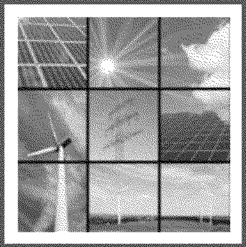

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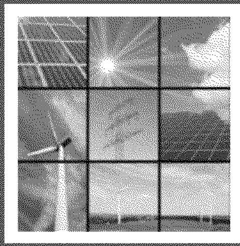
California Energy Systems for the 21st Century

California Energy Systems for the 21st Century Workshop

January 20, 2013



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CES-21 Workshop Agenda

- Welcome
- Introductions – 10 minutes
  - CES-21 Board of Directors: Jane Yura, Doug Kim, Jeff Nichols, Dan Kammen, Mani Chandy, T.J. Glauthier
  - Liaison to Board of Directors: Ed Randolph
- Overview of Workshop Objectives - 15 minutes
  - Discussion of the proposed research and priorities
  - Review the business case for proposed research
  - Policy requirements adopted in D.12-12-031 (OP 10 and 12)
- Research Area Presentations + Q&A - 45 minutes each
  - Electric Resource Planning: Redacted & Tom Edmunds (LLNL)
  - Electric Operations: Robert Sherick (SCE) & Liang Min (LLNL)
  - Gas Operations: Redacted & Lee Glascoe (LLNL)
  - Cyber Security: Corey McClelland (SDG&E) & John Grosh (LLNL)
- Next Steps - 15 minutes
  - Updates to CES-21 research projects and business cases
  - Next CES-21 Board Meeting
- Adjourn

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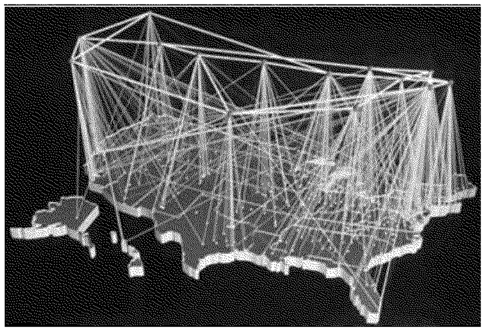
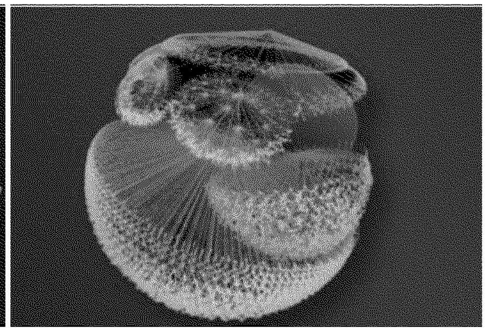
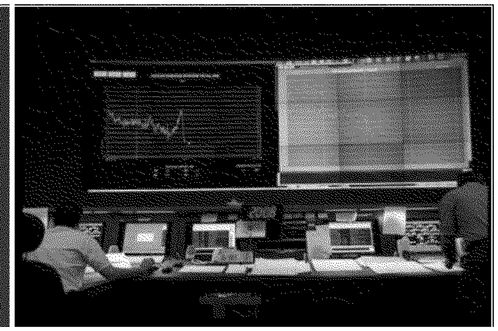
CES-21 is built around areas of collaboration







Electric Resource Planning

- Planning (day to years ahead) simulations at scale
- Wind and solar forecasting
- Impact of intermittency associated with renewables

Electric and Gas System Operations

- Operations (seconds to minutes ahead) simulation at scale
- Storage and demand response
- Real-time diagnostics and control

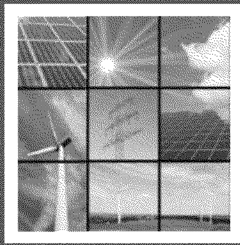
Cyber Security

- Analytics and situational awareness of the grid
- Efficient algorithms to effectively capture, analyze, and share data on demand

Advanced Computing Services

CES-21 Potential Projects

CES-21 Potential Projects – Year 1	Estimated Costs
Electric Resource Planning	
• Planning Engine • Flexibility Metrics and Standards • Ensemble Weather Forecasting • Cyber-Physical Support of Hydropower Generation	$4.6M $2.2M $2.5M $1.2M
Electric System Operations	
• Distribution Modeling and Optimization • Real Time Hybrid Digital Simulation • Integrated Transmission and Distribution Model • Electric System Monitoring and Control	$3.0M $3.8M $2.8M $3.3M
Gas System Operations	
• Sensor Fusion • Geographic Data Integration for Risk Management • Advanced Modeling and Simulation Environment	$2.3M $1.7M $2.2M
Cyber Security	
• Advanced Threat Analysis Center • Modeling and Simulation	$7.2M $5.1M



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Electric Resource Planning

Integrated high resolution weather and electric resource models will be used to quantify uncertainly and to optimize planning and investment decisions given the 33% RPS and other structural changes in the grid to ensure system performance, reliability, and efficiency.

Redacted (PG&E)

Tom Edmunds (LLNL)

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Electric Resource Planning proposed projects

- Planning Engine ($21M, 5years)
  - Develop higher resolution, larger-scale models of renewable generation, demand response, and grid-scale storage that are required for the evolving grid
- Flexibility Metrics and Standards ($6M, 3 years)
  - Define operating flexibility metrics and targets based on a probability measure of the occurrence, the magnitude, and the duration of ramping shortages at different time intervals
- Ensemble Weather Forecasting ($8M, 3 years)
  - Develop an ensemble-based forecasting system to improve forecast accuracy and provide uncertainty bounds
- Cyber-Physical Support of Hydropower Generation ($9M, 5 years)
  - Development of a next-generation hydrographic data network and predictive modeling toolbox to support hydropower planning and operations activities

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Electric Resource Planning
Planning Engine

Need:

Utilities currently use commercial off-the-shelf and in-house developed modeling tools for planning to integrate increasing renewable resources, and demand-side resources. For many urgent and longer-term planning and policy questions, these models are computationally limited in their ability to represent the complexity of the electric grid, the time-scale of key generation resources and transmission assets, or the responsiveness of electrical storage. It is very time consuming to run multiple scenarios of some of these existing planning models.

Objective:

Enhance the performance of commercial software so that it can be used to analyze more complex grid planning problems at larger scale. The added complexity introduced by intermittent renewable generation and demand response will be key areas of focus. Topical studies that are required to support large scale models (e.g., generate input parameters or assess viability of solutions generated) will also be performed.

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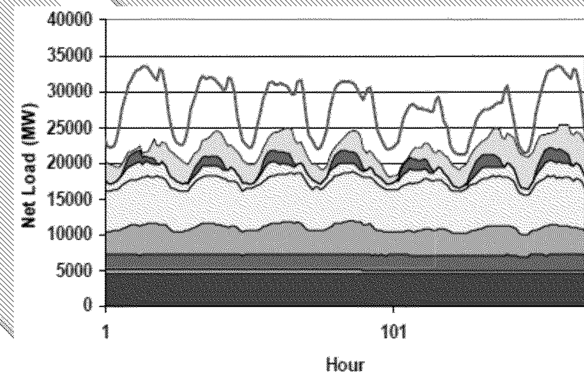
Electric Resource Planning
Planning Engine

Approach:

Identify common building block and potential synergies with other business cases (PM1-24):
To avoid duplication, this phase will identify new methodologies and code to support the proposed business cases. Coordinate their development so that they can be used in other business cases. Integrate generation, transmission, and distribution planning tools.

Design and test tools for evaluation of demand response programs for renewable integration (PM1-24):
Scope out possible operating attributes that will be useful in the design of future demand side programs aimed at facilitating the integration of intermittent renewable resources.



