Grid Oscillation Detection, Analysis, & Application Developments

Presented by
Ning Zhou
Pacific Northwest National Laboratory

To: California Energy Commission
Transmission Research Program Discussion Group

September 29, 2009
Costa Mesa, CA

Project Team:
Henry Huang
Ning Zhou
Frank Tuffner
Yousu Chen
Jeff Dagle
John Hauer

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

Outline

- ❖ Introduction

1. A Mode Meter Tool.

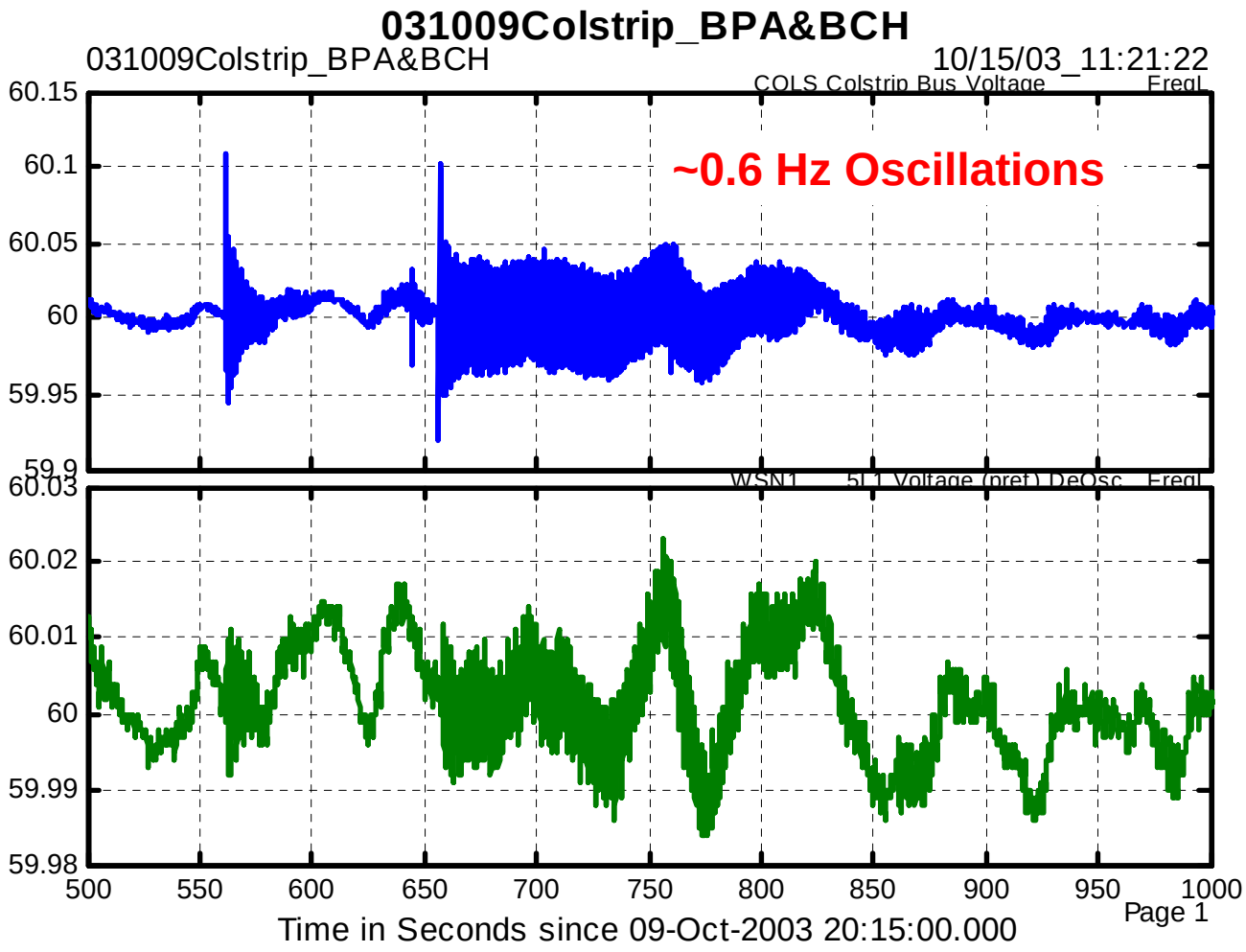
   - Oscillation detection and analysis.

2. Modal Analysis for Grid Operation.

   - Power flow adjustment for damping improvement

- ❖ Results & Conclusions

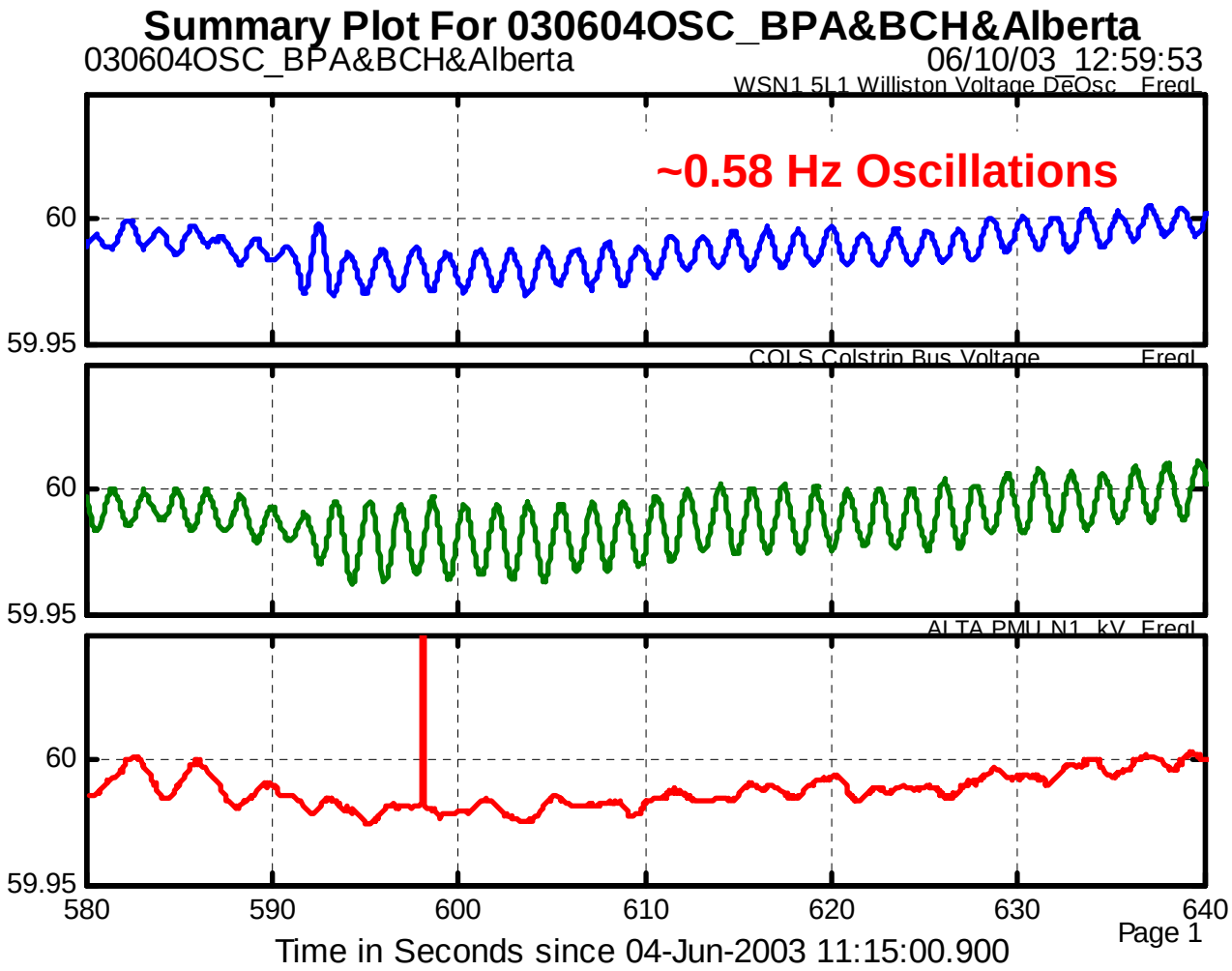
Past Oscillation Events – 2003/10/09



orthwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

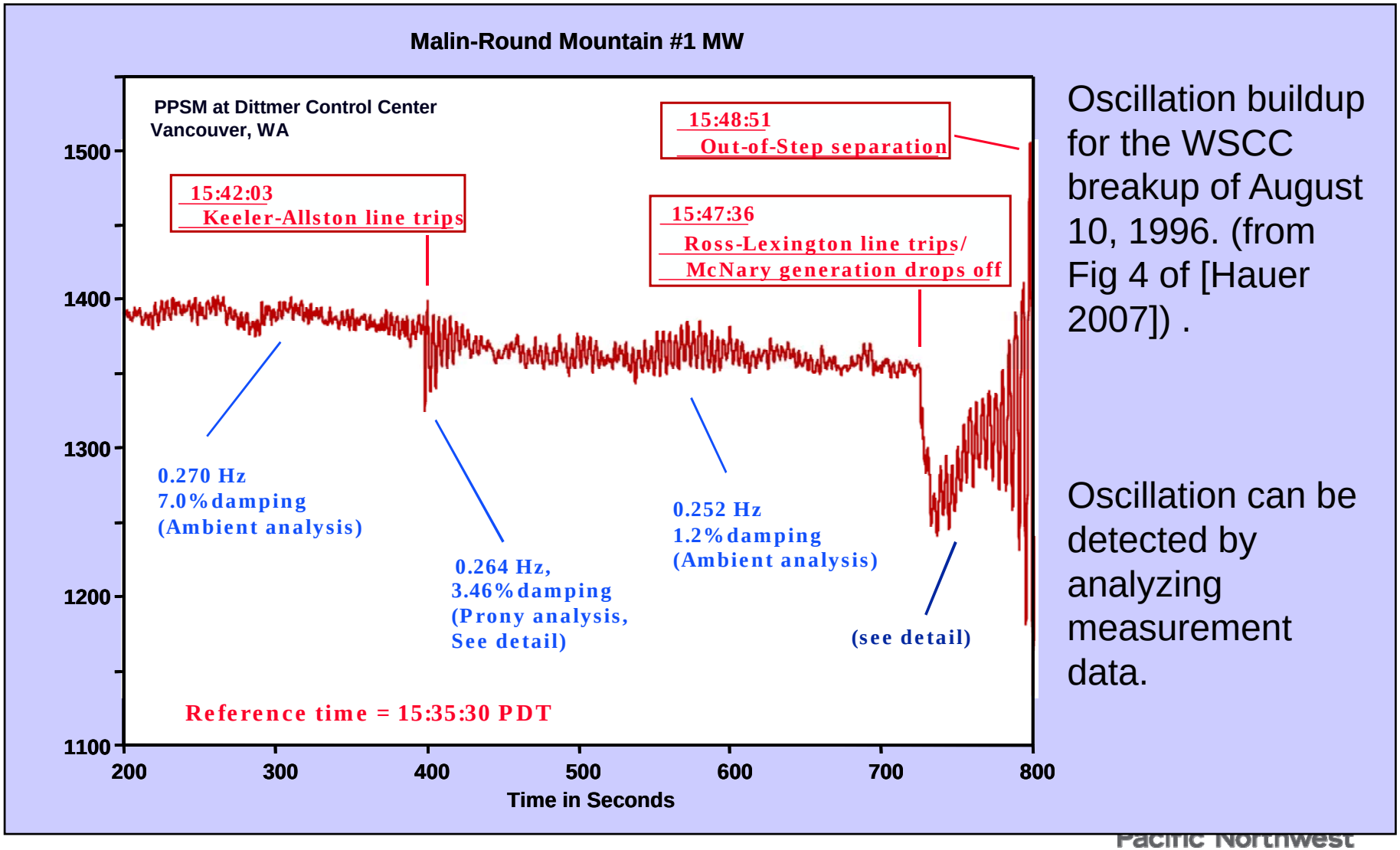
Past Oscillation Events – 2003/06/04



orthwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Mode Identification from Block Processing



