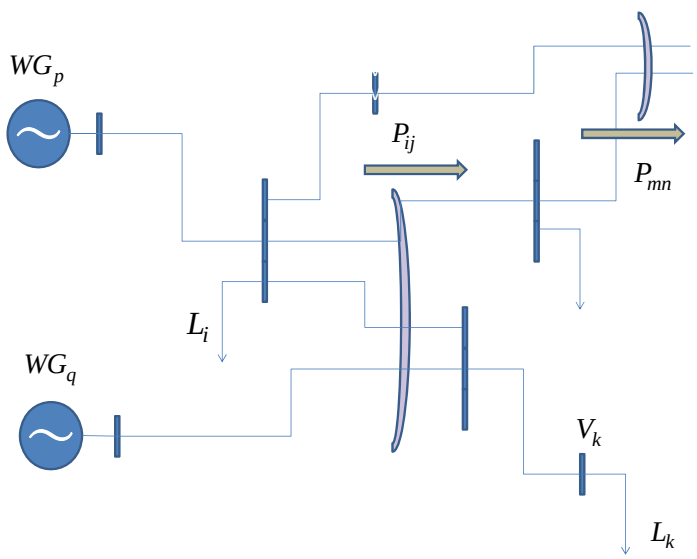
The *probability distribution of transmission flows* can be obtained by multiple *Monte Carlo runs,* where the power mismatches caused by forecasting errors and variability in different parts of the system are simulated repeatedly using *the state-space and variability models* described below in this report. Resulting power flow variations in the analyzed transmission paths are obtained with the help of *linearized incremental power flow model* and power transfer distribution factor (PTDF) factors as described below.

This section describes how the probability distribution of these flows can be obtained (the probability distribution – PDF, and cumulative distribution – CDF functions).

Because the flows can demonstrate certain mutually correlated and non-parametric statistical behaviors, it is important to select an adequate form of representing the PDF and CDF functions. The analytical form (based on certain known distributions, e.g., normal distribution) hardly serves this purpose. The flow distributions can also demonstrate certain autocorrelation, especially between short subsequent dispatch intervals. That is why multidimensional histograms were selected for this work as an approach to describe the multidimensional distributions of power flows on multiple critical paths of the system.

Figure 8 gives an example of a system part, where two critical paths are shown, P_{ij} and P_{mn}. Variations of power transfers in interfaces i-j and m-n are caused by wind generators WG_p, WG_q,… and loads L_i, L_k,….

Figure 62: Example Part of a Power System



The collective impact of variability and forecast uncertainty from all these resources can be depicted as follows.

Probability of Violation of Transmission Limits

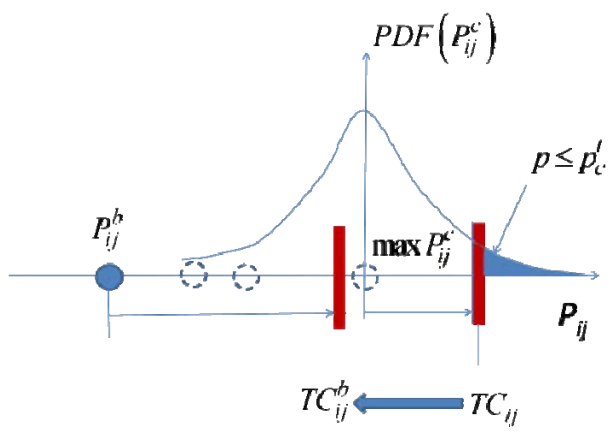
The user will specify maximum acceptable probabilities of violating transmission limits caused by random variations of uncertain parameters around their forecasts in the base case, p_b^t, and under contingency conditions, p_c^t. In case of limits induced by stability conditions, this probability should be zero. This figure shows a distribution $PDF\left(P_{ij}^c\right)$ of possible values of i-j

power flow in the most limiting contingency. (PDF stands for the probability density function.) The probability of having a power flow above the limit TC_{ij}, corresponding to the most limiting contingency, where $P_{ij} = \max P_{ij}^{c}$, is

$$p = \int_{TC_{ij} \le \tau < \infty} PDF(\tau) d\tau \tag{3}$$

This probability of having the flow above the thermal limit in this contingency should be kept below a user specified level, $p \le p_c^t$. If this probability exceeds p_c^t, the power flow in the base case P_{ij}^b should be additionally limited by adding a more restrictive limit TC_{ij}^b to be enforced during system operation, as shown in Figure 63.

Figure 63: Probabilistic Limits for Base Case Conditions and Contingencies



Therefore, the TC-adjustment algorithm will be as follows:

1. Select one of congested transmission paths, i-j.
2. Calculate PDF functions and probabilities (3) for all contingencies and the base case.
3. Find the most limiting contingency, where the probability of exceeding the transmission thermal constraint is greater than its acceptable value, p_c^t, $p > p_c^t$. If, for all analyzed contingencies, $p \le p_c^t$, go to step 7.
4. Adjust the base-case loading on path i-j, by the value ΔP_{ij}, which makes $p \le p_c^t$ in the most limiting contingency.
5. Check if the adjustment works for all remaining contingencies, so that $p \le p_c^t$. If, for some contingencies, the probability of violation still exceeds the limit level p_c^t, increase the adjustment ΔP_{ij} accordingly.

6. Adjust the power transfer limit in the base case using ΔP_{ij}.

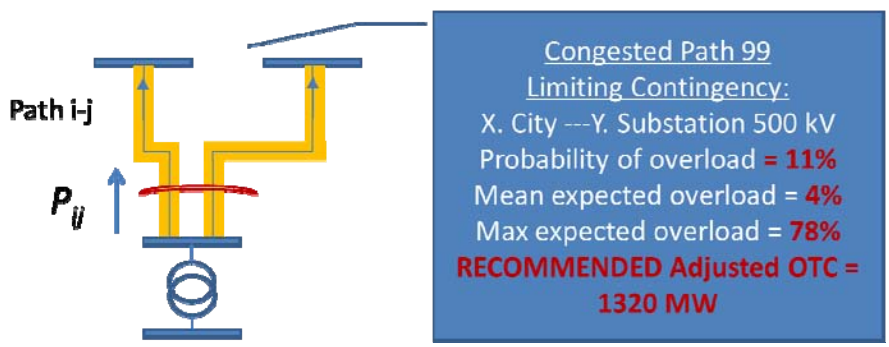
$$TC_{ij}^{b} = TC_{ij} - \Delta P_{ij} \tag{4}$$

7. Check if the probability of exceeding the thermal limit is greater than its limit in the base case, that is, if p is greater than p_b^t or not. If yes, additionally adjust ΔP_{ij} and $TC_{ij}^{b} = TC_{ij} - \Delta P_{ij}$.

8. Repeat the procedure for all analyzed transmission paths and contingencies.

A summary of output parameters of the algorithm is provided in Figure 10. When the probability of thermal overloads exceeds its threshold value, say $p_c^t = 0.5\%$, transmission facilities forming the corresponding path i-j will be highlighted on the system map, and a call-out box will appear on the screen near the path. In the box, the most limiting contingency will be displayed, along with predicted probability of an overload in this contingency, expected mean and expected maximum magnitudes of the overload, and the recommended adjusted operating transfer capability (OTC) limit TC_{ij}^{b} that should be obeyed in base-case condition to reduce the probability of overload to an acceptable minimum.

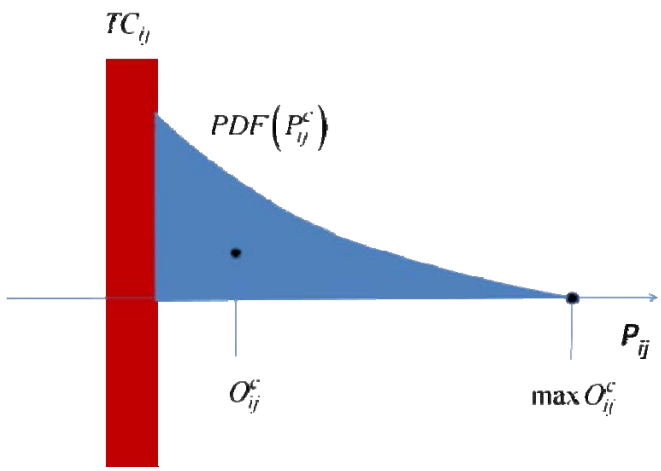
Figure 64: Advisory Information for Probabilistic Assessment of Congested Transmission Paths



The probability of overload p is calculated using Eq. (3). Note that this is a conditional probability; that is, it is assumed that the contingency has happened already when it is calculated. The mean expected overload O_{ij}^{c} is estimated using Eq. (5), and the maximum overload O_{ij}^{c} corresponds to the maximum power transfer $P_{ij}^{c} = \max P_{ij}^{c}\big|_{P_{ij}^{c}=0}$, where the PDF reaches zero – see Figure 65.

$$O_{ij}^{c} = \frac{\int_{TC_{ij} \le \tau < \infty} \left(\frac{P_{ic}^{c} - TC_{ij}}{TC_{ij}} \right) PDF(\tau) d\tau}{\int_{TC_{ij} \le \tau < \infty} PDF(\tau) d\tau} \quad [\%] \tag{5}$$

Figure 65: Mean and the Maximum Overloads

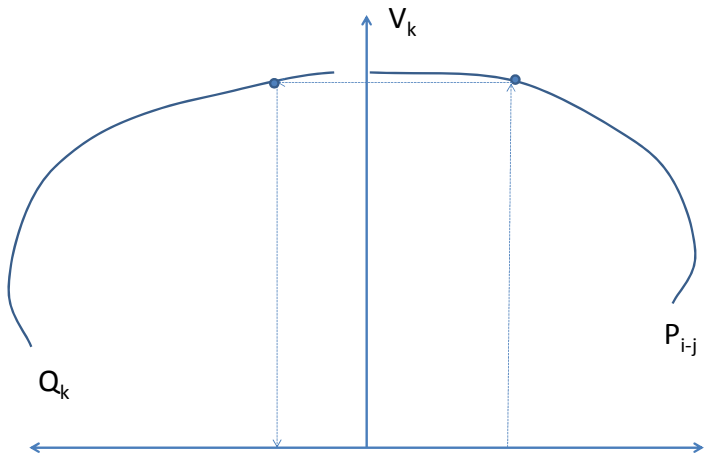


Probability Distribution of Voltage Levels and Reactive Power Margins

The proposed approach includes P-V and Q-V curves produced by the RTVSA software tool as described above. The RTVSA tool stresses selected transmission paths one by one by gradual changes of system nodal power injections (generation and load) in certain proportions. For selected buses and selected contingencies, P-V and Q-V curves are produced. They link the power flow in a selected path *P*ij with voltage magnitude *V*k and reactive power *Q*k at selected buses. The same curves can be used to translate PDF functions calculated for the flow *P*ij. This idea is shown in Figure 66.

In the proposed method, Monte Carlo simulations are used to build a comprehensive probabilistic model and determine TT outputs. For each Monte Carlo run, certain value of *P*ij is determined. Based on this value and P-V curve, voltage levels *V*k at the most important bases *k* are determined. Q-V curves help to link these values with the reactive power injections corresponding to these voltages. Ultimately, through multiple simulations, histograms, PDF and CPF functions can be determined for voltages *V*k and reactive power values *Q*k. The rest of the analysis is similar to the one described above for the probabilistic transmission flows.

Figure 66: The Idea of Using P-V and Q-V Curves to Obtain Probability Distributions of Voltages and Reactive Power



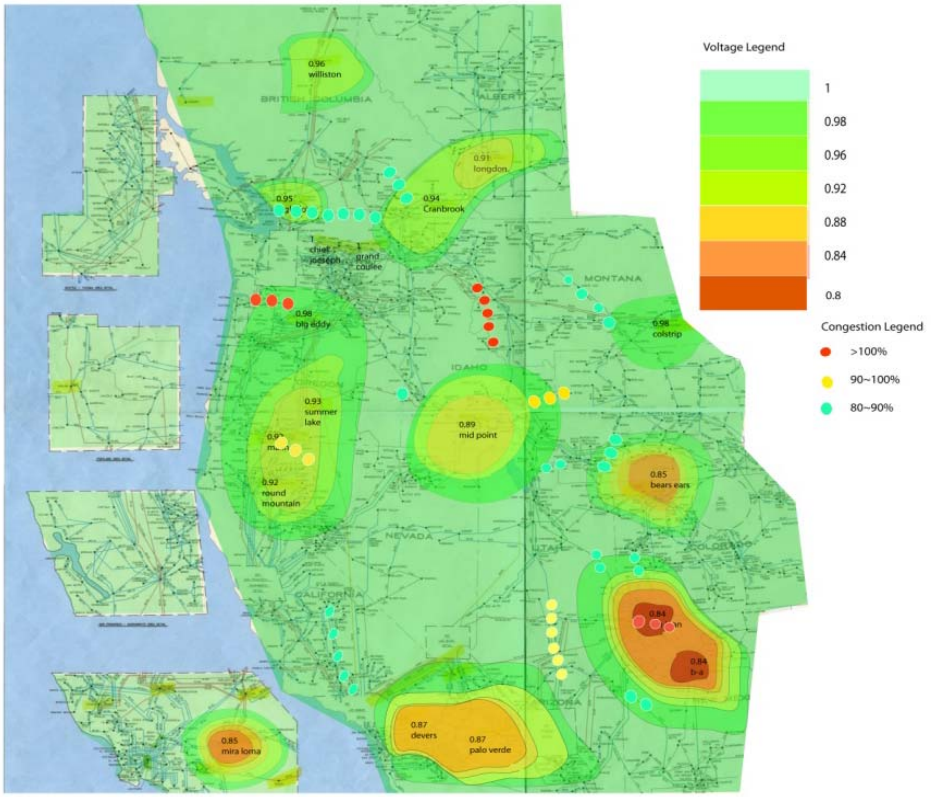
CHAPTER 4:
Connectivity with Visualization Software

Software tools provide advanced visualization capabilities and are widely used at California ISO. Integration of the TT tool developed by PNNL with the existing visualization software will eliminate unnecessary duplication of the effort in this area. Nevertheless, before this integration really happens, PNNL has developed certain prototype displays to demonstrate the performance and features of the TT tool.

Results of the analysis are represented on a map containing the California system or all WECC systems. Two conceptual designs of the map are shown in Figure 67 (conventional map design) and Figure 68 (Google Earth based map design).

In Figure 67, dotted lines represent potentially congested paths, where the average overload or probability of overload exceed their user-specified thresholds. Contours show voltage levels expected in the system.

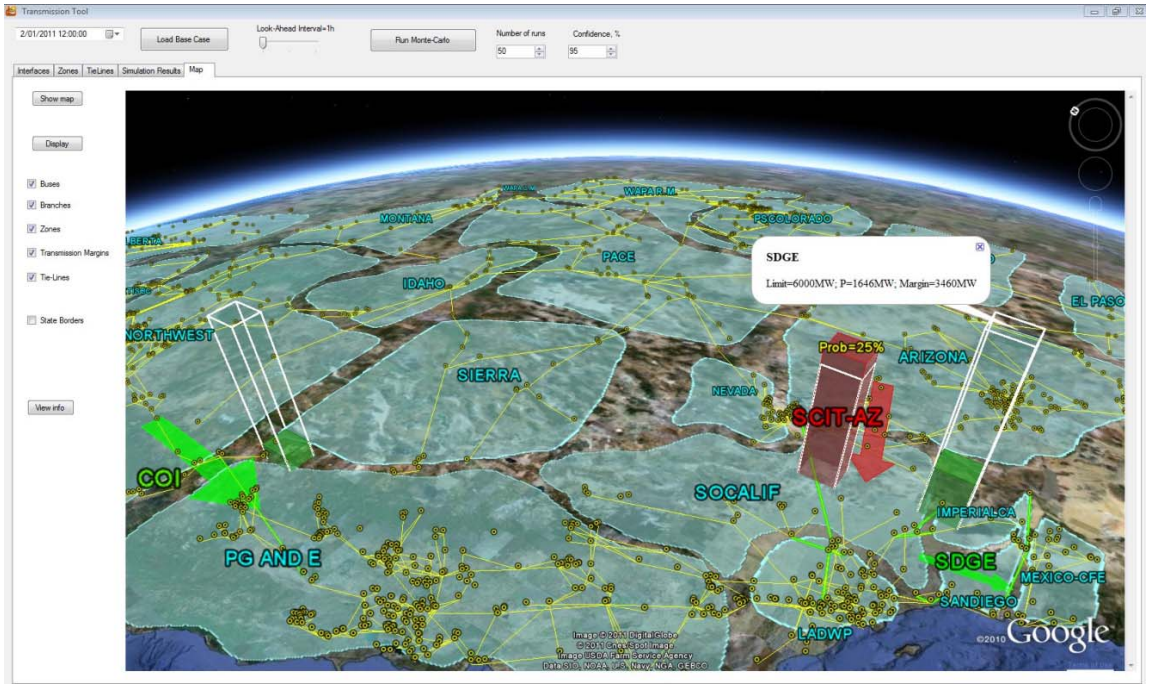
Figure 67: A Conceptual Screen for Visual Presentation of Transmission Tool Results on a Conventional Map



In Figure 68, arrows show congested paths. Congested transmission interfaces and buses with potential voltage problems can be highlighted on the Google Earth display. Depending on probability of transmission and voltage limits violation, different colors can be used. Three-dimensional bars and cylinders can be used to show the size and probability of transmission congestions or voltage stability problems. The filling of the bars reflects the expected maximum load on these paths in the most critical contingency. If the probability of overload or the average overload exceed their user-specified thresholds, the filling overflows the bar and its color becomes red.

Real-time dispatchers can select the look-ahead time (up to several hours ahead), specify the alarming threshold probability for system problems and voltage levels, and establish desirable security margins with respect of the maximum overload or minimum voltage level leading to thermal violation, voltage collapse, or transient instability.

Figure 68: A Google Earth Design of the TT Screen



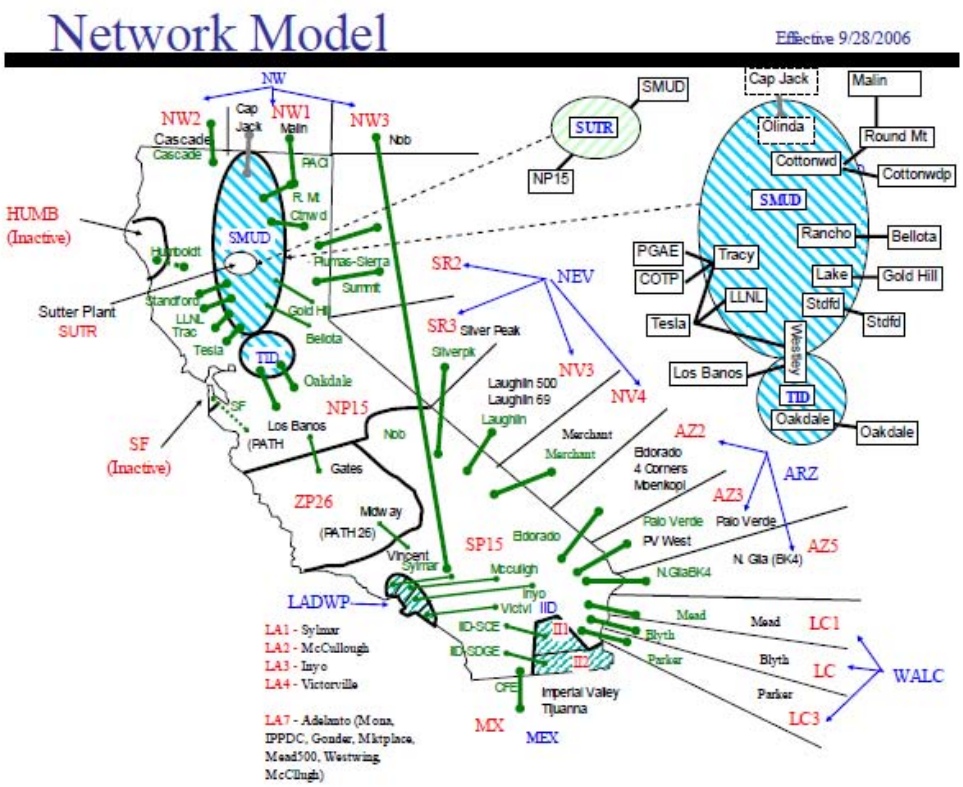
CHAPTER 5: Methodology

The methodology developed for the TT tool consists of the linearized power system congestion model and state space uncertainty model. The state space uncertainty model is described in detail in Makarov et al. (2010).

Power System Congestion Model

Figure 15 shows a one-line diagram of congested paths within and around the California ISO control area (Department of Market Monitoring 2007).

Figure 69: Active Congestion Zones and Branch Groups (Department of Market Monitoring 2007)



There are nine interfaces in this power system model analyzed by the prototype tool. Table 4 provides a description on these system interfaces and the number of lines in each interface. Interfaces are transmission lines between two control areas (Figure 16). Some major interfaces are monitored and some transmission lines are not. Some control areas have multi-line interfaces between them (see interface 2 between Area 1 and Area 2 in Figure 17).

Table 4: Interface Description

Interface	Number of Lines in Interfaces
COI-NW	3
EOR-AZ	6
HM	4
PATH26(N2S)-PGE	3
SCIT-AZ	26
SCIT-NW+AZ	26
SDGE	7
SDGE+CFE	6
WOR-AZ	14

Figure 70. Interfaces Between Two Areas

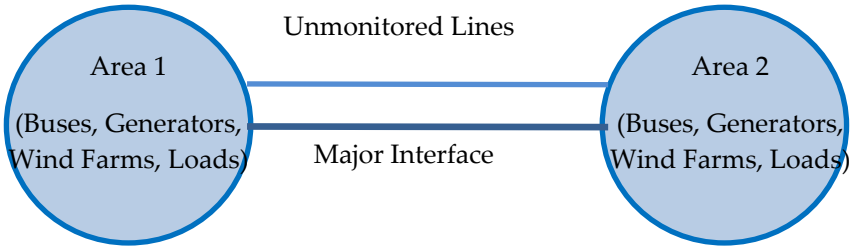
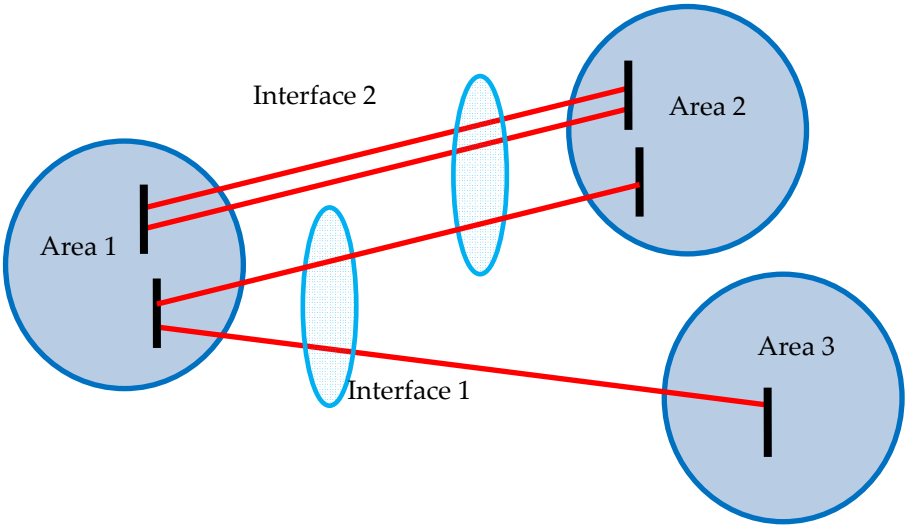


Figure 71. Multi-Line Interfaces Between Areas



Linearized Incremental Power Flow Model and PTDF

The system managed by California ISO is a complex one. A description of the system model as it relates to this project is given below. The prototype tool does not address the full complexity of this system model. A simplified linearized version of this full model is used to meet the objectives of this project.

The proposed power flow linearized incremental model is used in this project to evaluate the incremental impacts of wind, solar, and load variability and uncertainty on power transfers in the analyzed paths. The model allows simplifying and speeding up multi-variant computations needed to implement a probabilistic assessment of power transfer and voltage variability using the Monte Carlo method. The incremental analysis is conducted around selected base cases and contingencies produced using the full AC system model. The procedure used to create the incremental model using Power World Simulator software is presented and illustrated in this section using an example of the WECC system model.

In the WECC documents, the term "area" is used to describe regionally aggregated elements of an electric power system. To provide a more specific definition of uncongested areas of the transmission grid and to avoid confusion with the term "control area" (a.k.a. "balancing authority"), we will use the term "zone". Zones are connected through congested interfaces, but there is no congestion within a zone.

The full WECC system model used in the study consists of 15,580 buses, 19,844 branches, and 3,030 generators. A total of 21 zones are defined in the model (Table 5). This structure corresponds to the WECC area structure given by WECC (2007).

