Department of Energy

Funds-In Agreement for Research and Development

Appendix A—California Energy Commission

Exhibit A - Statement of Work
Exhibit B - Task Deliverables, Schedule,
Exhibit C - Budget
Exhibit D - List of Contacts and Addresses
Exhibit E - Confidential Deliverables and Intellectual Property Lists

Prepared by Lawrence Livermore National Laboratory
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I. Title of project

Planning for Generation, Storage, and Demand Response to Accommodate Intermittent Generation

II. Energy Commission RFP identification

Not applicable

III. Background

The U.S. Department of Energy/National Nuclear Security Administration ("DOE/NNSA") owns the Lawrence Livermore National Laboratory ("LLNL"), which is a national security federally funded research and development center. Lawrence Livermore National Security, LLC holds a contract with DOE/NNSA for the management and operations of LLNL (referred to interchangeably as either the "Facility Operator" or the "Contractor").

The California Energy Resources Conservation and Development Commission (Energy Commission) is an agency organized under the laws of the State of California with a principal place of business at 1516 Ninth Street, Sacramento, California 95814.

IV. Project Goals and Objectives

Problem Statement

The anticipated increase in deployment of wind and solar generation in the State of California will pose challenges to grid operation. The remaining resources on the grid would need to provide more capacity to ramp up and down to accommodate variations in intermittent generation. The availability of low cost sensors, communication, and computational resources – in conjunction with dispatchable demand such as plug in electric vehicles – offers an opportunity to use advanced optimization and control technologies to manage the integration of intermittent generators.

This study will compare the costs of alternative technologies that provide regulation of electric generation under high penetration of intermittent renewables. Regulation could be provided using dispatchable generation, storage, and demand response, which may be available at a range of response times and energies. The principal investigators will estimate regulation requirements by modeling electricity dispatch under uncertainty, and then assessing the resulting mismatches between the total generation and the actual loads. The role of demand response -- implemented either through market structures or automatically in response to grid state -- is a key system design issue that will be explored. This study will also assess the potential for system instabilities given the penetration of renewables.

The work will extend the current practice of modeling a few days of a single year to infer the adequacy of system resources to accommodate intermittent generation. A key deliverable of the study is a large scenario bank that other researchers and designers could use for other studies. The work will build on previous studies of the integration of storage and intermittent generation conducted by one of the researchers on this project[1,2,3,4]. The study will also utilize grid analysis and stability methods developed by a second researcher[5]. Finally, it will utilize importance sampling and computational statistics techniques developed at LLNL[6].

V. Technical and economic/cost performance objectives

A. The overall technical goal of this project is to evaluate the effectiveness of alternative demand response and storage technologies that could be deployed on the grid.

The specific, technical objectives of the project are:

- Develop scenarios that probabilistically characterize the requirements for system regulation under high penetration of intermittent generation
- Develop a simulation testbed that includes forecasting, unit commitment, and economic dispatch algorithms that use the scenarios to evaluate alternative technologies that can provide regulation
- Characterize performance of a range of candidate demand response, storage, and generation technologies to be evaluated

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[1] Lamont, Alan D., Assessing the Economic Value and Optimal Structure of Large-Scale Electricity Storage ,LLNL-JRNL-422364 (October 2010).

[2] Lamont, Alan D., Assessing the long-term system value of intermittent electric generation technologies, *Energy Economics* Volume 30, Issue 3 (May 2008).

[3] Lamont, Alan D., T. Nakata, and K. Kubo, Design for renewable energy systems with application to rural areas in Japan, *Energy Policy,* Volume 33, issue 2, pp. 209 – 219 (2005).

[4] Lamont, Alan D., and G. Berry, Carbonless Transportation and Energy Storage in Future Energy Systems", in *Innovative strategies for CO2 stabilization,* Robert G. Watts, ed., Cambridge University Press (2001).

[5] Top, Philip, Watching the Grid, Purdue University Dissertation (2007).

[6] Glaser, R. E., Stochastic Engine Final Report: Applying Markov Chain Monte Carlo Methods with Importance Sampling to Large-Scale Data-Driven Simulation, UCRL-TR-202878 (March 2004).

B. The overall economic/cost goal of this project is to identify methods and algorithms that could reduce the cost of electric power to California ratepayers.

