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Real Time Grid Reliability Management 2005 (without appendices)

Authors
Eto, Joe
Parashar, Manu
Leiseutre, Bernard
et al.

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REAL TIME GRID RELIABILITY MANAGEMENT 2005

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Lawrence Berkeley National Laboratory

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Project Manager: Joe Eto
Authors: Joe Eto, Manu Parashar, Bernard Lesieutre, Nancy Jo Lewis
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Preface

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

The PIER Program, managed by the California Energy Commission conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $15 million annually for natural gas RD&D.

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

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

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

Real Time Grid Reliability Management 2005 is the draft final report for the Real Time Grid Reliability Management 2005 project (contract number 500−02−004) conducted by the Consortium for Electric Reliability Technology Solutions (CERTS). The information from this project contributes to PIER's Transmission Research Program. For more information on the PIER Program, please visit the Energy Commission's Web site at http://www.energy.ca.gov/pier or contact the Energy Commission at (916) 654−5164.

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Report Organization

The Real Time Grid Reliability Management 2005 project consists of three parallel technical tasks:

- Task 2.0: Develop a Real-Time Voltage Security Assessment (VSA) Prototype Tool;
- Task 3.0: Real-Time Applications of Phasors for Monitoring, Alarming and Control;
- Task 4.0: Improving Dynamic Load and Generator Response Performance Tools.

The tasks funded under this work authorization were coordinated by Consortium for Electric Reliability Technology Solutions (CERTS) for the Energy Commission's PIER Transmission Research Program. Tasks 2 and 3 were the second phases of a multi-project ongoing RD&D activity, while Task 4 was a new project. Earlier phases of the research on Tasks 2 and 3 were sponsored by PIER through a RD&D contract with LBNL (Contract #: 150−99−003) and through several task orders funded through the California Institute for Energy and Environment Contract #500−24−004 (BOA#20).

Additional funding through two separate subsequent work authorizations has been provided to build upon the work initiated in this work authorization. Follow-on work for Task 2: Develop a Real Time Voltage Security Assessment (VSA) Prototype Tool and Task 3: Real-Time Applications of Phasors for Monitoring, Alarming and Control has been funded under Contract #500−02−004: MR−041, Real Time System Operations (RTSO) 2006–2007. Follow-on work for Task 4: Improving Dynamic Load and Generator Response Performance Tools has been funded under Contract #500−02−004: MR−049, WECC Load Modeling Transmission Reliability Research Project.

An overview of Real Time Grid Reliability Management 2005 is provided in the Project Introduction. Additional reporting is organized separately for each technical task.

Project Introduction

The increased need to manage the California electricity grid more actively in real time is a result of the ongoing transition from a system operated by vertically-integrated utilities serving native loads to one operated by an independent system operator supporting competitive energy markets. In effect, markets are replacing utilities in performing the match between generation and demand. System operators must both ensure reliability as they have always done and now also facilitate the operation of these newly created markets. This transition has confronted system operators with dramatic changes from past practices including new and greatly increased numbers of market participants and the resulting dramatic increase in the volumes of energy trades, often over long distances.

To meet these new challenges, operators have had, until now, only the previous generation of grid management tools. These tools were designed for a vertically-integrated and centrally-controlled system whose relatively predictable conditions did not require the kind of minute-by-minute decision making resulting from the operation of today's electricity markets. For example, the traditional approach for managing reliability is to use models to analyze, months in advance, a pre-determined set of contingencies for peak load conditions and then set conservative operating limits for the system. Yet, managed and unmanaged power outages, transmission congestion, energy price spikes, frequency abnormalities, and voltage degradation routinely occur at times other than peak load and, sometimes, as a result of contingencies not previously considered. As a result, traditional management tools are increasingly inadequate and practices must be updated.

In light of these developments, the best strategy for managing reliability is to equip the system operator with better real-time information about actual operating margins so that he can better understand and manage the risk of operating closer to the edge. In some cases, these tools must be able to analyze geographically dispersed events in real-time, which require using time-stamped data in order to conduct dynamic system analysis, alarm operators, and, in the future, enable dynamic response through automatic system controls. The strategic direction the Energy Commission is sponsoring for its research includes: (1) enhancement of tools that obtain and translate real-time data for analysis and operator actions, and (2) advanced monitoring tools with time synchronized phasor data. These tools and technologies will also set the stage for a future smart electricity grid that will be able to automatically sense and respond to system emergencies.