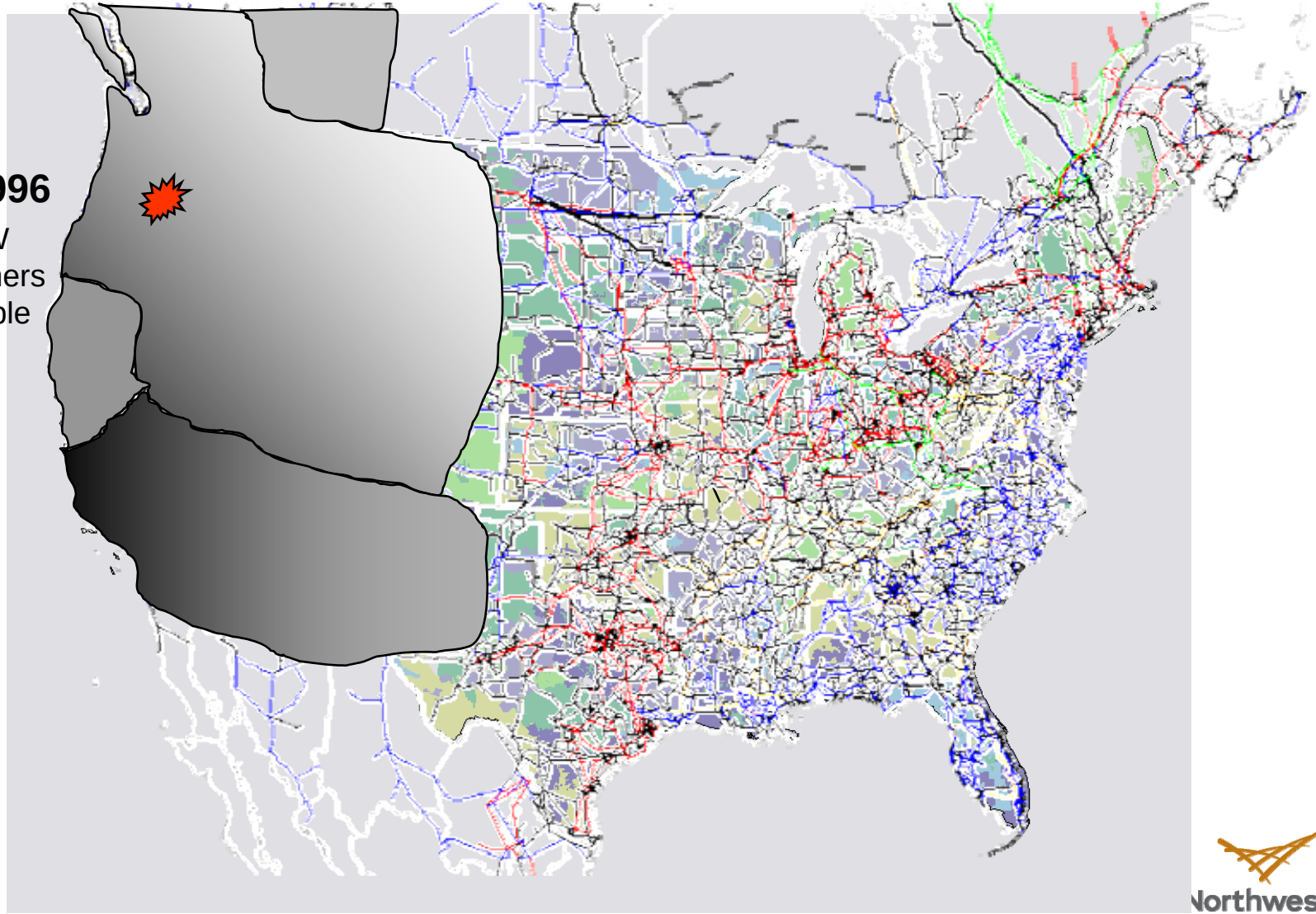
Oscillation buildup for the WSCC breakup of August 10, 1996. (from Fig 4 of [Hauer 2007]) .

Oscillation can be detected by analyzing measurement data.

Blackout in Aug, 1996

Aug. 1996

30,000 MW
8M customers
~24M people



Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Some Outages/Seperation Caused by the Oscillation

- Hong Kong electric Co. (1991)
- Southern Brazil (1970-1980, 1984)
- Ghana-Ivory Coast (1985)
- Taiwan (1985)
- Western Australia (1982, 1983)
- Scotland-England (1978)
- South East Australia (1975)
- Min-continent area power pool (1971, 1972)
- Western Electric Coordinating Council (1964, 1996)
- Italy-Yugoslavia-Austria (1971-1974)
- Saskatchewan-Manitoba Hydro-Western Ontario (1996)
- Detroit Edison (DE-Ontario Hydro – Hydro Quebec) (1960s, 1985).

B. Pal, B. Chaudhuri, *Robust Control in Power Systems*, Springer US, 2005

Causes of Oscillation

- **Transmit bulk power over long distances.**
  - ***There is an upper-limit on how much power can be transferred from remote area. (This limits can come from power grid oscillation.)***

Outline

- ❖ Introduction

1. A Mode Meter Tool.

   - Oscillation detection and analysis.