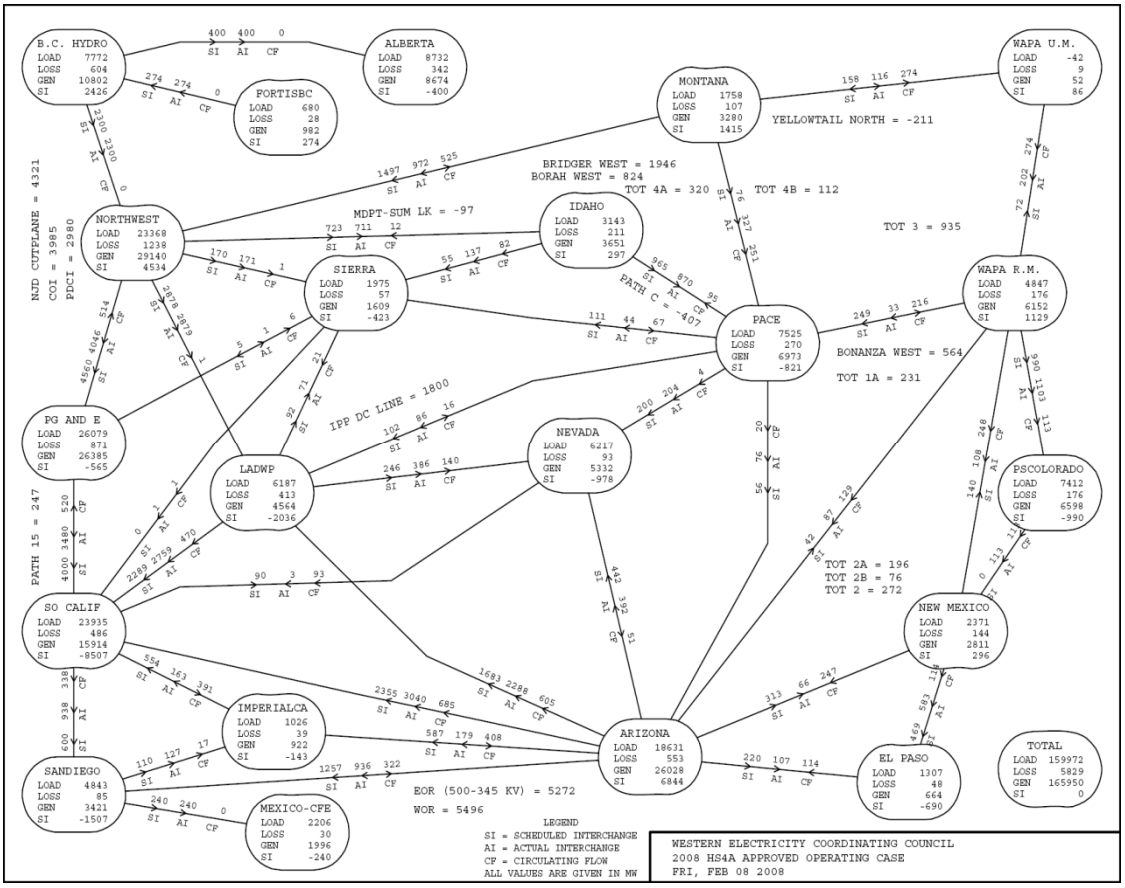
Table 5. Zonal Information

Zone Number	Zone Name	Zone Number	Zone Name
10	NEW MEXICO	50	B.C.HYDRO
11	EL PASO	52	FORTISBC
14	ARIZONA	54	ALBERTA
18	NEVADA	60	IDAHO
20	MEXICO-CFE	62	MONTANA
21	IMPERIALCA	63	WAPA U.M.
22	SANDIEGO	64	SIERRA
24	SOCALIF	65	PACE
26	LADWP	70	PSCOLORADO
30	PG AND E	73	WAPA R.M.
40	NORTHWEST		

In the proposed model, some uncongested zones may belong to several control areas, and some control areas may consist of several zones.

Figure 72 shows the zonal structure of the WECC system model as provided by WECC (2007). Figure 73 presents the key WECC transmission paths (WECC 2005). Information regarding the operating transfer limits between the zones can be found in the WECC 2008 Path Rating Catalog and other WECC official documents (WECC 2008a, 2008b).

Figure 72: Zonal Structure of the WECC System



Mathematical Definition of the Incremental Model

The incremental impact analysis is used to find a relationship between variations of the total zonal active power imbalance and related active power-flow variations in selected transmission interfaces.

The active power-flow variation in the interface between the zones *i* and *j* can be calculated as:

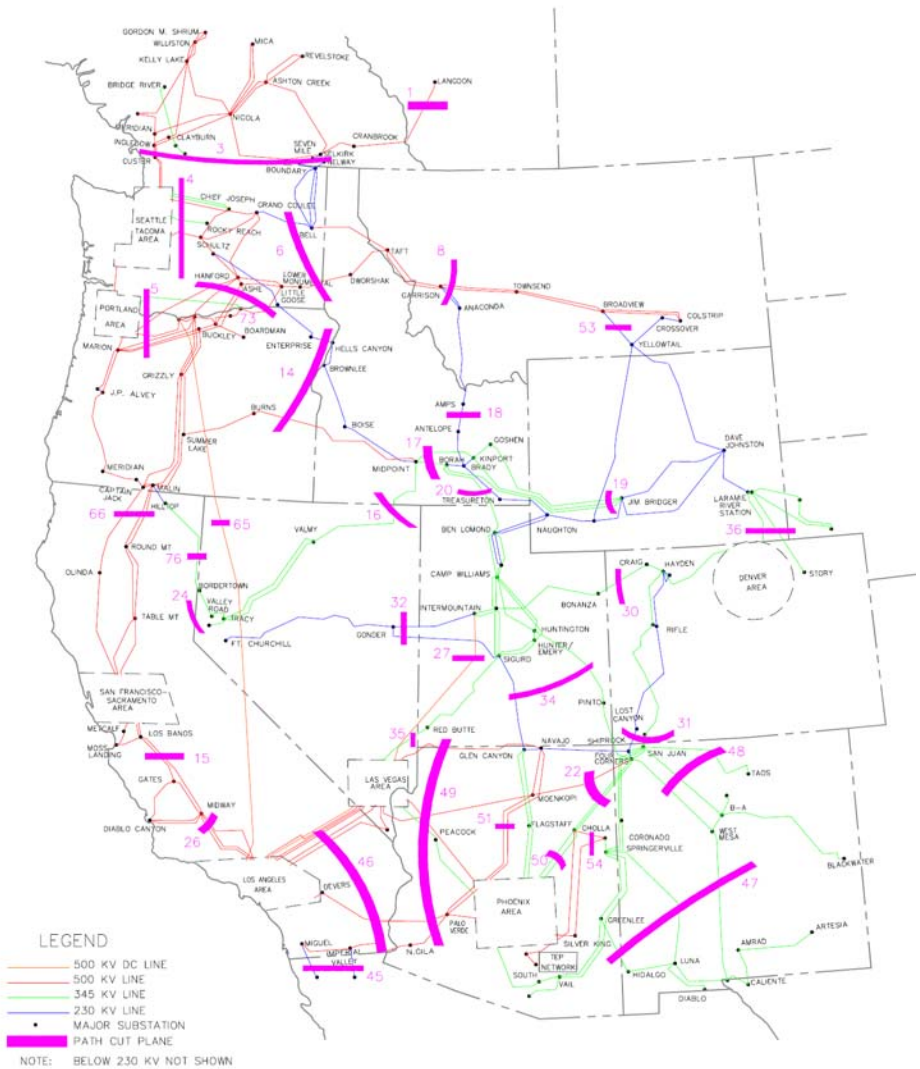
$$\Delta P_{ij} = \sum_{n=1}^{N} PTDF_n^{ij} \Delta P_n \tag{6}$$

where N = the number of zones in the system,

ΔP_n = variation of total active power generation in zone n, and

$PTDF_n^{ij} = \dfrac{\Delta P_{ij}}{\Delta P_n}$ = a power transfer distribution factor reflecting the influence of generation in zone n on the power flow in the interface i-j.

Figure 73. WECC System Transmission Lines And Paths (WECC 2005)



Incremental Model Development Using Power World Simulator

The Power World Simulator software can be used to create the incremental zonal model of the WECC system. A fragment of the interface PTDFs table calculated for the WECC zonal model using Power World simulator is presented in Table 6.

For example, if generation in the New Mexico zone increases by 200 MW, power flow through interface New Mexico – PS Colorado will change by 200 · 0.05 = 10 MW, because the impact of New Mexico zone on New Mexico – PS Colorado interface is equal to PTDF = 5% (see Table 7).

Table 6: Interface PTDFs (%)

Name	NEW MEXICO	EL PASO	ARIZONA	NEVADA	IMPER-IALCA	SOCALIF	LADWP	PG AND E	NORTHWEST
NEW MEXICO-PSCOLORADO	5	2.2	1.4	1	1	0.9	0.5	0.5	0
NEW MEXICO-WAPA R.M.	7.8	8.1	6.3	4.3	4.3	4.1	1.7	2.1	-0.2
EL PASO-NEW MEXICO	-19.2	30.8	1.4	0.5	0.7	0.6	0.2	0.3	0.1
ARIZONA-NEW MEXICO	-69.9	-25.1	8.3	6.6	6.3	6.4	3.9	4.4	1.9
ARIZONA-EL PASO	-19.4	-72.2	2	1	1.2	1.1	0.7	0.9	0.6
ARIZONA-NEVADA	1.9	3	5.7	-44.5	4.6	3	0.8	1.7	0.7
ARIZONA-IMPERIALCA	0.7	0.8	2.1	0.7	-21.6	-0.7	-0.1	-0.3	-0.2
ARIZONA-SANDIEGO	6.7	8.2	9.6	3	-7.1	-5.3	-0.2	-1.2	-0.3
ARIZONA-SOCALIF	25.4	29	29.7	-2	-12.3	-15.8	-7.3	-11.8	-8
ARIZONA-LADWP	19.5	24	29.2	13.3	7.7	-11.2	-11	-12.5	-9.2
ARIZONA-PACE	11.8	12	10	5.1	5.9	4.9	-3	0.4	-3.6
ARIZONA-WAPA R.M.	2.4	3.1	3.2	2.2	2.2	2.1	1	1.2	0
NEVADA-SOCALIF	0.6	0.8	1.1	12.2	0	-1.7	-0.6	-1.4	-0.9
NEVADA-PACE	0.6	1.6	3.8	6.7	4	4.3	-0.8	1.4	-1.4
MEXICO-CFE-SANDIEGO	-1.3	-1.3	-1.5	-1.3	-1.3	-1.3	-1.2	-1.4	-1.4
IMPERIALCA-SANDIEGO	-0.1	-0.1	0.3	0.3	18.9	-0.1	0.1	0.1	0.1
IMPERIALCA-SOCALIF	0.1	0.3	0.8	-0.2	56.7	-1	-0.7	-0.9	-0.8
SANDIEGO-SOCALIF	3.2	4.7	6	0.1	8.7	-8.4	-3.1	-4.5	-3.6
LADWP-NEVADA	2.5	2.8	3.2	-36.4	2.9	3.3	1.3	2.3	0.9
LADWP-SOCALIF	13.8	17.7	22.1	46.8	2.3	-16.6	61.3	-17.1	-12.6
LADWP-NORTHWEST	0	0	0	0	0	0	0	0	0
LADWP-SIERRA	1	1	0.6	0.3	0.2	0	2.4	-0.9	-0.9
LADWP-PACE	-1.8	-1.9	-1.6	-1.3	-1.1	-0.9	24.9	-0.1	-0.1

The incremental model approach results were compared with the real full AC power flow model results to validate the accuracy of the incremental model approach. An example of interface power flows calculated using the full system model, estimated using the incremental model, and the estimation errors are given in Table 7. Table 7 also validates the estimation

accuracy of the incremental model for contingencies. It can be seen that the MW error of the linearized incremental model is very small.

Table 7: Interface Power Flow Validation

	Contingency 1			Contingency 2			Contingency 3		
Interface Name	Full model, MW	Incremental model, MW	Error, MW	Full model, MW	Incremental model, MW	Error, MW	Full model, MW	Incremental model, MW	Error, MW
NEW MEXICO-PSCOLORADO	-91.1	-91.1	0	-91.2	-91.1	-0.1	-91.1	-91.1	0
NEW MEXICO-WAPA R.M.	-88.9	-88.564	-0.336	-88.3	-87.9	-0.4	-89.5	-88.9	-0.6
EL PASO-NEW MEXICO	-292.5	-292.418	-0.082	-292.5	-292.75	0.25	-292.4	-292.25	-0.15
ARIZONA-NEW MEXICO	113.3	113.958	-0.658	109.7	107.65	2.05	115.9	117.15	-1.25
ARIZONA-EL PASO	365.9	365.992	-0.092	364.2	364	0.2	366.8	367	-0.2
ARIZONA-NEVADA	440.5	440.574	-0.074	437.5	438.25	-0.75	443.6	441.75	1.85
ARIZONA-IMPERIALCA	250.5	250.436	0.064	250.7	251.1	-0.4	250.2	250.1	0.1
ARIZONA-SANDIEGO	979.1	978.854	0.246	978.1	979.85	-1.75	978.4	978.35	0.05
ARIZONA-SOCALIF	3369.9	3368.54	1.36	3387.5	3395.1	-7.6	3356.7	3355.1	1.6
ARIZONA-LADWP	2663.3	2661.956	1.344	2685.6	2692.5	-6.9	2648	2646.5	1.5
ARIZONA-PACE	-77	-76.952	-0.048	-65.4	-65	-0.4	-82.7	-83	0.3
ARIZONA-WAPA R.M.	-64.6	-64.4	-0.2	-64.6	-64.4	-0.2	-64.6	-64.4	-0.2
NEVADA-SOCALIF	67.9	67.762	0.138	70.7	70.75	-0.05	65.8	66.25	-0.45
NEVADA-PACE	196.4	196.552	-0.152	201.7	201.2	0.5	193.7	194.2	-0.5
MEXICO-CFE-SANDIEGO	-154.9	-155.048	0.148	-149.6	-150.4	0.8	-157.2	-157.4	0.2
IMPERIALCA-SANDIEGO	-87.1	-87.118	0.018	-87.4	-87.45	0.05	-87	-86.95	-0.05
IMPERIALCA-SOCALIF	191.9	191.744	0.156	194.2	194.4	-0.2	190.5	190.4	0.1

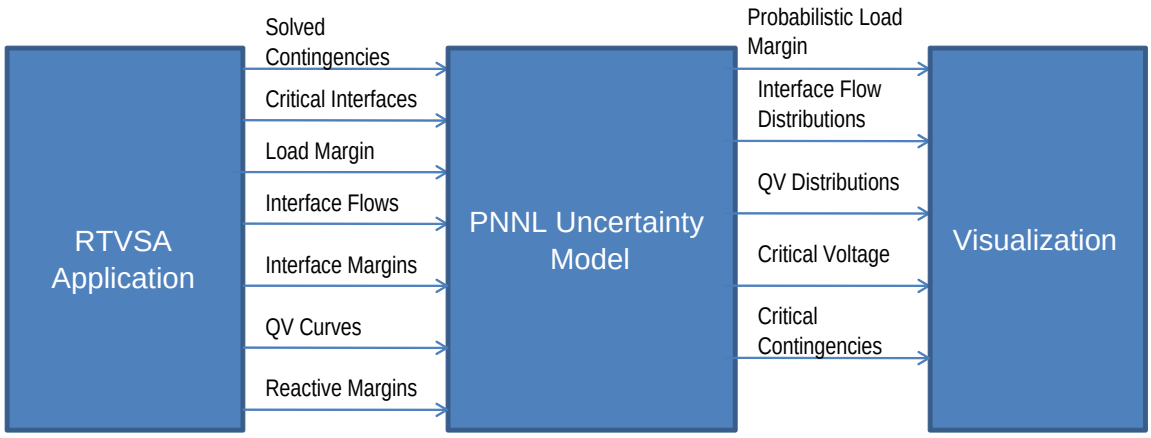
CHAPTER 6:
High Level Transmission Tool Description

This section gives a description of the TT tool on a block-diagram level.

Connectivity Diagram with Real-Time Voltage Stability Analysis Tool and CAISO Visualization Software

Figure 74 illustrates the connections and type of information to be exchanged PNNL's TT and RTVSA and visualization software. Details of the shown information exchange were provided in the previous section of this report.

Figure 74: Connections and Type of Information to be Exchanged PNNL's TT and RTVSA and Visualization Software

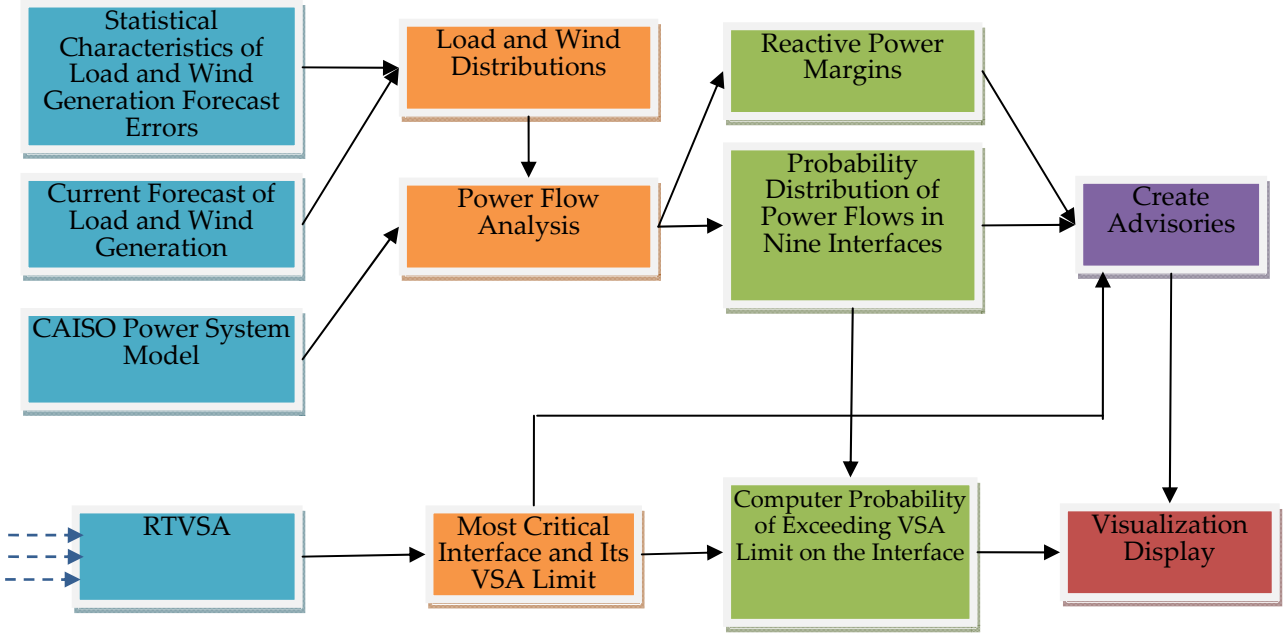


Internal System Architecture

The TT utilizes the output of existing RTVSA tool in California ISO to predict the available probabilistic voltage stability margin along the most important congested paths, worst case voltage drop, and reactive power margin for 1 to 3 hours ahead of time and in 5-minute resolution for a given set of contingencies. If congestion and voltage problems exist in the system, the tool suggests control actions in the form of advisory messages to mitigate the problem.

Figure 75 illustrates the internal architecture of the TT.

Figure 75: Architecture of the Transmission Tool



Platform

The transmission tool is a stand-alone application for a PC with Microsoft Windows operating system. The database used by the tool is Oracle Express. The transmission tool was developed in Visual Studio 2008, primarily Visual Basic, using Oracle Express. The tool will provide connectivity with the existing RTVSA tool and secondarily, for display purposes, with the visualization tool. An electronic help system is included with the application.

System Features and Benefits for CAISO

The analyzed impacts of TT include:

1. Impacts on congestion;
2. Impacts on voltage and transient stability margins, and
3. Impacts on voltage reductions and reactive power margins.

The impacts are analyzed in the base case and under all user-specified contingencies, so that the most limiting contingency is determined and addressed.

Information provided to the real-time dispatchers by transmission tool includes:

1. The *probability of violation of transmission constraints*; this probability can be compared against the corresponding threshold risk levels specified by the users. If the violation probability exceeds the threshold, the TT issues advisory information suggesting an increase of the security margin helping to lower the probability of violation to an acceptable level.

2. The *average and the maximum size of violations*; the average size of violations are compared against their user-specified thresholds. If the average expected violation exceeds a user-specified threshold, the TT issues advisory information suggesting an increase of the security margin helping to lower the average size of violation to an acceptable level.
3. The available *probability-based security margin* (a distance to violation) and recommendations on its increase whenever is required, and
4. Visualization of the transmission impacts, real-time dispatcher alerts and advisory information on a WECC or California system map.

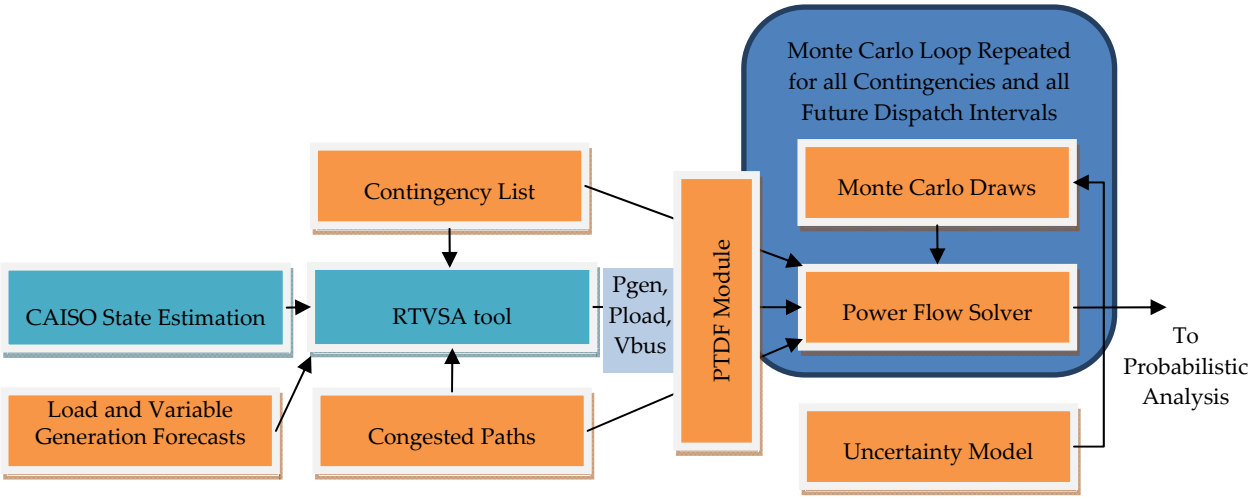
The proposed transmission tool has several very important advantages and opportunities for the California system operators:

- *Better quantification of available security margins*. Because the analyzed transmission impacts are caused by random variations of forecast errors in different parts of the system, they are not predictable in a deterministic sense. Based on a statistical analysis of multiple forecast errors, the tool provides a unique opportunity to adjust security margins depending on the risk (expected size and probability) of potential transmission violations.
- *Better reliability level*. By adjusting the system security margins on critical paths in the system, the tool helps to prevent potential violations caused by random variations of system load and variable generation around their forecasted values.
- *Better utilization of transmission assets*. In cases when the deterministic security margin is excessive, the tool will provide recommendations to reduce this margin based on the actual variability of the flows in the analyzed critical paths.
- *Better situation awareness and predictive system monitoring*. The TT algorithm is run for multiple look-ahead dispatch intervals and possible contingencies. Based on this information, system dispatchers will be informed about potential violations and associated risks on all critical paths in the system, and on the most critical contingencies as well as the expected time to violations.
- *Preventive control*. Because of its look-ahead feature, the TT algorithm leaves some time for mitigation measures, helping to reduce the expected size and probability of violations to an acceptable level.

Module 1: Power Flow Module

The power flow module contains a power flow solver based on the linearized incremental model. The power flow solver obtains power flow snapshots for all contingencies and future dispatch intervals from the RTVSA tool (e.g., generation, load and bus voltages etc.). The PTDF module produced PTDF factors used in the power flow solver. The uncertainty model is based on the state model described above. The Monte Carlo draws various system zonal loads and variable generation around their forecasted values based on the state uncertainty model. Figure 76 shows the structure and connectivity of the power flow module.