Picture of PEV

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Electric Resource Planning
Planning Engine

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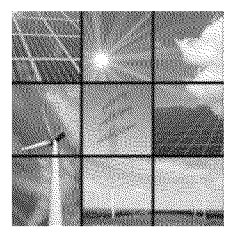
Approach: (con't)

Enhanced representation of the transmission system in production simulation models (PM1-36):
Enhance the representation of the transmission system in production simulation models to better understand the implication of intermittent resources on transmission reliability

Transmission system planning (PM12-48):
Builds on a prototype methodology for transmission reliability studies developed by EPRI for probabilistically modeling the uncertainty related to the output of variable generation such as wind and PV power along with coincidental loads

Picture of transmission line



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Electric Resource Planning
Planning Engine

Approach: (con't)

Investment and market analysis tools (PM12-24):
Use conventional financial analysis, market equilibrium models, and other analytical approaches to evaluate alternative investment opportunities and to analyze market structures

IT infrastructure planning (PM24-45):
Use grid and communication network simulation tools to identify requirements and IT architectures that meet reliability requirements in a cost effective manner

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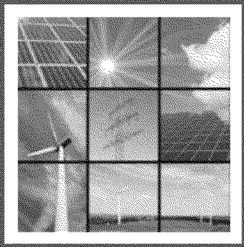
Electric Resource Planning

Planning Engine

Research or service needed	Potential Collaborators
Grid modeling tools	1. Energy Exemplar 2. GE 3. Ventyx 4. UC Berkeley 5. Princeton University 6. EPRI
MIPS solver	1. IBM

Electric Resource Planning
Planning Engine

Deliverable	Due Date
Report on enhanced transmission in production simulation models and software demonstration	PM17
Report on common building blocks and software demonstrations	PM24
Report on demand response programs	PM24
Report on transmission planning case studies	PM24
Report on energy storage markets and model demonstration	PM24
Report on transformer replacement model and data sets	PM24
Report of transmission planning model and software demonstration	PM33
Report on IT requirements	PM33
Report on IT architecture recommendations	PM45
Report on integrated planning tools and software demonstrations	PM48



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Electric Resource Planning
Planning Engine

Potential customer benefits

1. Improved planning tools can lead to improved capital utilization and consequent reduction of the fixed cost of the grid by guiding policy initiatives and design of preferred resource programs
2. The tools can also help reduce operating costs and emissions by providing more effective algorithms for unit commitment and economic dispatch
3. The tools can assist in determining the operating attributes of new resource additions needed to maintain reliability in face of increased system variability and uncertainty
4. The enhanced planning tools will help reduce costs and improve reliability of the grid by:
   - Optimizing the use of existing capital equipment given the large variability and uncertainty introduced by intermittent generation and customer demand
   - Identifying the most cost effective generation and transmission additions
   - Facilitating the evaluation and design of effective demand response resources
   - Ensuring a reliable power grid under extreme weather conditions and component failures

Electric Resource Planning

Flexibility Metrics and Standards

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Need:

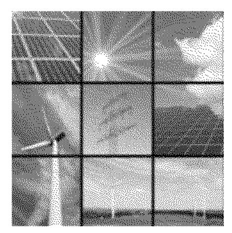
Introducing high levels of intermittent renewable generation will result in greater uncertainty of operation and the need for more rapid ramping to follow net loads.

We require a metric to 1) measure the adequacy of the generation fleet to meet ramping requirements and respond to unforeseen changes, 2) assess the requirements for flexible capacity, and 3) measure the contribution of new generation capacity to meeting the requirements.

Objective:

The project will a) design operating flexibility metrics based on probabilities of ramping requirements, and b) test candidate metrics in simulations of weather forecasts, and system decision making for unit commitment and economic dispatch.

This will rely on LLNL capabilities for realistically modeling atmosphere forecasts and conditions, developing probabilistic estimates of future conditions, and simulating operational sequences of unit commitment and economic dispatch to measure the performance of the system.



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Electric Resource Planning
Flexibility Metrics and Standards

Approach:

Define problem and characteristics of tools to needed to address the problem (PM1-3):
Define the problem and review methodologies and analytical tools that could be used to solve the problem

Select base model for testing cases (PM3-5):
Review and critique existing flexibility metrics and tools now in use and under development and select a base model

Develop the infrastructure to generate multiple weather dependent data (PM6-10):
Initial experiments will be conducted to understand what modeling approach and computational resources will be required to do develop possible flexibility metrics

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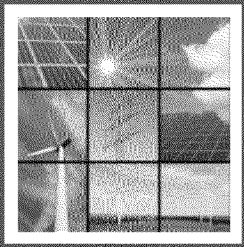

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Electric Resource Planning
Flexibility Metrics and Standards

Approach: (con't)

Develop the infrastructure to automate the running of many scenarios in batch mode through the optimizer (PM10-16):
Set up model so it can be run in batch mode with many predefined scenarios

Develop Flexibility Metrics (PM16-20):
Develop flexibility metrics in consultation with CAISO

Develop a prototype model to quantify flexibility metrics (PM20-30):
Develop metric prototype model to track and calculate the flexibility metric deficiencies, but will not yet be integrated with the unit-commitment and dispatch model

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Electric Resource Planning
Flexibility Metrics and Standards

Approach: (con't)

Integrate the flexibility metric prototype with the base model (PM30-33):
Integrate the selected flexibility targets into a larger optimization which can be solved in workstations used by the utilities, CAISO and other parties in 4 hours per weather year

Document the model (PM34-36):
Document new or improved model

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Electric Resource Planning

Flexibility Metrics and Standards

Research or service needed	Potential Collaborators
Definition of problem and definition of metric	1. University College, Dublin
Integrate metric into unit commitment and dispatch	1. Princeton University

Electric Resource Planning
Flexibility Metrics and Standards

Deliverable	Due Date
Definition of problem and characteristics of needed tools	PM3
Select base model	PM3
Weather and renewable generation scenarios, and associated load, wind and solar generation inputs for selected model	PM10
Software infrastructure to automate the running of many scenarios	PM10
Select flexibility metrics	PM12
Prototype model to calculate the expected amounts and probability of flexibility deficiencies	PM12
Prototype code to optimize commitment and dispatch that integrates the flexibility metrics. Flexibility metrics prototype model	PM24
Results of testing and sample analysis	PM24
Model documentation	PM36

Electric Resource Planning
Flexibility Metrics and Standards

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Potential customer benefits

1. More accurate estimate of load following requirements given a resource mix and operating policies for unit commitment and dispatch
2. Identification of cost effective capacity additions to provide flexibility
3. Reduction in incidences of flexibility shortages and the costs they incur
4. In CES-21 application these were estimated at a value of $552 million through improved resource planning

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Electric Resource Planning
Ensemble Weather Forecasting

Need:

Optimizing short-term purchases of new wind and solar generation presents a unique demand for accurate weather forecasts. Extending recent developments in high-resolution mesoscale weather forecasting are needed to resolve terrain-driven flows and intermittent wind ramp events as well as estimate hourly changes in incoming solar radiation due to clouds and aerosols.

Objective:

The overarching scope of the proposal is to develop an ensemble-based forecasting system to improve forecast accuracy and provide uncertainty bounds that reflect the inherent uncertainties in those predictions.

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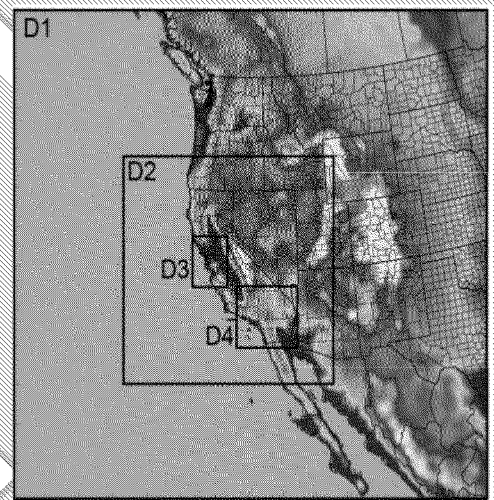
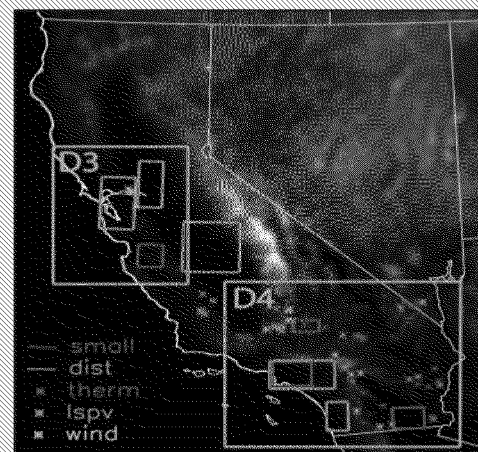
Electric Resource Planning
Ensemble Weather Forecasting

Approach:

Build infrastructure for computations, data analysis, and data sharing (PM1 -12):
The basic infrastructure includes an interface for sharing data between LLNL and the IOUs/CAISO, benchmarked wind and solar production models integrated with WRF output, and software tools to view the simulation results. In this phase, we will also develop a set of data analysis products that characterize the probabilistic ensemble output, e.g. ensemble means and variance, confidence intervals, and ramp characteristics.