2. Modal Analysis for Grid Operation.

   - Power flow adjustment for damping improvement

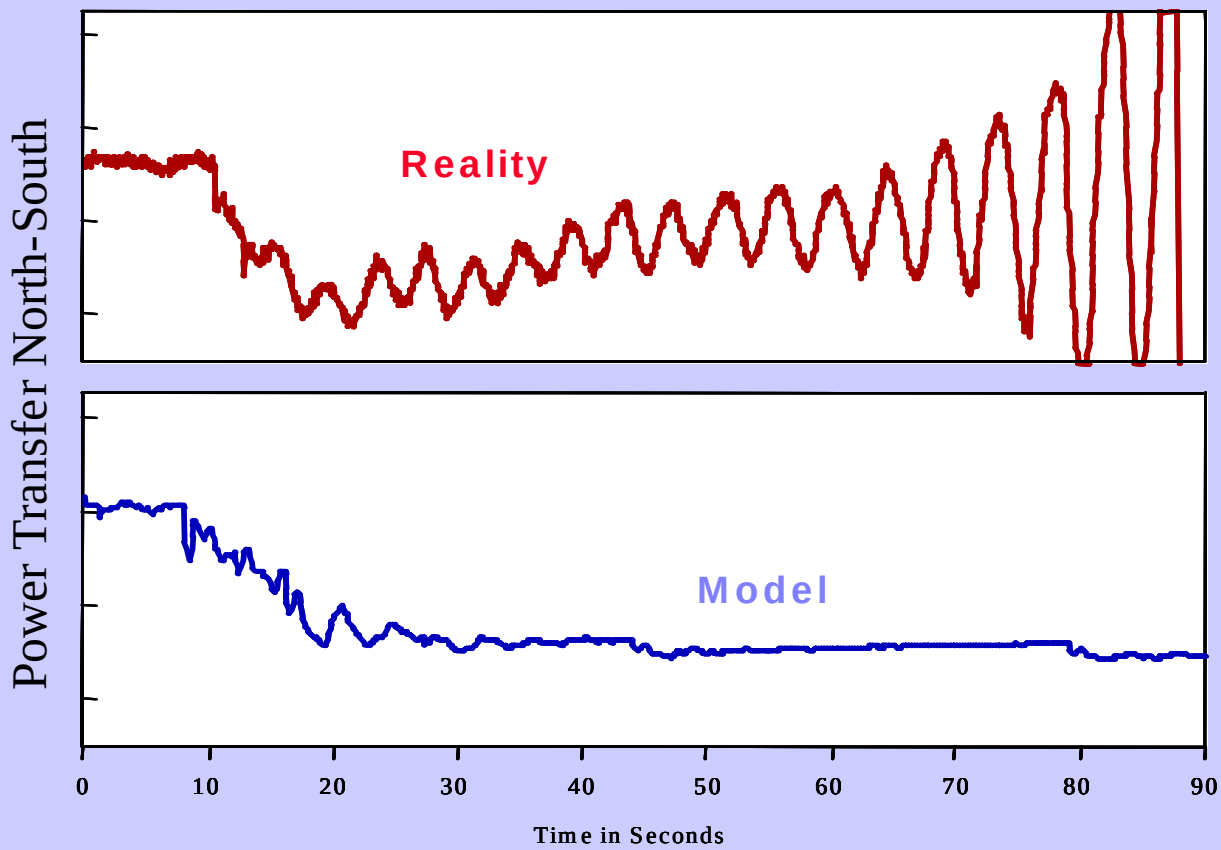
- ❖ Results & Conclusions

Damping Ratio

thwest
LABORATORY

Proudly Operated by Battelle *Since 1965*

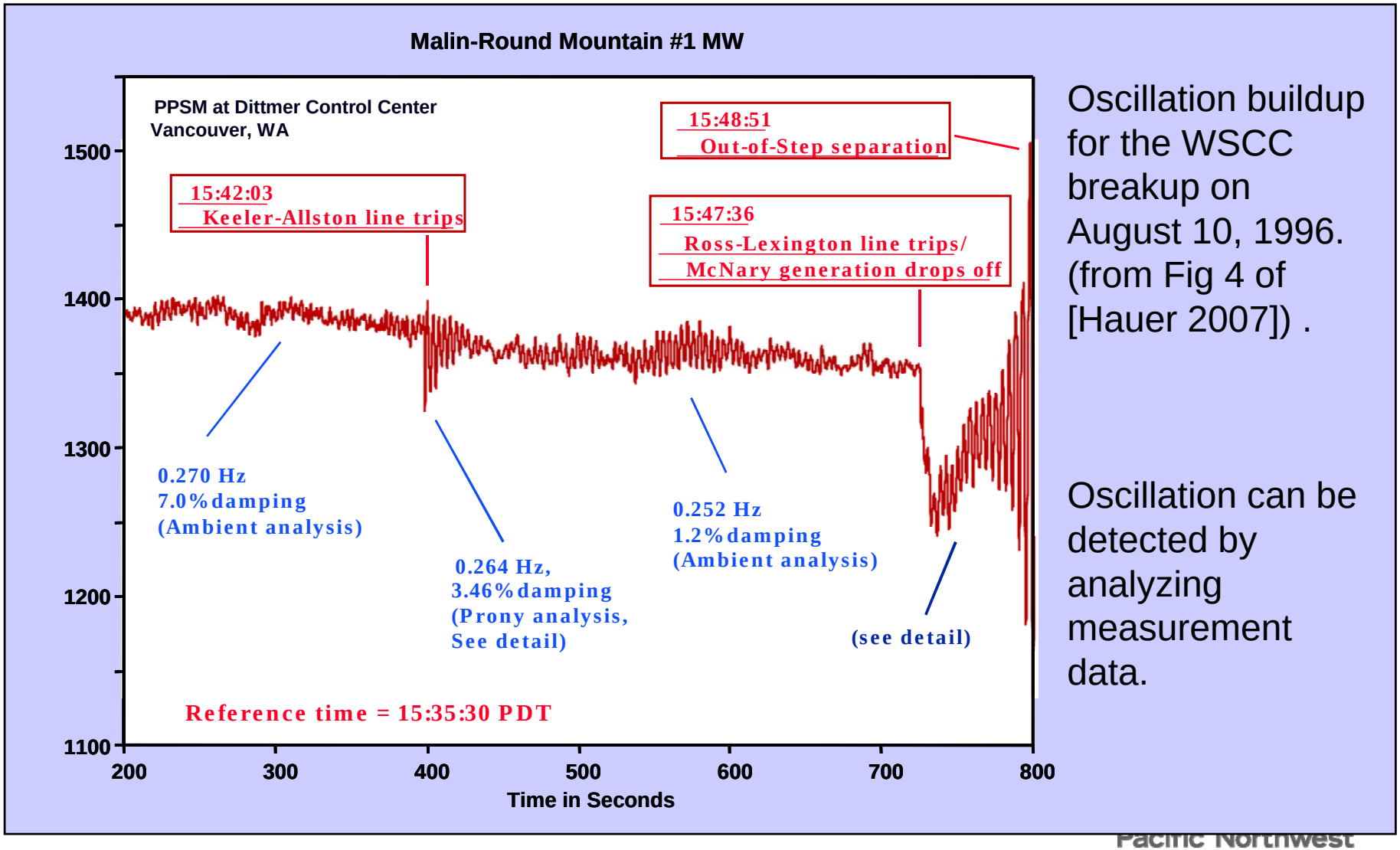
Component-based Modeling Method



Initial Results from the Comprehensive Simulation Model using Component-based Modeling Method

[1] Kosterev, D. N., C. W. Taylor, and W. A. Mittelstadt, "Model Validation for the August 10, 1996 WSCC System Outage," IEEE Transactions on Power Systems, vol. 14, no. 3, pp. 967-979, August 1999.

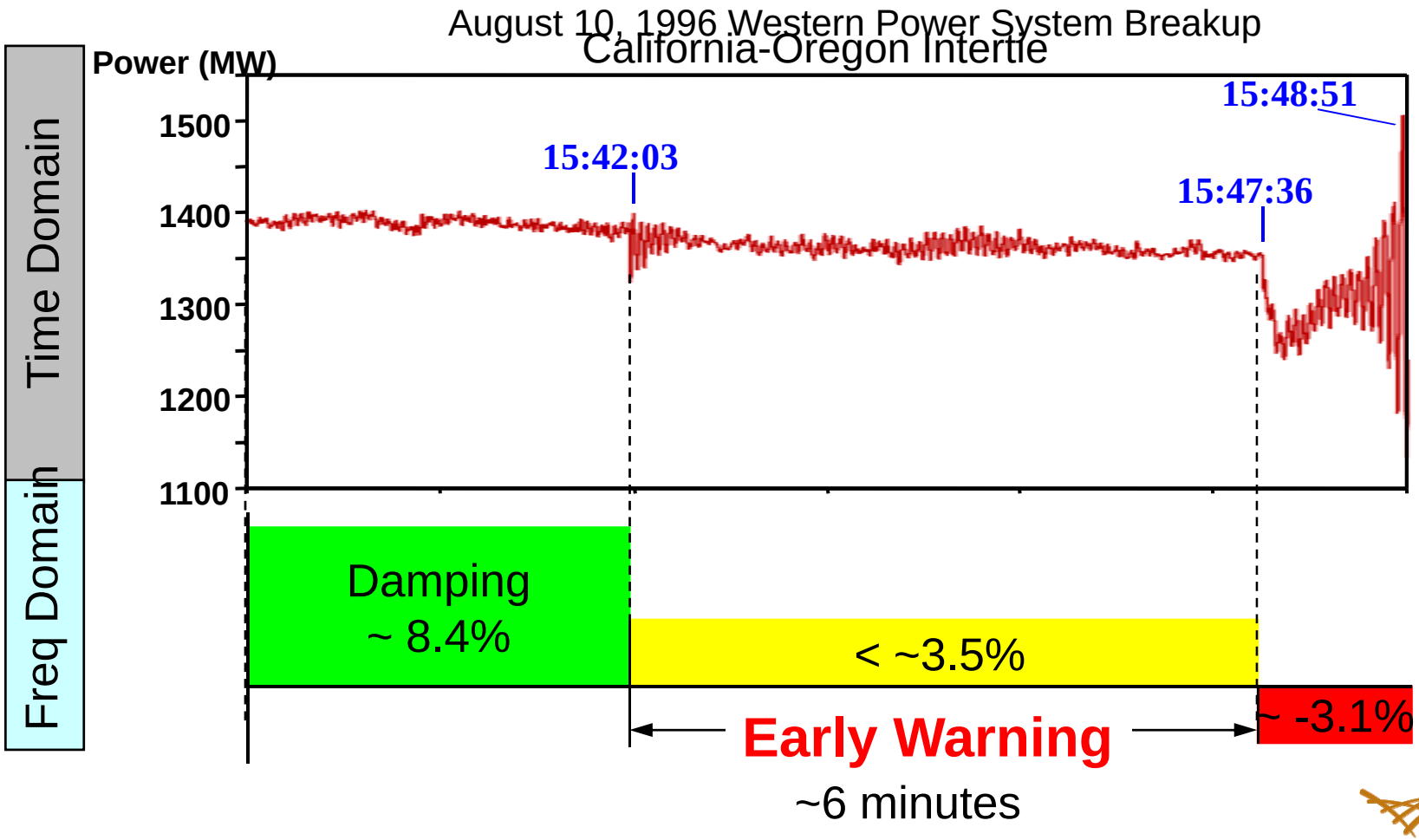
Measurement based Modeling (Identification)



Oscillation buildup for the WSCC breakup on August 10, 1996. (from Fig 4 of [Hauer 2007]) .

Oscillation can be detected by analyzing measurement data.

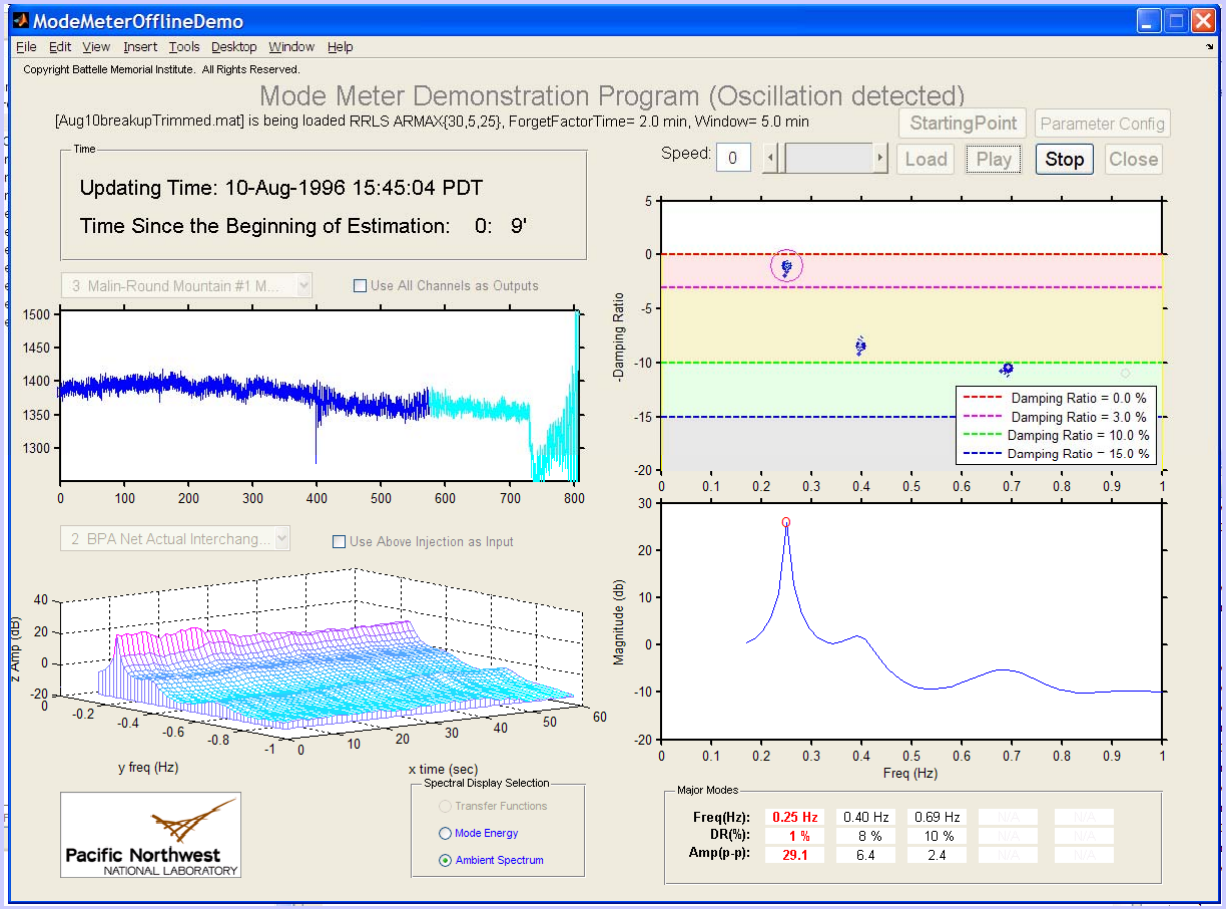
Past Oscillation Events – 1996/08/10



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Mode Identification from R3LS (01)