The specific, economic/cost objective of the project is to estimate the cost impacts of integrating intermittent generation using current methods and policies.

VI. Preliminary Activities

1.1 Attend Kick Off Meeting

The Facility Operator's Project Manager (Principal Investigator) shall attend a "kick off" meeting with the Commission Contract Manager to review the Energy Commission's expectations for: accomplishing tasks described in the work statement; administrative requirements in the terms and conditions of the contract (e.g., invoicing, statements vesting title, prior approvals, data disclosure limitations, monthly progress reporting format and content, etc.); and the Energy Commission's roles and responsibilities. The location of this meeting shall be designated by the Commission Contract Manager.

1.2 Describe Synergistic Projects

None.

1.3 Identify Required Permits

No permits are required.

1.4 Obtain Required Permits

No permits are required.

1.5 Prepare Production Readiness Plan

Production Readiness Plan not required.

VII. Description of tasks to be performed

TECHNICAL TASKS

GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

ARIMA	Autoregressive Integrated Moving Average
CPR	Critical Project Review
DOE	U.S. Department of Energy
Energy Commission	California Energy Commission
LLNL	Lawrence Livermore National Laboratory
PIER	Public Interest Energy Research
WECC	Western Electricity Coordinating Council

SCOPE OF WORK

This Agreement includes a set of administrative tasks and a set of technical tasks. The remainder of this work statement defines these technical tasks. Task descriptions include goals, Contractor activities, and deliverables. The deliverables, such as test plans, technical reports and other interim deliverables, for each task are defined below. The Contractor shall submit a draft of each deliverable, unless described differently in the technical tasks, to the Commission Contract Manager for review and comment in accordance with the approved Schedule of Deliverables. Deliverables not requiring a draft version are indicated by marking "(no draft)" after the deliverable name.

The Commission Contract Manager will provide written comments back to the Contractor on the draft deliverable within 10 working days of receipt. If no written comments are received within 10 working days, then the draft deliverable shall be deemed accepted as provided. Once agreement has been reached on the draft (or deemed accepted as otherwise provided above), the Contractor shall submit the final deliverable to the Commission Contract Manager. The Commission Contract Manager shall provide written approval of the final deliverable within 5 working days of receipt. If no written approval of the final deliverable is provided within 5 working days of receipt, then the final deliverable will deemed approved as provided. Key elements from this deliverable shall be included in the Final Report for this project.

When creating technical deliverables, the Facility Operator shall use and follow, unless otherwise instructed in writing by the Commission Contract Manager, the latest version of the PIER Style Manual published on the Energy Commission's web site:

http://www.energy.ca.gov/contracts/pier/contractors/index.html

Technical Task List

Task 2.1	*Load and Generation Scenarios*
Task 2.2	*Forecast Algorithm*
Task 2.3	*Unit Commitment and Dispatch Algorithms*
Task 2.4	*Data Archiving System*
Task 2.5	*Sub-hourly System Variations*
Task 2.6	*Regulation Requirements Generation*
Task 2.7	*Definition of Regulation Strategies*
Task 2.8	*Simulate Regulation Strategies*
Task 2.9	*Preliminary Assessment of System Stability*
Task 2.10	*Outreach to Stakeholder Community*

Task 2.1 Load and Generation Scenarios

The goal of this task is to develop scenarios over net loads and renewable availability. These scenarios must be internally consistent with the correct correlation between loads and generation. To ensure consistency between loads and generation in the initial phase of the project, the Contractor will base these scenarios on observed loads and renewable generation from past years. It is expected that the renewable generation data for past years will be partially based on observed generation data and partially inferred from available wind speed and solar data. Stochastic variations of the time histories will be generated. It is not anticipated that this set of scenarios will cover the full range of plausible future conditions. A broader range of future scenarios covering infrequent and extreme conditions will be developed in a later task.

The Contractor shall:

- Establish requirements for scenarios (e.g. proper correlation between loads and renewable generation)
- Identify existing data sets that can be used
- Develop and execute procedures to synthesize scenarios on generation, as needed
- Develop and execute algorithms to provide stochastic variations on the scenarios
- Prepare a memo describing scenario requirements and procedures for developing data sets
- Prepare archived data sets

Deliverables:

- Memo describing scenario requirements and procedures for developing data sets
- Archived data sets

Task 2.2 Forecast Algorithm

The goal of this task is to utilize relatively simple and easily implemented algorithms for forecasting the variations in loads and renewable generation to be used as input to the unit commitment and dispatch algorithms. Multiple regression, Autoregressive Integrated Moving Average (ARIMA), and other statistical models fit to historical data for the month will be examined. Models with daily and hourly time steps will be developed.