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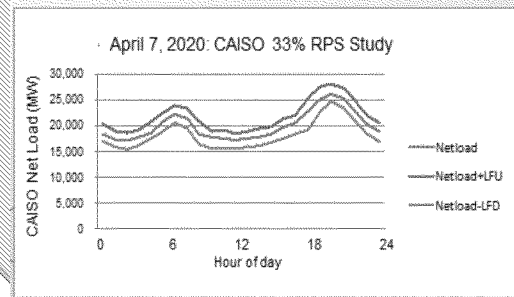
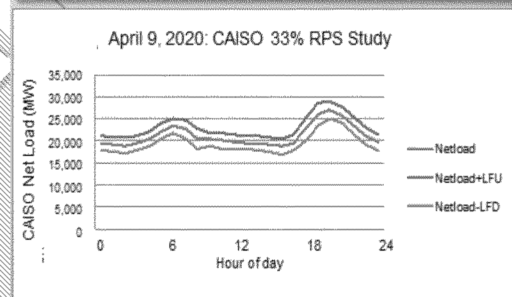
Electric Resource Planning
Ensemble Weather Forecasting

Approach: (con't)

Multi-physics ensemble forecasting (PM6-21):
Modify the existing WRF multi-physics ensemble configuration developed for the CEC-funded LLNL study, to focus on existing wind and solar generation. We will deliver real-time ensemble forecasts to the IOUs and CAISO, and receive back a report on how the real-time forecasts were used and any cost avoidance provided by quantification of uncertainty.

Multi-analysis ensemble forecasting (PM18-33)
Develop a multi-analysis ensemble framework, and use it to deliver real-time ensemble forecasts to the IOUs and CAISO. We will receive feedback on how these forecasts were used and how they compare with the multi-physics ensembles previously used.





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Electric Resource Planning
Ensemble Weather Forecasting

Approach: (con't)

Analysis of forecasting methodology performance (PM30-36):
Assemble a data set of both multi-physics and multi-analysis ensembles over the same time periods. Using the archived deterministic forecasts from those time periods, we will compare the performance of the three approaches. We will summarize how the probabilistic information was best utilized in operations. These analyses will all be included in a final report.

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Electric Resource Planning

Ensemble Weather Forecasting

Research or service needed	Potential Collaborators
Experience evaluating the use of ensemble forecasts in an operational setting	1. CAISO
Extensive experience in ensemble forecasting, especially multi-analysis forecasting, developer of WRF	1. NCAR
Wind resource data sets	1. NREL
End user of wind forecasts, experience in making weather-to-power conversions	1. Infigen 2. Cool Earth Solar
Expertise in solar tracking and short term prediction	1. UCSD

Electric Resource Planning
Ensemble Weather Forecasting

Deliverable	Due Date
60 days of real-time day-ahead and 3 hour-ahead WECC generation forecasts and estimates of uncertainty based on 30 multi-physics ensemble members delivered to CAISO and IOUs	PM18
Report documenting the multi-physics ensemble forecast model configuration and the associated prediction skill based on standard statistical metrics	PM21
60 days of real-time day-ahead and 3 hour-ahead WECC generation forecasts and estimates of uncertainty based on 30 multi-physics and 30 multi-analysis ensemble members delivered to CAISO and IOUs	PM30
Report documenting the multi-analysis ensemble forecast model configuration and the associated prediction skill based on standard statistical metrics	PM33
Final project report describing the prediction skill and operational cost savings associated with the multi-physics and multi-analysis ensemble forecast approaches and providing recommendations on the optimal generation forecast design for California	PM36

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Electric Resource Planning
Ensemble Weather Forecasting

Potential customer benefits

1. The CAISO, which can use these products to:
   - Make better net load predictions, allowing for more optimal unit commitment decisions and transmission line scheduling (for day-ahead forecasts).
   - Make better planning decisions related to the resources necessary for load following (for 3-hour ahead forecasts).
   - Purchase only the necessary quantity of reserves to account for the net load uncertainty faced on a daily basis.
   - Purchase additional reserves on days when the net load forecast is highly uncertain, thereby reducing the chance of over/underproduction and the expenses associated with them.
2. The IOUs and other wind/solar generation owners, who will benefit from both improvements in the overall accuracy of forecasts of critical parameters, as well as uncertainty bounds in those predicted parameters
3. The rate-payers, who will ultimately benefit by increased reliability and lower cost of electricity

Electric Resource Planning
Cyber-Physical Support of Hydropower

Need:

- Climate change will negatively impact hydroelectric generation by 2020-2025
- Adaptation to changing climatic inputs – less snow, more variable precipitation, higher temperatures – required to minimize water spills (generation losses) and better manage reservoir reserves
- Water is becoming a very expensive commodity, and more so in the future

Improved predictive planning and scheduling tools to manage hydroelectric water resources are needed to adapt to increasing vulnerabilities and uncertainties of changing climatic water inputs while meeting today's evolving resource flexibility needs

Objective:

Develop and apply a HPC predictive modeling toolbox and information management capability to a) support hydropower planning and operations activities under increasingly uncertain and changing climatic inputs; and b) design of future smart hydrological data networks.

LLNL's HPC surface/subsurface/atmospheric modeling & data management capabilities have been proven and distinctively qualified to solve the problem

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California Energy Systems for the 21st Century

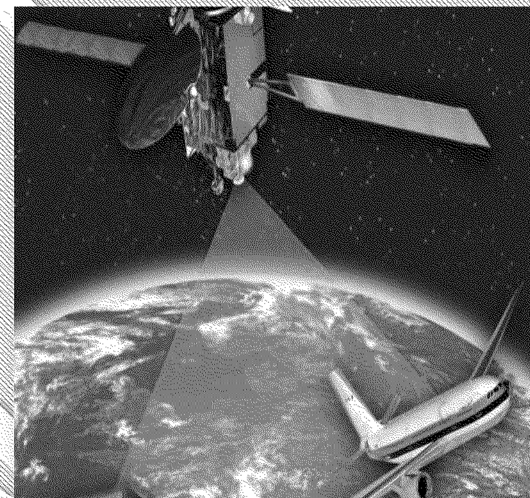
Electric Resource Planning

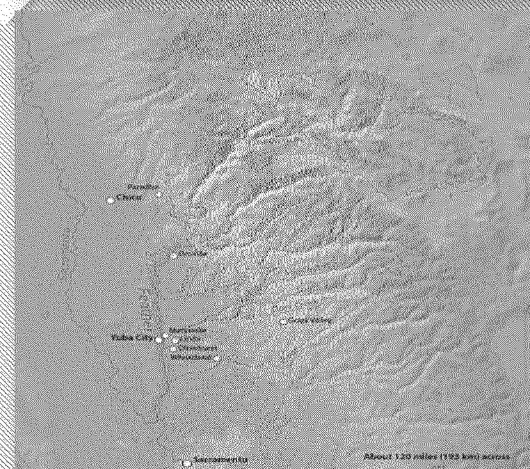
Cyber-Physical Support of Hydropower

Approach:

Information Management System (PM1-8):
Build a system to retrieve daily satellite data on snow cover and energy balance components from multiple sources, blend with ground based data, and develop real time value added products, including gridded, spatial estimates of snowpack water content and snowmelt

Sensor-Information Network (PM12-36):
Develop a system to integrate data from wireless sensor networks involving hundreds to thousands of individual sensors into quality controlled real time spatial estimates of water and energy balance attributes. (Note: this task only occurs in the event of separate co-funding and is not factored into budget calculations)





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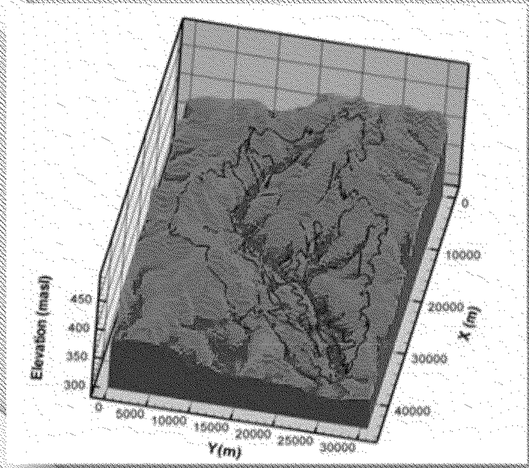
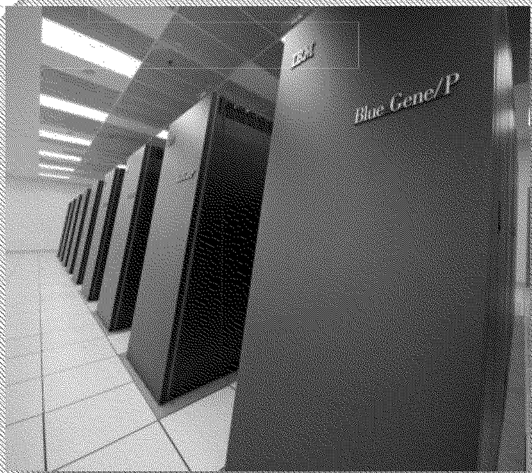
Electric Resource Planning
Cyber-Physical Support of Hydropower

Approach: (con't)

Modeling Toolbox (PM1-36):
A variety of modeling tools, for hydrologic forecasting, hydraulic routing, diagnostic analysis, and planning are required. This phase will provide these in a toolbox that shares input data and output features, to help assure consistency between the various models

Decision Support (PM30-60):
The decision-support framework will provide tools to extract and visualize information of interest from the measured and modeled data, to assess uncertainties, and to optimize operations





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Electric Resource Planning
Cyber-Physical Support of Hydropower

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Research or service needed	Potential Collaborators
Flexible information-management capabilities for hydrologic data	1. UC Merced (Sierra Nevada Res. Inst.) 2. UC Berkeley (CITRUS)
Satellite snow cover products	1. JPL/NASA
Potential co-funding sources for expanded ground-based hydrologic sensor networks	1. State of California, DWR 2. State of California, CEC (EPIC)
Support for PRMS operational model used by PG&E	1. USGS 2. UC Merced (Sierra Nevada Res. Inst.)