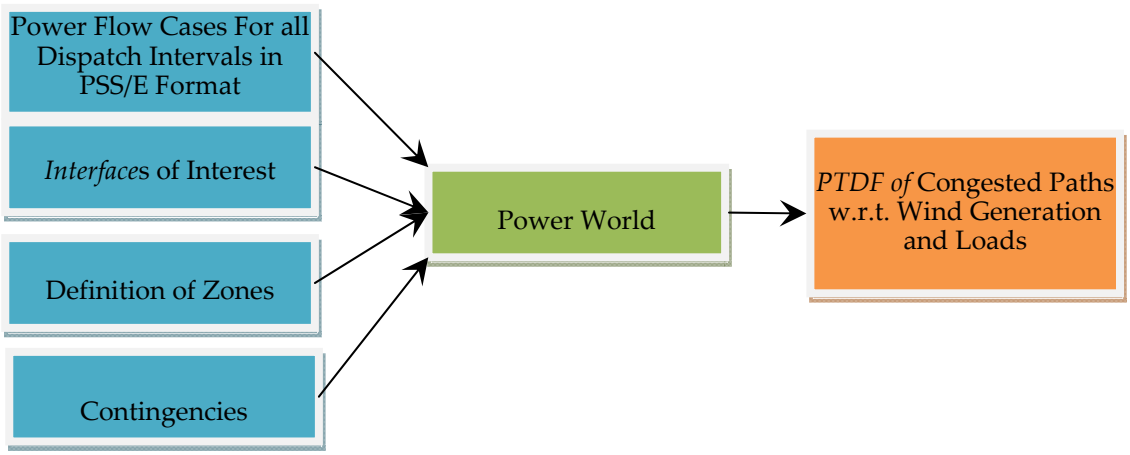
Figure 76: Power Flow Module



Module 2: PTDF Module

The purpose of the PTDF (power transfer distribution factor) module is to generate sensitivity of power flows in the analyzed congested paths to the changes in zonal loads and generation produced by Monte Carlo draws. This information is used by the power flow solver to evaluate changes of the power flows in congested paths caused by variations of zonal loads and generation from their forecasted values. In the industrial-grade version of the tool, the PTDF factors will be calculated internally. In the current prototype, these factors are calculated using Power World. The schematics of the PTDF module is shown in Figure 77.

Figure 77: PTDF Module

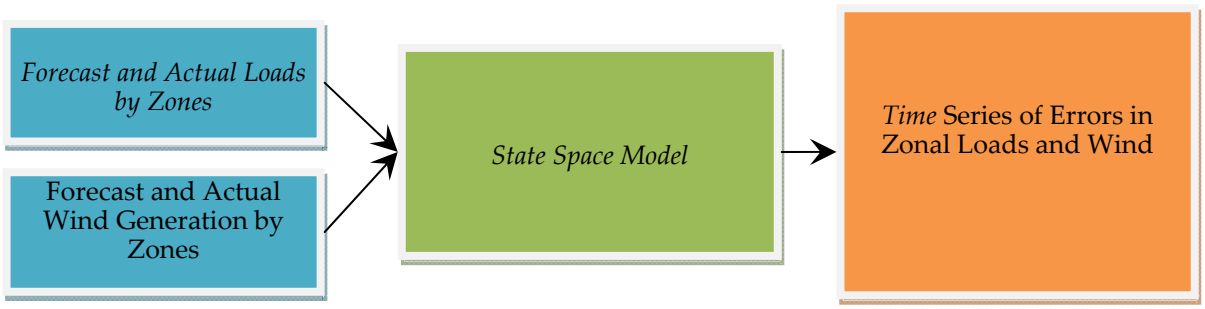


A snapshot of power flow cases for all analyzed contingencies and look-ahead dispatch intervals are received from the RTVSA application in PSLF format. The results of PTDF calculations are written into a database.

Module 3: Uncertainty Module

This module uses historical time series data on a number of variables (called state space variables) such as zonal loads, wind generation from various farms, etc. The actual information is compared with the forecasts, and the differences are used to build the state space model (WECC 2008a). The state space model preserves essential characteristics of the original data such as mathematical expectation, standard deviation, auto- and cross-correlation. The model produces numerous sets of generated samples that repeat statistical footprint of the original data (during the Monte Carlo draws).

Figure 78: Uncertainty Module



Module 4: Probabilistic Analysis

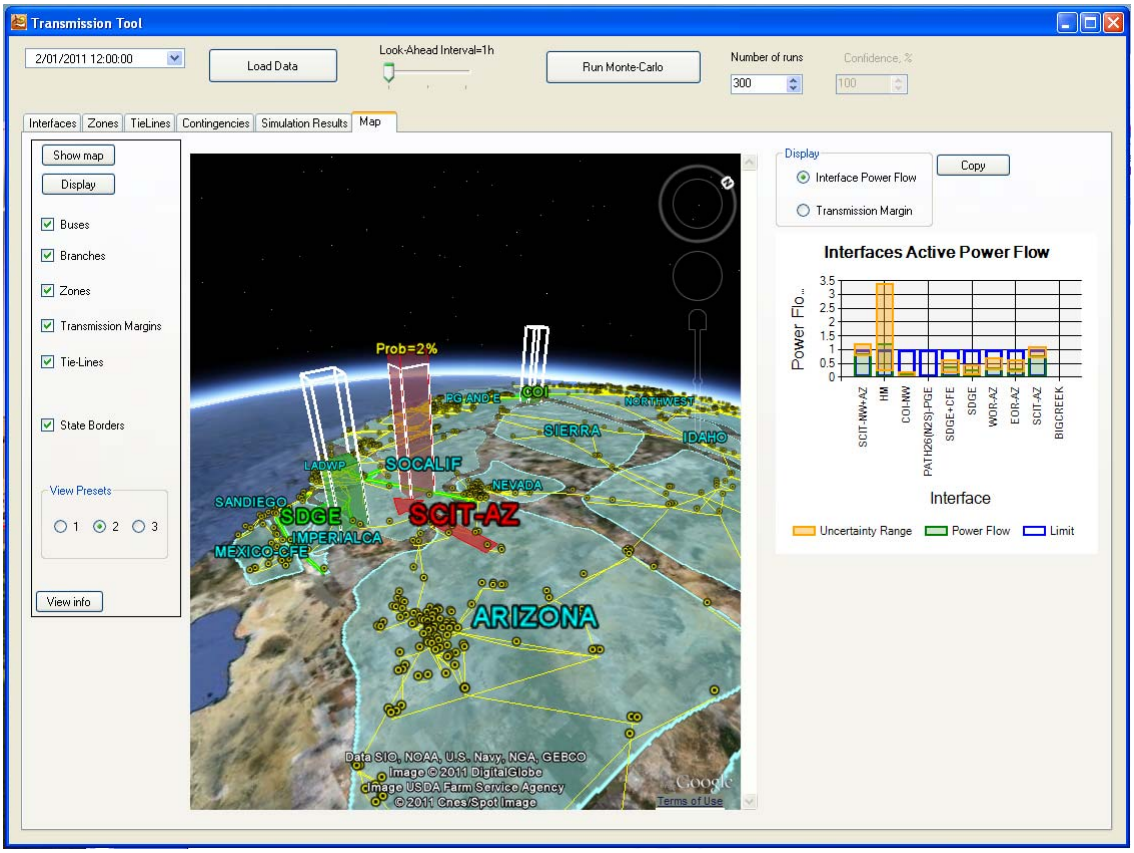
The output of power solver data collected for multiple Monte Carlo draws is fed into the probabilistic analysis module. The module builds histograms of power flows in selected critical paths, voltage levels at specified buses, and reactive power margin. The histograms are then converted into PDF and CDF of the corresponding variables. The distributions are compared against the corresponding transmission limits (posed by thermal, voltage, voltage and transient stability, and reactive power constraints). This comparison helps to evaluate the probability of system problems, and their average and maximum size, as described above.

CHAPTER 7:
User Interface Prototype

Graphic User Interface (GUI)

This project was conducted with the idea of interfacing the transmission tool with the visualization tools. Nevertheless, for the purposes of demonstration of our prototype TT capabilities and possible ways of presenting its results, PNNL created its own visualization output and graphical user interface (GUI). Figure 79 shows a snapshot of the main GUI of the prototype transmission tool. Figure 79 also displays active power flows in 10 critical interfaces (right upper corner of the GUI panel). The tool provides 1-hour ahead, 2-hour ahead, and 3-hour ahead analyses. Actual locations of substations and transmisison lines are plotted on the Google Earth platfom incorporated in the transmisison tool. Unacceptable probabilities of power flows exceeding their transmission limits are identified as red bars in Figure 79.

Figure 79: Main GUI of the Transmission Tool



Presenting Simulation Results

Figure 80 shows the interfaces' active power flows along the uncertainty range, and the limits are also shown in Figure 80.

Figure 80: Interfaces Active Power Flow

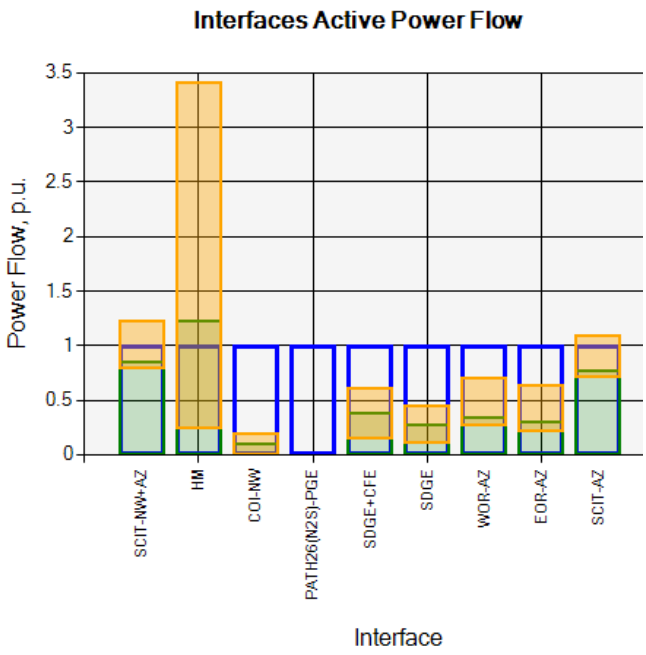


Figure 81 shows the transmission load margin in terms of interface active power flows along 10 interfaces.

Figure 81: Transmission Load Margin

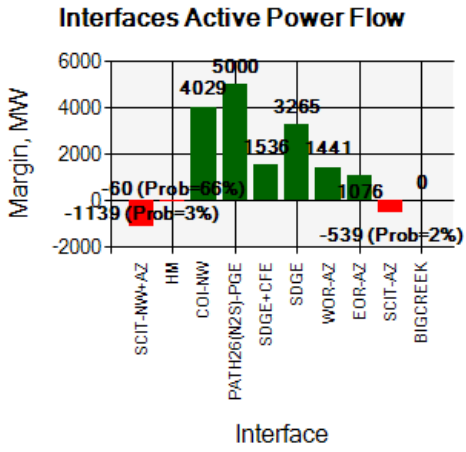


Figure 82 shows results of the incremental power flow simulations in a table format. The probability distributions of the power flow for different interfaces are also provided in the tool. The user can pick up any interface of interest to see the distribution.

Figure 82: Simulation Results – Incremental Power Flow

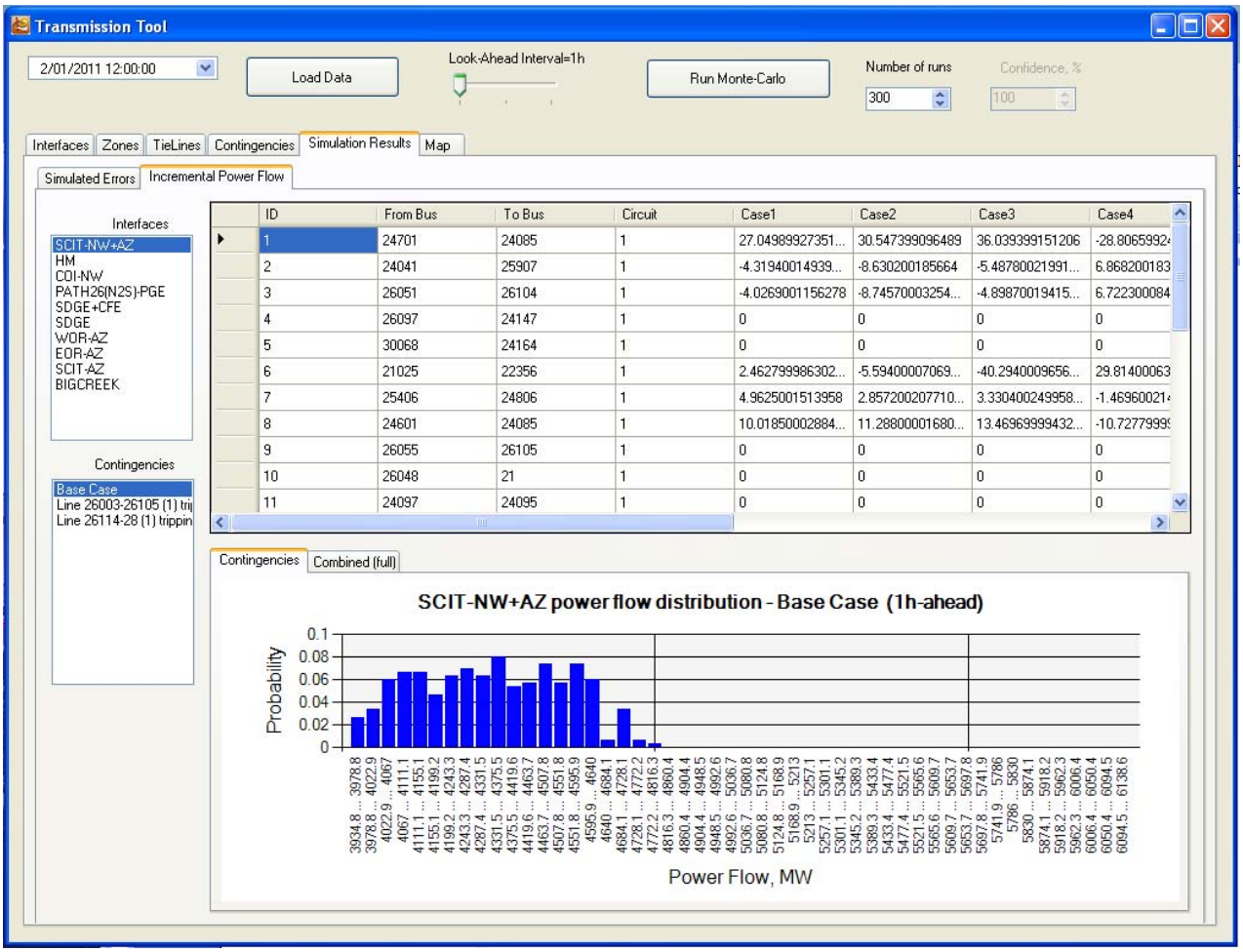
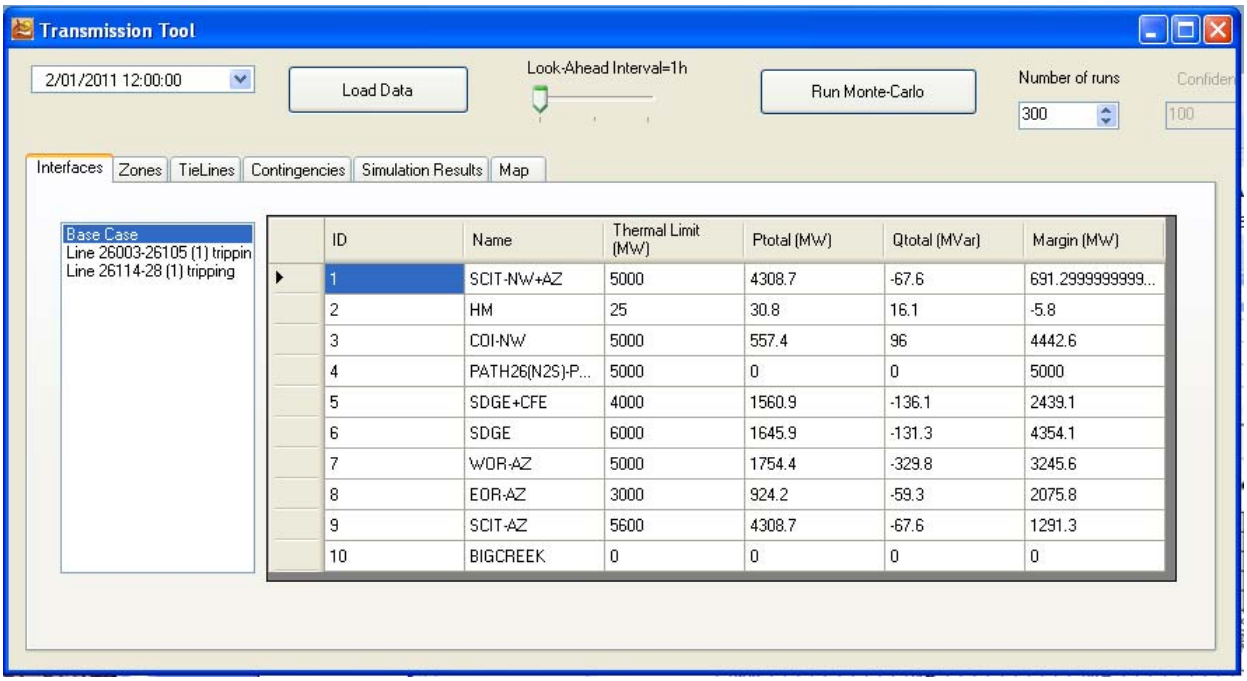


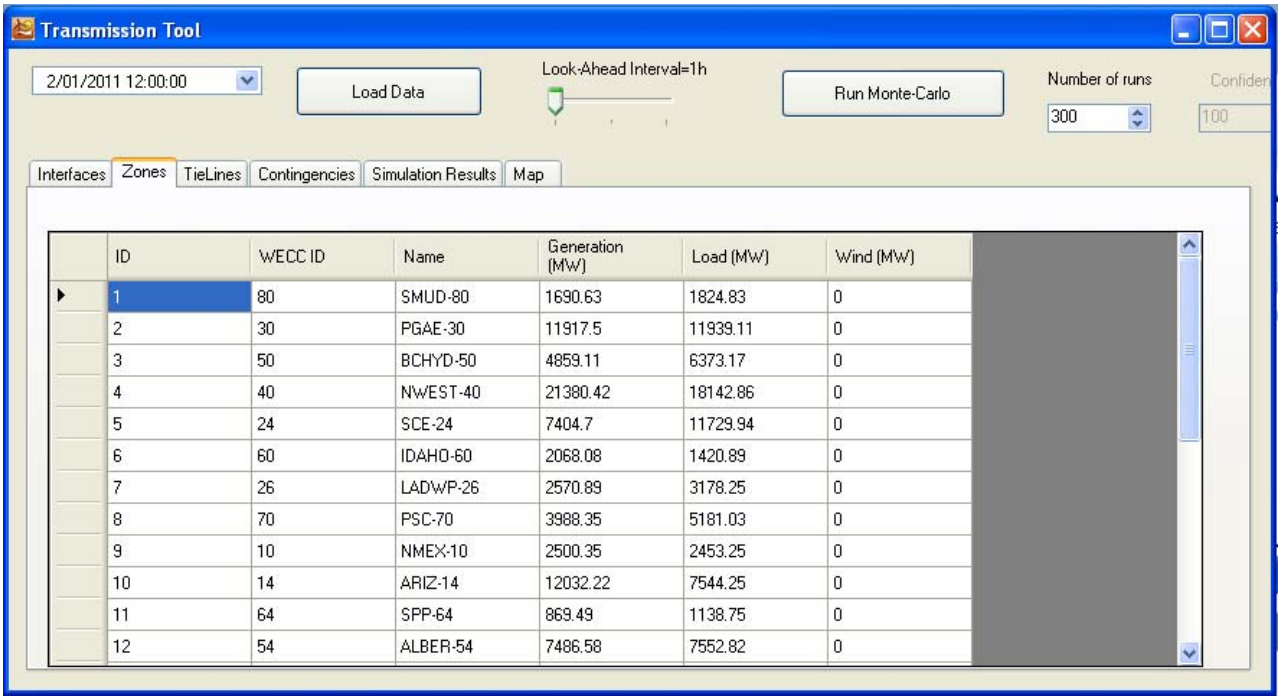
Figure 83 shows the interface data for the base case and two contingency cases. The data items include interface thermal limits (MW), total active power (MW), total reactive power (MVAr) and power flow margin (MW). Figure 84 shows the information regarding zones. The generation (MW), load (MW) and wind generation (MW) are shown in the table.

Figure 83: Interfaces' Information



ID	Name	Thermal Limit (MW)	Ptotal (MW)	Qtotal (MVar)	Margin (MW)
1	SCIT-NW+AZ	5000	4308.7	-67.6	691.2999999999...
2	HM	25	30.8	16.1	-5.8
3	COI-NW	5000	557.4	96	4442.6
4	PATH26(N2S)-P...	5000	0	0	5000
5	SDGE+CFE	4000	1560.9	-136.1	2439.1
6	SDGE	6000	1645.9	-131.3	4354.1
7	WOR-AZ	5000	1754.4	-329.8	3245.6
8	EOR-AZ	3000	924.2	-59.3	2075.8
9	SCIT-AZ	5600	4308.7	-67.6	1291.3
10	BIGCREEK	0	0	0	0

Figure 84: Zonal Information



ID	WECC ID	Name	Generation (MW)	Load (MW)	Wind (MW)
1	80	SMUD-80	1690.63	1824.83	0
2	30	PGAE-30	11917.5	11939.11	0
3	50	BCHYD-50	4859.11	6373.17	0
4	40	NWEST-40	21380.42	18142.86	0
5	24	SCE-24	7404.7	11729.94	0
6	60	IDAHO-60	2068.08	1420.89	0
7	26	LADWP-26	2570.89	3178.25	0
8	70	PSC-70	3988.35	5181.03	0
9	10	NMEX-10	2500.35	2453.25	0
10	14	ARIZ-14	12032.22	7544.25	0
11	64	SPP-64	869.49	1138.75	0
12	54	ALBER-54	7486.58	7552.82	0

Figure 85 through

Figure 87 show power flow distributions of the base case, contingency case 1, and contingency case 2 (1-hour ahead) for the interface of San Diego Gas & Electric (SDG&E).

Figure 85: Probability of Power Flow for Base Case

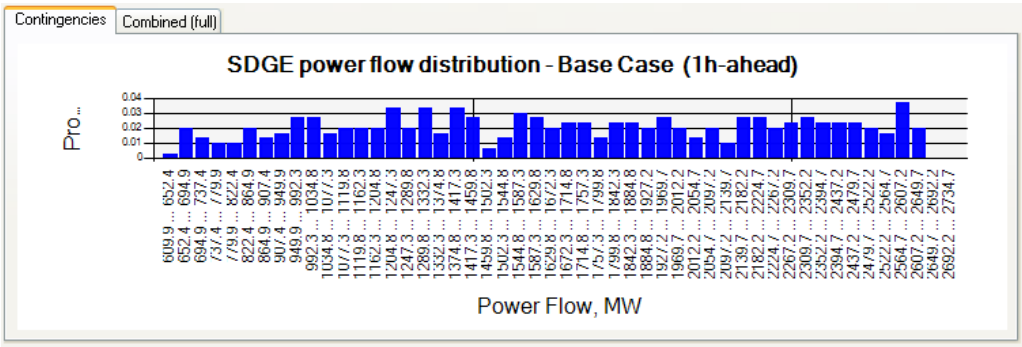


Figure 86. Probability of Power Flow for Contingency Case – 1

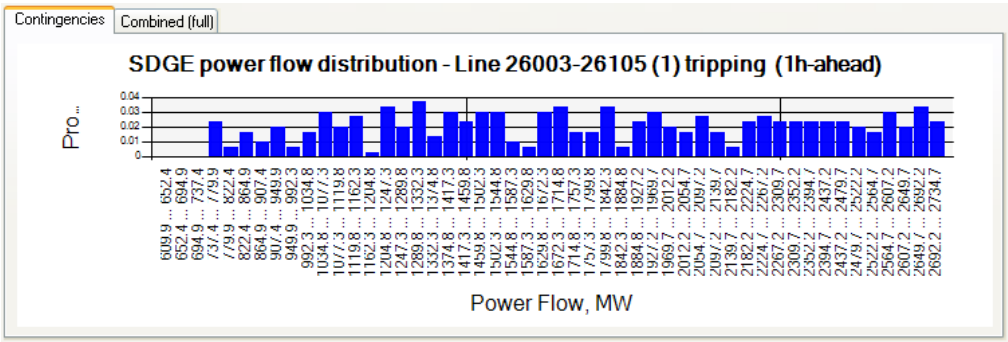


Figure 87. Probability of Power Flow for Contingency Case – 2

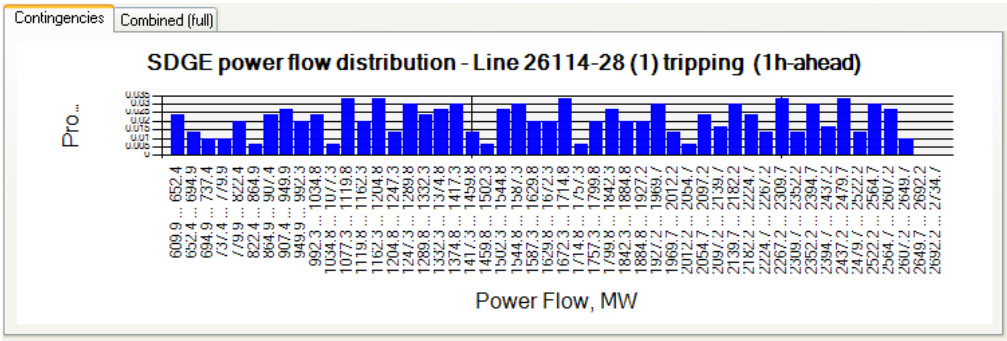
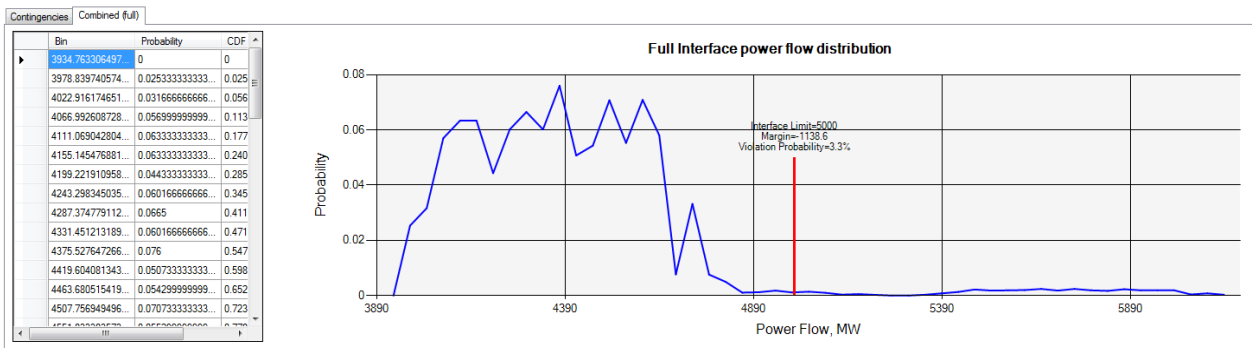


Figure 88 shows the probability of an interface power flow exceeding the limit.