A companion strategy is to also address known deficiencies in the offline modeling tools that continue to be needed to ground the use of improved real-time tools. The risk of blackouts exacerbated by inaccurate models was clearly illustrated by the August 10, 1996 blackout (and others) in which simulations after the event were unable to replicate the event. Since that time, Western Electric Coordinating Council (WECC) members have improved some aspects of their modeling tools, yet it is well accepted that the models for load response remain deficient. Recent, close call events in the West, in which slow voltage recovery from faults has increased concern about uncontrolled, cascading voltage collapse (i.e., blackouts) continue to remind us of the need to improve these load models.

The costs of blackouts are high. The August 14th 2003 blackout was estimated to have cost in the range of $4 billon and $10 billion in the United States (at least $2.3 billion in Canada) (U.S.-Canada Power System Outage Task Force 2004), and a recent report estimates that power system disturbances cost $80 billion annually in the United States (LaCommare and Eto 2006).

The overall goals of this project are to:

- Improve the reliability and quality and cost/value of California's electricity through the use of new and better real-time operational tools.
- Develop two prototype real-time operational tools to meet California Independent System Operator (CA ISO) specifications.
- Initiate the transfer of these prototypes to a vendor for implementation as production-grade operating tools.
- Prioritize options for data collection to improve the load and generator models used by CA ISO and WECC.

The objectives of this project are to:

- Develop and conduct first-ever demonstration of two prototype real-time software tools for CA ISO (Task 2.0 and 3.0); and
- Prepare a scoping study report on improving load and generator response models (Task 4.0).

The tasks funded under this work authorization represent the second phase of an ongoing multi-project RD&D activity that is being coordinated by CERTS for the Energy Commission's PIER Transmission Research Program. Earlier phases of this research were sponsored by PIER through a RD&D contract with LBNL (Contract #150−99−003) and through several task orders funded through the California Institute for Energy and Environment (BOA#20).

Additional funding through two separate subsequent work authorizations has already been provided to build upon the work initiated in this work authorization. Contract #500−02−004, MR−041, Real Time System Operations (RTSO) 2006–2007 extends Task 2.0: Develop a Real Time Voltage Security Assessment (VSA) Prototype Tool and Task 3.0: Real-Time Applications of Phasors for Monitoring, Alarming and Control. Contract #500−02−004: MR−049, WECC Load Modeling Transmission Reliability Research Project has initiated the research identified in Task 4.0: Improving Dynamic Load and Generator Response Performance Tools.

Tasks and deliverables described below refer solely to accomplishments that have been completed under the funding for this work authorization.

Abstract

The increased need to manage California's electricity grid in real time is a result of the ongoing transition from a system operated by vertically-integrated utilities serving native loads to one operated by an independent system operator supporting competitive energy markets. During this transition period, the traditional approach to reliability management – construction of new transmission lines – has not been pursued due to unresolved issues related to the financing and recovery of transmission project costs. In the absence of investments in new transmission infrastructure, the best strategy for managing reliability is to equip system operators with better real-time information about actual operating margins so that they can better understand and manage the risk of operating closer to the edge. A companion strategy is to address known deficiencies in offline modeling tools that are needed to ground the use of improved real-time tools.

This project: (1) developed and conducted first-ever demonstrations of two prototype real-time software tools for voltage security assessment and phasor monitoring; and (2) prepared a scoping study on improving load and generator response models. Additional funding through two separate subsequent work authorizations has already been provided to build upon the work initiated in this project.

Keywords: Electricity grid, reliability, real-time operator tools, voltage security, time synchronized phasor measurements, dynamic load models, dynamic generation response

1.0 Task 2.0: Develop a Real-Time Voltage Security Assessment (VSA) Prototype Tool

1.1 Executive Summary

California Independent System Operator (CA ISO) system operators need to know how to more effectively manage the grid and its reactive resources, including coordination with other organizations (interconnected system operators, load-serving entities, and generators), within today's changed operational environment, especially during periods of system stress. Conducting voltage security assessments is the principal means for achieving this end. The problem of voltage security assessment is exacerbated by the effects of multiple transfers through the network that result from the buying and selling of electric power across the boundaries of control areas in which the point of production and the point of delivery may be in geographically distant locations. CA ISO does not have a real-time dispatcher's tool for voltage security assessment (VSA). In this task, CERTS conducted a technical assessment of algorithms, developed a first prototype incorporating contingency ranking, continuation power flow and hyperplanes, and a prepared prototype functional specification. This task is the middle phase of a multi-project research activity through which CERTS is developing VSA prototype real-time operational tools that implement, test and demonstrate key CA ISO requirements for a future production-quality VSA tool. The VSA prototype tool implemented a traditional continuation power flow algorithm within a hyperplane framework that enabled contingency ranking. The accuracy of the VSA prototype tool was validated by comparing its results to those calculated by an industry standard off-line planning analysis tool. The VSA prototype tool also included wide-area visuals to support operators in managing voltage and Voltage-Ampere Reactive (VAR) resources on the transmission system. When completed in the final, subsequent phase of this research, CA ISO will use the results of this research to procure a production-quality tool that will become part of a suite of advanced computational tools for CA ISO congestion management, which is slated for implementation over the next few years.