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California Energy Systems for the 21st Century

Electric Resource Planning

Cyber-Physical Support of Hydropower

Deliverable	Due Date
Information Management System	PM8
Sensor-Information Network (only if co-funding approved)	PM36
Modeling Toolbox	PM36
Decision Support	PM60

Electric Resource Planning
Cyber-Physical Support of Hydropower

Potential customer benefits

1. Less lost water – Reduction in multi-million dollar water spills over 10-year period
2. Improve data collection system – Better define anticipated hydrologic changes
3. Adaptation to changing climate – New cyber-physical decision tools will replace increasingly unreliable statistical decision tools
4. New decision making tools – Transferable to other watersheds (e.g., Pitt River)
5. Streamline and increase efficiency in IOU predictive and hardware tools
6. Ancillary advantages – Safety, Ecosystem sustenance, Flood protection and management

Timelines and annual cost for projects in *Electric Resource Planning*

Planning Engine

Total Project Cost: $21.2M

YR1	YR2	YR3	YR4	YR5
$4.6M	$6.0M	$6.2M	$4.4M	

Flexibility Metrics and Standards

Total Project Cost: $5.7M

YR1	YR2	YR3	YR4	YR5
$2.2M	$2.0M	$1.5M		

Ensemble Weather Forecasting

Total Project Cost: $8.0M

YR1	YR2	YR3	YR4	YR5
$2.5M	$2.9M	$2.6M		

Timelines and annual cost for projects in *Electric Resource Planning*

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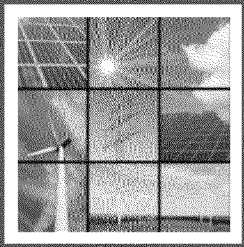
California Energy Systems for the 21st Century

Cyber-Physical Support of Hydropower

Total Project Cost:

$8.6M

YR1	YR2	YR3	YR4	YR5
$1.2M	$1.8M	$1.8M	$1.9M	$1.9M



Electric System Operations

High fidelity models of multiple grid components will be developed, and then integrated to inform system-based simulations of grid operations. These simulations will inform operational decisions and shape the design of future monitoring and control systems.

Robert Sherick (SCE)

Liang Min (LLNL)

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Electric System Operation proposed projects

- Distribution Modeling and Optimization ($6M, 2years)
  - Develop a detailed model of the distribution grid, analyze various emerging technology adoption scenarios, determine market and control mechanisms that would optimize the balancing of resources and demand, review the impacts on grid infrastructure, and evaluate methods to optimize distributed resources and demand response
- Real Time Hybrid Digital Simulation ($15M, 5 years)
  - Develop high-performance hybrid digital simulator supporting integrated electromechanical and electromagnetic transient simulations to evaluate impacts from intermittent resources on system stability
- Integrated Transmission and Distribution Model ($9M, 3 years)
  - Develop an integrated transmission and distribution model to analyze reliability impacts of increased renewable penetration in the distribution network and restoration capabilities during Blackstart conditions
- Electric System Monitoring and Control ($14M, 4 years)
  - Develop tools and methods to analyze synchrophasor patterns and system events to improve transmission system monitoring and identify mitigation strategies to improve the stability of the transmission system during stress conditions

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Electric Operations
Distribution Modeling and Optimization

Need:

Emerging technology devices (e.g. photovoltaic panels, controllable thermostats, plug-in electric vehicles, storage) are being interconnected to the distribution grid allowing new opportunities to balance resources and demands. These devices are presently encouraged through a series of incentive programs that are intended to increase the adoption of the technology, but there is no mechanism to optimize across the technologies.

Objective:

This research will develop a detailed model of the distribution grid; build adoption scenarios for renewable generation, plug-in electric vehicles, demand response, and storage; analyze impacts to customers and the grid of different adoption scenarios; and identify market mechanisms to enable interaction amongst devices to optimize resources and minimize consumption. As part of this effort, high performance computing platforms will be used to solve these high resolution problems.

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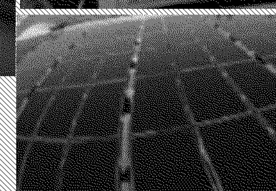
Electric Operations
Distribution Modeling and Optimization

Approach:

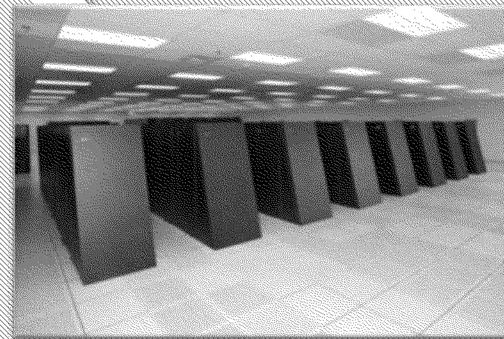
Modeling Framework and Model Development/Validation (PM1-12):
This phase will develop a detailed model of the distribution grid for the state of California. The model will be validated against actual feeder data collected by the three IOUs. The model will require using HPC services from LLNL Computing. The computer request is for 20,000 core hours per week for the PY1. The model will need near exclusive use of a ~20,000 cores cluster.

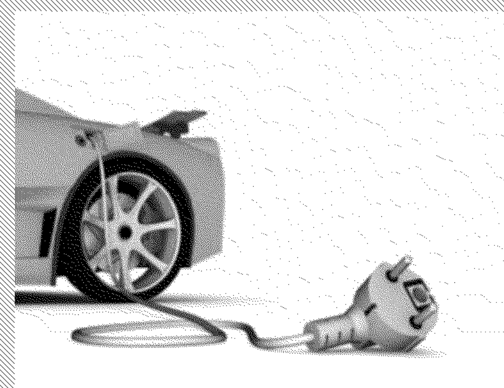


Electric Operations
Distribution Modeling and Optimization

Approach: (con't)

Computational Runs, Analysis, Recommendations (PM13-24):
This phase will use the model developed in the previous phase to analyze various adoption scenarios, determine market and control mechanisms that would optimize the balancing of resources and demand, identify the impacts on grid infrastructure, and determine impacts on customer rates. The model will require using HPC services from LLNL Computing at a much higher rate than PY1 in order to run multiple scenarios.





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Electric Operations
Distribution Modeling and Optimization

Research or service needed	Potential Collaborators
Distribution grid modeling tools	1. Pacific Northwest National Laboratory 2. EPRI 3. CYME 4. ETAP
Market Optimization	1. California Institute of Technology

Electric Operations
Distribution Modeling and Optimization

Deliverable	Due Date
Modeling framework	PM6
Validated distribution grid model	PM12
Model specification report	PM12
Scenario runs and analysis	PM24

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Electric Operations
Distribution Modeling and Optimization

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Potential customer benefits

1. Analysis of technology adoption scenarios
2. Identify Energy Efficiency opportunities across the state
3. Identify Demand Response opportunities across the state
4. Identify rate impacts to different customer classes and technology adopters
5. Evaluate voltage and VAR control and implementation strategies
6. Quantify the value derived from active power control of inverters
7. Identify impacts on distribution infrastructure, mitigation strategies, and cost allocation methods
8. Identify market and control systems to optimize resources and demand within a region

Electric Operations

Real Time Hybrid Digital Simulation

Need:

The stability of the grid's frequency has traditionally relied on the mechanical inertia resulting from rotating machines. Recently, an increasing proportion of energy from PV and wind generation in California feeds the grid through solid-state, switch-controlled electronics which lack the mechanical inertia from rotating machines and whose dynamic behavior does not inherently stabilize the grid.

Objective:

This project proposes to develop the first high-performance hybrid digital simulator in the power energy community supporting integrated electromechanical and electromagnetic transient simulation. The hybrid simulator will leverage existing tools and models developed on the EMTP-type simulator at the California IOUs and combine the speed and memory available on a High Performance Computing platform.

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Electric Operations
Real Time Hybrid Digital Simulation

Approach:

Prototype coupled software simulator (PM1-12):
Develop a prototype software simulator to evaluate algorithms and coupling capabilities for hybrid Dynamic Stability Assessment (DSA) and EMTP-Type applications

High Performance Dynamic Stability Assessment Tool (PM3-30):
Develop the high-performance dynamic stability assessment tool in the power industry.