Figure 88: Probability Distribution of a Power Flow



Database Structure

The data used in the transmission tool include: interfaces, zones, and tie lines information. Two contingency cases are used for demonstration purposes.

Table 8 through Table 12 show examples of the data used in the transmission tool. The data provided in the tables are for demonstration purpose only and do not correspond to a real case.

Table 8: Contingency Cases

ID	Description	Probability
1	Line 26003-26105 (1) tripping	3%
2	Line 26114-28 (1) tripping	2%

Table 9: Transmission Limits and Margin for Base Case

ID	Name	Thermal Limit (MW)	P Total (MW)	Q Total (MVAr)	Margin (MW)
1	SCIT-NW+AZ	5000	4308.7	-67.6	691.3
2	HM	25	30.8	16.1	-5.8
3	COI-NW	5000	557.4	96	4442.6
4	PATH26(N2S)-PGE	5000	0	0	5000
5	SDGE+CFE	4000	1560.9	-136.1	2439.1
6	SDGE	6000	1645.9	-131.3	4354.1
7	WOR-AZ	5000	1754.4	-329.8	3245.6

8	EOR-AZ	3000	924.2	-59.3	2075.8
9	SCIT-AZ	5600	4308.7	-67.6	1291.3

Table 10: Transmission Limits and Margin for a Contingency Case

ID	Name	Thermal Limit (MW)	P Total (MW)	Q Total (MVAr)	Margin (MW)
1	SCIT-NW+AZ	5000	5685.1	1139.5	-685.1
2	HM	25	60.1	-3.1	-35.1
3	COI-NW	5000	125.5	379.3	4874.5
4	PATH26(N2S)-PGE	5000	0	0	5000
5	SDGE+CFE	4000	1560.6	-133.7	2439.4
6	SDGE	6000	1739.1	-144.6	4260.9
7	WOR-AZ	5000	3111.7	-407.3	1888.3
8	EOR-AZ	3000	1634.3	154.1	1365.7
9	SCIT-AZ	5600	5685.1	1139.5	-85.1

Table 11: Zonal Information

ID	WECC ID	Name	Generation (MW)	Load (MW)	Wind (MW)
1	80	SMUD-80	1690.63	1824.83	0
2	30	PGAE-30	11917.5	11939.11	0
3	50	BCHYD-50	4859.11	6373.17	0
4	40	NWEST-40	21380.42	18142.86	0
5	24	SCE-24	7404.7	11729.94	0
6	60	IDAHO-60	2068.08	1420.89	0
7	26	LADWP-26	2570.89	3178.25	0
8	70	PSC-70	3988.35	5181.03	0
9	10	NMEX-10	2500.35	2453.25	0
10	14	ARIZ-14	12032.22	7544.25	0
11	64	SPP-64	869.49	1138.75	0
12	54	ALBER-54	7486.58	7552.82	0
13	62	MONT-62	1004.07	-623.07	0
14	90	TID-90	349.79	283.21	0
15	22	SDGE-22	916.7	2532.92	0
16	18	NEVAD-18	2647.7	2059.28	0
17	73	WAPRM-73	3475.82	2692.75	0
18	65	PACE-65	4424.74	4153.22	0
19	20	CFE-20	1158.68	1072.36	0
20	52	FORTS-52	265.54	595.44	0
21	21	IMPER-21	724.79	631.67	0
22	19	WAPLC-19	1723.97	799.84	0
23	41	CRAGV-41	0	0	0

24	63	WAPUM-63	-0.29	64.96	0
25	39	TRNBY-39	0	0	0

Table 12: Tie Line Information

ID	From Bus	To Bus	Circuit	P (MW)	Q (MVAr)
1	24701	24085	1	197.8	11.7
2	24041	25907	1	69.9	-29.2
3	26051	26104	1	105.1	-30.5
4	26097	24147	1	238.4	4.3
5	30068	24164	1	0	0
6	21025	22356	1	-19	52.8
7	25406	24806	1	-57.4	-2.9
8	24601	24085	1	-37.4	-18.3
9	26055	26105	1	0	0
10	26048	21	1	0	0
11	24097	24095	1	0	0
12	89	88	1	0	0
13	26003	26105	2	450.1	-30.1
14	26099	26094	1	235	96.5
15	24041	25908	1	69.9	-29.2
16	26003	26079	1	828.9	5
17	24701	24085	1	197.8	11.7
18	24601	24085	1	-37.4	-18.3
19	30061	24163	1	0	0
20	26003	26115	1	723	-25.7
21	21007	24804	1	36.5	19.4
22	80	24165	1	0	0
23	21076	24806	1	58.5	-7.7
24	22536	22360	1	798.9	-47
25	26003	26105	1	450.1	-30.1
26	15021	99012	1	0	0

CHAPTER 8: Conclusions

In this report, the development of a prototype transmission tool is presented. The design consideration, system architecture, simulation results and graphic user interface are described. The system architecture and system features are described. The power system model and the methodology to determine probabilistic thermal congestion limits based on power transfer distribution factor are presented. The five key system modules (e.g., power flow module, PTDF module, uncertainty module, probability congestion module and interface module) are also discussed in the report. This tool can be a very innovative and useful operating tool for reliable operations of power systems for grid operators. Future work could be to install and test the tool in a real control center using an actual system model and data.

CHAPTER 9: References

Bigwood Systems, Inc. 2012. "BSI's Real-Time Voltage Stability." Bigwood Systems, Inc. [Online.] Available: http://www.bigwood-systems.com/products.asp?ItemID=118&rcid=69&pcid=0&cid=69.

Chiang, H.-D., L. Jin, M. Varghese, S. Ghosh, and H. Li. 2009. "Linear and Nonlinear Methods for Contingency Analysis in On-Line Voltage Security Assessments." In Proc. IEEE General Meeting, July 26-30, 2009.

Department of Market Monitoring – California ISO. 2007. "Inter-Zonal Congestion Management Market." April 2007. [Online.] Available: http://www.caiso.com/1bb7/1bb77ace17280.pdf.

Li, H., H.-D. Chiang, and J. Tong. 2004. "An On-Line Tool for Voltage Stability Assessment and Control of Large-Scale Power Systems." *Bulk Power System Dynamics and Control - VI*, Aug. 22-27, 2004, Cortina d'Ampezzo, Italy. [Online.] Available: areeweb.polito.it/eventi/irep2004/Session%20B1/B1_4.pdf.

Makarov, Y. V., J. F. Reyes-Spindola, N. Samaan, R. Diao, and R. P. Hafen. 2010. "Wind and Load Forecast Error Model for Multiple Geographically Distributed Forecasts." *Proc. 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants*, Québec City, Québec, Canada, October 18-19, 2010.

Salem-Natarajan, D., L. Zhao, W. Shao; M. Varghese, S. Ghosh, M. Subramanian, G. Lin, H.-D. Chiang, and H. Li. 2008. "State Estimator for CAISO Market and Security Applications – Relevance and Readiness." *IEEE PES General Meeting*, Pittsburgh, Pennsylvania, USA, July 20-24, 2008. [Online.] Available: www.ece.neu.edu/~abur/CAMS/CA-ISO.ppt.

Varghese, M., D. Salem-Natarajan, S. Ghosh, H. D. Chiang, and H. Li. 2008. "Design and Implementation of Real-Time Voltage Stability Analysis at CAISO." Proc. of IEEE General meeting, July 2008.

WECC – Western Electricity Coordinating Council, Technical Studies Subcommittee. 2008a. WECC 2008 Path Rating Catalog. January 2008. Western Electricity Coordinating Council, Salt Lake City, Utah.

WECC – Western Electricity Coordinating Council, Operating Transfer Capability Policy Committee. 2008b. Approved 2008 - 2009 Winter Operating Transfer Capability (OTC) Limits. Western Electricity Coordinating Council, Salt Lake City, Utah. October 31, 2008. Available at http://www.wecc.biz/documents/library/OTC/2008-2009%20Winter%20Operating%20Transfer%20Capability%20(OTC)%20Limits%20(2)%20(3).pdf

WECC – Western Electricity Coordinating Council. July 2007. "WECC Data Preparation Procedural Manual for Power Flow and Stability Studies," Rev. 5.0. Western Electricity Coordinating Council, Salt Lake City, Utah. Accessed December 2009 at http://www.wecc.biz/documents/library/SRWG/dppm5.0.pdf.

WECC – Western Electricity Coordinating Council. October 25, 2005. "WECC Reliability Coordination Center Requirements: Request for Information and Pricing (RFIP)." Western Electricity Coordinating Council, Salt Lake City, Utah. Accessed November 2009 at http://www.wecc.biz/documents/2005/News/WECC_RCC_RFIP_10-25-05.pdf (undated webpage).

CHAPTER 10: Glossary

CAISO	California Independent System Operator
CDF	cumulative distribution function
CEC	California Energy Commission
CIEE	California Institute for Energy and Environment
CPF	continuation power flow
EMS	energy management system
ISO	Independent System Operator
MW	megawatt
OTC	operating transfer capability
PDF	probability density function
PIER	Public Interest Energy Research
PNNL	Pacific Northwest National Laboratory
PTDF	power transfer distribution factor
RD&D	research, development, and demonstration
RTVSA	real-time voltage stability analysis
TC	transmission constraint
TT	transmission tool
VSA	voltage stability analysis
VSA&E	voltage stability analysis and enhancement
WECC	Western Electricity Coordinating Council

APPENDIX K:
Technology Transfer Activities Final Report

Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

TECHNOLOGY TRANSFER REPORT

Prepared for: California Energy Commission

Prepared by: California Institute for Energy and Environment

University of California

ciee

FEBRUARY 2012

CEC-500-07-037

Prepared by:

Primary Author(s):
Lorraine Hwang
Merwin Brown

CIEE
2087 Addison Street
2nd Floor
Berkeley, CA 94704-1103
510.643.1440
uc-ciee.org

Contract Number: 500-07-037

Prepared for:

California Energy Commission

Jamie Patterson
Contract Manager

Fernando Pina
Office Manager
Energy Systems Research Office

Mike Gravely
Deputy Division Chief
Energy Research & Development Division

Laurie Ten Hope
Deputy Director
Energy Research & Development Division

Robert P. Oglesby
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

ACKNOWLEDGEMENTS

The authors are grateful to the California Institute for Energy and Environment (CIEE) Electric Grid Research team, Lloyd Cibulka, Jim Cole, Gilda Garcia, Larry Miller, and Sascha von Meir for developing and managing the RD&D projects in this report and providing their insights into the technology and transfer process. The Electric Grid Research team is grateful to the stakeholders and researchers who supported, conducted and developed the efforts discussed here. This includes the 3 major investor owned utilities in California – Pacific Gas and Electric, San Diego Gas and Electric, and Southern California Edison, – the California ISO, the Multidisciplinary Center for Earthquake Engineering Research , the Pacific Earthquake Engineering Research Center, Pacific Northwest National Laboratory, and Virginia Tech. This work was funded by the California Energy Commission PIER program under Contract 500-07-0037. The report was prepared by the CIEE. CIEE makes no warranties as to the suitability of this product for any particular purpose.

PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Technology Transfer is the interim report for the Transmission Research project (contract number 500-07-037, conducted by the California Institute for Energy and Environment. The information from this project contributes to PIER's Energy Systems Integration Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

ABSTRACT

The energy sector is undergoing tremendous change as pressure increases to create a clean energy economy. Successful transformation will depend on the development of new technologies. These new technologies must be effectively transferred, usually in the form of new information, to the various participants along the technology development value chain, from technology concept through product deployment and ultimately to the end user. Technology transfer can by inhibited by lack of financial, human resources, or organizational capacity; or a hostile legal, regulatory, institutional or social climate. Technology transfer takes place through tacit, passive and active knowledge sharing, cooperative involvement, demonstration projects, and the creation of patents, licensing and standards. Example activities include organization of and participation in local and national stakeholder and industry meetings and workshops, published papers, demonstration projects, operator training, and standards recommendations.

Keywords: Technology transfer, knowledge sharing, technology

Please use the following citation for this report:

Hwang, Lorraine, and Merwin Brown. CIEE. Publication year. ***Technology Transfer Report.*** California Energy Commission. Publication number: CEC-XXX-2012-XXX.

TABLE OF CONTENTS

PREFACE ..... **ii**

ABSTRACT ..... **iii**

TABLE OF CONTENTS ..... **iv**

TABLE OF FIGURES ..... **vi**

EXECUTIVE SUMMARY **1**

CHAPTER 1: Introduction **7**

CHAPTER 2: Technology Transfer **8**

CHAPTER 3: Barriers to Technology Transfer **10**

Financial 10

Legal and Regulatory 11

Organizational Capacity 11

Institutional and Social 11

Human Capacity 12

CHAPTER 4: Technology Transfer Activities **13**

Passive Information Sharing 13

Active Information Sharing 13

Tacit Information Sharing 13

Cooperative Involvement 14

Demonstration Projects 15

Patents, Licensing, and Standards 15

CHAPTER 5: Applications of Technology Transfer in this Contract **16**

Example 1. Knowledge Transfer through Passive and Active Participation 16

Example 2. Advisory Groups 17

Example 3. Demonstration Projects 19

Example 4. Operator Training 19

Example 5. Standards Development 20

CHAPTER 6: Next Steps **21**

Task 2.2 Analysis of the Seismic Performance of Transformer Bushings 21

Task 2.3 Analysis of the Seismic Performance of Substation Post Insulators 22

Task 3.1 Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the California ISO, Bonneville Power Administration and Pacific Gas and Electric Control Areas 23

Task 3.2 Oscillation Detection and Analysis 24

Task 3.3 Application of Modal Analysis for Grid Operation (MANGO) on the Western Interconnection 25

Task 4.1 Adaptive Relaying Technology Development and Measurements 26

Task 4.2 Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation 27

CHAPTER 7: Conclusions **30**

GLOSSARY **31**

REFERENCES **32**

APPENDIX A: Technology Transfer Activities by Project **33**

APPENDIX B: Project Fact Sheets **49**

APPENDIX C: Conferences, Meetings & Workshops Attended **50**

APPENDIX D – Advisory Group Meetings – Non Project Related **62**

TABLE OF FIGURES

Figure 1. Ten steps to commercialization for a successful technology venture as outlined by the MIT Technology Licensing. 8

EXECUTIVE SUMMARY

Introduction

The energy sector is undergoing tremendous change as pressure increases to curb carbon emissions and create a clean energy economy. Policy drivers within the State of California are envisioned to become a catalyst for transforming the region's energy infrastructure. This includes a high penetration of renewable electric generation to meet our energy needs.

Increasing pressure to curb costs and avoid negative environmental impacts has slowed the pace of investment in electric grid infrastructure for about 3 decades resulting in a grid that is constrained and stressed. New grid technologies will be needed to make renewable generation deployment easier and less costly, especially technologies that make the grid smarter. The research, development and demonstration (RD&D) investment in advancing the maturity of these new technologies is substantial. If this investment is not to be wasted, the technology must be effectively transferred, ultimately to the end user, but also to the various participants along the technology development value chain, from technology concept through product deployment.

Technology Transfer

Transferring technology from its creator to a user often for economic benefit is known as technology transfer. Technology transfer is closely related to knowledge transfer in both transferring the intellectual property, knowledge and skills as well as physical technologies and methodologies. Key in successful technology transfer is early recognition of promising new technologies. These must be nurtured from the research through development, demonstration, and deployment (commercialization). The federal government through the Department of Energy alone invested $26.4 billion in 2011 in energy research. Other entities performing RD&D in the U.S. electricity sector such as the electrical equipment manufacturers, utilities, the Electric Power Research Institute, and state-funded agencies such as the California Energy Commission, invest hundreds of millions more each year.

Barriers to Technology Transfer

Breaking down barriers to technology transfer is essential to provide smooth and timely implementation of new technology. At every stage of the technology transfer process risks exist along the path to market adoption. Challenges come from many sources and can be from the lack of resources including:

- Financial. Funding for an endeavor is necessary throughout its entire lifecycle. Incentives in the form of tax credits, matching funds, cost recovery policies or direct rebates to the consumer can help to offset some costs and financial risk to the developer.
- Legal and Regulatory. Without enabling policy and regulatory framework or removal of outmoded policy and regulation that hinders progress, new technologies may have difficulties becoming adopted. Establishing a clear, transparent and consistent regulatory and permitting process across state, local and federal agencies can reduce conflict among stakeholders and speed implementations.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

- Institutional and Social. Capacity is built through maintaining a strategic vision, governance and leadership, relationship building, developing resources, delivery and good management. An organization must be able to continue to maintain professional interactions and industry associations to keep up with evolving technologies.
- Human. Lack of human capacity can stall adoption. Both scientific and technical expertise must be made available to advance, install, operate and maintain new technology.

Technology Transfer Activities

To advance science and technologies through the research, development and demonstration process requires the transfer of knowledge from one party to another at various stages involving many different knowledge communities. Technology transfer covers a gamut of interactions between researchers, entrepreneurs and the end users. The following is a list of activities that can connect the communities together:

- Passive information sharing. Sharing occurs through publication of final reports, peer reviewed journal articles and other sources. Research findings once published waits to be found by an entrepreneur who has a practical problem to solve. In a fast changing industry, this wait may prove to be too long.
- Active information sharing. Knowledge transfer occurs through personal interactions. Exchange often occurs in a formal setting such as a conference, workshop, seminar, discussion forum, training or consultancy. Timeliness is preserved in addressing current problems.
- Tacit information sharing. Tacit knowledge is built over time both informally and formally. Informal information sharing and relationship building may occur actively through conversations, a coffee break, or a chance exchange at a conference to both grow the participants' knowledge base and industry network. Formal information sharing may occur through education and training to create the next generation of scientists, engineers and technicians.
- Cooperative involvement. Stakeholder involvement in the decision making process increases the likelihood of technology transfer of being successful and timely. Stakeholder consensus helps to ease acceptances of new technologies as well as to build early support by incorporating information sharing, and communication of values and views. This same cooperation can enhance the development and adoption of new regulatory and policy actions that remove technology transfer barriers as well.
- Demonstration projects. Demonstration projects are a special form of cooperative involvement. Demonstrations increase the acceptance of new technologies since the host often invests tangible resources in terms of equipment and personnel. Close involvement of industry personnel also builds tacit knowledge as they install, operate and monitor its performance as well as helps to build confidence in a new technology. This technology transfer activity can probably also be the most effective at reducing the risk of new technology adoption.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

- Patents, licensing, and standards. The development of industry standards, usually through community involvement, is one indication of the proliferation of a new technology. An agreed information exchange protocol, communication interface, or performance standard gives added insurance that a new technology will work as expected.

Applications of Technology Transfer in this Contract

In application, most technology transfer activities cannot be singularly categorized. Knowledge transfer occurs in many modes depending on the complexity and purpose of the activity. Within electric grid research this is apparent as technology transfer involves many different communities and personnel within these communities at different stages within the process. The California Institute for Energy and Environment's Electric Grid Research program is active in all stages of the process. The following examples highlight applications of the different technology transfer activities:

- Example 1. Knowledge Transfer through Passive and Active Participation

  All final reports for the California Energy Commission's Public Interest Energy Research (PIER) program and Fact Sheets can ultimately be found at: http://www.energy.ca.gov/research/reports_pubs.html.

  The CIEE website, http://uc-ciee.org, contains the CIEE library - a compendium of progress toward California's energy research goals. Housed are the CIEE work products related to sponsored projects and research development activities: draft and final reports, fact sheets, published papers, case studies, white papers, conference proceedings, papers, posters and presentations; and press releases. Accessible to all, the collection is a growing framework for advancing research and policy in a timely manner, in California and beyond.

- Example 2. Advisory Groups

  Cooperative involvement in electric grid research in this PIER program focused on the Policy Advisory Committee (PAC) and the Technical Advisory Committees (TAC) which support it. Committee membership was composed primarily of personnel from the 3 major investor owned utilities (IOU) in California – Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE)– and the California ISO (CAISO,) and chaired by an Energy Commission commissioner. Additional participants were often included to share knowledge on the meeting's focus including the Assistant Secretary of the Office of Electricity for the U.S. Department of Energy, and a representative of the Bonneville Power Association.

- Advisory group meetings were a forum for communication between the stakeholders and research and development community. Meetings often had several objectives to:
  - update participants on current national and state policy trends in energy;

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

- educate participants about the status and findings of research in the community including, IOUs, universities and national laboratories; and
- provide a forum for stakeholders to participate in the decision making process by identifying their pressing problems, the technologies needed to address these problems, and selecting the research activities for the highest priority technologies requiring additional development.

- Example 3. Demonstration Projects

  The IOUs often provide not only the facility for hosting a new technology but staff time to implement and monitor. One example is the *Wide-Area Energy Storage and Management System Project*. This phase of the project partnered private sector technology - Beacon Power, with major power balancing authorities – California Independent System Operator (CAISO) and Bonneville Power Administration (BPA), and a major utility, Pacific Gas and Electric (PG&E), with research performed at a national laboratory, Pacific Northwest National Laboratory (PNNL). With access to these facilities, researchers designed and monitored experiments to determine the performance characteristics of the hydro flywheel systems and evaluated the performance characteristics of a PG&E Sodium Sulfur Battery Storage Facility. Testing scenarios were prepared in cooperation with BPA and CAISO. Participation by BPA and CAISO will aid deployment of wide area energy storage and managements systems between the two balancing authorities as well as commercialization of the control algorithms.

- Example 4. Operator Training

  Effective use of new tools depends not only involving the end user in their development but also training end users in its usage. This is especially important in the operation of the electric grid when near real-time decision-making affects grid reliability. An example of this is the *Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation* project. PNNL worked closely with CAISO in developing, testing and installing the system as well as training operators. The project involved CAISO engineers and operators throughout to ensure system compatibility and to incorporate feedback for the control room operators (end user). The system is now operating in a real time environment at CAISO.

- Example 5. Standards Development

  To develop effective standards, the characteristics of the technology and its performance in actual usage must be understood. An example of this process is the *Analysis of Seismic Performance of Transformer Bushings* project. The approach here required the development of highly complex modeling, and use of the most advanced seismic simulators available at the Structural Engineering and Earthquake Simulation Lab (SEESL) at the State University of New York (SUNY), Buffalo to test specimens. Through the graduate program at SUNY Buffalo, SEESL graduate students learned the latest advancements in algorithm development, analysis and testing. This knowledge becomes further shared as these students are employed in industry and the methodology gains acceptance through familiarity. Members from PG&E, SDG&E, SCE, Western Area Power Administration and private industry including members of the IEEE 693 Standards Committee have

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

advised this project. Adoption of the new proposed standards will provide manufacturers with the information they need to build bushings with predictable performance, and hopefully greater survivability in seismic events, thus preventing power interruptions.

Next Steps

Next steps for individual projects are highly dependent on where each is in the research and development process. The following summarizes these for each project funded under this contract.