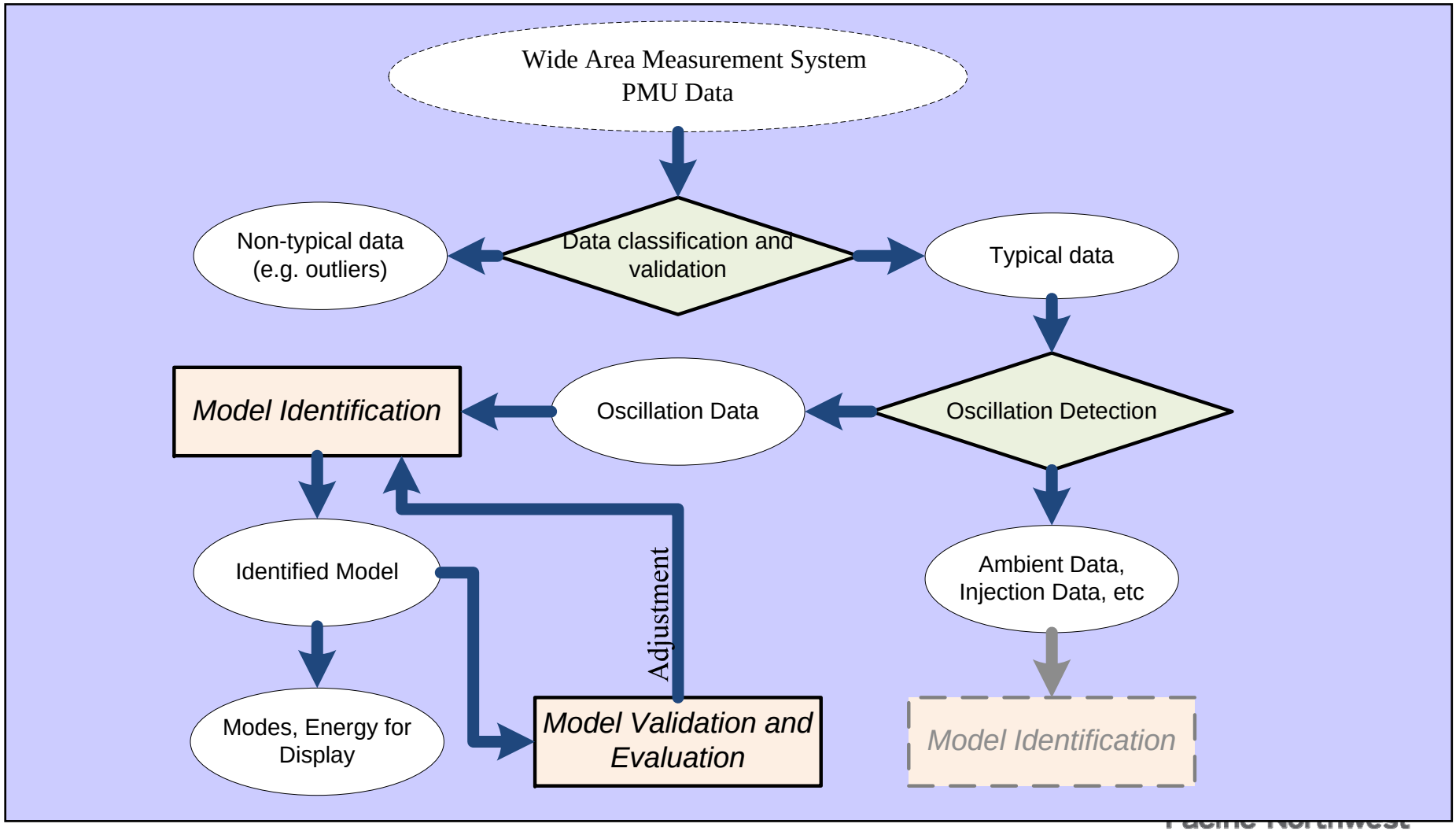
Application of R3LS mode meter on the Malin-Round Mt. measurement taken on Aug 10th, 1996.

(*Video Demo*)

Focus of Study

- On-line algorithms.
- Improve accuracy and increase speed of detection.
  - Check the data.
  - Adapt the algorithm according to the feature of the data
- Reduce false alarm and missing alarm.
  - Data and model validation

Focus of Study



1996 black out

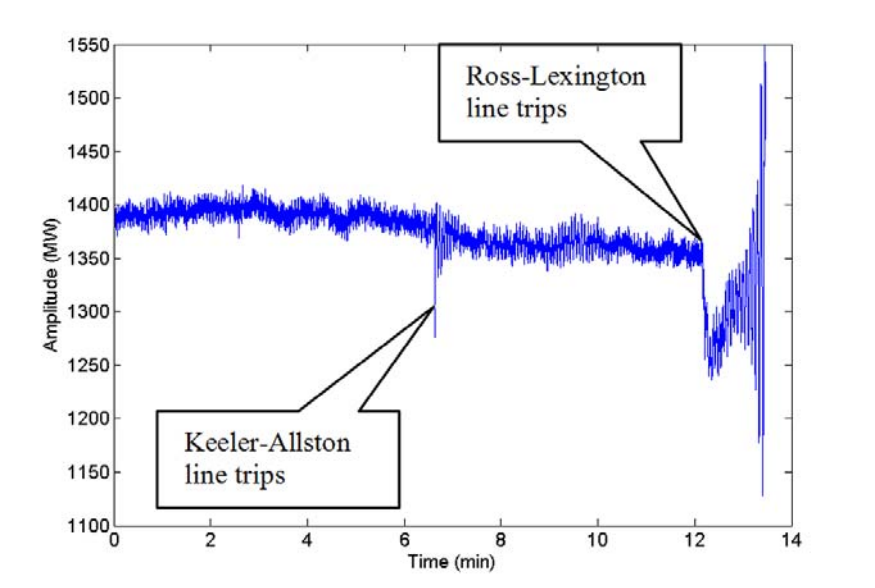
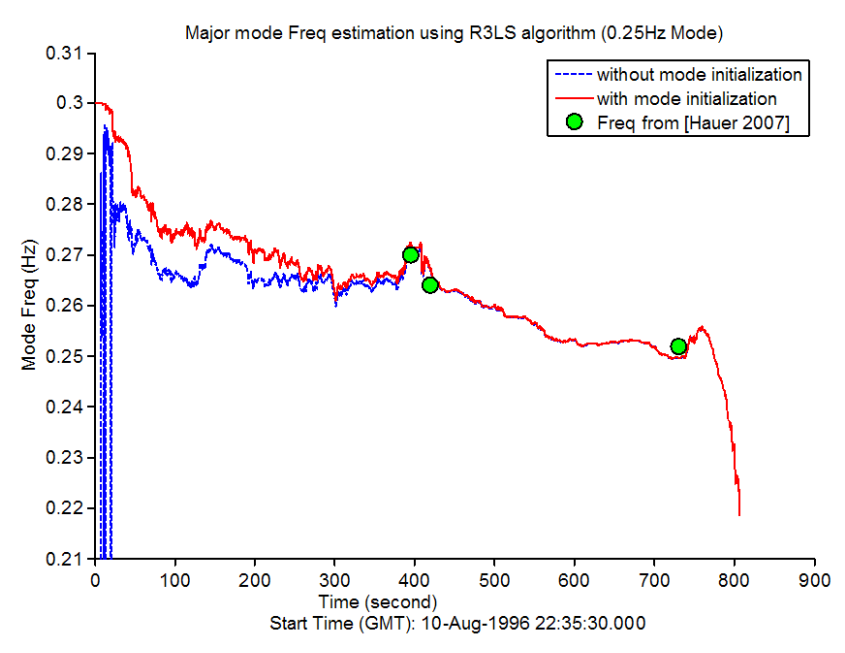
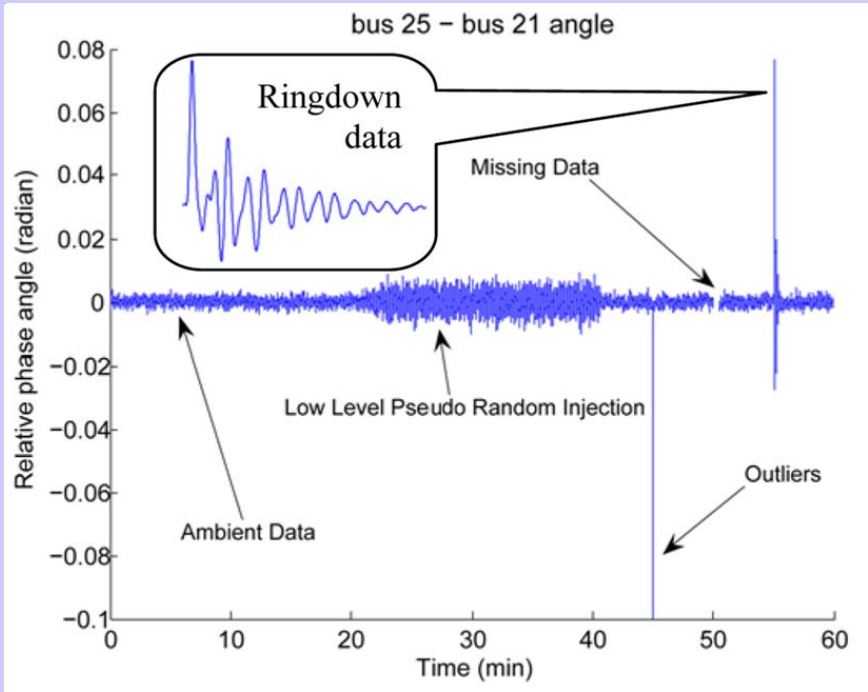