Hybrid Simulator Algorithms (PM12-54):
Investigate and develop efficient algorithms for the parallel solution of coupled TS and EMTP-Type applications

Software Development and User Interface Development (PM30-54):
Develop the software and user interface

RTDS Lab at Southern California Edison

This picture is from LLNL's HPC Website

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Electric Operations
Real Time Hybrid Digital Simulation

Research or service needed	Potential Collaborators
Modeling tools	1. GE 2. EPRI 3. PowerTech Lab 4. Manitoba HVDC Research Center
Real-time digital simulator	1. RTDS Technologies 2. OPAL-RT technologies
Energy grid research	1. PSERC 2. University of Tennessee CURENT 3. Florida State University FREEDM

Electric Operations

Real Time Hybrid Digital Simulation

Deliverable	Due Date
Memo report documenting choice of the transient stability and EMTP-type tools to be used for final simulator development	PM6
Design document for initial prototype simulator	PM6
Prototype software of hybrid simulator	PM12
Memo report on performance of initial parallelization of the transient stability codes for massive contingency analysis	PM12
Initial design document for final simulator software	PM15
Memo report on performance of initial parallelization of linear solvers	PM18
Release 1.0 of hybrid simulator	PM24
Memo report on demo results	PM27
Release 1.0 of high performance DSA tool	PM30

Electric Operations

Real Time Hybrid Digital Simulation

Deliverable (con't)	**Due Date**
Final design document for simulator software	PM30
Release 2.0 of hybrid simulator using enhanced algorithms	PM36
Design document of the GUI	PM42
Software tool	PM48
Memo report documenting further performance modifications and release 3.0 of software	PM48
Memo report on testing results	PM54
Software Manual and Report	PM54

Electric Operations

Real Time Hybrid Digital Simulation

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Potential customer benefits

1. Improved real time simulation capability related to integration of renewable resources that are critical to meeting California' Renewables Portfolio Standard
2. Reduced wide-scale blackouts and avoid customer costs of outage through real-time simulation capability
3. Improved visibility of the health of the system and precision to locate risks may reduce the incidence of blackouts, and hence avoid customer outage costs
4. Improved planning may reduce instances when operators mitigate for worst-case scenarios, avoiding potential overbuilding and reducing overall costs

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Electric Operations

Integrated Transmission and Distribution Model

Need:

The existing models used in transmission reliability assessment include models for the transmission network only. These models include an accurate representation of generation connected at the transmission level. However, the distributed generation is typically modeled as a reduction in load. With the increase in the distributed renewable penetration, there is a growing need to accurately capture the impact of the distributed generation on transmission reliability.

Objective:

This project proposes to develop the an integrated transmission and distribution model that analyzes interactions across the two systems. These interactions are more complicated and provide more opportunities through the increasing adoption of distributed resources. For example, these resources could provide a valuable addition to blackstart plans but there have not been integrated systems to evaluate their use.

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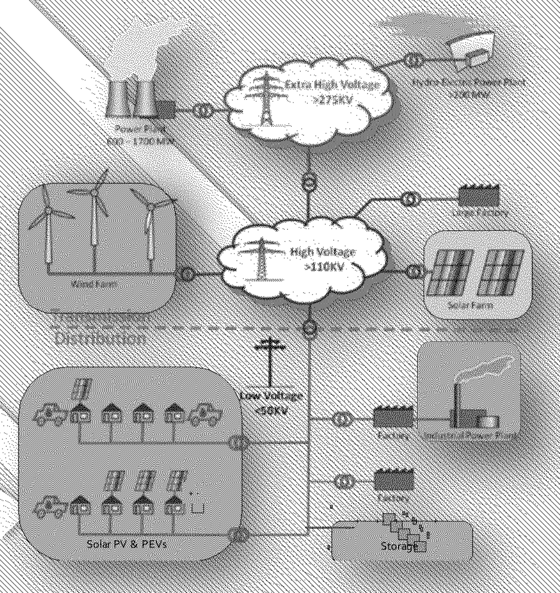
Electric Operations

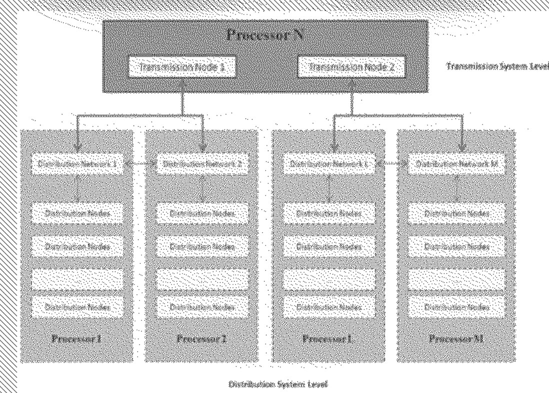
Integrated Transmission and Distribution Model

Approach:

Integrated Transmission and Distribution Steady-state Model Development (PM1-15):
A single transmission model will be advanced then parallel instances of the distribution software for each substation on the transmission network will be advanced, this coupled model leads to a natural decomposition of the domain; the distribution models will be solved in parallel enabling the use of thousands of processors

Integrated Transmission and Distribution Dynamic Model (PM16-36):
A dynamic transmission model will be added into the integrated platform and then ascertain how strongly it will need to couple the computations in order to balance between efficient parallel computation and numerical accuracy





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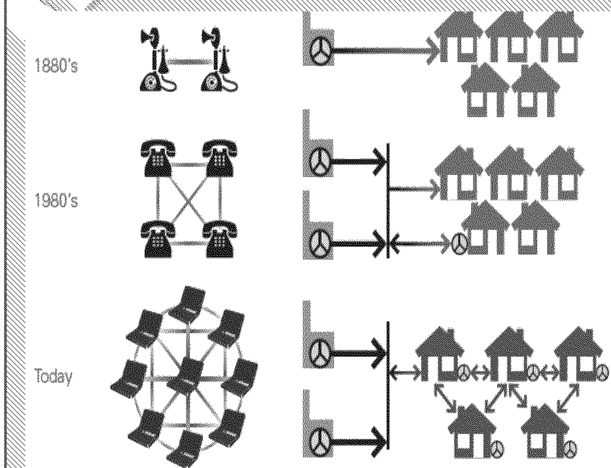
Electric Operations
Integrated Transmission and Distribution Model

Approach: (con't)

Restoration Capabilities in Extreme Scenarios Title (PM13-30):
The integrated T&D model will be used to investigate black-start strategy options to establish backbone transmission paths in San Francisco area

Integrated Electric Grid and Information Network Simulation (PM12-36):
The integrated T&D model will be leveraged by the "Modeling and Simulation to Identify Cyber Security Vulnerabilities" project under the cyber research area to model the combined transmission, distribution, and information networks



This picture is from SCE's Smart Grid Roadmap

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Electric Operations

Integrated Transmission and Distribution Model

Research or service needed	Potential Collaborators
Transmission modeling tools	1. GE 2. Powerworld
Distribution modeling tools	1. Pacific Northwest National Laboratory 2. EPRI 3. CYME 4. ETAP

Electric Operations

Integrated Transmission and Distribution Model

Deliverable	Due Date
Design document	PM6
Release 1.0 of the integrated transmission and distribution model	PM12
Memo report on verification results of T&D model	PM15
Release 1.0 of the restoration assessment software	PM18
Memo report on assessment results of T&D model	PM21
Memo report on study results of restoration software	PM24
Release 2.0 of the integrated transmission and distribution model	PM27
Release 2.0 of the restoration assessment software	PM30
Release 3.0 of the integrated transmission and distribution model	PM36
Memo report on performance test results of T&D model	PM36

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Electric Operations

Integrated Transmission and Distribution Model

Deliverable (con't)	**Due Date**
Release 3.0 of the restoration assessment software with the interface with operator training simulator	PM36
Data format change to read CIM data	PM42
Refined software tool	PM42
Use cases	PM48

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Electric Operations

Integrated Transmission and Distribution Model

Potential customer benefits

1. More comprehensive utilization of already purchased and deployed technology (i.e. Smart Meters)
2. Leverage the existence of data to reduce outages and costs through efficiency
3. Enable a smoother integration of distributed energy resources
4. Avoid potentially unnecessary redundant capacity buildup as more accurate planning becomes available
5. By identifying restoration impacts and weaknesses, strategies regarding upgrading/ investing in infrastructure, procuring, building, replacing generation can be improved.
6. With improved strategies, restoration time may be shortened beyond standards and requirements set by NERC requirements; improving customer satisfaction

Electric Operations
Electric System Monitoring and Control

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Need:

One of key operational issues faced by California utilities is the ability to manage intermittent resources effectively while utilizing grid assets efficiently. With the increasing amounts of intermittent resources, stability analysis becomes more critical than ever to understand the possible issues and to develop mitigation plans. Detailed system data (e.g. synchrophasors, digital fault recorders, SCADA) is collected and analyzed for discrete events, but large scale correlation and pattern recognition have not been employed due to the quantify of data.