Task 2.2 Analysis of the Seismic Performance of Transformer Bushings

Further work is recommended to convert the findings from this project to specifications for the manufacturers, utilities and regulatory bodies. In addition, further studies are necessary to account more directly for the conductors connected to the bushings and the other equipment. As demonstrated here, installed conditions alter the performance of substation equipment and require complex testing and validation to ensure their survivability during a seismic event.

Task 2.3 Analysis of the Seismic Performance of Substation Post Insulators

Further work is recommended to refine the findings from this project to specifications for the manufacturers, utilities and regulatory bodies. Additional study is also recommended to model switch support structures for post insulators in two- and three-dimensions; to design and upgrade switch support structures for seismic qualification; to determine the acceptability of uniaxial or triaxial testing of disconnect switches; for adjusting characteristics of support systems in base isolation; and to study the impact of substation failure on the electric grid.

Task 3.2 Oscillation Detection and Analysis

Further work includes extensive testing studies with large amount of field measurement data and subsequent revisions and improvements of the algorithms as a result of this testing, and producing actionable information to increase damping, effectively suppressing the oscillations.

Task 3.3 Application of Modal Analysis for Grid Operation (MANGO) on the Western Interconnection

As the immediate next step, the first stage is to evaluate and improve the MANGO method with the full Western Electricity Coordinating Council system. The second stage is to test and demonstrate the MANGO method with actual measurement in a control room environment. In the third stage, as a longer term effort, the proposed MANGO method can be extended for the smart grid environment and the integration of renewable resources.

Task 4.1 Adaptive Relaying Technology Development and Measurements

The next step in development of adaptive relaying methods is a laboratory test at the California utilities using on-line data from a real system. These tests will reveal additional details on the limitations of available commercial equipment and other possible limitations due to non-technical requirements in the availability and sharing of the required wide area data and information among the California utilities.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 4.2 Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation

Next steps would increase the robustness and performance of the tool while handling imperfect information typically available in control centers, improve the probabilistic models to additionally reduce regulation requirements, add additional model components reflecting new sources of uncertainty, put more emphasis on the regulation requirements posed by the new NERC control performance standards, and deploy the tool in the CAISO control center (and potentially in the IOUs' and other control centers in California).

Conclusions

Technology transfer is a contact sport. It cannot be done in isolation. It requires communication and contact across communities leveraging each community's knowledge and skills. In increasingly complex and specialized research, funding and legal environments, expert knowledge has been recognized as a required element of success. State and federal funded research plays an important role in many of the steps providing resources at every stage. In particular, California's PIER program plays a role in this by connecting researchers to end users and technology providers.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 1: Introduction

The energy sector is undergoing tremendous change as pressure increases to curb carbon emissions and create a clean energy economy. Policy drivers such as California's AB32: Global Warming Solutions Act sets a greenhouse gas (GHG) reduction goal of 1990 emission levels by 2020 and an 80% reduction of 1990 emissions by 2050. Much like the rest of the United States, the bulk of California GHG emissions come from the transportation and electrical generation sector. To help meet these emission reduction goals, the generation sector, investor-owned utilities, electric service providers and community choice aggregators are required under a series of legislative efforts (2002 SB1078, 2006 SB107, 2011 SB2) to procure 33% of their energy resources from renewable energy by 2020 The additional goal from Governor Brown's *Clean Energy Jobs Plan* of building 20,000 MW of renewable energy including 12,000 MW of localized electricity generation by 2020 in combination with the Renewable Portfolio Standard (SB107) is envisioned to become a catalyst for transforming the region's energy infrastructure.

High penetrations of renewable generation pose significant changes and challenges for the electric grid. Optimal renewable resources are not always located where they are needed nor where electricity delivery infrastructure exists to accommodate it. Renewable resources without additional on demand balancing capacity can also be highly variable. Both of these characteristics put additional burden on the infrastructure of the grid to dispatch the necessary resources to operate reliably and efficiently and challenges the policies that govern it.

Increasing pressure to curb costs and avoid negative environmental impacts has slowed the pace of investment in electric grid infrastructure for about 3 decades resulting in a grid that is constrained and stressed. While building additional infrastructure can increase capacity by adding wires, towers and power plants, these traditional solutions alone will not meet the demands put on the grid by stakeholders including utilities, customers, governmental and public interest groups. New grid technologies will be needed to make renewable generation deployment easier and less costly, especially technologies that make the grid smarter. Some of these potential technologies do not exist and are identified only in terms of a problem that needs solving. Many existing nascent technologies require additional research, development and demonstration (RD&D) before they can become commercial. The RD&D investment in advancing the maturity of these new technologies is substantial. Some will fail. However, If this investment is not be wasted, the technology must be effectively transferred, ultimately to the end user, but also to the various participants along the technology development value chain, from technology concept through product deployment.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 2:
Technology Transfer

Transferring technology from its creator to a user often for economic benefit is known as technology transfer. Technology transfer is closely related to knowledge transfer in both transferring the intellectual property, knowledge and skills as well as physical technologies and methodologies. Typical steps to commercialization are illustrated in Figure 1 (MIT, 2005). To execute often requires a community of researchers, entrepreneurs, venture capitalists, industry experts, and management professionals. All may have a role in the lifecycle of a market ready technology.

Technology transfer begins with basic research. The role of basic research to serve society through the transfer of technology was recognized soon after World War II. Significant long term investment by the government both in national laboratories and research programs at this time were later to be augmented by private industry. With patent and licensing protections emplaced, both universities and private industry also recognized that discoveries in basic research can be translated into tangible benefits that can both improve the health and prosperity of the broader community for generations to come. In particular, the federal 1980 Bayh-Dole Act allowed universities and small businesses control over their intellectual property developed from federal money stimulating both additional research and commercialization. The legacy today of society's investments in basic research has resulted in many improvements in the electric sector including the development of nuclear power, photovoltaics, new generation wind turbines, high temperature low sag conductors, and phasor measurement units. None of these technologies occurred in isolation but were dependent on advanced research in materials, power electronics, communications and computation among others.

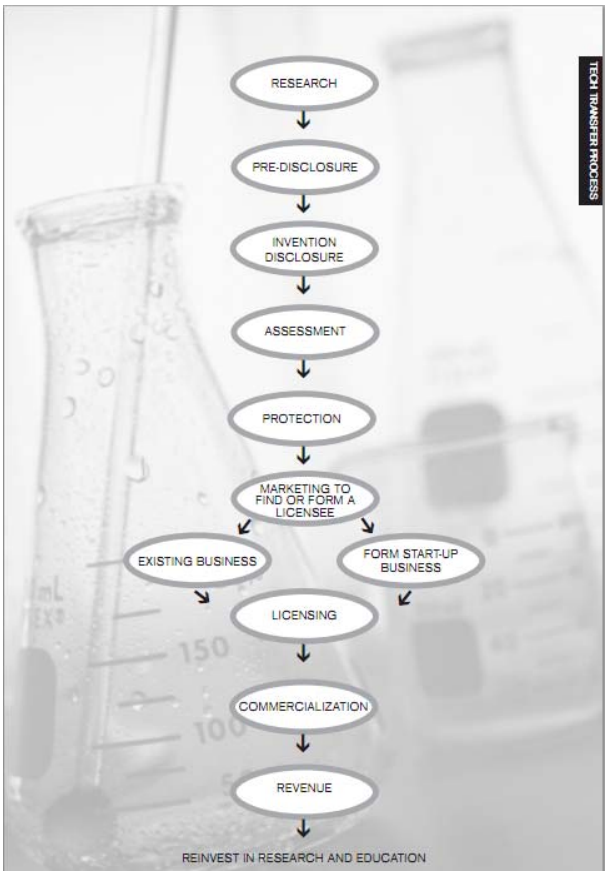


Figure 1. Ten steps to commercialization for a successful technology venture as outlined by the MIT Technology Licensing Office.
Source: (MIT 2005).

Key in successful technology transfer is early recognition of promising new technologies. These must be nurtured from the research through development, demonstration, and deployment (commercialization) perhaps tracked through a Stage-Gate system. Proof of concept through a demonstration project is only the beginning of the trek across the Valley of Death for new technologies. Over 50% of all new businesses fail within the first year and 95 percent within the

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

first five years. Substantial investment of capital – financial, physical, intellectual and social, is risked before revenues are ever realized in a commercial product. The federal government through the Department of Energy alone invested $26.4 billion in 2011 in energy research. Other entities performing RD&D in the U.S. electricity sector such as the electrical equipment manufacturers, utilities, the Electric Power Research Institute, and state-funded agencies such as the California Energy Commission invest hundreds of millions more each year.

Unlike financial and physical capital, the intellectual and social capital of an organization is difficult to quantify. Access to the knowledge, skills and experience are intangible assets necessary for success. Outreach is necessary to create networks between the different knowledge communities of research, industry, finance, business and regulatory experts. Many aspects of the energy industry in particular are entrenched and entangled in a web of established practices and heavy regulation. Hence, linking expert guidance built on industry knowledge can help create roadmaps to guide projects through and out of the Valley of Death.

Technology transfer through all steps does not occur without the transfer of knowledge. The form of this nexus depends on the circumstances and occurs on different time scales. For example what value a published finding may deliver in terms of accuracy and precision of knowledge, might be trumped by the value of a formal presentations and informal conversations where urgency is more important. More efficient and effective is the knowledge transferred in a hands-on demonstration.

Often requiring more time to acquire is the tacit knowledge built from experience. Tacit knowledge, unlike explicit knowledge, cannot be codified. It is acquired through personal contact and involvement. Tacit knowledge continues to build over time in an environment – university, corporate, or governmental, in which an individual learns the culture and skills of an industry. Tacit knowledge once absorbed into the culture of an organization reduces the barriers to the adoption of new technologies.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 3:
Barriers to Technology Transfer

Breaking down barriers to technology transfer is essential to provide smooth and timely implementation of new technology. At every stage of the technology transfer process, risks exist along the path to market adoption. Challenges come from many sources and can be from the lack of financial, legal, organizational, social, and/or human capacity.

Financial

Funding for an endeavor is necessary throughout its entire lifecycle. Basic research initially must be adequately funded. Support must continue for promising research until it has advanced far enough to be recognized to have practical applications. Additional capital is then necessary to continue its development and to demonstrate its application until the technology is accepted. Technology development still must compete within a company for its limited resources. In the energy sector, infrastructure upgrades are costly and the decision support tools must also exist to show its cost effectiveness to the enterprise. Even for the consumer, initial capital outlay is a barrier to adoption of green and/or energy efficient technologies. Due to the economies of scale and familiarity, old technology is often cheaper to both acquire and maintain. Learning and gaining experience with new technology often requires time often at the expense of productivity. Incentives in the form of tax credits, matching funds, cost recovery policies or direct rebates to the consumer can help to offset some costs and financial risk to the developer.

CFL. The adoption of compact fluorescent light (CFL) bulbs has been slow even with financial incentives and extensive consumer education. New regulations in California will phase out the use of incandescent light bulbs by 2018 Newer more efficient LED lighting are emerging in the market but have yet to gain a foothold except in specialty applications.
Source: <http://www.kftc.org/images-1/blog/Lightbulb.jpg/image_preview>.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Legal and Regulatory

Without enabling policy and regulatory framework or removal of outmoded policy and regulation that hinders progress, new technologies may have difficulties becoming adopted. Policy drivers such as California's renewable portfolio and low carbon fuel standards incentivize innovation and can lead to fast forwarding technology to meet the created demand. This alone sometime is not sufficient. A tangle of regulations and lack of cooperation and coordination between sectors can make implementation of a new technology burdensome. Establishing a clear, transparent and consistent regulatory and permitting process across state, local and federal agencies can reduce conflict among stakeholders and speed implementations.

RPS. California's renewable portfolio standards (RPS) mandates that 33% of the State's energy come from renewable sources.
Source: <http://www.nsk.com/industries/images/wind01.jpg>.

Organizational Capacity

The organizational capacity must exist for all stakeholders. Capacity is built through maintaining a strategic vision, governance and leadership, relationship building, developing resources, delivery and good management. An organization must be able to continue to maintain itself through professional interactions and industry associations to keep up with evolving technologies.

Institutional and Social

The institutional and social climate must be receptive to innovation and change. The "not invented here" syndrome prevalent in some organizations resists outside technology. This attitude could be due to the lack of information and/or trust. Sometimes there exists preference for proprietary technology. In house solutions are often thought to be inherently better due to the ability to control and tailor the technology to specific needs. This customization trades off with costs and speed of implementation as well as the benefits of industry standardization and large markets.

Lack of information and trust affects all sectors. Availability of actionable technological information helps manufacturers improve their products. End users also require information to both understand how a product works and be of benefit.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Human Capacity

Lack of human capacity can stall adoption. Both scientific and technical expertise must be available to advance install and operate new technology. Management must be skilled to deal with unexpected problems as well as have the knowledge and skill to optimize a project. An adequate workforce pipeline is necessary for knowledge feedback and to maintain system expertise. Without expertise in installation, operation, and maintenance newly implemented technology maybe prone to failure eroding trust and negating any advantages.

Workforce Development. Developing a qualified workforce will support widespread implementation of new technologies.
Source: < http://www.epa.gov/greeningepa/images/PV_installation.jpg >

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 4:
Technology Transfer Activities

To advance science and technologies through the research, development and demonstration process requires the transfer of knowledge from one party to another at various stages which involves many different knowledge communities. Research maybe conducted at a university, national laboratory, or by a private entity. End users for the electric grid technology typically are utilities but can be considered as large as their customer base. In between are the entrepreneurs and business developers who bring the ideas to market. Knowledge ultimately must be transferred from the research communities to the end users, but a successful process in reality is complex web of interactions amongst all.

Technology transfer covers a gamut of interactions between researchers, entrepreneurs and the end users. The following is a list of activities that can connect the communities together.

Passive Information Sharing

Traditionally, scientific sharing occurs through publication of final reports and peer reviewed journal articles. Research findings once published waits to be found by an entrepreneur who had a practical problem to solve. This passive form of information sharing does not require personal interaction and hence does not respond to or initiate action nor is it alterable. Passive information is available at the convenience of its consumer and is available as reports, documents and recordings increasingly being searchable and accessible over the worldwide web. In this mode, many years may pass before a research result is translated into a technology that finds its path to market. In a fast changing industry this wait might prove to me too long. Though, in rare cases, novel results are communicated through mass media.

Active Information Sharing

Active information sharing transfers knowledge through personal interactions. Participants establish a dialogue in the exchange of knowledge. Exchange often occurs in a formal setting such as a conference, workshop, seminar, discussion forum, training or consultancy. Active information sharing has the power to communicate research results in near-real time removing the delays of formal publication when being used in a passive information sharing capacity. Active information sharing is powerful in its ability to target its audience to its potential user. Timeliness is preserved in addressing current problems.

Tacit Information Sharing

I hear and I forget.
I see and I remember.
I do and I understand.
Confucius

Tacit knowledge is built over time both informally and formally. Informal information sharing and relationship building may occur actively through conversations, a coffee break, or chance exchanges at conference to both grow the participants' knowledge

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

base and industry network. Informal exchanges give participants the chance to learn from one another dispensing corporate, historical as well as current knowledge. Informal gatherings can lead to brainstorming from different perspectives and expertise. Learning from industry in the power sector is critical when the costs of demonstration projects are high and knowledge is highly specialized.

Tacit information sharing also occurs in formal settings. Education and training creates the next generation of scientists, engineers and technicians. This workforce pipeline is essential to the continuity of any industry. Classroom knowledge relies on memory and abstraction which restricts learning in most students. Hands-on experience - learning by doing - increases knowledge retention, critical thinking, and skill proficiency through self-discovery (Harry and Rillero, 1994). Through hands-on training, such as training grid operators on tools through simulation, knowledge once passed through on the job training is gained more quickly increasing productivity.

> *We have a habit in writing articles published in scientific journals to make the work as finished as possible, to cover up all the tracks, to not worry about the blind alleys or describe how you had the wrong idea first, and so on. So there isn't any place to publish, in a dignified manner, what you actually did in order to get to do the work.*
>
> **Richard Feynman, 1966**

Both inn industrial and academic research, heavy importance is placed on promoting positive or "correct" results. Information on paths explored but proven unfruitful become part of the tacit corporate knowledge but may never be communicated to a wider audience. Reinvestigating these dead ends consumes both time and money. Understanding what is impossible under today's paradigms will push the development of new paradigms in the future. Such knowledge sharing can occur in "Gordon Conference" like settings or, more likely, in less structured exchanges. However, the need for formal sharing pathway has yet to be commonly recognized.

Cooperative Involvement

When stakeholders of a technology are involved in the decision making process, technology transfer has an increasingly higher likelihood of being successful and timely. The decision making process begins with problem identification. Information then must be gathered to both further define the problem and identify possible solutions. The solutions could be the need for a new technology that requires research activity, or demonstration. Stakeholder involvement promotes democratization and transparency critical in the development of partnerships. They contribute specialized and institutional knowledge - highlighting both conflicting objectives and possible solutions. Stakeholder consensus helps to ease acceptances of new technologies as well as to build early support by incorporating information sharing, and communication of values and views. This same cooperation can enhance the development and adoption of new regulatory and policy actions that remove technology transfer barriers as well.

For many technologies, especially those ultimately used by consumers, such as high efficiency light bulbs, involving the end user can be challenging because of the diversity in such a large population. The development and technology transfer of technologies for use by the electric grid, on the other hand, involve a relatively small well defined class of end users, and therefore

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

face fewer difficulties involving the user. Hence, the cooperative involvement in the electric grid research program is a highly effective mechanism in technology transfer.

Demonstration Projects

Demonstration projects are a special form of cooperative involvement. While laboratory tests and simulations are often key in the development of new technologies, demonstrations *in situ* under real life conditions are often necessary to prove a new technology especially in an industry as conservative as the operation of the electric grid. Demonstrations increase the acceptance of new technologies since the host often invests tangible resources in terms of equipment and personnel. Close involvement of industry personnel also builds tacit knowledge as they install, operate and monitor its performance as well as helps to build confidence in a new technology. This technology transfer activity can probably also be the most effective at reducing the risk of new technology adoption.

Patents, Licensing, and Standards

The issuing of patents and licenses and development of industry standards is a milestone in technology transfer. A patent protects intellectual property and preserves commercial value through licenses for use. There, however, is no guarantee of end user acceptance or commercial success. History is littered with examples of technology which the market has failed to win over consumers e.g. Microsoft Vista, Segway, HD DVD, etc. whether due to poor product performance, missed consumer expectations, being eclipsed by newer technology or poor regulatory environment.

The development of industry standards, usually through community involvement, is one indication of the proliferation of a new technology. A multitude of designs and protocols can make a new technology hard to implement as well as perform poorly, killing wide spread acceptance. An agreed information exchange protocol, communication interface, or performance standard gives added insurance that a new technology will work as expected.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 5:
Applications of Technology Transfer in this Contract

In application, most technology transfer activities cannot be singularly categorized. Knowledge transfer occurs in many modes depending on the complexity and purpose of the activity. Within electric grid research this is apparent as technology transfer involves many different communities and personnel within these communities at different stages within the process. CIEE's Electric Grid Research program is active in all stages of the process. The following examples highlight applications of the different technology transfer activities. Technology transfer activities for each project in this contract are described in Appendix A.

Example 1. Knowledge Transfer through Passive and Active Participation

Documenting research results and presenting at conferences is a time honored way of making knowledge widely available. Electronic publishing and the conversion of back issues of paper journals into electronic form has made information increasingly accessible due to its searchability over the internet. For example, all final reports for the California Energy Commission's (Energy Commission) Public Interest Energy Research (PIER) program and Fact Sheets can be ultimately found at: http://www.energy.ca.gov/research/reports_pubs.html.

The recently updated CIEE website, http://uc-ciee.org, connects users to organizational resources and as well as to partners in government, national labs, non-profits, industry and academia. The website contains the CIEE library - a compendium of progress toward California's energy research goals. Housed are the CIEE work products related to sponsored projects and research development activities:

- Draft and Final Reports
- Fact Sheets
- Published Papers
- Case Studies
- White Papers
- Conference proceedings, papers, posters and presentations
- Press releases

Accessible to all, the collection is a growing framework for advancing research and policy in a timely manner, in California and beyond.

Appendix A lists, by project, the materials produced under this work contract. Each project has a published draft Final Report and Fact Sheet (Appendix B) describing the research, relevance and significant outcomes. In addition, research from these contracts have produced 46 published papers and reports, 6 dissertations and have distributed knowledge through 97

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

presentations at workshops, meetings and conferences on the national and international level. The largest conferences (e.g., the IEEE T&D Conference & Expo) had over 2,000 attendees encompassing participants from industry, academia, governmental and nongovernmental organizations.

Knowledge is routinely shared through active participation as presenters in industry conferences, seminars workshops, and part of expert panels, e.g.

- Institute of Electric and Electronics Engineers (IEEE)
- Renewable Energy Secure Communities
- i-PCGRID
- North American Synchrophasor Initiative (NASPI)
- International Colloquium on Environmentally Preferred Advanced Power Generation
- Department of Energy National Energy Technology Laboratory (NETL) review meeting for Transmission Reliability and NETL Advanced Synchrophasor projects

Appendix C lists meetings and conferences participated in support of this contract. The list includes a brief description of the conference and the title of the paper presented at over 50 meetings CIEE Electric Grid Research (EGR) team members participated in often as keynote or invited speakers. As respected industry professionals, the EGR team participated on several industry expert and national review panels not directly funded by this contract. Like similar research and development organizations, professional activities in support of the mission are important in supporting continuing education, maintaining community connections and contributing to system wide planning across organizations on the state and national level. CIEE or other industry groups (e.g. IEEE) provided funds that enabled EGR to continue work which enhances national and international information exchange, develops research programs, reviews current state of the art, and contributes to identifying current challenges and possible solutions. Attendance and presentations at meetings e.g. CAISO Planning, Electric Power Research Institute (EPRI), California Public Utilities Commission (CPUC), and i4Energy workshops, provided added value to the State of California by both ensuring that California's challenges are address and to enhance coordination across stakeholders. The outgrowth of such efforts are typically are projects which help to sustain California's leadership in clean energy while providing a secure and reliable electric grid.

Example 2. Advisory Groups

Cooperative involvement in electric grid research in this PIER program focused on the Policy Advisory Committee (PAC) and the Technical Advisory Committees (TAC) which support it. Committee membership was composed primarily of personnel from the 3 major investor owned utilities (IOU) in California – Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDG&E) and Southern California Edison (SCE) –and the California ISO (CAISO), and chaired by an Energy Commission commissioner. Additional participants were often included to share knowledge on the meeting's focus, including the Assistant Secretary of the Office of Electricity

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

for the U.S. Department of Energy, and a representative of the Bonneville Power Association. The electric grid PAC met 1-4 times each year addressing high level issues (8 meetings). The TAC met as needed to meet Commission research goals.

Advisory group meetings were a forum for communication between the stakeholders and research and development community. Meetings often had several objectives to:

- update participants on current national and state policy trends in energy;
- educate participants about the status and findings of research in the community including, IOUs, universities and national laboratories; and
- provide a forum for stakeholders to participate in the decision making process by identifying their pressing problems, the technologies needed to address these problems, and selecting the research activities for the highest priority technologies requiring additional development.

PAC meetings took advantage of other technology transfer activities held at the same time. Fall meetings in 2008 and 2009 were held with workshops focusing on PIER funded research project results. These meetings, open to the public, brought together the electric grid community, policy makers, and regulators highlighting accomplishments of and disseminating knowledge acquired under the program. These workshops reached out nationally attracting attendees from both in and out of state.

Meetings hosted by PG&E, SCE, SDG&E and CAISO often included tours of new state-of-the-art transmission operation facilities and research laboratories. Participants had an opportunity to learn about the capabilities, practices, and research and operational issues actively being studied by the host. The information gained will allow for synergistic activities in future research planning as well as leveraging native expertise and infrastructure.

A series of targeted TAC meetings were also held on pressing research topics identified by PAC and TAC members. Membership was fluid depending on subject matter and available expertise, but was usually composed of mid-level management and senior engineers from the electric grid community. Meetings occurred over a shorter periods for rapid response. The goal of these meetings was to assess the state of the art, discuss stakeholder needs, identify knowledge gaps and develop the research portfolios and strategies.

- Fault Current Controller Technology Evaluation: Develop evaluation criteria and a field test program with a host utility to perform field trials of emerging technologies to manage fault current levels in the electric grid.
- Identification and prioritization of research efforts to improve the capacity and reliability of the transmission & distribution systems, including high-temperature, low-sag (HTLS) conductors, real-time rating systems and equipment, underground cable systems, and high-voltage DC transmission systems.
- Distribution System Monitoring: Investigate the requirements for monitoring, data acquisition, system analysis, and control methodologies for distribution systems with high penetration of new renewable energy generation, electric vehicles, demand response, and other new and emerging technologies.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Appendix D lists and briefly describes the PAC TAC meetings held in support of this contract.