Fig. 9 Recorded real power flow from Malin to Round Mountain (Reference time: Aug 10th, 1996, 15:35:30 Pacific Daylight Time)

Mode estimation using R3LS algorithm

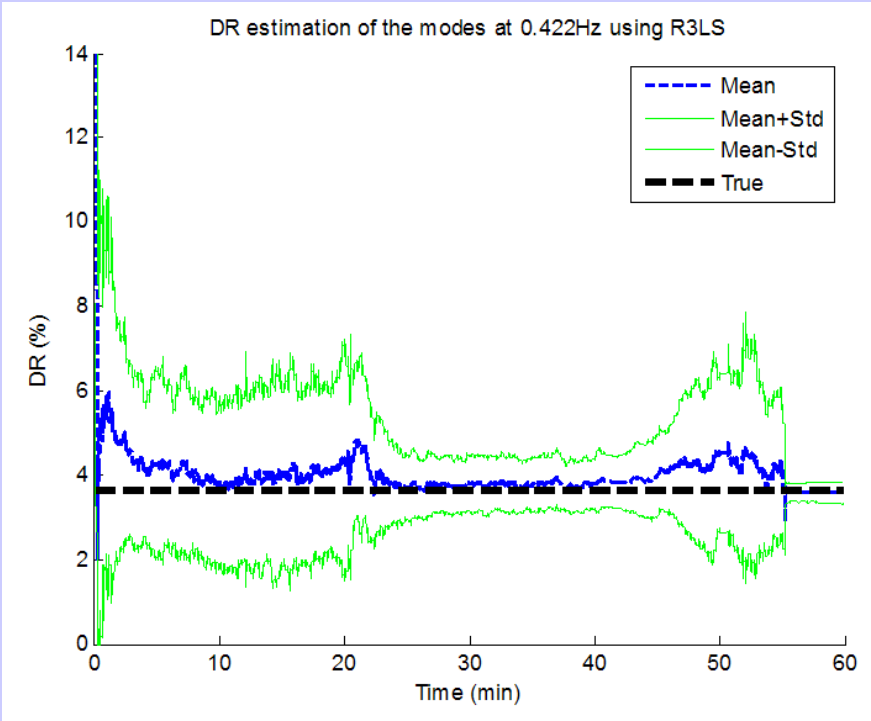


A Comprehensive Test (1) R3LS algorithm



Time plot of combined ambient, low- level pseudo-random probing, outlier, missing data and ringdown from 17-machine model with stationary modes.

Mode estimation of the major mode around 0.422 Hz of the 17-machine model with stationary modes.



Outline

- ❖ Introduction

1. A Mode Meter Tool.

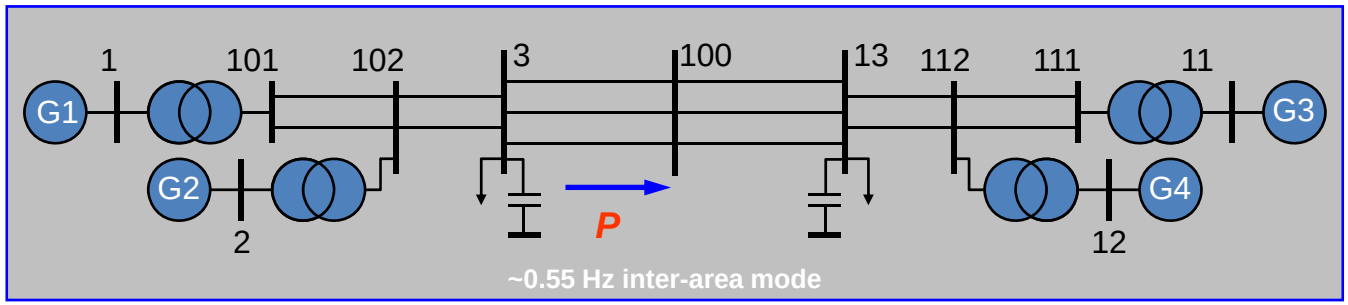
   - Oscillation detection and analysis.

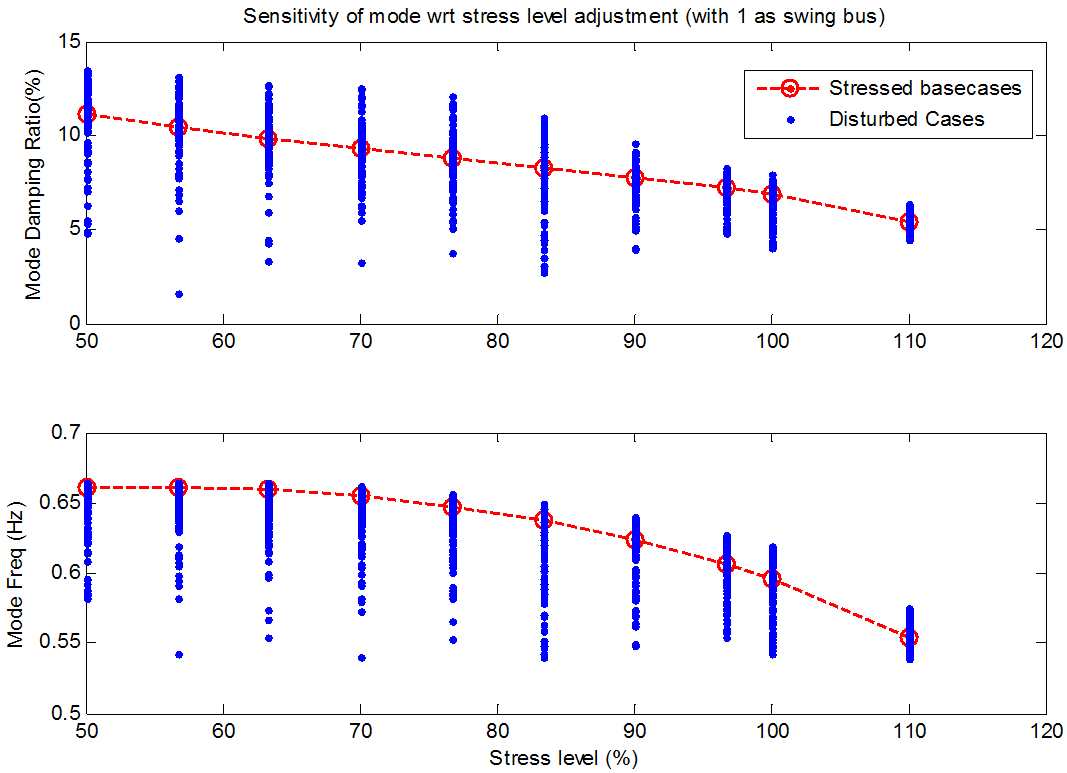
2. Modal Analysis for Grid Operation.