Objective:

The goal of this project is to develop methods to monitor and control the bulk power system and methods to increase the analytical capabilities of the utilities. The objectives of this project are to:

- Develop a predictive engine based on data mining and pattern recognition algorithms
- Develop adaptive protection and control schemes to mitigate system instability
- Increasing transmission path capability through reliable use of actual system conditions

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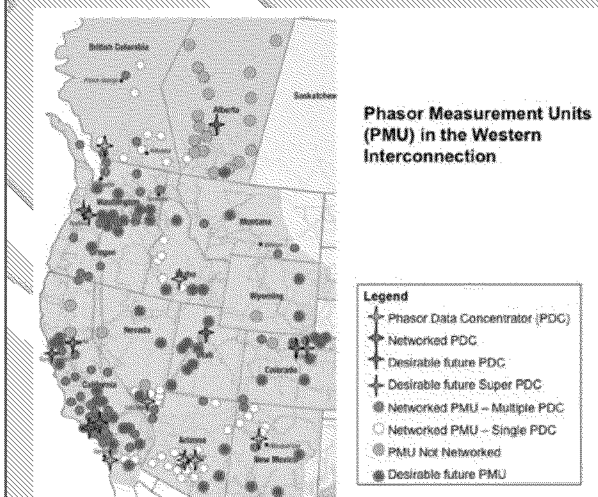
Electric Operations

Electric System Monitoring and Control

Approach:

Situational Awareness (PM1-PM39):
Utilize the considerable computational resource at LLNL to correlate the sub-second data (such as PMU and DFR data) with the second by second data (such as SCADA data), along with historical events on the system

Adaptive Protection and Control (PM16-27):
Use system stress under normal and N-1 contingencies as an input to special protection schemes to more accurately control the bulk power system to reduce generation dropping and load shedding



Source: Western Interconnection Synchrophasor Program

Electric Operations

Electric System Monitoring and Control

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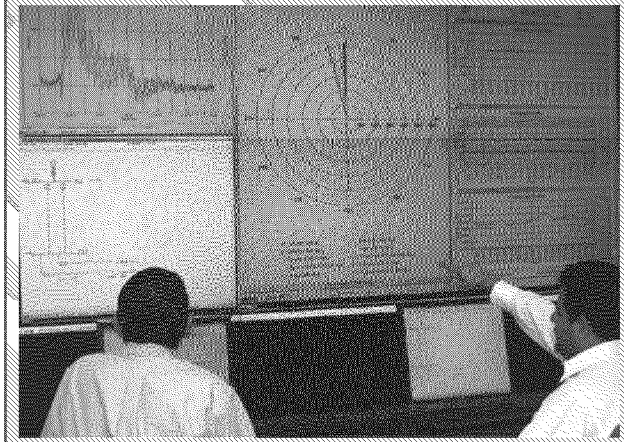
Approach:

Dynamic Transmission Paths Capability (PM28-39):
use the dynamic stability state indicated by the predictive engine to determine transmission paths capability based on actual system conditions as opposed to ratings based on traditionally conservative assumptions and off-line studies

Final Report, Documentation, and Technology Transfer (PM 40 - 45):
Prepare a final report that will document the algorithms, all the validation results, and the experience gained from this project



This picture is from SCE's Smart Grid Roadmap

Electric Operations
Electric System Monitoring and Control

Research or service needed	Potential Collaborators
Monitoring and control tools	1. Grid Protection Alliance 2. Electric Power Group 3. GE Energy 4. Alstom
Data management	1. OSI Soft
Grid research	1. Power System Engineering Research Center 2. University of Tennessee's CURENT center

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Electric Operations

Electric System Monitoring and Control

Deliverable	Due date
Collected historical events data	PM3
Prepare and enhanced off-line simulation tool	PM9
Prototype algorithm and data mining	PM9
Memo report on offline training results	PM12
Technical report on algorithm, offline training results and initial verification results	PM15
Conceptual design memo report	PM18
Memo report on algorithm development	PM21
Create scenarios for test	PM24
Create scenarios for test	PM26
Phasor data exchange architecture	PM27
Final report on phase 2	PM36
Report on phase 1	PM39

Electric Operations
Electric System Monitoring and Control

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Potential customer benefits

1. Improved monitoring capability and system dynamics understanding to reduce overall system outages through early warning and mitigation plans.
2. Reduced generation and load dropping on special protection schemes.
3. Increased wide area system awareness and understanding to increase transmission capacity.
4. More detailed modeling capabilities and longer dynamic analysis to increase overall understanding of interplay between transmission and distribution systems with substantial amounts of intermittent generation.

Timelines and annual cost for projects in *Electric Operations*

Distribution Modeling and Optimization

Total Project Cost:	YR1	YR2	YR3	YR4	YR5
$6.1M	$3.0M	$3.1M			

Real Time Hybrid Digital Simulation

Total Project Cost:	YR1	YR2	YR3	YR4	YR5
$15.4M	$3.8M	$3.7M	$3.9M	$4.0M	

Integrated Transmission and Distribution Model

Total Project Cost:	YR1	YR2	YR3	YR4	YR5
$8.8M	$2.8M	$3.1M	$2.9M		

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Timelines and annual cost for projects in *Electric Operations*

Electric System Monitoring and Control

Total Project Cost:

$13.9M

YR1	YR2	YR3	YR4	YR5
$3.3M	$3.7M	$3.5M	$3.4M	

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California Energy Systems for the 21st Century

Gas System Operations

Advanced system modeling along with collection, extraction, fusion and analysis of multiple data sources that characterize the gas pipeline network and its operation will inform advanced risk analysis processes to ensure the safety and reliability of the gas pipeline system.

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Lee Glascoe (LLNL)

Gas System Operation proposed projects

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- Sensor Fusion ($7M, 3years)
  - Combine orthogonal data input from magnetic flux leakage, electromagnetic acoustic transducer, calipers, and ultrasound techniques to comprehensively assess pipeline health and integrity
- Geographic Data Integration for Risk Management($5M, 3 years)
  - Develop and demonstrate tools that enable the integration of large amounts of both traditional (paper records) and non-traditional (electronic data and models) forms of gas infrastructure and environmental information to support comprehensive integrity assessments
- Advanced Modeling and Simulation Environment ($12M, 5 years)
  - Develop and demonstrate tools to enable comprehensive parametric simulations of the transmission and distribution gas system including a quantified uncertainty framework to enhance modeling accuracy as well as the level of understanding and confidence in modeling results

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Gas System Operation
Sensor Fusion

Need:

Current pipeline inspection methods employ multiple vendors to locate anomalies with known risk profiles. Anomalies are detected using a suite of sensor capabilities (e.g. magnetic flux leakage, ultrasound, calipers), and repeated inspections are performed over time; however, currently there is no capability (commercial or PG&E internal) to simultaneously leverage multiple data sources and measurements to identify potential anomalies and track pipeline integrity over time.

Objective:

The objective is a comprehensive understanding of pipeline integrity through analysis leveraging multiple sensors and repeated measurements over time, with the ultimate goal of reducing risk to the public due to possible pipeline failure. Secondary objectives include greatly reduced inspection costs and scalable architectures for integration with future sensor systems and geospatial inputs.

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Gas System Operation
Sensor Fusion

Approach:

Data Import (PM1-12):
Provide a survey of all appropriate PG&E in-line inspection data types and formats

Sensor Fusion (PM9-21):
Reviewing tools and sensor combination analyses to optimize sensor selection and integration

Pipeline Application (PM21-36):
Introduction of sensor fusion algorithms and processes to pipeline features and information storage will be performed

Change Detection (PM32-48):
Develop pipeline in-line inspection change detection capabilities (optional and therefore not included in cost estimate)

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Gas System Operation
Sensor Fusion

Approach: (con't)

Integration of ARV tools in In Line Inspection (PM48-60):
Application of the results to the operational procedures of in-line Inspection, including proposals for the evolution of the requirement standards API 1163 supported by the pipeline industry

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Gas System Operation
Sensor Fusion

Research or service needed	Potential Collaborators
Experience in high throughput sensor processing	1. Teres Technology
Data Compression	1. University of California, Berkeley
Gas pipeline research	1. Pipeline Research Council International 2. NYSEARCH 3. INGAA

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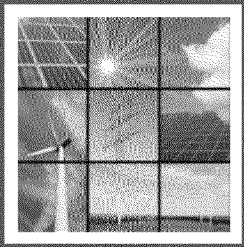
Gas System Operation
Sensor Fusion

Deliverable	Due Date
Analysis of existing and LLNL-acquired pipeline ILI/NDE data	PM12
Demonstration of prototype of ARV and sensor fusion architecture applied against targeted test defects	PM18
Demonstration of pipeline defect database	PM30
Demonstration of pipeline integrity change-detection defects (not in cost estimate)	PM48
Demonstration of prototype ARV (not in cost estimate)	PM57



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Gas System Operation
Sensor Fusion

Potential customer benefits

1. Improved, more accurate and dynamic understanding of risk to the public due to possible pipeline failure
2. Greatly reduced inspection costs
3. Informative and predictive integrity analysis capability
4. Scalable architectures for integration with future sensor systems and geospatial inputs

Gas System Operation
Geographic Data Integration for Risk

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Need:

Integrity Management Programs aim to develop a quantitative understanding of risk to and from natural gas pipelines and facilities. However risk assessment is not a static analysis; comprises the historical and current state of the natural gas system, accounting for population movements and previous repairs that need to be integrated in a coherent information set.