Example 3. Demonstration Projects

The electric grid community is actively involved in research and development as providers of technology and hosts for field tests and demonstrations sites. In particular, the IOUs provide not only the facility for hosting a new technology but staff time to implement and monitor. In the process, information is shared between the knowledge communities about the technologies and their performance. One example is the *Wide-Area Energy Storage and Management System (WAEMS) Project*.

The overall goal of the multi-phase WAEMS project is to develop the principles, algorithms, market integration rules, a functional design, and a technical specification for an energy storage system to help cope with unexpected rapid changes in wind generation power output. The resulting system would have the ability to store excess energy, control dispatchable load and distributed generation, and utilize inter-area exchange of the excess energy between the CAISO and Bonneville Power Administration (BPA) control areas. This phase of the project partnered private sector technology - Beacon Power, with major power balancing authorities - CAISO and BPA, and a major utility, PG&E, with research performed at a national laboratory, Pacific Northwest National Laboratory (PNNL). With access to these facilities, researchers designed and monitored experiments to determine the performance characteristics of the hydro and flywheel system and evaluated the performance characteristics of a PG&E Sodium Sulfur Battery Storage Facility. Testing scenarios were prepared in cooperation with BPA and CAISO. Participation by BPA and CAISO will aid WAEMS deployment between the two BAs and commercialization of the control algorithms.

Example 4. Operator Training

Effective use of new tools depends not only involving the end user in their development but also training end users in its usage. This is especially important in the operation of the electric grid when near real-time decision making affects grid reliability. An example of this is the *Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation* project. An important component in the response to the challenge of intermittent wind and solar generation on the California power grid is to develop an appropriate set of operational tools to analyze and visualize its impact and to predict the associated ramping needs in a timely manner. PNNL worked closely with CAISO to develop the system and its specifications. CAISO provided historical data so the system could be tested and evaluated offline. Once proven the system was moved to the online environment linked with Energy Management System, tested, installed at designated CAISO control facilities, and operators trained. The project involved CAISO engineers and operators throughout to ensure system compatibility and to incorporate feedback for the control room operators (end user). The system is now operating in a real time environment at CAISO.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Example 5. Standards Development

The electric grid community is actively involved in developing the commercial specifications and standards for new technologies. To develop effective standards, the characteristics of the technology and its performance in actual usage must be understood. An example of this process is the *Analysis of Seismic Performance of Transformer Bushings* project.

The goal of this research project is to develop a revised IEEE Standard 693 for qualification of transformer bushings. Laboratory testing and past failures during seismic events have made it clear that current standards are inadequate: manufacturers are building bushings that successfully qualify according to the Standard, yet are known to fail in service at lower seismic levels than they were tested to. Clearly, the Standard is not taking into account all the factors that cause bushings to fail during earthquakes, particularly the interactions between the bushing and the transformer as actually installed in service. The research approach requires the development of highly complex modeling, and use of the most advanced seismic simulators available at the Structural Engineering and Earthquake Simulation Lab (SEESL) at the State University of New York (SUNY), Buffalo, to test specimens in the laboratory according to "as-installed" conditions, i.e., with the bushings mounted on equipment that simulates actual transformer installations. Through the graduate program at SUNY-Buffalo, SEESL graduate students learned the latest advancements in algorithm development, analysis and testing. This knowledge becomes further shared as these students are employed in industry and the methodology gains acceptance through familiarity. Members from PG&E, SDG&E, SCE, Western Area Power Administration and private industry including members of the IEEE 693 Standards Committee Working Group have advised this project. Adoption of the new proposed standards will provide manufacturers with the information they need to build bushings with predictable performance, and hopefully greater survivability in seismic events, thus preventing power interruptions.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 6:
Next Steps

Technology transfer occurs in stages. From its inception as a research idea through successful commercialization, many activities occur. A continual effort to assess needs and keep abreast of research is necessary to identify opportunities in technology transfer. Meeting with stakeholders and attending industry conferences and workshops, for example, are essential to maintain relevancy.

Next steps for individual projects are highly dependent on where each is in the research and development process. A research project often just starts out as an idea maybe through a long process of identifying possible solutions to a particular problem or a chance conversation with a colleague. That idea must next be proven to be feasible solution. From this proof of concept study, scaling-up, bench marking, and qualifying the technology occur before a solution is ready for real world testing. Sometimes this stage may take years as technologies are reworked and reevaluated and retested consuming public and/or private capital. Once passed this stage, depending on its nature, the project may be ready for commercial investment, adopted as a standard and/or formulated into policy.

The following introduces each project funded under this contract and summarizes their next steps.

Task 2.2 Analysis of the Seismic Performance of Transformer Bushings

Transformers are key elements in the electric transmission system and the bushings that are bolted onto a transformer are one of the pieces of electrical equipment most vulnerable to seismic damage. In the event of a significant earthquake, failure of a bushing takes the transformer out of service, causing a severe disruption of electric service. Acquiring and installing a replacement bushing is an expensive and labor-intensive task, and one that can significantly delay recovery of power service after a disruption. Laboratory testing and past failures during seismic events have made it clear that current standards are inadequate: manufacturers are building bushings that successfully qualify according to standards, yet are known to fail in service at lower seismic levels than they were tested to. Clearly, standards are not taking into account all the factors that cause bushings to fail during earthquakes.

This project identified weaknesses of the current qualification procedures which ignore the as-installed conditions of transformer bushings, and also minimize the importance of strength capacity-demand issues. Through adequate quantification, this study pointed to measurements and protocol requirements for qualification of bushings that can withstand predefined seismic requirements. These recommendations have been presented to the IEEE 693 Standard Working Group, and are under consideration for inclusion in future revisions of the Standard.

Such recommended requirements for qualification of bushings are as follows: (1) Develop procedures of qualifications that compare the strength demands to strength capacities in mechanical terms; (2) Determine strength capacity of bushings by either testing them to failure,

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

statically or dynamically, or by strength computations by manufacturers; (3) Testing the bushings to generate seismic strength demand using seismic simulators according to a desired severity; (4) Determine the desired seismic severity from current requirements to include identified dynamic properties of bushings and mounting conditions, though interaction factors, or using simplified analytical models; (5) Modify the design requirements for the cover of transformer tanks to reduce, or eliminate, the interaction issues; (6) Further develop methods of reducing seismic demands on all components of transformers by using protective systems.

The last three recommendations require further development and basic research, to convert the findings from this project to specifications for the manufacturers, utilities and regulatory bodies. In addition, further studies are necessary to account more directly for the conductors connected to the bushings and the other equipment. As demonstrated here, installed conditions alter the performance of substation equipment and require complex testing and validation to ensure their survivability during a seismic event.

Task 2.3 Analysis of the Seismic Performance of Substation Post Insulators

Disconnect switches are a key component of power transmission and distribution systems that either control the flow of electricity between all types of substation equipment or isolate the equipment for maintenance. Disconnect switches and other equipment including the insulator components have experienced severe damage by earthquakes over the past years. To avoid any possible energy dissipation, power leakage or substations shutdowns due to earthquake damages, the IEEE guidelines for seismic testing and qualification of disconnect switches are in continuous development and update. This study conducted experimental and finite element simulations towards developing recommendations to IEEE693 for seismic qualification of high voltage electrical substation disconnect switches.

The experimental program consisted of both static and dynamic tests for porcelain and composite insulator posts. Substructured dynamic testing was conducted to validate the concept of substructuring for use in hybrid simulation (HS) testing. A HS system for testing a single insulator post was successfully developed which can be used in making design decisions of disconnect switches.

Several topics can be considered for future work:

- Development of HS testing of disconnect switches for multi-degree-of-freedom two- and three-dimensional analytical models structures. The HSS presented in this report used a SDOF computational model for representing the switch support structure in the analytical substructure of the system.
- Development of further applications of HS testing aimed at structural upgrading of existing electrical substation equipment and testing-based-design of new electrical substation equipment. One framework, that can be of great benefit to switch manufacturers if properly verified, is the use of HS to determine the support structure stiffness limits for which a switch is seismically qualified.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

- Development of criteria to determine when it is acceptable to use uniaxial instead of triaxial testing of disconnect switches.
- Investigation of the use of base isolation for adjusting the characteristics and dynamic properties of the support structures of disconnect switches to mitigate earthquake damage.
- Investigate the performance of large electrical substation networks and generation, transmission and distribution systems under earthquakes, natural disasters, or other reliability threats.

Task 3.1 Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the California ISO, Bonneville Power Administration and Pacific Gas and Electric Control Areas

The multi-phase WAEMS project aimed to develop the principles, algorithms, market integration rules, a functional design, and technical specifications for an energy storage system to cope with uncertainties and unexpected rapid changes in renewable generation power output. The resulting WAEMS system would store excess energy, control dispatchable load and distributed generation, and use inter-area exchange of the excess energy between the CAISO and BPA Balancing Authorities. In addition, the project aimed to provide a cost-benefit analysis and develop a business model for an investment-based practical deployment of such a system.

In this phase, Phase II, the project demonstrated that stand-alone sodium-sulfur battery storage for regulation and load-following services was not economical. However, the performance of a prototype WAEMS controller that operates a flywheel energy storage system in conjunction with a hydropower plant for regulation service demonstrated satisfactory field test results using actual BPA and CAISO regulation signals. Lastly, the breakeven price of the WAEMS regulation service was calculated to be slightly higher than the current average price for regulation in the CAISO market.

Based on these results, the next phase of WAEMS research should focus on (1) practical deployment of the WAEMS that provides balancing services (including both load-following and regulation services) to the CAISO and BPA balancing authorities and (2) commercialization of the control algorithms developed in Phases 1 and 2 of the WAEMS project.

A near-term goal should be commercialization of a shared storage system between CAISO and BPA. A longer term goal should be development of methodologies for operating both fast and slow resources and sharing these resources over multiple control areas to facilitate the renewable integration and operate the power grids reliably and economically.

To meet these goals, next steps would include:

- enhancing the WAEMS controller so that it is more robust and can provide load following services;
- field testing more energy storage technology options, such as Li-ion battery energy storage; and

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

- assisting BPA and CAISO to deploy a WAEMS system between BPA (offer a hydropower plant) and CAISO (offer a fast-acting energy storage device).

Another potential area of future research is the development of an energy storage evaluation toolbox that incorporates the models, algorithms, methodologies, and standardized testing signals developed previously. This toolbox would help users find optimal configurations and assess the performance and economics of different energy storage solutions, enabling them to answer the following questions:

- Are the selected energy storage devices capable of providing the required services as expected?
- How much fast-regulating energy storage device capacity is needed for a given regulation/load-following signal?
- What is the cost of the service?

Such research will provide information for power grid operators to make decisions on building the most economical energy storage portfolio that best meets the renewable-integration requirements.

Task 3.2 Oscillation Detection and Analysis

Unstable oscillations can cause power grid breakups and even large-scale power outages, such as the power outage that occurred on August 10, 1996 in the western interconnection. The value of large-scale outage avoidance for the WECC system is estimated to be over one billion dollars over the next 40 years. Most major tie lines in WECC system are often constrained by stability limits, which are more limiting than the thermal limits. By providing accurate and timely information about the oscillation modes of power grid, the study results from this project can help lower the probability of large-scale blackouts, and increase the power grid efficiency. Developing early warnings for unstable modes to allow the grid to operate at its full capacity, while staying within the stability boundary.

The method developed in this project is expected to have significant impact on power grid operation, as it will improve reliability and avoid significant economic losses. This oscillation study is a major breakthrough in the sense that it significantly lowers false and missing alarms, as well as shortens detection time by applying oscillation detection and analysis algorithms properly. However, the study is also limited in the sense of real world applications, and requires additional efforts to realize the full benefit.

First, the method was only tested with a small, simplified model and limited number of field measurement cases. Even though the initial testing shows promising results, it needs further studies to guarantee sufficient robustness and reliability under typical operating conditions. Such a requirement was necessary for a useful control room tool. Thus, future work includes extensive testing studies with large amount of field measurement data. Revisions and improvements shall occur on the algorithm as a result of this testing.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Second, the project only focused on the detection and analysis of oscillations. With the oscillation information available, a natural next step is to produce actionable information to increase damping, effectively suppressing the oscillations.

Once the two proposed studies are complete, the benefit of oscillation study can be fully realized through improved reliability and efficiency of power grid operation.

Task 3.3 Application of Modal Analysis for Grid Operation (MANGO) on the Western Interconnection

System oscillation problems are one of the major threats to the grid stability and reliability in California and the Western Interconnection. These problems result in power fluctuations, lower grid operation efficiency, and may even lead to large-scale grid breakup and outages. Significant economic consequences have been observed in past oscillation events. Recent development of smart grid technologies poses even a larger problem in system oscillations. For example, renewable energy sources reduce system inertia and add more uncertainty; energy efficient loads introduce new dynamics, as well as uncertainty. These all change system oscillation behaviors and will likely make them even more difficult to manage. The need becomes apparent in enabling timely control actions for power system operation, so as to improve small signal stability and facilitate smart grid deployment. The solution has both economic and environmental implications.

Different from traditional modulation control, which works well for local oscillation problems but does not effectively address inter-area oscillations, the project aimed to solve this problem by developing an operation procedure termed Modal Analysis for Grid Operation (MANGO). The MANGO procedure includes three steps: recognizing small signal stability problems, implementing operating point adjustment using modal sensitivity, and evaluating the effectiveness of the adjustment. Central to this procedure is a method for estimating modal sensitivity using real-time phasor measurements or other time-synchronized measurements. The results indicated the strong controllability of oscillations by operation actions and the effectiveness of the proposed MANGO method.

This project has laid an excellent foundation towards the long-term goal of developing an operational tool for improving small signal stability. To achieve this long-term goal, additional research and development efforts are needed.

As the immediate next step, the first stage is to evaluate and improve the MANGO method for the full WECC system. The initial test results with the full WECC system are promising, but the work needs to be extended in several aspects regarding multi-mode interference, topology impact, and noise rejection. The WECC system provides unique opportunities for these studies. It has multiple oscillation modes. Adjustment for improving damping for one mode should not harm another mode. The interference among multiple modes should be studied. This research showed that topology affects modal properties and in turn MANGO procedures. Topology information should be included in generating operation recommendations, which has not yet been studied. So far, the studies have been based on simulated "clean" data, which is necessary in the evaluation stage because the true answer is known with simulation. But in real-life applications, actual measurement data contain noise. The noise also needs to be simulated to

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

study how the noise affects the results and how to improve the MANGO method for noise rejection. After these aspects are studied, the work in this stage prepares the method for testing with actual measurement data.

The next step - second stage, is to test and demonstrate the MANGO method with actual measurement in a control room environment. Due to limited phasor measurements available today, this research was performed with simulated data. Actual measurements, representing realistic scenarios and system characteristics, would be the ultimate test of the proposed method. Findings will further improve the method. As MANGO aims at an operator-oriented measure, it is important to identify implementation strategies with operating procedures for control room use. Only when the MANGO measure is included in operating procedures, can the benefit be actually realized in improving power grid reliability. Therefore, it is important to collaborate with power companies in integrating the MANGO procedure to operation procedures. Considering the schedule of the Western Interconnection Synchrophasor Program[1] (WISP) project the installation of additional 250+ PMUs, this stage is expected to be in the timeframe of the next 2-3 years. By the end of this stage, an operational tool is expected to be ready for pilot testing in control rooms.

In the third stage, as a longer term effort, the proposed MANGO method can be extended for the smart grid environment. Once the MANGO procedure is fully tested in the traditional grid environment, its extension to the smart grid environment would become necessary. This would be beyond generation adjustment. It could include the adjustment of storage and responsive smart loads, and at the same time, consider characteristics of intermittent renewable energy sources. The MANGO adjustment needs to take into account the natural variations in the generation to avoid under- or over-adjustment issues. Renewable energy, smart loads, and energy storage are posing unprecedented challenges but also providing new opportunities in the area of system oscillation mitigation.

Task 4.1 Adaptive Relaying Technology Development and Measurements

Blackouts are the results of cascading phenomena in power systems. In a large percentage of cases, hidden failures due to unexpected power system configurations, or misoperations of some protection systems, are important contributing factors in the sequence of events leading to a blackout. Adaptive relaying and wide area measurement systems (WAMS) have been proposed as a possible solution to hidden failures by providing improved protection system supervision in order to make protection systems adaptive to the prevailing system state.

[1] Led by the Western Electricity Coordinating Council (WECC), the Western Interconnection Synchrophasor Program (WISP) is installing more than 250-300 new or upgraded Phasor Measurement Units (PMU). Together, these synchrophasors can identify and analyze system vulnerabilities in real time, as well as detect evolving disturbances on the Western bulk electric system. Scheduled for completion in April 2013, this "early warning" mechanism will enable WECC and WISP's Partner Entities to take timely actions to that will help in avoiding widespread system blackouts (http://www.wecc.biz/awareness/Pages/WISP.aspx)

Through the use of real-time wide area synchronized phasor measurements, it is possible to determine optimum protection policies and settings for critically located relaying systems.

This projected was a proof of concept of four adaptive protection enhancements aimed to improve the reliability of the California electric grid. The project team:

- Developed a scheme for supervising back-up zones with remote phasor measurements so that back-up protection is not allowed to operate when it is not appropriate.
- Developed a load shedding algorithm by simulating various contingency conditions on the California power system model, and assessed its efficacy for taking control action to prevent islanding.
- Developed techniques to use wide area measurement systems to adjust the loss-of-field relay settings automatically as the system Thévénin (equivalent) impedance changes. Algorithms were developed to determine the proper method for setting these relays. Verification of the appropriateness of the developed logic by simulations was performed.
- Developed methodology to design a robust damping controller using remote phasor measurements on a multi-mode, multi DC line system for a large system along with suggested limits on the allowed delay. Methodology was developed to extend the results to FACTS[2] devices and generator excitation systems as the control mechanisms.

This research has moved the proposed schemes from conceptual enhancements to proven concepts applicable to the California grid. The next step in this development is a laboratory test at the California utilities using on-line data from a real system. These tests will reveal additional details on the limitations of available commercial equipment and other possible limitations due to non-technical requirements in the availability and sharing of the required wide area data and information among the California utilities.

Task 4.2 Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation

Regulation is a process of providing minute-to-minute system balance by adjusting the power output of generators connected to the automatic generation control system. Regulation is an expensive resource - the annual price of regulation could significantly exceed $120 million in California.

Most of CAISO's "once-through cooling" generating units along California's Pacific coast are expected to be retired or retrofitted within the next decade. These units have traditionally been used to provide balancing services for CAISO, and their retirement could potentially create a deficiency in available regulation resources. The consequent decline in available regulation resources coupled with the growth of renewable generation, will likely significantly increase the price of regulation as more regulation procurement is needed. These challenges motivate

[2] Flexible AC Transmission Systems

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CAISO to obtain a tool capable of predicting the needed procurement of up- and down-regulation services in the day-ahead market.

The objective of this project is to develop an approach to procuring regulation capacity that would minimize the regulation capacity required during some operating hours without compromising CAISO's control performance characteristics. The chosen approach predicts CAISO's regulation requirement on a day-ahead basis by calculating the required regulating capacity, ramping rate and ramp duration, including upward and downward, for each operating hour of a day.

Three methods were implemented. In the first method, the probability distributions of area control error (ACE) components, including the interchange error component, frequency error component, metering error correction component, automatic time error correction component, and inadvertent interchange payback component, are evaluated separately and summed to evaluate the regulation requirement. The second method predicts regulation requirements based on a statistical analysis of area control error signals and applied regulation data. The third method is similar to the second, but is based on the new Balancing Authority ACE limit (BAAL) standard. A statistical approach is used in all three methods to determine the regulation requirement. Results show that using the proposed methods can save CAISO an average of 10% of its current regulation procurement, satisfying current control standards. With the new BAAL control standard imposed, the savings could reach 30%.

Next steps would increase the robustness and performance of the tool while handling imperfect information typically available in control centers, improve the probabilistic models to additionally reduce regulation requirements, add additional model components reflecting new sources of uncertainty, put more emphasis on the regulation requirements posed by the new NERC control performance standards, and deploy the tool in the CAISO control center (and potentially in the IOUs' and other control centers in California).

The following specific steps are suggested:

1. Address data interpretation and quality issues to ensure robustness of the tool.
2. Develop and implement a new generation of statistical methods to address non-stationary characteristics of forecast errors especially for wind and solar resources. Further improve the accuracy and robustness of the tool.
3. Model probabilistically uninstructed deviation of generating units
4. Model probabilistically system frequency to obtain dynamically changed BAAL limits that is then used in calculating regulation requirements.
5. Update hourly estimated regulation requirements for the next 24 hours, and implant self-validation technique to warn system operator if previous estimates have large deviation from updated calculated values.
6. Provide support and adjustments needed for the trial use and actual implementation of the new BAAL control performance standard at CAISO.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

7. Get CAISO feedback on the tool performance in their control center. Address the additional requests from the CAISO. Finalize the tool for actual integration into CAISO system as a fully supported product used as part of CAISO operations.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

CHAPTER 7: Conclusions

Technology transfer is a contact sport. It cannot be done in isolation. It requires communication and contact across communities leveraging each community's knowledge and skills. In an increasingly complex and specialized research, funding, and legal environments expert knowledge has been recognized as a required element of success. This is officially acknowledged in many university, corporate and government environments which have seen in the last decade the creation of technology transfer offices as an essential part of their business model whose purposes are to create linkages between the development communities and to break down barriers to bring new ideas to market.

From within the academic community alone (Baker et al., 2010):

- "More than 6,000 new U.S. companies were formed from university inventions.
- 4,350 new university licensed products are in the market.
- 5,000 active university-industry licenses are in effect, mostly with small companies.
- More than 153 new drugs, vaccines or in vitro devices have been commercialized from federally funded research since enactment of Bayh-Dole.
- Between 1996 and 2007 university patent licensing made:
- a $187 billion impact on the U.S. gross domestic product,
- a $457 billion impact on U.S. gross industrial output; and
- 79,000 new jobs in the United States."

> The Better World Project shows how technology transfer – the process of licensing and commercializing academic research – improves people's lives contributes to the economy and supports tomorrow's discoveries.
>
> **John Fraser**

State and federal funded research plays an important role in many of the steps providing resources at every stage. In particular, California's PIER program plays a role in this by connecting researchers to end users and technology providers. Public funded research is open and transparent enhancing coordination and eliminating duplication of effort. "Since it began at the California Energy Commission in 1996, PIER has invested more than $700 million in energy research, development and demonstration projects with millions in tangible ratepayer benefits. PIER has also attracted more than $510 million in federal and private funding to California over the last decade …" (California, 2011b) and $1.3 billion in private sector investment since 1999 (California, 2011a). Investments have directly and indirectly generated over 30,000 jobs California, 2011b). Recent American Recovery and Reinvestment Act (ARRA) funding for energy-related projects and rebates have increased this funding by $314.5 million in 2010 California, 2010).

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

GLOSSARY

ACE	Area Control Error
BAAL	Balancing Authority ACE Limit
BPA	Bonneville Power Administration
CAISO	California ISO
CEC	California Energy Commission
CFL	Compact Fluorescent
CIEE	California Institute for Energy and Environment
CPUC	California Public Utilities Commission
DOE	Department of Energy
EGR	Electric Grid Research
EPRI	Electric Power Research Institute
HS	hybrid simulation
HTLS	high-temperature, low-sag
IEEE	Institute of Electric and Electronics Engineers
IOU	Independent System Operator
MANGO	Modal Analysis for Grid Operation
NASPI	North American Synchrophasor Initiative
NERC	North American Energy Reliability Corporation
NETL	National Energy Technology Laboratory
PAC	Policy Advisory Committee
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PMU	Phasor Measurement Units
PNNL	Pacific Northwest National Laboratory
RD&D	Research, development and demonstration
RPS	Renewable Portfolio Standard
SCE	Southern California Edison

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

REFERENCES

MIT. Massachusetts Institute of Technology, Technology Licensing Office. The Inventor's Guide to Tech Transfer. May 2005. 9 March 2012 < http://web.mit.edu/tlo/www/downloads/pdf/inventors_guide.pdf >.

Baker, P, E.B. Barish, J. Elliott, R.N. Fuller, M.R. Henderson and D. Perilstein. *The Positive Impact of Academic Innovations on Quality of Life,* The Better World Report, 2010. 9 March 2012 <http://www.betterworldproject.org/documents/AUTM10BWR_FNL.pdf>.

California. California Energy Commission. ARRA Funded Programs Investing in California's Energy Future. 180-2010-003. 2010. 9 March 2012 <http://www.energy.ca.gov/2010publications/CEC-180-2010-003/CEC-180-2010-003.PDF>.

California. California Energy Commission. Growth in the Green Economy, 500-2011-048, 2011a. 9 March 2012 <http://www.energy.ca.gov/2011publications/CEC-500-2011-048/CEC-500-2011-048-BR.pdf >.

California. California Energy Commission. How Public Research Powers California, 500-2011-030. 2011b. 9 March 2012 <http://www.energy.ca.gov/2011publications/CEC-500-2011-030/CEC-500-2011-030-BR.pdf>.