1.2 Introduction

California Independent System Operator (CA ISO) system operators need to know how to more effectively manage the grid and its reactive resources, including coordination with other organizations (interconnected system operators, load-serving entities, and generators), within today's changed operational environment, particularly during periods of system stress. The problem of voltage security assessment is exacerbated by the effects of multiple transfers through the network that result from the buying and selling of electric power across the boundaries of control areas in which the point of production and the point of delivery may be in geographically distant locations. CA ISO does not have a real-time dispatcher's tools for voltage security assessment (VSA). To meet CA ISO specifications, CERTS is developing a VSA prototype real-time operational tool that will implement, test and demonstrate the key elements of a future production-quality VSA tool.

The VSA Project consists of three tracks including data requirements, algorithms, and prototype development. There are four phases for each track. The phases include platform development and initial research, algorithm development and the proof-of-concept simulations, and data integration and project expansion. Figure 1 illustrates the multi-year research roadmap for the VSA project. The roadmap identifies the activities completed under this contract, which are identified as the second phase of research for each track. It also identifies earlier activities accomplished under #BOA20 and activities on a subsequent phase that are being conducted through a follow-on contract, #500−02−004, MR−041, Real Time System Operations (RTSO) 2006–2007.

1.2.1 Background and Overview

Over the past 40 years, more than 30 major blackouts worldwide have been related to voltage instability and collapse. Among them, at least 13 voltage-related blackouts occurred in the United States, including two major blackouts in the Western Interconnection in 1996 and a wide-scale blackout in the Eastern Interconnection in 2003. Several times, the blackout investigation teams have identified the need for on-line or real-time power flow and stability tools and indicators of voltage performance in a real-time operating environment in order to help prevent future blackouts.

Currently, CA ISO real time operations do not have a real-time dispatcher's VSA tool and corresponding wide-area visuals to manage the voltage and VAR resources on the transmission system, and to identify the following:

- Voltage security margin calculation.
- Worst-case contingencies leading to voltage collapse and/or contingencies with insufficient voltage stability margin.
- Abnormal reductions of nodal voltages.
- Contingency ranks according to a severity index for system problems.
- System conditions with insufficient stability margin.