Objective:

This project will improve the understanding and quantification of risk from and to natural gas infrastructure, in part, by creating tools that enable the integration of large amounts of both traditional (paper records) and non-traditional (electronic data and models) forms of gas infrastructure and environmental information to support comprehensive integrity assessment studies as well as asset operation integrity, maintenance, and long-term planning.

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Gas System Operation

Geographic Data Integration for Risk

Approach:

Spatially explicit risk associated with population distribution (PM1-36):
Make multi-attribute risk assessment more informative in time and space with regard to public risk by integrating a temporally- and spatially-explicit population database with the available GIS information

Extraction of geographical information from historical maintenance records (PM1-24):
Enable a computer-assisted information extraction system for expedited and automated improvement of the gas records system

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Gas System Operation

Geographic Data Integration for Risk

Approach: (con't)

System-Wide Risk Assessment of PG&E's Natural Gas System (PM24-36):
A comprehensive safety and economic risk assessment of PG&E's entire natural gas system

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Gas System Operation
Geographic Data Integration for Risk

Research or service needed	Potential Collaborators
GIS provider	1. ESRI
Risk assessment	1. Lawrence Berkeley National Laboratory 2. Sandia National Laboratory 3. University of California, Berkeley 4. University of California, Santa Barbara 5. University of California, Los Angeles 6. Stanford University 7. EPRI 8. PRCI 9. Gas Technical Institute
Population dynamics	1. Oak Ridge National Laboratory 2. Sonoma State University
Energy informatics	1. University of Southern California

Gas System Operation

Geographic Data Integration for Risk

Research or service needed	Potential Collaborators
Optical character recognition	1. ABBYY 2. Parascript 3. A2iA 4. Google 5. Adobe 6. OmniPage
Document management	1. EMC Documentum 2. SAP 3. IBM 4. Xerox Docushare

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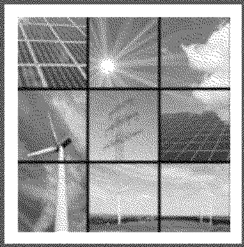
Gas System Operation

Geographic Data Integration for Risk

Deliverable	Due Date
Presentation of segment-base impact quantification	PM7
Presentation of pilot population-based spatial evacuation matrix	PM10
Pilot workflow of document extraction complete	PM11
Presentation of scoping of integration of population risk into PG&E's system	PM12
Report on Integrated Computer-assisted Geographic information extraction tool to support project next step decision	PM13
Expansion of population risk assessment product, accounting for data accuracy and multiple regions	PM20
Presentation of visualization gaps and needs	PM24
Report on methodology of integration of toll with PG&E's system	PM24
Assessment report of other risks to natural gas infrastructure	PM24



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Gas System Operation
Geographic Data Integration for Risk

Potential customer benefits

1. A high resolution understanding of time dependent impact to the public in case of a potential pipeline failure that will support a cost effective risk-based assessment to prioritize system improvements such as shut-off valve installation, inspection and maintenance
2. Leveraging databases and models developed for a broad range of security and business applications by the National Laboratories provides a reliable solution at a minimal cost
3. Enabling new possibilities in operation and resource management to minimize response time, reduce costs, and improve safety
4. Exploring how population movement and density forecasts can be used to optimize work and investments on the pipeline network
5. Providing a reliable, fast and cost-effective method to process very large numbers of historical records of assets for pipeline maintenance and risk assessment
6. Accelerating the development of understanding quantitative comprehensive risk-based integrity management plans that are currently limited by the lack of accurate and reliable data

Gas System Operation
Advanced Modeling and Simulation Environment

Need:

PG&E currently makes extensive use of pipeline modeling software for system planning purposes. Planning needs are evolving due to the integration of renewable energy sources, the availability of substantially more monitoring data on the transmission and distribution networks, and new opportunities to improve system operations by using simulations as a tool to guide operators for complex real time decisions. High fidelity modeling will provide insight into complex "what if" scenarios for planning and operation purposes, as well as potentially to detect leaks or other equipment failures.

Objective:

We will develop and implement an advanced calibration methodology for PG&E pipeline models to automate what is currently a costly and time-consuming calibration process and to increase the accuracy of the calibrated models. In addition tools will be developed to support intensive parametric simulations to improve gas system planning and operation.

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Gas System Operation
Advanced Modeling and Simulation Environment

Approach:

Model Calibration and Accuracy Quantification (PM1-24):
Automate the calibration process for models in a way that is compatible with the IOU's existing modeling tools.

Operational Enhancement through Contingency Planning Tools, Visualization Capabilities and Other Software Enhancements (PM12-36):
Address more complex networks and the integration of increasing amounts of available data (e.g. Smart Meters) and develop visualization tools that allow planners to leverage modeling results for complex decision making.

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Gas System Operation
Advanced Modeling and Simulation Environment

Research or service needed	Potential Collaborators
Pipeline modeling tools	1. GL Noble Denon 2. Energy Solutions International 3. Gregg Engineering 4. ATMOS International 5. Simulation Software Limited 6. Eucalypt 7. Liwacom
Expertise in pipeline modeling	1. Sandia National Laboratory 2. Lawrence Berkeley National Laboratory 3. University of California, Santa Barbara
Research organization	1. Pipeline Research Council International 2. Pipeline Simulation Interest Group

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Gas System Operation

Advanced Modeling and Simulation Environment

Deliverable	Due Date
Complete assessment of selected commercial software as applies to anticipated automation and visualization efforts	PM3
Complete vendor selection for post-Phase 1 modeling completed, or decision to move forward with an in-house model	PM9
Presentation on automated calibration capability using commercial software for backbone model	PM10
Selection of additional model for automated calibration	PM10
Selection of demonstration planning need to be addressed by advanced visualization tools	PM10
Presentation on automated calibration using commercial software for backbone model	PM12
Complete assessment of optimization capabilities of selected software and options for increasing robustness	PM12

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Gas System Operation

Advanced Modeling and Simulation Environment

Deliverable (con't)	**Due Date**
Presentation on automated calibration capability for additional model	PM20
Delivery of uncertainty quantification and accuracy assessment software for pipeline operations with complete documentation	PM24
Presentation on advanced visualization capability for selected planning exercise	PM36

Gas System Operation
Advanced Modeling and Simulation Environment

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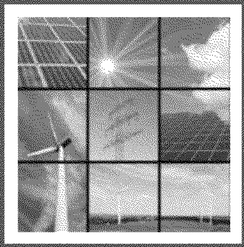
Potential customer benefits

1. Avoid unplanned disruption (curtailments) of gas service during a Cold Weather Day event or an Abnormal Peak Day event.
2. Diagnose system response to a gas leak with confidence and offer repair solutions that reduce system disruption.
3. Accurate knowledge of system capacity and customer usage allows crew members to reduce the response time during emergency (such as a gas leak), thereby reducing natural gas emissions.
4. Effective simulation environment results in faster response to planning and operation requests. The benefits are multiplied during emergency scenarios to respond to a gas leak and implement repair alternatives.