Harry, D.L., and P. Rillero. *Perspectives of Hands-On Science Teaching*. 1994. 9 March 2012 < http://www.ncrel.org/sdrs/areas/issues/content/cntareas/science/eric/eric-2.htm>.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

APPENDIX A:
Technology Transfer Activities by Project

Task 2.2 Analysis of the Seismic Performance of Transformer Bushings

Final Report: *In review. Final drafts will be available at:* http://uc-ciee.org/all-documents

Fact Sheet: http://uc-ciee.org/downloads/SB_FactSheet.pdf

Publications:

TECHNICAL REPORTS

Benassi, A. and Reinhorn, A.M. (2009), "Modeling of Conductors in Electrical Equipment & Sensitivity Studies", *MCEER Task Report –MCEER-TR-09-01*, University at Buffalo – the State University of New York.

Koliou, M., Filiatrault, A., Reinhorn A.M., and Oliveto N., (2011), "Seismic Protection of Electrical Transformer Bushing Systems by Stiffening Techniques", *MCEER Technical Report –MCEER-11-00xx*, University at Buffalo – the State University of New York (*in press*).

Reinhorn A.M., Filiatrault, A., Muhammad F. and Kong, D., (2012), "Evaluation of Seismic Performance of High Voltage Transformer Bushings", *Final Report* to *California Energy Commission,* Publication number: CEC-XXX-2012-XXX (*in review*).

Reinhorn A.M., Filiatrault, A., Muhammad F., Oliveto N., Oikonomou K and Koliou, M., (2011), "Evaluation of Transformer Bushings: Current and Recommended Practice" *MCEER Task Report –MCEER-TR-11-01*, University at Buffalo – the State University of New York.

Reinhorn A.M., Oikonomou K., Roh H., Schiff A., Kempner L., (2011), "Modeling and Seismic Performance Evaluation of High Voltage Transformers and Bushings", *MCEER Technical Report –MCEER-11-0004*, University at Buffalo – the State University of New York (*in press*).

Reinhorn, A.M. (ed), (2011), "Proceedings of the Workshop on Improving Earthquake Response of Substation Equipment", *MCEER Technical Report –MCEER-11-0003*, University at Buffalo – the State University of New York.

Reinhorn, A.M. and Oikonomou K. (2010), "Modeling of Transformers: 500kVv and 230 kV Cover Amplifications ", *MCEER Task Report –MCEER-TR-10-01*, University at Buffalo – the State University of New York.

DISSERTATIONS /THESES

Benassi, A. and Reinhorn, A.M. (2009), "Modeling of Conductors in Electrical Equipment & Sensitivity Studies", *MS Thesis,* University of Bologna Italy – prepared at University at Buffalo-the State University of New York (A.M.Reinhorn, adviser).

Koliou, M., (2011), "Seismic Protection of Electrical Transformer Bushing Systems by Stiffening Techniques", *MS Thesis*, (Filiatrault, A., Reinhorn A.M., advisers) University at Buffalo – the State University of New York.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Kong, D., (2010), "Evaluation and Protection of High Voltage Electrical Equipment Against Severe Shock and Vibrations", *PhD Dissertation*, (A.M.Reinhorn, adviser), University at Buffalo, (SUNY), Buffalo, NY.

Muhammad F., (2011), "Seismic Evaluation and Qualification of Transformer Bushings", *PhD Dissertation*, (A.M.Reinhorn, adviser), University at Buffalo, (SUNY), Buffalo, NY (expected Dec, 2011).

Oikonomou, K., (2010), "Seismic performance evaluation of high voltage transformer bushings", *MS Thesis*, (Reinhorn A.M., adviser) University at Buffalo – the State University of New York.

PAPERS WITH PRESENTATIONS

Cimellaro, G.P., Reinhorn, A.M. and Schiff, A., (2009), "Evaluation of Hollow Core Composite Insulators", *Proceedings of ASCE/TCLEE Conference 2009*, Paper #251, Oakland CA, June 29-July 1, 209-220.

Kong, D. and Reinhorn, A.M. (2009), "Seismic Evaluation and Protection of High Voltage Disconnect Switches", *Proceedings of ASCE/TCLEE Conference 2009*, Paper #252, Oakland CA, June 29-July 1, 221-231.

Muhammad F., Roh H., Oikonomou K., Reinhorn A.M., (2010), "Seismic Evaluation of Transformer Bushings", *Abstract and Presentation at 2010 ASCE/SEI Structures Congress,* May 12-15, 2010, Orlando, FL.

Oikonomou K., Roh H., Reinhorn A.M., Schiff A., Kempner L., (2010), "Seismic performance evaluation of high voltage transformer bushings", *Proceedings of 2010 ASCE/SEI Structures Congress,* May 12-15, 2010, Orlando, FL, 2724-2735.

Presentations:

Constantinou M.C., and Reinhorn A.M., (2011), "Seismic Isolation of Transformers", *Quake Summit 2011,* NEES & MCEER Annual Meeting, Buffalo NY, 8-10 Jun.

Koliou, M., (2011), "Seismic Protection of Electrical Transformer-Bushing Systems Incorporating Flexural Stiffeners", *Proceedings of Eighth International Conference on Structural Dynamics EURODYN 2011*, Leuven, Belgium, 4-6 July.

Koliou, M., (2011), "Seismic Protection of High Voltage Transformer – Bushing Systems Incorporating Flexural Stiffeners", *Quake Summit 2011,* NEES & MCEER Annual Meeting, Buffalo NY, 8-10 June.

Muhammad, F. (2011), "Testing of Transformer Bushings and Lessons Learned", *Quake Summit 2011,* NEES & MCEER Annual Meeting, Buffalo NY, 8-10 June.

Oikonomou, K. (2011), "Modeling of Electrical Transformers and Seismic Performance Evaluation of High Voltage Bushings", *Quake Summit 2011,* NEES & MCEER Annual Meeting, Buffalo NY, 8-10 June.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Oliveto, N., (2011), "Modeling of Electrical Composite Post Insulators", *(A.M. Reinhorn, adviser),* (A.M. Reinhorn, adviser), *at Quake Summit 2011,* NEES & MCEER Annual Meeting, Buffalo NY, 8-10 June

Reinhorn, A.M, (2010), "Evaluation of Transformer Bushings"(Schiff, A. and Kempner L. co-authors) *MCEER Report to IEEE Committee 693 Meeting, Buffalo NY, October 22, 2009.*

Reinhorn, A.M, (2011), "Evaluation of Transformer Bushings: Current and Recommended Practice", (Schiff, A. and Kempner L. co-authors) *MCEER Report to IEEE Committee 693 Meeting, Chicago, IL, May 16, 2011.*

Reinhorn, A.M. (2011), "Seismic Behavior and Protection of Electrical Equipment - An Overview", *Quake Summit 2011, NEES & MCEER Annual Meeting, Buffalo NY, 8-10 June.*

Reinhorn, A.M., Schiff A., and Kempner L. (2010), "Evaluation and Protection of Transformer Bushings" *MCEER Report to IEEE Committee 693 Meeting, Buffalo NY, October 23, 2008.*

Advisory Committee Meetings:

July 1, 2009	California Institute for Energy and Environment, Oakland, California
October 13, 2009	Pacific Earthquake Engineering Research Center, Richmond, California
January 13, 2010	Pacific Earthquake Engineering Research Center, Richmond, California

Miscellaneous:

October 24, 2008	MCEER-CEC-BPA International Workshop on Improving Earthquake Response of Substation Equipment *Hosted Workshop*

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 2.3 Analysis of the Seismic Performance of Substation Post Insulators

Final Report: *In review. Final drafts will be available at:* http://uc-ciee.org/all-documents

Fact Sheet: http://uc-ciee.org/downloads/SI_FactSheet.pdf

Publications:

Günay, S. and Mosalam K.M. "Real Time Hybrid Simulation of Porcelain and Polymer Electrical Insulator Posts Using A Smart Shaking Table and Comparison with Full Dynamic Testing," Proceedings of the 2012 Canadian Society for Civil Engineering Annual Conference, Edmonton, Canada, June, 6-9, 2012.

Günay, S. and Mosalam K.M. "Real-Time Hybrid Simulation of Electrical Insulator Posts Using A Smart Shaking Table," Proceedings of the 15th World Conference of Earthquake Engineering (15WCEE), Lisbon, Portugal, Sept., 24-28, 2012.

Mosalam K.M. and Günay, S., "Overview of Hybrid Simulation Framework with Application Examples," Proceedings of a Workshop in Honor of Prof. P. Gulkan, Middle East Technical University, Ankara, Turkey, Oct., 14, 2011.

Mosalam K.M., Günay, S., Moustafa, M., and Takhirov, S. "Experimental Investigation of the Seismic Performance of Substation Porcelain Post Insulators in High Voltage Disconnect Switches," Proceedings of the 15th World Conference of Earthquake Engineering (15WCEE), Lisbon, Portugal, Sept., 24-28, 2012.

Moustafa, M. and Mosalam K.M. "Finite Element Modeling and simulation of Substation Porcelain Post Insulators Subjected to Earthquake Loading," Proceedings of the 15th World Conference of Earthquake Engineering (15WCEE), Lisbon, Portugal, Sept., 24-28, 2012.

Presentations:

Günay, S., "real-Time Hybrid Simulation Example: Electrical Insulator," Hybrid Simulation Workshop, University of California, Berkeley, California, Feb., 24-25, 2011.

Günay, S. "Real Time Hybrid Simulation of Electrical Insulator Posts Using A Smart Shaking Table," Advances in Real-Time Hybrid Simulation Workshop, Lehigh University NEES Facility, Oct. 10, 2011.

Mosalam K.M., "Seismic Performance of Substation Post Insulators," Tongji University, Shanghai, China, July 26, 2010.

Mosalam K.M., "Hybrid Simulations and Sub-Structuring," Hybrid Simulation Workshop, University of California, Berkeley, California, Feb., 24-25, 2011.

Mosalam K.M., "Possible Collaboration Between nees@berkeley and Tsinghua University," Tsinghua University, Beijing, China, July 17, 2011.

Mosalam K.M., "Overview of Hybrid Simulation with Examples," Workshop in Honor of Prof. P. Gulkan, Middle East Technical University, Ankara, Turkey, Oct. 14, 2011.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Mosalam K.M., Moustafa, M., and Günay, S. "Seismic Performance of Substation Porcelain Post Insulators For Vertical-Break Disconnect Switches," Poster in the PEER Lifelines Program, 2011 PEER Annual Meeting, Berkeley, California, Sept., 30, 2011.

Advisory Committee Meetings:

October 14, 2009	Pacific Earthquake Engineering Research Center, Richmond, California
January 14, 2010	Pacific Earthquake Engineering Research Center, Richmond, California
March 18, 2010	Pacific Earthquake Engineering Research Center, Richmond, California
April 30, 2010	Pacific Earthquake Engineering Research Center, Richmond, California

Miscellaneous:

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 3.1 Wide-Area Energy Storage and Management System to Balance Intermittent Resources in the California ISO, Bonneville Power Administration and Pacific Gas and Electric Control Areas

Final Report: *In review. Final drafts will be available at:* http://uc-ciee.org/all-documents

Fact Sheet: http://uc-ciee.org/downloads/WAESMS_FactSheet.pdf

Publications:

Presentations:

Advisory Committee Meetings:

Miscellaneous:

June 15, 2010 Pacific Northwest National Laboratory, Richland, WA *Progress Review Meeting*

July 14, 2010 California ISO, Folsom, CA

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 3.2 Oscillation Detection and Analysis

Final Report: http://uc-ciee.org/downloads/ODA_Final_Report.pdf

Fact Sheet: http://uc-ciee.org/downloads/ODA_FactSheet.pdf

Publications:

PEER REVIEWED PAPERS

Follum, Jim, Ning Zhou and John Pierre, "Evaluation of Mode Estimation Accuracy for Small-Signal Stability Analysis," *2011 North American Power Symposium,* Boston, MA, August 4-6, 2011.

Zhou, Ning, Zhenyu Huang, Luke Dosiek, Dan Trudnowski, John W. Pierre, "Electromechanical Mode Shape Estimation Based on Transfer Function Identification Using PMU Measurements, " *IEEE PES General Meeting 2009*, Calgary, Alberta, Canada, July 26-30, 2009.

Zhou, Ning, Zhenyu Huang, Francis Tuffner, John Pierre, and Shuangshuang Jin, "Automatic Implementation of Prony Analysis for Electromechanical Mode Identification from Phasor Measurements," *2010 IEEE PES General Meeting*, Minneapolis, Minnesota, July 25-29, 2010.

TECHNICAL REPORTS

Zhou, Ning,Zhenyu Huang, Frank Tuffner, and Shuangshuang Jin, *Oscillation Detection Algorithm Development Summary Report and Test Plan*, Prepared for the California Institute for Energy and Environment and the California Energy Commission, Pacific Northwest National Laboratory, Richland, WA, October 2009.

Zhou, Ning, Zhenyu Huang, Frank Tuffner, Shuangshuang Jin, Jenglung Lin, and Matthew Hauer, *Algorithm Summary and Evaluation: Automatic Implementation of Ringdown Analysis for Electromechanical Mode Identification from Phasor Measurements*, Prepared for the California Institute for Energy and Environment and the California Energy Commission, Pacific Northwest National Laboratory, Richland, WA, Feb. 2010

Zhou, Ning, Zhenyu Huang, Francis Tuffner, Shuangshuang Jin, Jenglung Lin, and Matthew Hauer, *Oscillation Detection and Analysis*, Prepared for the California Institute for Energy and Environment and the California Energy Commission, Aug. 2010.

Presentations:

Zhenyu Huang, and Ning Zhou, "Grid Oscillation Detection, Analysis, & Mode Analysis for Grid Operation (MANGO)", presented to California ISO via Webconference, December 4, 2009.

Zhou, Ning, "Oscillation Detection and Analysis," presented to Bonneville Power Administration, Vancouver, WA, July 14, 2009.

Zhou, Ning, "R3LS Algorithm for Mode Meter Application", DOE Mode-Meter Project Research Update and Planning Meeting, Bozeman, MT, August 17, 2009.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Zhou, Ning, "Automatic Oscillation Detection for Mode Analysis," Bonneville Power Administration, Portland, OR, Aug 23 - 24, 2010

Zhou, Ning, "Oscillation Detection and Analysis", Research Seminar Series Organized by North America Chinese Power Professional Association, Sept 25, 2010.

Zhou, Ning, and Zhenyu Huang, "Oscillation Detection and Analysis", California Energy Commission/California Institute of Energy and Environment Project Kick-off Meeting, Seattle, WA, March 19, 2009.

Zhou, Ning, and Zhenyu Huang, "Grid Oscillation Detection, Analysis, & Application Developments", California Energy Commission (CEC) Transmission Research Program (TRP) Colloquium, Costa Mesa, CA, September 29, 2009.

Zhou, Ning, Zhenyu Huang, John Pierre, Dan Trudnowski, and Frank Tuffner "Oscillation Detection and Analysis", Bozeman, MT, Sept 08, 2010.

Zhou, Ning, Zhenyu Huang, Frank Tuffner, Shuangshuang Jin, Matt Hauer, and Kevin Lin, "Grid Oscillation Detection and Analysis", at the CEC/CIEE Public Interest Energy Research Program Review Meeting, Folsom, CA, June 22, 2010.

Zhou, Ning, Zhenyu Huang, Frank Tuffner, John Pierre, and Shuangshuang Jin, "Automatic Implementation of Prony Analysis for Electromechanical Mode Identification from Phasor Measurements," presentation at the IEEE Power and Energy Society General Meeting 2010, Minneapolis, MN, July 25-29, 2010.

Zhou, Ning, John Hauer, Jeff Johnson, Dan Trudnowski, and Zhenyu Huang, "BPA/PNNL DSI Toolbox for Analyzing PMU data", presented to Electric Reliability Council of Texas (ERCOT), Richland, WA, April 1, 2011.

Zhou, Ning, John Hauer, Jeff Johnson, Dan Trudnowski, and Zhenyu Huang, "BPA/PNNL DSI Toolbox for Analyzing PMU data", presented to the Western Electricity Coordinating Council, Richland, WA, March 8, 2011.

Zhou, Ning, Dan Trudnowski, and John Pierre, "Mode Meter Development", at the DOE/NETL Internal Program Review Meeting, Seattle, WA, June 10, 2010.

Zhou, Ning, Dan Trudnowski, and John Pierre, "Mode Meter Development", at the DOE Transmission Reliability Program Peer Review Meeting, Washington, DC, October 19-20, 2010.

Zhou, Ning, Dan Trudnowski, and John Pierre, "Mode Meter Development", DOE Transmission Reliability Program Internal Review Meeting, Washington, DC, June 14-15, 2011.

Zhou, Ning, Dan Trudnowski, John Pierre, Henry Huang, Frank Tuffner, Shuangshuang Jin, and Kevin Lin, "Mode Meter Related Work," Vancouver, WA, Dec 07, 2009

Advisory Committee Meetings:

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Miscellaneous:
June 15, 2010 Pacific Northwest National Laboratory, Richland, WA *Progress Review Meeting*
July 14, 2010 California ISO, Folsom, CA

Task 3.3 Application of Modal Analysis for Grid Operation (MANGO) on the Western Interconnection

Final Report: *In review. Final drafts will be available at:* http://uc-ciee.org/all-documents

Fact Sheet: http://uc-ciee.org/downloads/MANGO_FactSheet.pdf

Publications:

Chen, Yousu, Jason C Fuller, Ruisheng Diao, Ning Zhou, Zhenyu Huang, Frank K Tuffner, "The Influence of Topology Changes on Inter-area Oscillation Modes and Mode Shapes", in: Proceedings of the 2011 IEEE Power and Energy Society General Meeting, Detroit, Michigan, USA, July 24-29, 2011.

Diao, Ruisheng, Zhenyu Huang, Ning Zhou, Yousu Chen, Francis Tuffner, Jason Fuller, Shuangshuang Jin, and Jeff Dagle, "Deriving Optimal Operation Rules for Mitigating Inter-area Oscillations", in: proceedings of the 2011 IEEE Power and Energy Society Power System Conference and Exposition (PSCE), Phoenix, AZ, USA, March 20-23, 2011.

Huang, Zhenyu, Ning Zhou, Francis Tuffner, Yousu Chen, Daniel Trudnowski, William Mittelstadt, John Hauer, and Jeffery Dagle, "Improving Small Signal Stability through Operating Point Adjustment", in: Proceedings of the IEEE Power and Energy Society General Meeting 2010, Minneapolis, MN, July 25-29, 2010.

Huang, Zhenyu, Ning Zhou, Frank Tuffner, and Dan Trudnowski, "Use of Modal Sensitivity to Operating Conditions for Damping Control in Power Systems", in: Proceedings of the 44th Hawaii International Conference on System Sciences (HICSS), Kauai, Hawaii, January 4-7, 2011. *(invited paper)*

Zhou, Ning, Zhenyu Huang, Luke Dosiek, Dan Trudnowski, and John W. Pierre, "Electromechanical Mode Shape Estimation Based on Transfer Function Identification Using PMU Measurements", in: Proceedings of *PES-GM2009* – the IEEE Power and Energy Society General Meeting 2009, Calgary, Canada, July 26-30, 2009. *(invited paper)*

Zhou, Ning, Zhenyu Huang, Francis Tuffner, and Daniel Trudnowski, "A Modified Stepwise Linear Regression Method for Estimating Modal Sensitivity", in: Proceedings of the 2011 IEEE Power and Energy Society General Meeting, Detroit, Michigan, USA, July 24-29, 2011.

TECHNICAL REPORTS

Huang, Zhenyu, Ning Zhou, Frank Tuffner, Yousu Chen, John Hauer, Daniel Trudnowski, Jason Fuller, Ruisheng Diao, and Jeffery Dagle, "Modal Analysis for Grid Operation (MANGO): Feasibility, Solution Methods, and Application to the WECC System", Prepared for the California Institute for Energy and Environment and the California Energy Commission, Pacific Northwest National Laboratory, Richland, WA, December 2010.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Huang, Zhenyu, N Zhou, FK Tuffner, Y Chen, D Trudnowski, JE Dagle, and JF Hauer, "MANGO Framework and Its Applicability for the Western Interconnection", PNNL-18680, Prepared for U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, the California Institute for Energy and Environment and the California Energy Commission under Contract DE-AC05-76RL01830 Related Services, Pacific Northwest National Laboratory, Richland, WA, August 2009.

Huang, Z, N Zhou, F Tuffner, Y Chen, D Trudnowski, R Diao, J Fuller, W Mittelstadt, J Hauer, J Dagle, "MANGO – Modal Analysis for Grid Operation", prepared for the US Department of Energy Office of Electricity Delivery and Energy Reliability, September 2010.

Huang, Z, N Zhou, FK Tuffner, R Diao, DJ Trudnowski, Y Chen, JF Fuller, S Jin, JF Hauer, and JE Dagle, "Modal Analysis for Grid Operation (MANGO): Use of Modal Sensitivity for Damping Improvement through Generation Adjustment", Prepared for the US Department of Energy, Pacific Northwest National Laboratory, Richland, WA, October 2011.

Zhou, Ning, Zhenyu Huang, Frank Tuffner, Yousu Chen, John Hauer, Daniel Trudnowski, Jason Fuller, Ruisheng Diao, and Jeffery Dagle, "Modal Analysis for Grid Operations (Mango): Model and Methodology", Prepared for the California Institute for Energy and Environment and the California Energy Commission, Pacific Northwest National Laboratory, Richland, WA, March 2010.

Presentations:

Chen, Yousu, Jason C Fuller, Ruisheng Diao, Ning Zhou, Zhenyu Huang, Frank K Tuffner, "The Influence of Topology Changes on Inter-area Oscillation Modes and Mode Shapes", presentation at the 2011 IEEE Power and Energy Society General Meeting, Detroit, Michigan, USA, July 24-29, 2011.

Chen, Yousu, Zhenyu Huang, Ning Zhou, et al. "MANGO Topology Study", presented by Yousu Chen at the CEC/CIEE Public Interest Energy Research Program Review Meeting, Folsom, CA, June 22, 2010. Zhou, Ning, Zhenyu Huang, Francis Tuffner, and Daniel Trudnowski, "A Modified Stepwise Linear Regression Method for Estimating Modal Sensitivity", presentation at the 2011 IEEE Power and Energy Society General Meeting, Detroit, Michigan, USA, July 24-29, 2011.

Diao, Ruisheng, Zhenyu Huang, Ning Zhou, Yousu Chen, Francis Tuffner, Jason Fuller, Shuangshuang Jin, Jeff Dagle, "Deriving Optimal Operation Rules for Mitigating Inter-area Oscillations", presentation at the 2011 IEEE Power and Energy Society Power System Conference and Exposition (PSCE), Phoenix, AZ, March 20-23, 2011.

Diao, Ruisheng, Zhenyu Huang, Ning Zhou, et al. "Design of Operational Control Rules for Mitigating Inter-area Oscillation via Decision Tree Approach", presented by Ruisheng Diao at the CEC/CIEE Public Interest Energy Research Program Review Meeting, Folsom, CA, June 22, 2010.

Huang, Zhenyu, "Modal Analysis for Grid Operations (MANGO)", presented to BPA, Vancouver, WA, July 14, 2009.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Huang, Zhenyu, "Modal Analysis for Grid Operations (MANGO)", CERTS/DOE OE Transmission Reliability Real Time Grid Reliability Management Program Review, Washington, DC, June 9, 2009.

Huang, Zhenyu, and Ning Zhou, "Modal Analysis for Grid Operation (MANGO)", California Energy Commission/California Institute of Energy and Environment Project Kick-off Meeting, Seattle, WA, March 19, 2009.

Huang, Zhenyu, and Ning Zhou, "Modal Analysis for Grid Operations (MANGO) – Power Flow Adjustment for Damping Improvement", DOE Mode-Meter Project Research Update and Planning Meeting, Bozeman, MT, August 17, 2009.

Huang, Zhenyu, and Ning Zhou, "Modal Analysis for Grid Operations (MANGO) – Power Flow Adjustment for Damping Improvement", Oscillation Mitigation Meeting, Richland, WA, September 4, 2009.

Huang, Zhenyu, and Ning Zhou, "Modal Analysis for Grid Operations (MANGO)", presented by Ning Zhou at the DOE Transmission Reliability Program Peer Review Meeting, Washington, DC, October 19-20, 2010.

Huang, Zhenyu, Ning Zhou, et al. "Modal Analysis for Grid Operations (MANGO)", presented by Ning Zhou at the DOE/NETL Internal Program Review Meeting, Seattle, WA, June 10, 2010.

Huang, Zhenyu, Ning Zhou, Ruisheng Diao, and Frank Tuffner, "Modal Analysis for Grid Operations (MANGO)", presented to the Western Electricity Coordinating Council, Richland, WA, March 8, 2011.Huang, Zhenyu, Ning Zhou, Ruisheng Diao, and Frank Tuffner, "Modal Analysis for Grid Operations (MANGO)", presented to Electric Reliability Council of Texas (ERCOT), Richland, WA, April 1, 2011.