   - Power flow adjustment for damping improvement

- ❖ Results & Conclusions

Damping can be controlled

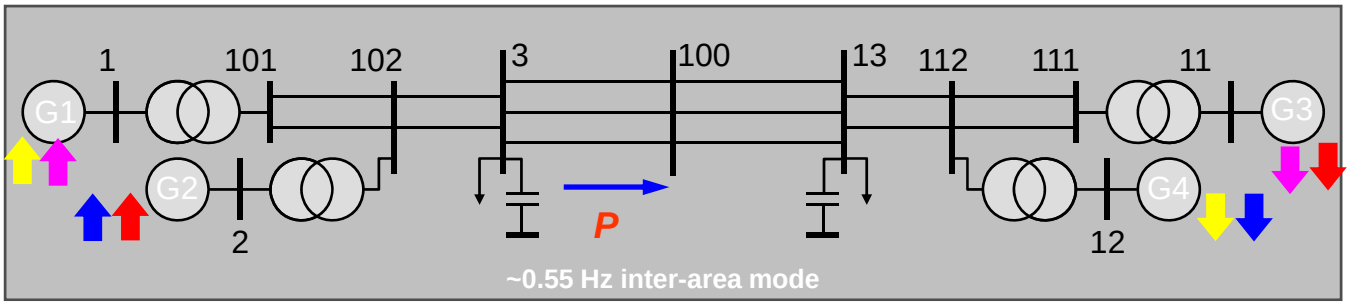


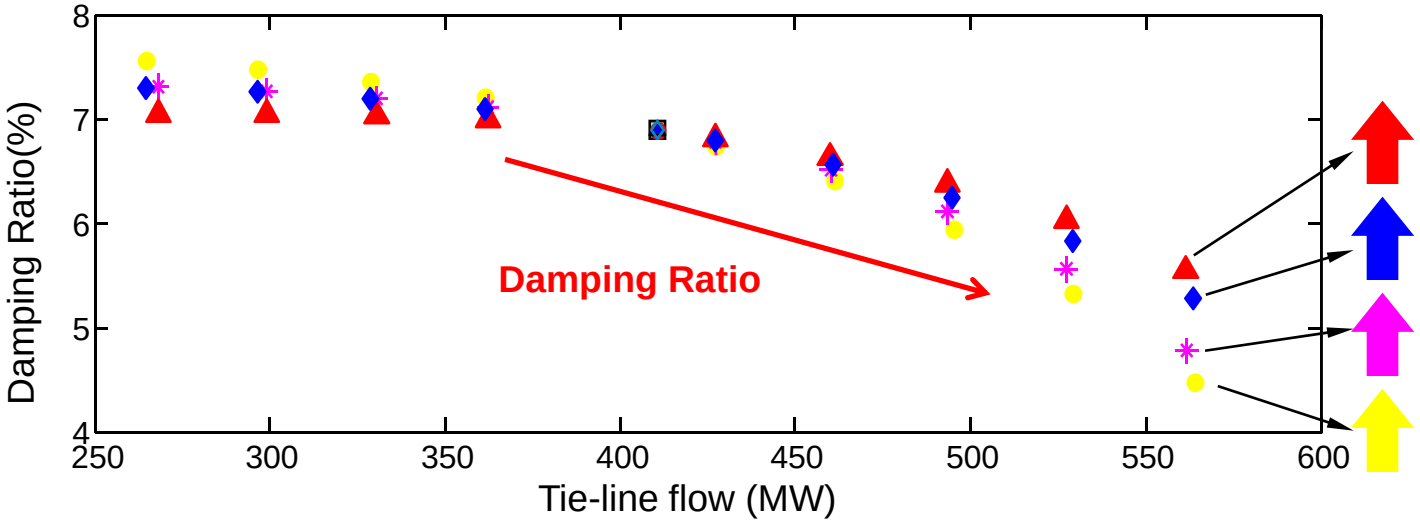


Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

A 2-Area Case – selected generators



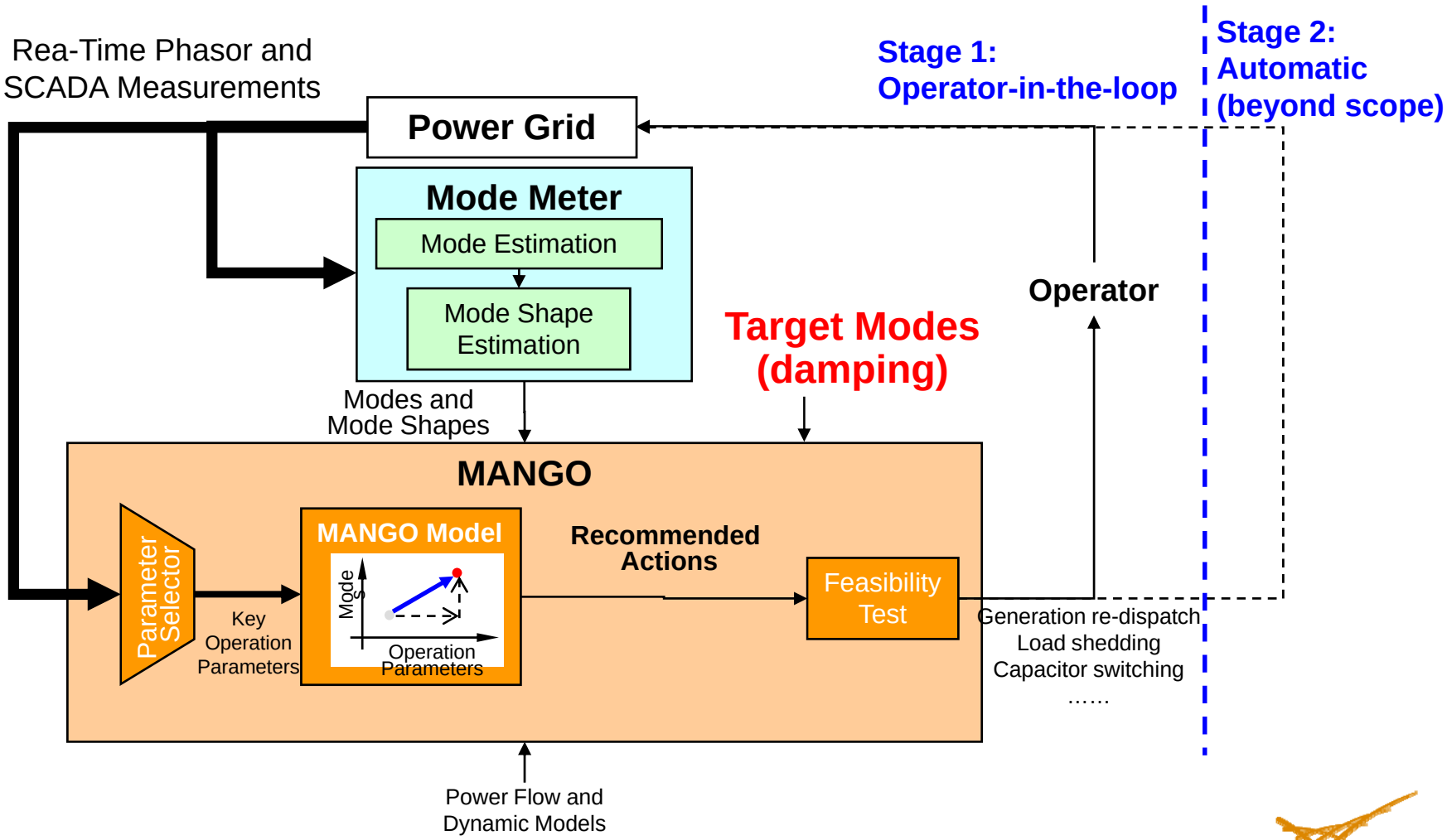


➔ Strong correlation

➔ Effect is non-linear with different adjustment patterns

Pacific Northwest NATIONAL LABORATORY

MANGO Vision



Pacific Northwest
NATIONAL LABORATORY

Scope of MANGO

- **Derive recommended operation actions based on modal analysis results**
  - Mitigate low damping via power flow pattern adjustment
  - Develop methodology for power flow pattern adjustment based on relationship of modal damping and grid operation parameters
  - Example output: *"Generator A's output needs to be adjusted by X MW to improve damping from Y% to Z%"*
- **Implement with operators in the loop**
  - Link with current grid operating procedures (e.g. AGC, BPA Standing Order 303, NERC TOP-004-1, TOP-007-0, TOP-008-1, IRO-006-3, TLR)
  - Operators review recommended actions
  - Operators have full control of the actions

Pacific Northwest
NATIONAL LABORATORY

Model-Based Modal Studies

- Objective: Looking for Damping Indicators

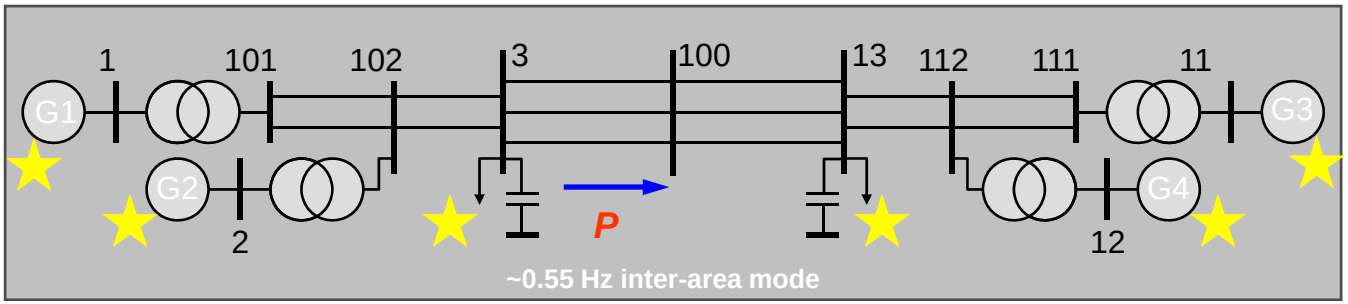
- Modal Sensitivity

  $$\Delta damping = K\ \Delta parameter$$

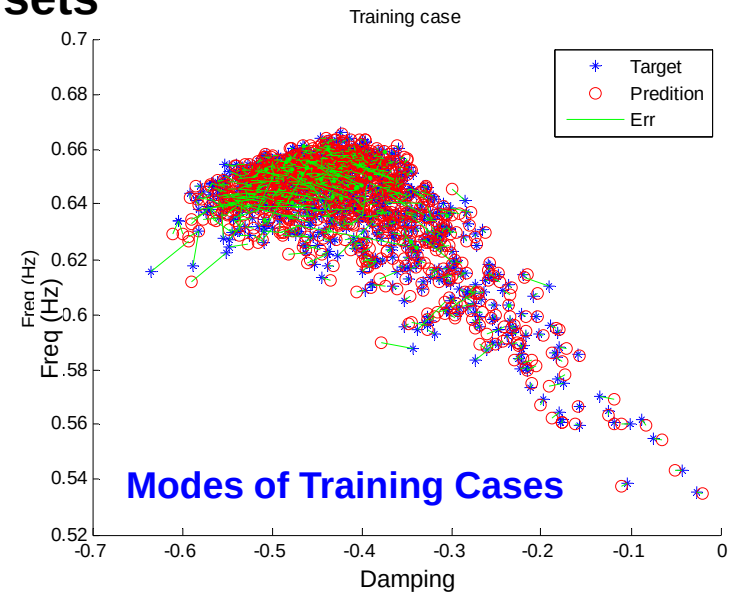
  - Modal Sensitivity w.r.t. Tie-Line Flow
  - Modal Sensitivity w.r.t. Individual Generation
  - Relative Modal Sensitivity
- Modal Participation
  - Relative Modal Participation
- Intertie Energy
- Relative Mode Shape