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Timelines and annual cost for projects in *Gas System Operations*

Sensor Fusion

Total Project Cost: $7.2M

YR1	YR2	YR3	YR4	YR5
$2.3M	$2.4M	$2.5M		

Geographic Data Integration for Risk Management

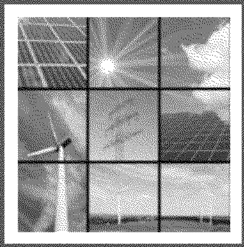
Total Project Cost: $4.7M

YR1	YR2	YR3	YR4	YR5
$1.7M	$1.5M	$1.5M		

Advanced Modeling and Simulation Environment

Total Project Cost: $11.7M

YR1	YR2	YR3	YR4	YR5
$2.2M	$2.3M	$2.5M	$2.4M	$2.3M



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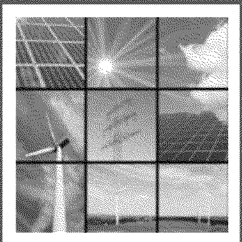
Cyber Security

Collection, extraction, fusion and analysis of grid network and device data will be used to develop models and simulations of cyber events impact to grid operations. These simulations, coupled with advanced analytics of actual cyber-industrial control systems data, will provide the IOUs with the situational awareness and system impact information needed to mitigate, contain, and respond to cyber attacks that may compromise grid performance or ratepayer privacy.

Cory McClelland (SDG&E)

John Grosh (LLNL)



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Cyber Security proposed projects

- Advanced Threat Analysis Center ($36.5M, 5years)
  - Develop tools and algorithms to analyze large amounts of the IOU network data to detect advanced cyber attacks and improve situational awareness; develop tools to determine vulnerabilities in hardware, firmware, and software that support the operation of California's critical infrastructure.
- Modeling and Simulation ($27M, 5 years)
  - Build a computational simulation codes that couples the industrial controls systems communication infrastructure with generation, transmission and distribution networks, storage, and loads to simulate cyber attack and defense.

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Cyber Security
Advanced Threat Analysis Center

Need:

A highly-coordinated and structured cyber, physical, or blended attack on the bulk power system, could result in long-term, difficult to repair damage to key system components in multiple simultaneous or near-simultaneous strikes. Unlike "traditional," probabilistic threats, a coordinated attack would involve and intelligent adversary with the capability to bring the system outside the protection provided by current planning and operating practices. An outage could result with the potential to affect a wide geographic area and cause large population centers to lose power for extended periods.

Objective:

This project includes two key components:

- **Threat Modeling and Data Mining:** Develop tools and algorithms to mine and analyze large amounts of the IOU operational data over long periods of time to discover and implement corrective actions to reduce the impact of advance persistent threats on California's critical infrastructure.
- **Vulnerability Analysis:** Develop tools to determine the extent of cyber vulnerabilities in hardware, firmware, and software that support the operation of California's critical infrastructure.

Cyber Security
Advanced Threat Analysis Center

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Approach:

Threat Modeling and Data Mining (PM1-60):
Analyze the data that IOUs collect to monitor and maintain their networks for anomalies, emerging threats, and overall network health.

Vulnerability Analysis (PM1-60):
Analyze hardware, software, and protocols throughout the IOU cyber infrastructure for vulnerabilities.

Transition to IOUs (PM36-60):
Transition the tools, techniques, and data to a contractor for continued support

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Research or service needed	Potential Collaborators
Industrial control system mapping	1. Sandia National Laboratories
Control system security testing	1. Idaho National Laboratory
Visualization of cyber data	1. Invincea
Data sharing of cyber data	1. Internet Systems Consortium

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Deliverable	Due Date
Data model, v1	PM3
Data-sharing agreements signed by IOUs	PM6
Secure data portal	PM8
Best-effort maps and catalog of IOU infrastructure	PM9
Candidate list of hardware, software, etc. for vulnerability analysis	PM9
Prototype data aggregation and collection system, v1	PM12
Data model, v2	PM12
Network map for 1 IOU	PM12
Firmware / Hardware / Software ready for analysis	PM13
Prototype data analysis / machine learning techniques	PM15
Data aggregation and collection system, v2	PM16
Prototype tools for analyzing ICS firmware, v1	PM18
Prototype build of alerting and response framework, v1	PM18

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Deliverable (con't)	**Due Date**
Vulnerability analysis of a selected piece of software, hardware, or network protocol	PM18
Test analysis of firmware	PM20
Network map for all 3 IOUs	PM24
Tools for firmware analysis, v2	PM30
Initial threat mitigation and best practices report, v1	PM30
Refined Data analysis / machine learning techniques	PM30
End-to-end demonstration of data collection, aggregation, analysis and alerting	PM36
Draft transition plan	PM36
Revised transition plan	PM44
Threat mitigation and best practices report, v2	PM48
Threat mitigation and best practices report, v3	PM60
ATAC transitioned to IOUs	PM60

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Potential customer benefits

1. Define and develop "forward looking" technology, strategies and tools
2. Increase the security of California's critical infrastructure.
3. Create a line of defense against today's advanced persistent threats
4. Strengthen cyber security environment by expanding cyber education
5. Define and develop enduring deterrence strategies and programs

Cyber Security
Modeling and Simulation

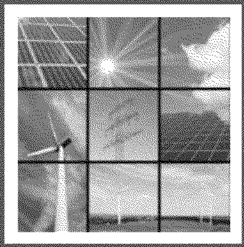
Need:

Emerging cyber threats require detailed models to identify vulnerabilities and develop mitigation strategies. Because the grid is coupled at several levels, a comprehensive model has to be developed to a sufficient level of detail to identify vulnerabilities and paths across those levels. The increasing use of edge devices with two-way communication creates an emerging threat to grid control systems. These devices and their interaction with utility back office systems and control systems are growing in complexity. Detailed models identifying control characteristics and communication protocols have not been developed for a large-scale analysis across the State of California.

Objective:

We propose to build and successively refine a computational model that couples

- Communication infrastructure
- Primary electric generation and transmission behavior
- Utility distribution networks
- Utility-operated energy storage, beyond hydro
- End-user loads and generation
- Utility ICS systems



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Cyber Security

Modeling and Simulation

Approach:

Baseline Device, Topology and Traffic (PM1-60): Collect and archive baseline data on deployed grid and communication devices, and communication traffic traces.

Coupled Model Development (PM6-44): Develop communications model coupled to transmission-distribution model.

Cyber Attack Scenarios and Modeling (PM18-60): Develop various cyber-attack scenarios. With the IOUs and ATAC perform joint assessment of likely risk and scale of consequences. For selected scenarios develop detailed attack, detection, response, and recovery models, and analyze and assess the model accuracy and performance. Demonstrate multiple response options for a given attack scenario

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Cyber Security
Modeling and Simulation

Research or service needed	Potential Collaborators
Real-time grid simulator	1. RTDS Technologies
Coupled models	1. Oak Ridge National Laboratory
SCADA system security	1. Pacific Northwest National Laboratory

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Cyber Security
Modeling and Simulation

Deliverable	Due Date
Catalog dB design document	PM6
Communications media and protocols survey	PM6
Communications and Grid Component catalog, v1	PM6
Grid & Communications Topology, v1	PM6
Communications Data catalog	PM6
Communications and Grid Component catalog, v2	PM18
Grid & Communications Topology, v2	PM18
Measurement campaign design report	PM18
Communication and Grid model, v1	PM18
Coupled T&D+Communication model design report	PM18
As-deployed device models, v1	PM24
As-deployed device models, v2	PM30

Cyber Security
Modeling and Simulation

Deliverable (con't)	**Due Date**
T&D model development and T&D+Communication interim report	PM30
Measurement campaign interim report	PM30
Measurement campaign final report	PM42
T&D and T&D+Communication model final report	PM42
Cyber attack scenarios, v1 report	PM42
Deployment plan report	PM42
Cyber attack scenarios, v2 report	PM50
Measurement analysis report	PM60
Cyber attack model implementation report	PM60
Cyber attack model analysis report	PM60

Cyber Security
Modeling and Simulation

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Potential customer benefits

1. Ability to develop detection and mitigation strategies to emerging vulnerabilities before they can be exploited
2. Explore and evaluate incident response scenarios in advance of need, to improve the time to respond and recover
3. Capability to replay cyber incidents, with variations, to understand the range of risk exposures in similar situations, and the possible consequences of response strategies other those utilized at the time of incident
4. As a planning tool in assessing operational benefits and risk reduction that could be realized by future grid improvement proposals. Such information would enable rapid quantitative assessment of potential benefits as part of developing future rate cases
5. Provide training and exercise capability for incident detection and response
6. Evaluation of disaster response, recovery and restoration plans at the IOU and CALISO level, enabling all stakeholders to understand drivers and consequences outside their own domain

Timelines and annual cost for projects in *Cyber Security*

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Total Project Cost:

$36.5M

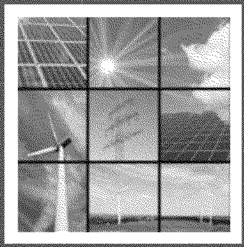
YR1	YR2	YR3	YR4	YR5
$7.2M	$8.3M	$7.5M	$6.9M	$6.6M

Modeling and Simulation

Total Project Cost:

$27.3M

YR1	YR2	YR3	YR4	YR5
$5.1M	$5.6M	$5.4M	$5.6M	$5.6M



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