The Contractor shall:

- Develop and implement multivariate forecasting models

Deliverables:

- None

Task 2.3 Unit Commitment and Dispatch Algorithms

The goal of this task is to compare existing unit commitment and dispatch algorithms given uncertain wind and solar generation patterns. The Contractor will compare existing deterministic algorithms (mixed-integer program) with other algorithms and heuristics currently used or proposed.

The mixed-integer programming algorithm in the Plexos grid modeling software will be used as a baseline. This standard software package is used to build a model of the grid and call an optimizer to solve the unit commitment and economic dispatch problem. It has been used to conduct renewable integration studies for California Independent System Operator Corporation. The software was originally configured to call the XPRESS mixed-integer solver. The Contractor has reconfigured the software to call the CPLEX optimizer that could be more effectively deployed on a high performance computing platform. The Contractor will compare performance of the algorithm assuming perfect forecasting and with varying degrees of forecast accuracy. This will provide an estimate of the value of better forecasting to facilitate integration of renewables. The Contractor will compare performance of this algorithm to approximate dynamic programming, genetic algorithms, simulated annealing, and other algorithms and heuristics that have been proposed for solving the unit commitment-economic dispatch problem.

The Contractor shall:

- Compare existing deterministic algorithms and down select for use in this study.

Deliverables:

- None

Task 2.4 Data Archiving System

The goal of this task is to archive intermediate and final results from the analyses at LLNL so they can be readily used for further analyses and report preparation. This task will also provide the foundation for disseminating the results under the dissemination task.

The Contractor shall:
- Define the database structure
- Develop input and retrieval processes and software utilities

Deliverables:
- None

Task 2.5 Sub-hourly System Variations

The goal of this task is to use the hourly data and system configuration to synthesize sub-hourly system behavior. This system variation on shorter time scales (minutes) will also require regulation.

The Contractor shall:
- Examine data from real time operations to estimate statistical variations in load and generation that occur in sub-hourly intervals
- Generate time histories of sub-hourly variations to be applied to the time histories produced by the dispatch model

Deliverables:
- None

Task 2.6 Regulation Requirements Time Histories

The goal of this task is to generate time histories of regulation requirements. Unit commitment and dispatch model will be executed for each scenario. At each time-step (hour or 15 minutes) the system will be dispatched based on the information about loads and generation available at that time. When the scenario is advanced a single time step, the realized load and generation will be revealed. This provides time series of the realized loads and generation. The sub-hourly variations developed in Task 2.5 will be added to these realizations. The difference between realized loads and generation is the difference that must be balanced through regulation. This produces a time history of regulation requirements for the scenario.

The Contractor shall:
- Create scripts for executing sequence of runs and archiving outputs

- Execute the model for each scenario to obtain time histories of loads, dispatched generation, renewable generation, and the resulting regulation requirements

Deliverables:
- None

Task 2.7 Definition of Regulation Strategies

The goal of this task is to define the sets of regulation resources and procedures to be tested. The specification of a set of regulation resources and procedures includes the technologies (e.g., automatic demand response, storage, combustion turbines), their operating characteristics (e.g., power, allowable frequency of dispatch, total energy), their capacities (e.g., max power, total energy), their cost characteristics, and operating procedures to be followed in applying them.

The Contractor shall:
- Develop a list of characteristics to be used to define regulation resources and procedures
- In conjunction with Energy Commission staff, define the sets of regulation resources and procedures to be tested (e.g. all ADR, all storage, combinations)
- Prepare a memo specifying the sets of regulation resources and procedures to be tested in the analyses

Deliverables:
- Memo specifying the sets of regulation resources and procedures to be tested in the analyses

Task 2.8 Simulate Regulation Strategies

The goal of this task is to determine the over/under generation that results after applying the sets of regulation resources and procedures to time histories of loads, renewable generation, and generation dispatch.