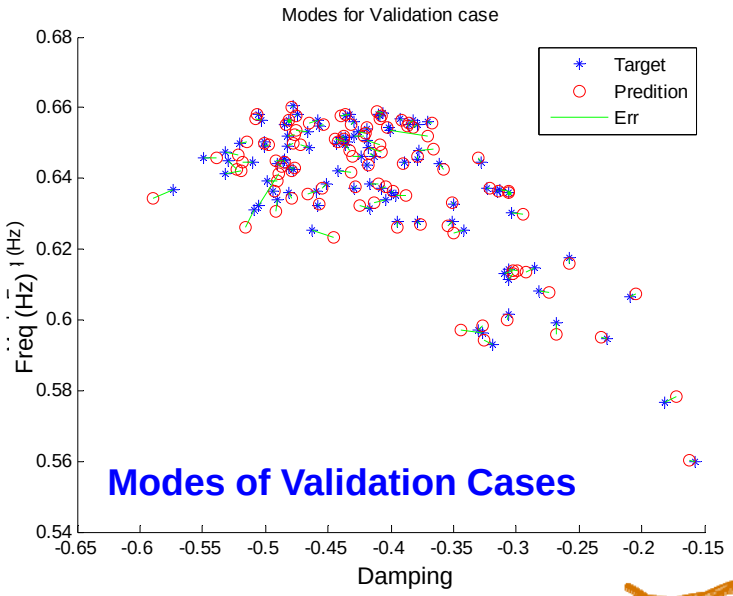
Pacific Northwest
NATIONAL LABORATORY

Non-Linear Mapping



- **Neural Network Implementation: 600 training sets and 200 validation sets**

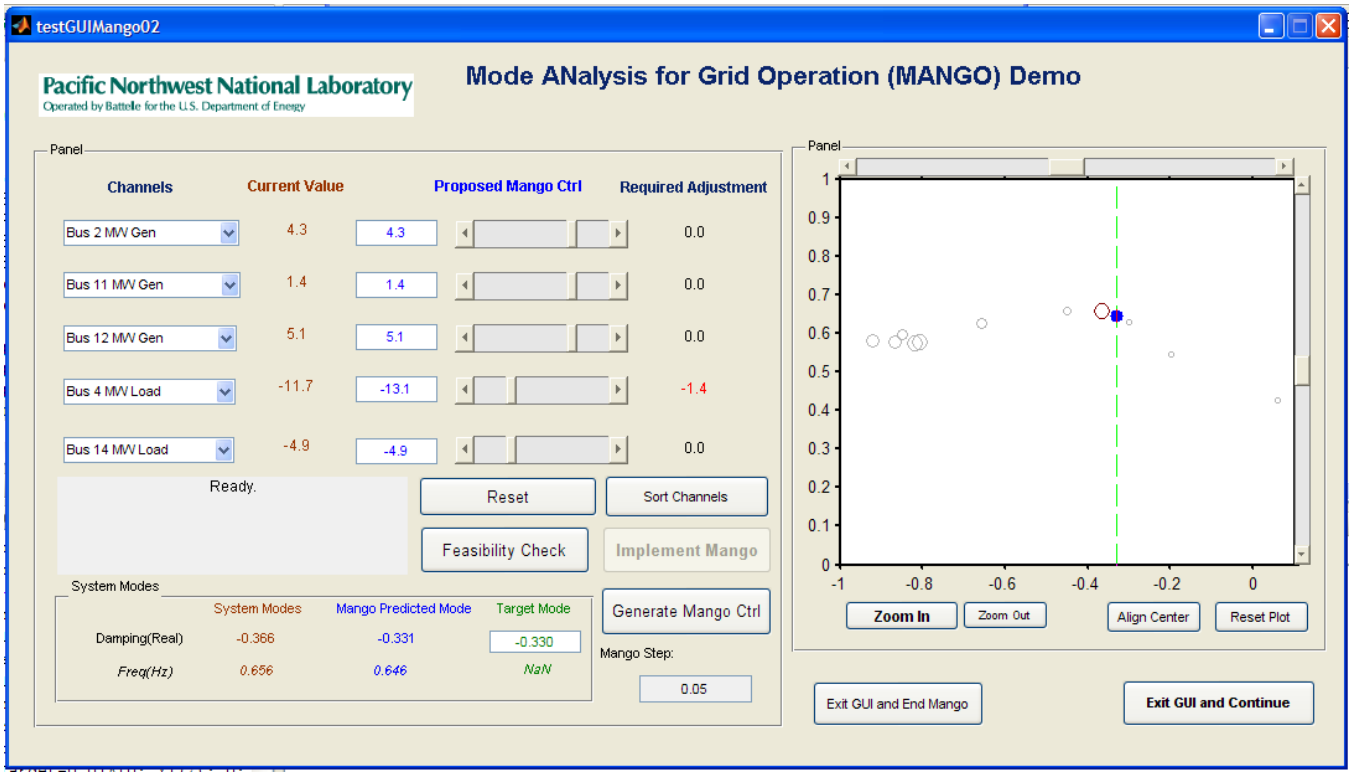




Pacific Northwest NATIONAL LABORATORY

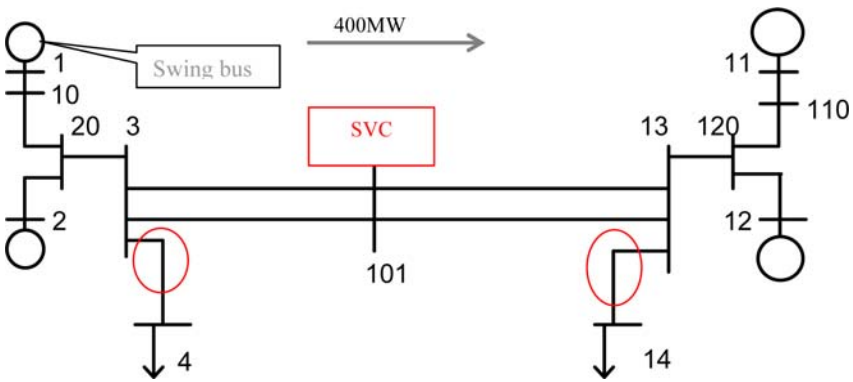
MANGO Demonstration with Test Systems

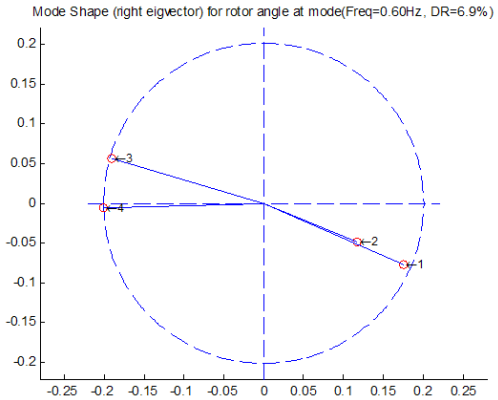
- Two Area Model
- MiniWECC model

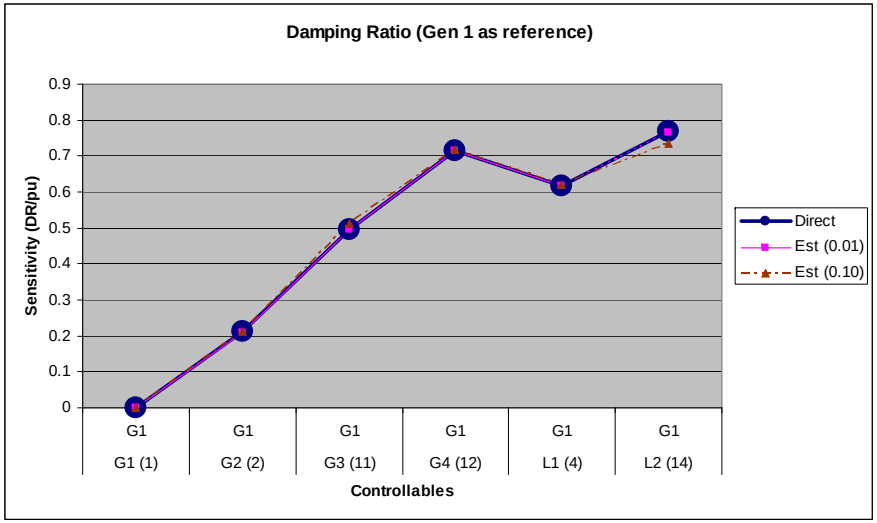


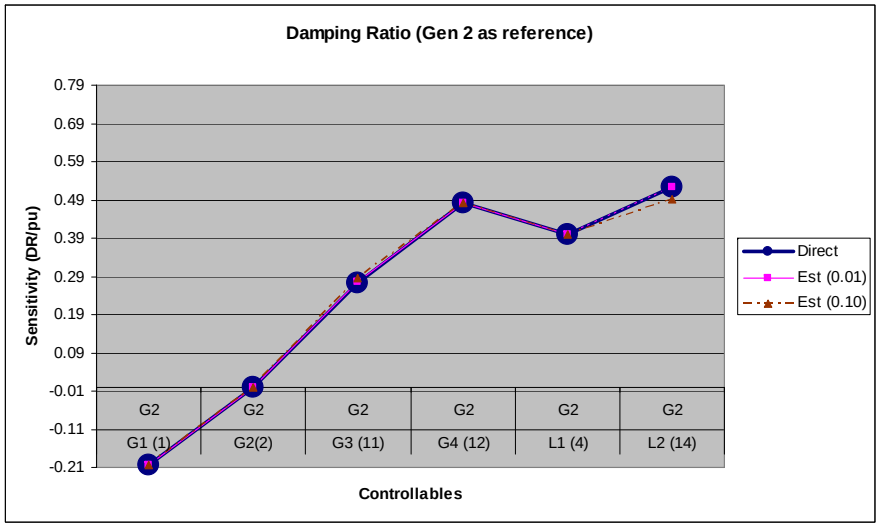
Pacific Northwest
NATIONAL LABORATORY

Sensitivity analysis for two area model





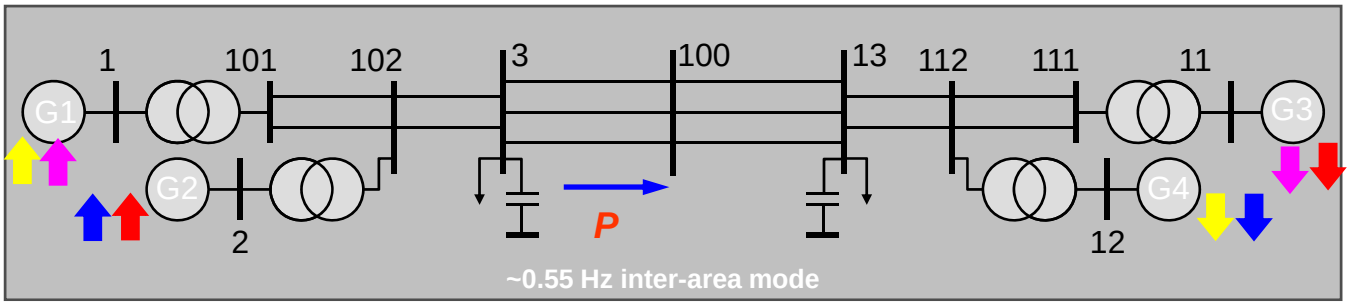


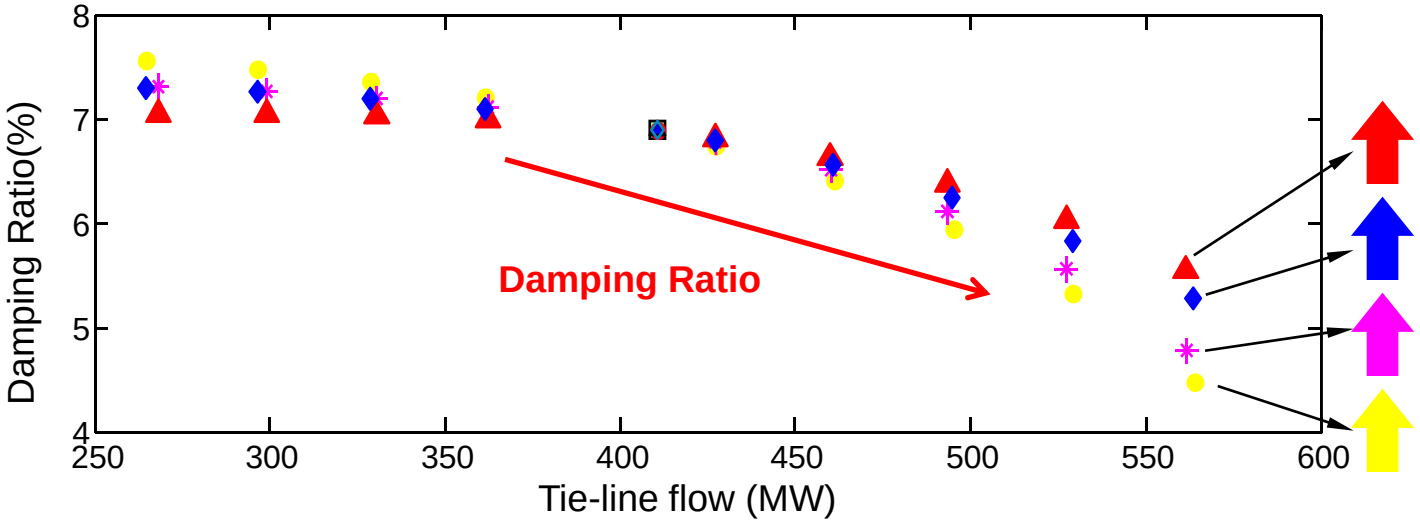


Note: Loads are treated as negative generation.