Huang, Zhenyu, Ning Zhou, Frank Tuffner, et al. "Modal Analysis for Grid Operations (MANGO)", presented by Frank Tuffner at the CEC/CIEE Public Interest Energy Research Program Review Meeting, Folsom, CA, June 22, 2010.

Huang, Zhenyu, Ning Zhou, Francis Tuffner, Yousu Chen, Daniel Trudnowski, William Mittelstadt, John Hauer, and Jeffery Dagle, "Improving Small Signal Stability through Operating Point Adjustment", presentation at the IEEE Power and Energy Society General Meeting 2010, Minneapolis, MN, July 25-29, 2010.

Huang, Zhenyu, Ning Zhou, Ruisheng Diao, Frank Tuffner, and Dan Trudnowski, "Modal Analysis for Grid Operations (MANGO)", DOE Transmission Reliability Program Internal Review Meeting, Washington, DC, June 14-15, 2011.

Huang, Zhenyu, Ning Zhou, Francis Tuffner, and Daniel Trudnowski, "Use of Modal Sensitivity to Operating Conditions for Damping Control in Power Systems", presentation at the 44th Hawaii International Conference on System Sciences (HICSS), Kauai, Hawaii, January 4-7, 2011. *Invited.*

Zhenyu Huang, and Ning Zhou, "Grid Oscillation Detection, Analysis, & Mode Analysis for Grid Operation (MANGO)", presented to California ISO via Webconference, December 4, 2009.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Zhou, Ning, and Zhenyu Huang, "Oscillation Detection and Analysis & Mode Analysis for Grid Operation (MANGO)", progress update presentation to California Energy Commission, Richland, WA, December 8, 2009.

Zhou, Ning, and Zhenyu Huang, "Grid Oscillation Detection, Analysis, & Application Developments", California Energy Commission (CEC) Transmission Research Program (TRP) Colloquium, Costa Mesa, CA, September 29, 2009. *Invited.*

Zhou, Ning, Zhenyu Huang, Luke Dosiek, Dan Trudnowski, and John W. Pierre, "Electromechanical Mode Shape Estimation Based on Transfer Function Identification Using PMU Measurements", in: Proceedings of *PES-GM2009* – the IEEE Power and Energy Society General Meeting 2009, Calgary, Canada, July 26-30, 2009. *Invited.*

Advisory Committee Meetings:

Miscellaneous:

June 15, 2010 Pacific Northwest National Laboratory, Richland, WA *Progress Review Meeting*

June 22, 2010 California ISO, Folsom, CA *Progress Review Meeting*

July 14, 2010 California ISO, Folsom, CA

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 4.1 Adaptive Relaying Technology Development and Measurements

Final Report: *In review. Final drafts will be available at:* http://uc-ciee.org/all-documents

Fact Sheet: http://uc-ciee.org/downloads/ARTD_FactSheet.pdf

Publications:

PEER REVIEWED PAPERS

De La Ree, J. , V. Centeno, J.S. Thorp, A.G. Phadke. "Synchronized Phasor Measurement Applications in Power Systems", IEEE Transactions on Smart Grid, Volume: 1, Issue: 1, 2010 , Page(s): 20 – 27. Digital Object Identifier: 10.1109/TSG.2010.2044815.

Ma, J., T. Wang, Z .Wang, J. Wu and J.S. Thorp. "Design of global power systems stabilizer to damp inter-area oscillations based on wide-area collocated control technique", IEEE Power and Energy Society General Meeting, 2011, Page(s): 1- 7. Digital Object Identifier: 10.1109/PES.2011.6039793.

Phadke, A.G., and J.S. Thorp. " Communication needs for Wide Area Measurement applications", Proceedings of CRIS 5th International Conference on Critical Infrastructures, Page(s): 1-7, 2010. Digital Object Identifier: 10.1109/CRIS.2010.5617484

DISSERTATIONS /THESES

Pal , Anamitra. *Coordinated Control of Inter-area Oscillations using SMA and LMI,* Dr. James S. Thorp, Committee Chair, December 2011.

Presentations:

Garlapti, S., J. Thorp. "Choice of Reference In CART Applications Using PMU Data", PSCC, Stockholm, Sweden, August 26, 2011.

Pal, A., "A Robust Control Technique for Damping Low Frequency Oscillations in the WECC" NASPI Meeting, Orlando, FL, January 2012.

Phadke, A. "Wide Area Measurement applications for improved protection", APAP-2011, Beijing, China, October 16, 2011. 2011. Keynote address.

Phadke, A. "Blackout Prevention in Power Systems", CRIS Workshop, Hanoi, Vietnam, November 16, 2011. 2011. Keynote address.

Phadke, A. "Recent developments in WAMS applications in Smart Grids", PowerGrid Indi a, Workshop, New Delhi, India, December 2, 2011. 2011. Keynote address.

Sambamoorthy, S. "Intelligent Load Shedding with Wide Area Measurement", NASPI Meeting, Orlando, FL, January 2012.

Tania, M. "Adaptive Loss of Field Relay Protection with Phasor Measurement", NASPI Meeting, Orlando, FL, January 2012.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Thorp, J. "The Power System as a Complex System Socially Coupled Systems and Informatics: Decision Making, Science & Computing in a Complex Interdependent World", Washington D.C., July 13, 2010.

Thorp, J "Synchrophasors in Smart Transmission", Seattle Washington, UKC, 2010, August 14, 2010.

Thorp, J ."Synchrophasors, Wide Area measurements and Control", Great Lakes Energy Institute, Cleveland OH, October 22, 2010,

Thorp, J. "Enlightened Transmission with PMUs, Jim Thorp, November 8 and 9 , 2010 Statistical and Applied Mathematical Sciences Institute (SAMSI) and Department of Mathematics, NC State,

Thorp, J. "Synchrophasors Wide Area Measurements and Control", Lockheed Martin Corporation, Bethesda, MD, May 17, 2011.

Thorp, J. "Adaptive Security Dependability", Lockheed Martin Corporation, Bethesda, MD, June 29, 2011.

Thorp, J. "New Developments in State Estimation", Lockheed Martin Corporation, Bethesda, MD, June 29, 2011.

Thorp, J. and A.G. Phadke. "Synchrophasors: Their Applications and Benefits", June 20, PacWorld Conference 2010 Dublin, Ireland. 2010.

Thorp, J., P. Zhang, and F. Gao. "Synchrophasor Detectives", SAMSI Workshop Scientific Problems for the Smart Grid, Raleigh, NC, October 3, 2011.

Thorp, J., P. Zhang, and F. Gao. "Synchrophasor Detectives ", Advanced Power System Automation and Protection 2011, Beijing International Convention Center, October 17, 2011. 2011.

Unknown. "Co-ordinated Control of Inter-area Oscillations using SMA and LMI", 2012 IEEE PES Innovative Smart Grid Technologies Conference Washington DC, Jan 16-20, Washington DC. 2012.

Advisory Committee Meetings:

Miscellaneous:

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Task 4.2 Developing Tools for Online Analysis and Visualization of Operational Impacts of Wind and Solar Generation

Final Report: http://uc-ciee.org/downloads/Day-ahead_Regulation_Final_Report.pdf

Fact Sheet: http://uc-ciee.org/downloads/OT_FactSheet.pdf

Publications:

Etingov, P.V., Y.V. Makarov, J. Ma, and Z. Huang "Incorporating of the Wind Generation Forecast Uncertainty Into Power System Operation, Dispatch, and Unit Commitment Procedures," *Proc. 9th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants*, Québec City, Québec, Canada, October 18- 19, 2010.

Etingov, P.V., Y. V. Makarov, N. Samaan , J. Ma, and C. Loutan, "Impact of the New BAAL Standard on the Regulation Reserve Requirements," *IEEE PES Transmission and Distribution Conference and Exposition*, Orlando, FL, May 7-10, 2012 (Submitted).

Makarov, Y. V., P. V. Etingov, Z. Huang, J. Ma, B. B. Chakrabarti, K. Subbarao, C. Loutan, and R. T. Guttromson, "Integration of Wind Generation and Load Forecast Uncertainties into Power Grid Operations," *IEEE PES Transmission and Distribution Conference and Exposition*, New Orleans, Louisiana, April 19-22, 2010.

Makarov, Y. V., P. V. Etingov, Z. Huang, J. Ma, and K. Subbarao, "Incorporating Wind Generation Forecast Uncertainty into Power System Operation, Dispatch, and Unit Commitment Procedures," IEEE *Transactions on Sustainable Energy*, Vol. 2, No. 4, October 2011.

Makarov, Y. V., P. V. Etingov, N. A. Samaan – Project Manager, J. Ma and C. Loutan, "*Predicting Day-Ahead Regulation Requirement for CAISO Balancing Area*," Final Project Report, PNNL-20676, California Energy Commission. August 2011. Makarov, Y. V., P.V. Etingov, N. A. Samaan, N. Lu, J. Ma, K. Subbarao, P. Du, and L. D. Kannberg, "Improving Performance of Power Systems with Large-scale Variable Generation Additions," IEEE PES General Meeting, San Diego, California, 22 – 26 July 22-26, 2012 (Accepted).

Makarov, Y. V., P. V. Etingov, N. A. Samaan, J. Ma, C. Loutan, M. Rothleder, and H. Alarian, "Estimation of the Regulation Requirements Taking Into Account Variable Generation to Comply with the New BAAL Standard," *AWEA Wind Power 2012 Conference & Exhibition*, Atlanta, GA June 3-6, 2012 (Submitted).

Makarov, Y. V., S. Lu, N. Samaan, Z. Huang, K. Subbarao, P. V. Etingov, J. Ma, N. Lu, R. Diao, , and R. P. Hafen, "Integration of Uncertainty Information into Power System Operations," *Proc. 2011 PES General Meeting*, 24-29 July 2011, Detroit, Michigan, USA. (Panel paper).

Presentations:

Makarov, Y. V., "New Phenomena in Bulk Power System Control," LCCC Lund Center for Control of Complex Engineering Systems Workshop on Dynamics, Control and Pricing in Power Systems, Lund, Sweden, May 17, 2011.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Makarov, Y. V., "New Phenomena in Bulk Power System Control," KTH Royal Institute of Technology Smart Grid Workshop, Stockholm, Sweden, May 24, 2011.

Makarov, Y. V., P. V. Etingov and C. Loutan, "Uncertainty Prediction Tools for System Operation," Presentation for WECC VGS, Salt Lake City, Utah, December 8, 2011.

Makarov, Y. V. P. V. Etingov, J. Ma, K. Subbarao, H. Huang, "Predicting Uncertainties for Real-Time and Day-Ahead Operations," Presentation for California Energy Commission Staff Workshop "Solar and Wind Forecasting: Achieving a 33% Solution", Presented by Jeff Dagle, Sacramento, CA, December 16, 2011.

Makarov, Y. V.,P. V. Etingov, J. Ma, K. Subbarao, and H. Huang, "Predicting Uncertainties for Real-Time and Day-Ahead Operations," Presentation for ISO New England (Web Meeting), Richland, WA, November 1, 2011.

Makarov, Y. V., P. V. Etingov, P. Du, K. Subbarao, H. Huang and J. Ma , "Wind and Solar Integration: Probabilistic Analysis and Visualization for Operations," Presentation for PJM Interconnection (Web Meeting), Richland, WA, August 8, 2011.

Makarov, Y. V., S. Lu, Z. Huang, K. Subbarao, P.V. Etingov, J. Ma, R.P. Hafen, R. Diao, and N. Lu, Ning, "Integration of Uncertainty Information into Power System Operations", Presentation at 2011 PES General Meeting, 24-29 July 2011, Detroit, Michigan, USA. (Panel paper).

Advisory Committee Meetings:

Miscellaneous:

June 15, 2010 Pacific Northwest National Laboratory, Richland, WA *Progress Review Meeting*

July 14, 2010 California ISO, Folsom, CA *Progress Review Meeting*

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

APPENDIX B:
Project Fact Sheets

See http://uc-ciee.org/all-documents

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

APPENDIX C:
Conferences, Meetings & Workshops Attended

2008

Event: PSERC Summer Workshop

Date: 4 August 2008

Location: Lake Tahoe, CA

Purpose: Member universities to formulate new electric power engineering research

Event: Department of Energy's 2008 Visualization & Controls Peer Review

Date: 21-22 October 2008

Location: Washington DC

Purpose: Become current on DOE real-time monitoring technology development effort

Event: The California Energy and Air Quality Conference

Date: 29 October 2008

Location: Southern California Edison, Diamond Bar, CA

Purpose: Presentation: *Renewable Energy Integration with Electric Transmission*

Event: *California Public Utilities Commission Internal Workshop focusing on technologies for reducing the visual and environmental impacts ("footprint") of transmission lines

Date: 13 November 2008

Location: San Francisco, CA

Purpose: Presentation: *Transmission Technologies for Increased Capacity and Reduced Impacts*

2009

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: Voltage Stability and Oscillation Damping Meeting

Date: 21-23 January 2009

Location: Southern California Edison, Rosemead, CA

Purpose: Identify new or expanded transmission operational research activities that improve transmission operations.

Event: *EPRI/ACORE Workshop

Date: 10-11 February 2009

Location: EPRI, Palo Alto, CA

Purpose: Participate in discussions on assembling a national Renewable Technologies development plan

Event: 2009 i-PCGRID Workshop

Date: 18-20 March 2009

Location: San Francisco, CA

Purpose: Invited presentation: *New Transmission Technologies for Renewable Integration*

Event: California Energy Commission Energy Storage Workshop

Date: 2 April 2009

Location: Sacramento, CA

Purpose: Stakeholder input on how energy storage can help meet California's Renewable Portfolio Standards goals.

Event: *California Smart Grid Research Symposium

Date: 7 April 2009

Location: University of California Irvine, Irvine, CA

Purpose: Invited Speaker

Event: R&D Planning meeting

Date: 23 April 2009

Location: California ISO, Folsom, CA

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Purpose: Strategic and tactical planning and scheduling of projects involving and benefitting California ISO. Discuss 2010-11 research needs.

Event: Western Regional Profiles Workshop

Date: 15 May 2009

Location: Sacramento, CA

Purpose: Invited Speaker (integrating renewable onto the electric grid)

Event: *R&D Planning meeting

Date: 1-2 June 2009

Location: California ISO, Folsom, CA

Purpose: Discuss grid oscillations

Event: North American Synchrophasor Initiative meeting

Date: 3-4 June 2009

Location: Sacramento, CA

Purpose: Meeting focused on synchrophasor operations and success stories throughout North America.

Event: Storage Summit

Date: 13-16 July 2009

Location: La Jolla, CA

Purpose: Major storage industry conference attended by technology developers, business and financial groups, utilities, regulators, researchers, etc.

Event: *Renewable Energy Technology Initiative Stakeholder Steering Committee Meeting

Date: 29 July 2009

Location: California Public Utilities Commission, San Francisco, CA

Purpose: Discuss work, which entails working with the IOUs in California to develop conceptual transmission plans that address the need for new and upgraded

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

transmission to accommodate the expected renewable energy projects for the state's 33% RPS goals.

Event: Infrastructure Technology Advisory Committee meeting

Date: 12 August 2009

Location: CIEE, Sacramento, CA

Purpose: Overview, update and member roundtable on technology needs and priorities

Event: PIER Distribution Program Policy Advisory Committee

Date: 5 August 2009

Location: Navigant, San Francisco, CA

Purpose: Invited Presentation on the Underground Cable Fault Analysis and Concentric Neutral Degradation Analysis projects

Event: *CAISO Transmission Planning Meeting

Date: 21 August 2009

Location: California ISO, Folsom, CA

Purpose: Discuss CAISO transmission planning needs.

Event: PIER Renewables: Milestone Meeting for Utility-Scale Renewable Energy Roadmap meeting

Date: 26 August 2009

Location: California Energy Commission, Sacramento, CA

Purpose: Information learned in contract effort to date was used as background for reviewing the study results

Event: Infrastructure Technology Advisory Committee meeting

Date: 16 September 2009

Location: CIEE, Sacramento, CA

Purpose: Project reviews and updates

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: *Pacific Northwest National Laboratory Project and Research Needs Review

Date: 8 December 2009

Location: Pacific Northwest National Laboratory, Richland, WA

Purpose: Review of current Pacific Northwest National Laboratory projects and ideas for future research to meet California needs.

Event: *EPRI Workshop - Enabling Transmission for Large Scale Renewable Integration

Date: 14-15 December 2009

Location: EPRI, Palo Alto, CA

Purpose: Develop the framework for integrating renewable generation into operations and planning

2010

Event: FCC Project Advisory Group Meeting

Date: 30 March 2010

Location: Irvine, CA

Purpose: Fault Current Controller project advisory meeting attended

Event: Focus Area I TAC Meeting

Date: 31 March 2010

Location: Irvine, CA

Purpose: Meeting of the Systems & Infrastructure Technical Advisory Committee, to review and strategize the Focus Area I Systems & Infrastructure R&D program.

Event: 2010 Renewable Energy Secure Communities Experts Symposium

Date: 13 April 2010

Location: University of California, Davis, Davis, California

Purpose: Share knowledge gained and lessons learned from studies on New Transmission Technologies for Renewable Integration to Workshop participants

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: Sacramento Municipal Utility District International Exchange

Date: 16 April 2010

Location: Sacramento Municipal Utility District, Sacramento, California

Purpose: International exchange meeting with representatives from Central and South America regarding renewable integration and smart grid at the invitation of the California World Trade Center

Event: 2010 IEEE PES Transmission and Distribution Conference and Exposition

Date: 19-22 April 2010

Locations New Orleans, Louisiana

Purpose: Invited Presentation: *Plausible Future for Electric Grid Architecture*

Event: Montreux Energy Clean Energy Roundtable

Date: 27-29 April 2010

Location: Paso Robles, California

Purpose: Get information and transfer what has been learned from CEC-PIER-funded research activities and strategic planning regarding the role of new electric grid in fulfilling the state's goals in clean energy and renewable energy deployment, and in adapting the grid to handle electric vehicles

Event: Pacific Northwest National Laboratory Project review

Date: 15 June 2010

Location: PNNL, Richland, WA and webcast

Purpose: Progress review meeting of several PIER projects

Event: Pacific Northwest National Laboratory Project review

Date: 22 June 2010

Location: CAISO, Folsom, CA

Purpose: Progress review meeting of oscillation detection and mitigation research

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: California ISO Pacific Northwest National Laboratory Project Review Meeting

Date: 14 July 2010

Location: Folsom, California

Purpose: Review meeting of current projects involving both California ISO Pacific Northwest National Laboratory

Event: Transmission Executive Forum West 2010

Date: 20 September 2010

Location: San Francisco

Purpose: Invited Presentation: New Electric Grid Technologies for Renewable Integration – The Need for Being Smarter

Event: *University of California-Lawrence Berkeley National Laboratory Discussion Group on Demand Response, Renewables and System Operation

Date: 28 September 2010

Location: Lawrence Berkeley National Laboratory

Purpose: Invited presentation: Renewables Integration and Smart Grids – A Framework for Research Needs

Event: PIER Security Advisory Committee meeting

Date: 30 September 2010

Location: California Energy Commission, Sacramento, California

Purpose: Invited Presentation: *Extreme Events Research Project*

Event: Department of Energy Peer Review Meeting

Date: 19-20 October 2010

Location: Washington, D.C.

Purpose: Invited Presentation: *Application of Advanced Wide Area Early Warning System with Adaptive Protection*

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: California Energy Commission Transmission Research Symposium Paving the Way for Renewables

Date: 25 October, 2010

Location: Sacramento, CA

Purpose: Review PIER sponsored research with focus on the issues of renewables integration.

Event: IEEE Power and Energy Systems meeting

Date: 15 November 2010

Location: San Francisco

Purpose: Invited Presentation: *New Grid Technology for Renewable Integration*

Event: Workshop on Smart Grid Road Mapping

Date: 17 December 2010

Location: Sacramento

Purpose: Highlight the PIER program's three Smart Grid research, development, and demonstration (RD&D) road mapping projects as a part of the 2011 Integrated Energy Policy Report

2011

Event: Distributech 2011

Date: 1-3 February 2011

Location: San Diego, California

Purpose: Distributech 2011 Conference & Exposition, a large industry conference focusing on distribution systems, distribution technologies and issues relating to impacts of renewables on distribution.

Event: i4energy Seminar

Date: 4 February 2011

Location: University California Berkeley, Berkeley, California

Purpose: **I**nvited Presentation: *Plausible Futures for Electric Grid Architecture – A Scenario Planning Exercise*

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: ICEPAG 2011

Date: 8-10 February 2011

Location: Costa Mesa, California

Purpose: Invited Presentation: *New Grid Technology for Renewable Generation Deployment*

Event: i4energy Seminar

Date: 11 February 2011

Location: University California Berkeley, Berkeley, California

Purpose: Invited Presentation: *Synchrophasors: How They are Making the Electric Grid Smarter*

Event: 2011 Renewable Energy Secure Communities Experts Symposium

Date: 22-23 February 2011

Location: University of California, Davis, Davis, California

Purpose: Invited Presentation: *The Electric Grid and RESCO Integration*

Event: iPCGRID Workshop on Innovations in Protection and Control for Greater Reliability Infrastructure Development

Date: 30 March -1 April 2011

Location: San Francisco, California

Purpose: Invited talk: (1) *Public Interest Energy Research Program and Energy Storage Program Overview*, by Merwin Brown on behalf of Avtar Bining (CEC), 2) invited talk Plausible Futures for the Grid of the 21st Century – A Scenario Planning Exercise.

Event: 2nd Annual IRES Conference

Date: 4 April 2011

Location: University of California, Davis, Davis, California

Purpose: Invited as Cal-IRES advisor

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: DOE NETL review meeting for Transmission Reliability and NETL Advanced Synchrophasor projects

Date: 14-15 June 2011

Location: Washington, D.C.

Purpose: Invited talk: *DOE Advanced Relay Demonstration* project.

Invited Panel Review Member: Merwin Brown

Event: *i4Energy forum

Date: 21 June 2011

Location: University California Berkeley, Berkeley, California

Purpose: International Forum between Danish and United States wind experts

Event: IEPR Workshop

Date: 22 June 2011

Location: California Energy Commission, Sacramento, CA

Purpose: Invited presentation: Distribution System Monitoring – Intelligence to manage variability and uncertainty

Event: *Current Challenges in Computing 2011

Date: 22-24 August 2011

Location: Napa, California

Purpose: Energy Resource Modeling. Spur discussion in the energy resource modeling community about how to advance the start-of-the-art by exploiting current and anticipated computational capability.

Event: Error! Bookmark not defined.Itron Users' Conference

Date: 20 September 2011

Location: Scottsdale, AZ

Purpose: Invited presentation: Integration of Distributed and Intermittent Resources – Coordination Challenges in Space and Time

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Event: *AEE Annual Conference 2011: Energy Security: Keeping the Power On

Date: 22 September 2011

Location: Downey, CA

Purpose: Invited Talk: A Modern Electric Grid for Meeting Renewable Energy Goals

Event: i4Energy PIER Conference

Date: 29 September 2011

Location: University California Berkeley, Berkeley, California

Purpose: Invited talks: *Addressing the Elephant in the Room: Analyzing Extreme Events, Raising the IQ of Electric Grid Protection Systems Merwin, Lorraine, Lloyd*

Event: *International Conference on Electric Power Quality and Utilization (EPQU)

Date: 17 October 2011

Location: Lisbon, Portugal

Purpose: Presentation: Integration of Distributed and Intermittent Resources – Coordination Challenges in Space and Time

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

APPENDIX D – Advisory Group Meetings – Non Project Related

Date, Hosted By

Policy Advisory Committee

2008

September 11-12 California Energy Commission, Sacramento, California

December 4 Southern California Edison, Rosemead, California

2009

March 27 Conference Call

June 5 California Independent System Operator, Folsom, California

September 29-30 Southern California Edison, Costa Mesa, California

December 3 Pacific Gas & Electric, Vacaville, California

2010

May 13 San Diego Gas & Electric, San Diego, California

2011

April 8 Southern California Edison, Westminster, California

Systems & Infrastructure Technical Advisory Committee Meeting

2009

August 12 California Institute for Energy and Environment, Sacramento, California

September 16 California Institute for Energy and Environment, Sacramento, California

November 3 California Institute for Energy and Environment, Sacramento, California

2010

July 21 California Institute for Energy and Environment, Sacramento, California

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.

Technical Advisory Committee Meeting

2011

March 28	California Institute for Energy and Environment,	Sacramento, California
May 5	California Independent System Operator, Folsom, California	
June 24	California Energy Commission, Sacramento, California	

Distribution Monitoring Working Group

2011

July 26	California Institute for Energy and Environment,	Sacramento, California
October 6	California Institute for Energy and Environment,	Sacramento, California

Distribution Monitoring for Renewables Integration

2011

July 27	California Institute for Energy and Environment,	Sacramento, California
October 5	California Institute for Energy and Environment,	Sacramento, California

*Travel expenses for meetings marked with * were funded by CIEE or the meeting host.