The Contractor shall:
- Develop automated algorithms to apply a set of regulation resources and procedures to the time histories of regulation requirements
- Apply the regulation resources and procedures to the time histories of regulation requirements to determine the resulting over/under generation time histories
- Develop summary data describing the effectiveness of the alternative regulation resources and procedures
- Prepare a memo describing the effectiveness of alternative regulation strategies

Deliverables:
- Memo describing the effectiveness of alternative regulation strategies

Task 2.9 Assessment of System Stability

The goal of this task is to use an existing model of the California state grid and Western Electricity Coordinating Council (WECC) interconnects to estimate load frequency response of several California regions and the implications for system stability. The model will be initialized using conditions established from the unit commitment solution on 15 minute intervals. The model will be subjected to a series of shocks including single point failures and anomalies, varying loads, and rapid changes in renewable generation. Each run will capture frequency deviations, transmission line overloads or other fault conditions, and under damped oscillations in the model. This series of tests will provide a standardized method of comparing the stability of various technologies and control algorithms, and characterize likely threat conditions when the grid is in various states.

The Contractor shall:

- Aggregate components in each region into a single unit of each type and build simplified models (single phase equivalent, constant voltage, and static reactive power flows) to test various control strategies
- Prepare a memo describing the models and results of system stability assessment

Deliverables:

- Memo describing model and results of system stability assessment

Task 2.10 Outreach to Stakeholder Community

The goal of this task is to develop a plan to make the knowledge gained, experimental results, and lessons learned available to key decision-makers.

The Contractor shall:

- At the request of the Energy Commission sponsor, attend workshops and meetings to present results of our work and instructions on access to the generated data sets.

Deliverables:

- None

Task 3.0 Reporting Tasks

All reports shall be delivered to:

Accounting Office, MS-2
California Energy Commission
1516 9th Street, 1st Floor

Sacramento, CA 95814

Task 3.1 Quarterly Progress Reports

The Contractor shall submit written Quarterly Progress Reports to the Commission Contract Manager, starting after the Department of General Service's contract approval date and continuing each quarter until the Final Report has been accepted by the Commission Contract Manager. Attachment A-1 provides a recommended format and content requirements for the Quarterly Progress Report.

Task 3.2 Final Report

The Final Report shall be a public document. If the Contractor will be preparing a confidential version of the final report as well, the Contractor shall perform the following tasks for both the public and confidential versions of the Final Report. When creating the Final Report, the Facility Operator shall use and follow, unless otherwise instructed in writing by the Commission Contract Manager, the latest version of the PIER Style Manual published on the Energy Commission's web site:

http://www.energy.ca.gov/contracts/pier/contractors/index.html

Subtask 3.2.1 Final Report Outline

- Contractor shall prepare and submit to the Commission Contract Manager for review an outline of the Final Report describing the original purpose, approach and results of the project.

- The outline shall be submitted to the Commission Contract Manager for review. The Commission Contract Manager shall determine if the outline is satisfactory. If the Commission Contract Manager determines that the outline is unsatisfactory, he or she will, in a timely manner, provide to the Contractor written comments, which indicate how the outline can be improved. The Contractor shall revise the outline to meet the Commission Contract Manager's requirements. Upon finding the final report outline satisfactory, the Commission Contract Manager shall provide to the Contractor written approval of it.

Subtask 3.2.2 Draft Final Report for Comment

- The Contractor shall prepare and submit to the Commission Contract Manager a draft Final Report on the project. The format of the report shall follow the approved outline.
- The draft final report shall be submitted to the Commission Contract Manager for review and to determine, in a timely manner, if it is satisfactory. If the Commission Contract Manager determines that it is unsatisfactory, he or she

will, provide to the Contractor written comments, which indicate how it can be improved. The Contractor shall revise the draft final report incorporating the Commission Contract Manager's corrections and required changes. Upon finding the revised draft to be satisfactory, the Commission Contract Manager shall provide to the Contractor written approval of it.

Subtask 3.2.3 Final Report

- The Contractor shall prepare the Final Report and submit it to the Commission Contract Manager after receiving the Commission Contract Manager's written approval of the draft Final Report. This task shall be deemed complete and accepted by the Commission only when the Commission Contract Manager approves the Final Report in writing (which shall not be unreasonably conditioned, withheld or delayed). Upon approval, the Contractor shall submit two unbound copies of the Final Report to the Commission Contract Manager.