Pacific Northwest NATIONAL LABORATORY

A 2-Area Case – selected generators





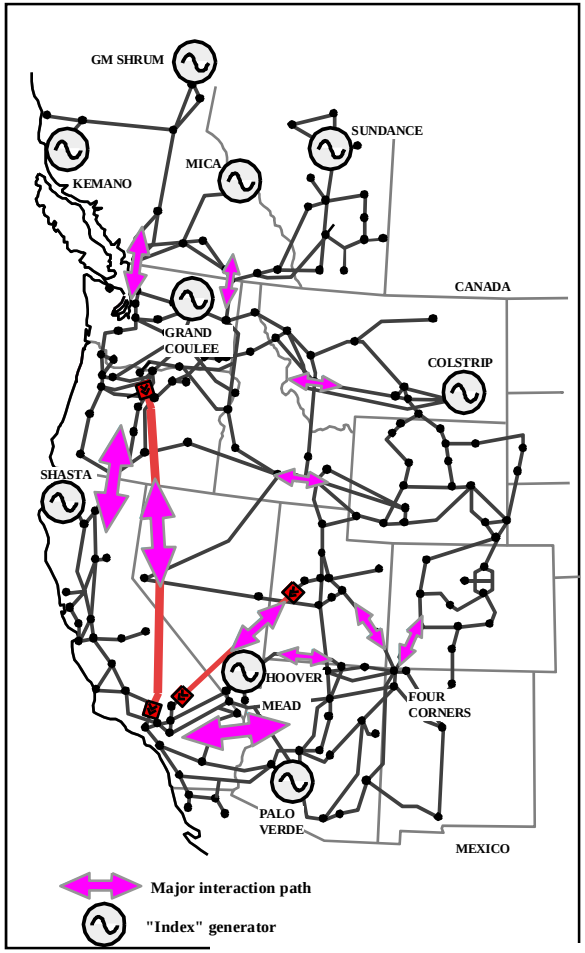
➔ Strong correlation

➔ Effect is non-linear with different adjustment patterns

Pacific Northwest NATIONAL LABORATORY

The WECC Case

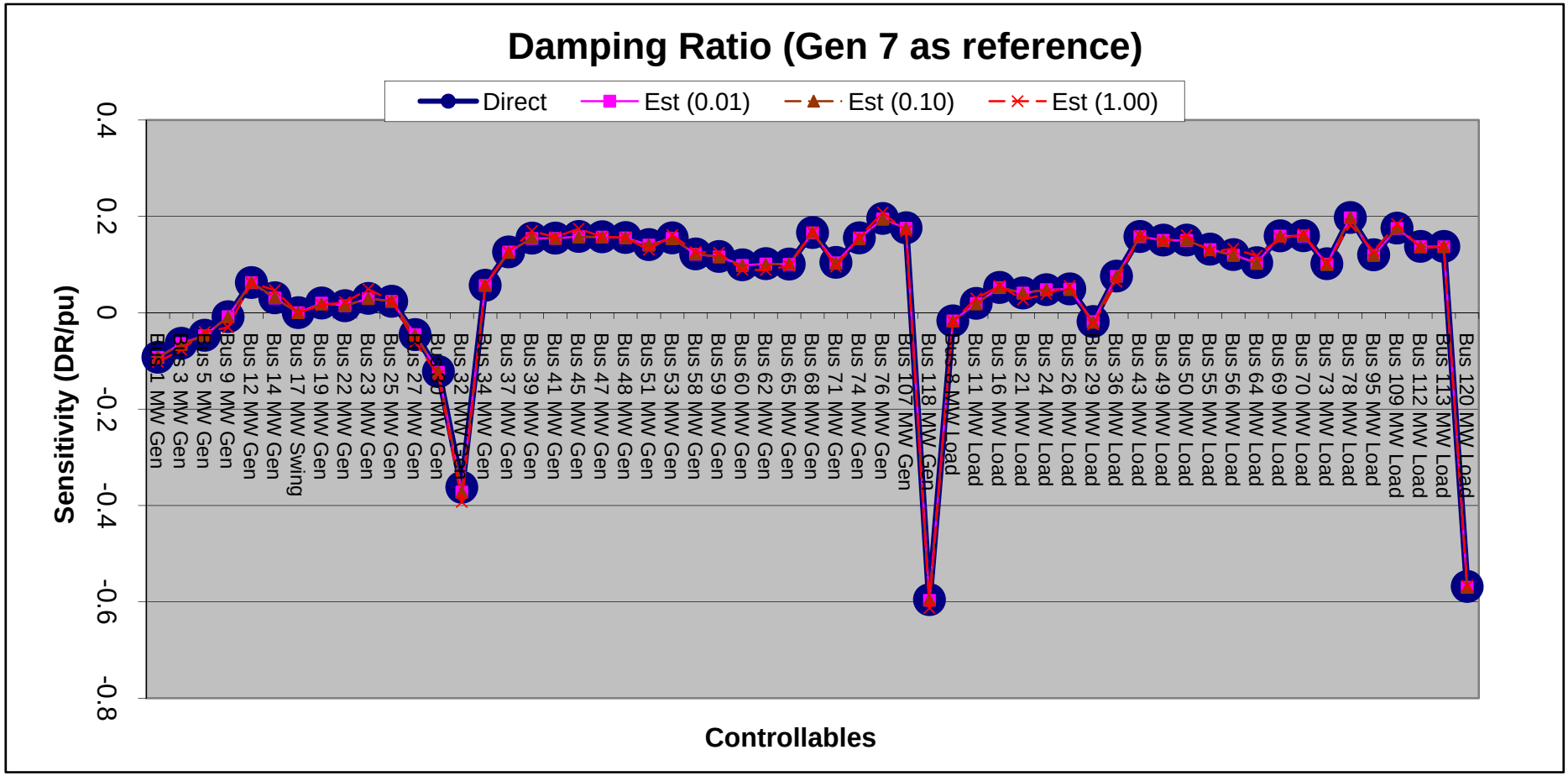
- **Multiple 2-Area Systems**



Map source: John Hauer, PNNL

Pacific Northwest
NATIONAL LABORATORY

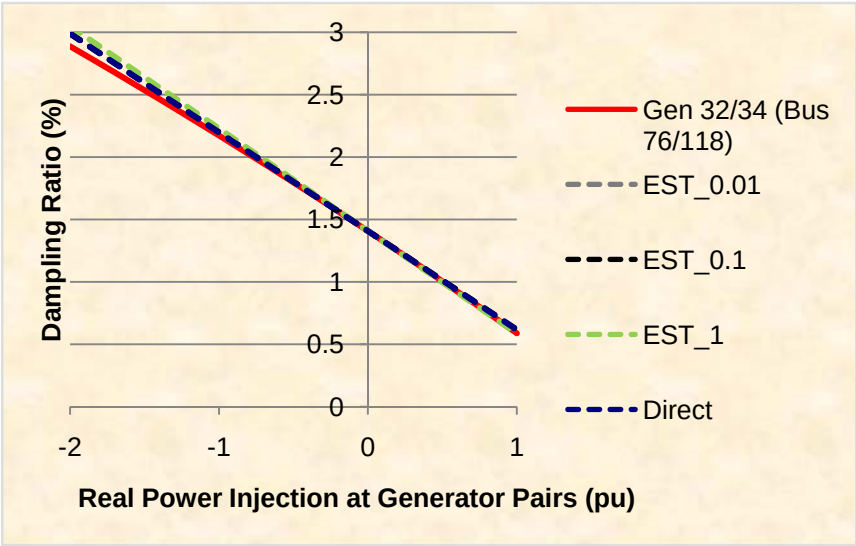
Sensitivity analysis for minniWECC model

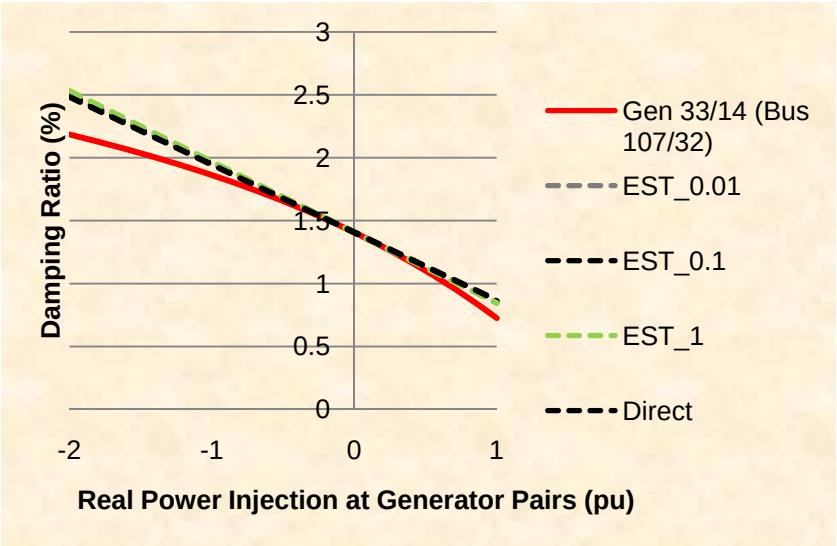


Note: Loads are treated as negative generation.

Pacific Northwest
NATIONAL LABORATORY

Damping Control through Tie-line Flow Adjustment Using Generator Pairs (1)





Pacific Northwest NATIONAL LABORATORY

Outline

- ❖ Introduction

1. A Mode Meter Tool.

   - Oscillation detection and analysis.

2. Modal Analysis for Grid Operation.

   - Power flow adjustment for damping improvement

- ❖ Results & Conclusions

Pacific Northwest
NATIONAL LABORATORY

Results and Conclusion

- Oscillations exist in power grids.
  - Oscillations limit the amount of power that can be transferred.
  - Oscillations may lead to power system breakup and outage.
- Measurement-based mode meter algorithms can help.
  - Improve accuracy and increase speed of mode identification.
  - Decrease the rate of false and missing alarm.
- Damping of oscillations can be improved through power flow adjustment by operators.
  - Build up the relationship between the controllable variables and mode damping.
  - Keep operators in loop to check applicability of proposed actions.

Questions?

Pacific Northwest
NATIONAL LABORATORY