Task 3.3 Final Meeting

Contractor shall meet with the Commission Contract Manager to present findings, conclusions, and recommended next steps (if any) for the project.

Contractor will also discuss with the Commission Contract Manager the following contract close-out items:

- What to do with any state-owned equipment (Options), if applicable
- Commission's request for specific "generated" data (not already provided in contract deliverables)
- Other "surviving" contracts provisions.

VIII. Critical Project Reviews

The Energy Commission will conduct critical project reviews at the conclusion of the following tasks:

(Note: Critical project reviews are meetings between the Facility Operator, the Energy Commission Contract Manager and other individuals selected by the Commission Contract Manager to provide objective, technical support to the Energy Commission. The purpose of these meetings to discuss with the Facility Operator the status of the project and its progress toward achieving its goals and objectives. These meetings may take place at the Energy Commission offices in Sacramento, or at another, reasonable location determined by the Commission Contract Manager.)

(Note: Prior to the critical project review meeting, the Facility Operator will provide the task deliverable(s) to the Commission Contract Manager

sufficiently in advance to allow the Contract Manager's review of the deliverable document(s) before the review meeting. If not already defined in the Work Statement, the Commission Contract Manager shall specify the contents of the deliverable document(s).)

(Note: At the project review meeting, the Facility Operator shall present the required technical information and participate in a discussion about the project with the Commission Contract Manager and other meeting attendees, if any.

(Note: Following the project review meeting, the Energy Commission will determine whether the Facility Operator is complying satisfactorily with the Work Statement and whether the project is demonstrating sufficient progress toward achieving its goals and objectives to warrant continued PIER financial support for the project.)

IX. Sponsor's Key personnel and Agreement Management

A. The name and area code/phone number of the California Energy Commission's Contract Manager is listed on Exhibit D and is the official technical contact for the Energy Commission.

The Sponsor's Contract Manager is responsible for the day to day project status, decisions and communications with the Facility Operator Project Manager (Principal Investigator). The Commission Contract Manager will review and approve all project deliverables, reports, and invoices.

The Sponsor may change the Contract Manager by notice given to the Facility Operator at any time signed by the Contract Officer of the Energy Commission.

B. The name and area code/phone number of the California Energy Commission's Contract Officer is listed on Exhibit D and will be the Contract Officer for the Agreement and is the official administrative contact for the Energy Commission.

X. Reserved

XI. Facility Operator's key subcontractors

The Facility Operator's key subcontractors are listed on Exhibit D in this agreement.

Facility Operator's key subcontractors may not be substituted without the Commission Contract Manager's prior written concurrence. Such concurrence shall be timely provided and not unreasonably withheld or conditioned. Delay in written concurrence may result in a work stoppage of subcontract work. All other

subcontractors may be substituted by Facility Operator, with written notification made to the Commission Contract Manager.

XII. Report standards

A. The report outline and format will be provided by the Sponsor's Contract Manager to the Facility Operator's Project Manager (Principal Investigator).

B. All reports shall be delivered to the Accounting address shown on Exhibit D.

C. Progress Reports. The Facility Operator shall prepare a Progress Report that summarizes all Agreement activities conducted by the Facility Operator to date, with an assessment of ability to complete the project within the current budget and any anticipated cost overruns. Each Progress Report is due to the Commission Contract Manager within 30 days after the end of the reporting period. The Commission Contract Manager will specify the report format and contents and the number of copies to be submitted.

(Note: Facility Operator will also participate in a Final Meeting with the Energy Commission to present the findings, conclusions, and recommendations. Both the Final Meeting and the Final Report must be consummated on or before the termination date of the Agreement.)

XIII. Schedule

The program will continue for 18 months after advance funding is received by Lawrence Livermore National Security, LLC.

XIV. Budget

SOW Appendix A, Exhibit C shows Energy Commission's Reimbursable Budget.

SOW Appendix A, Exhibit C shows the assessed value of the Federal Administrative Charge not charged to this project.

SOW Appendix A, Attachment A-2 shows assessed value of synergistic projects. The assessed value of such synergistic projects does not constitute a funding contribution or obligation (either cash or in-kind) on the part of the DOE or the Facility Operator.