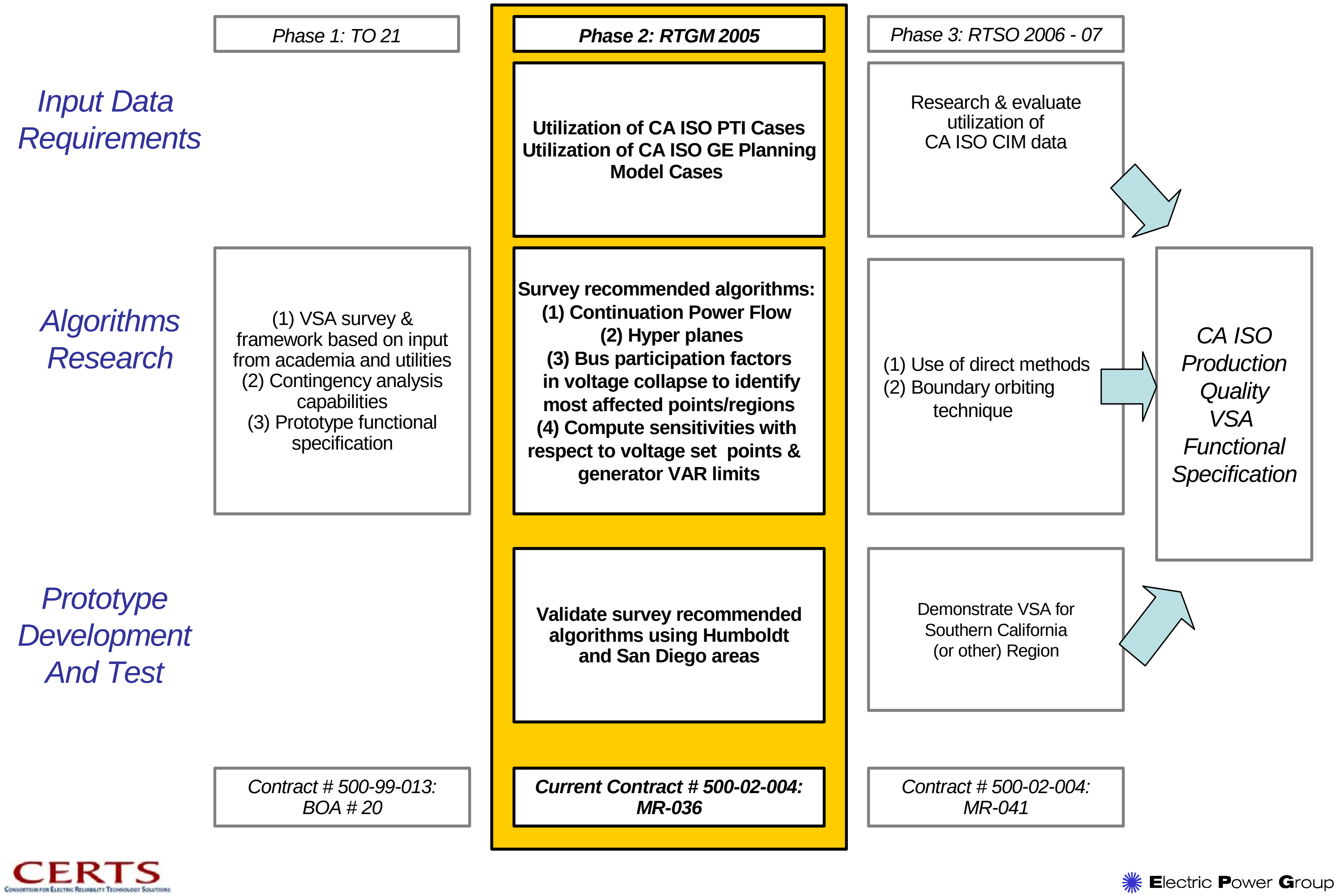

Figure 1. Multi Year Development Roadmap for CA ISO Voltage Security Assessment (VSA) Project

- Weakest elements within the grid and the regions most affected by potential voltage problems
- A real-time dispatcher's dashboard-type of display providing information about voltage problems at the normal look-ahead operating conditions and for the worst-case contingencies (contingencies with large severity ranks) that may appear in the future.

CERTS development of an initial VAR-Voltage Management prototype tool was funded by the Department of Energy (DOE) Transmission Reliability program in 1999 and 2000 as a direct response to CA ISO's desire to improve procedures for implementing WECC's revised voltage-VAR requirements. Prototype tailoring and enhancements for demonstration at CA ISO began under PIER support in 2001. Key project milestones under this earlier PIER funding have been: 1) in 2001–02, installation of initial prototype with snapshot displays of San Diego system, only; 2) in 2003, development of a full CA ISO system model, including incorporation of CA ISO user feedback, but still based on snapshots. In summer 2004, CA ISO developed a specification for a new real-time voltage security assessment tool that incorporates and extends the functionality of the original CERTS VAR-Voltage Management prototype for voltage security monitoring purposes. The prototype was enhanced to run contingency simulations and perform contingency ranking which is required for the Voltage Security Assessment prototype phase of the project, and these new features were tested on the CA ISO system.

In July of 2004, the TRP Program Review Committee recommended continued RD&D in this area; focusing on what VAR margins are needed around the system, on what they are now, and on identifying options for addressing short-falls as they arise. This Committee also recommended research on identifying the information needed by operators to make better operating decisions, including improving comfort and confidence in new real-time operating tools.

Under a prior contract, CERTS formulated a survey (Appendix A. Summary of Survey Results on Methodologies for use in Real-Time Voltage Security Assessment) to reach out to experts in this field for comments, information, suggestions, and recommendations related to the VSA project. The survey was sent to 51 experts in universities and in the power industry worldwide. The consensus opinion was that the continuation method hyperplane approximation approaches are well suited for VSA.

1.2.2 Task Objectives

The overall technical objective is to conduct research that will assist CA ISO in acquiring a production-quality, real-time dispatcher's VSA tool, including wide-area visuals to help them manage the voltage and VAR resources on the transmission system. The tool includes the following features:

- Voltage security margin calculation,
- Worst-case contingencies leading to voltage collapse and/or contingencies with insufficient voltage stability margin,
- Abnormal reductions of nodal voltages,
- Contingency ranks according to a severity index for system problems,

- System conditions with insufficient stability margin,
- Weakest elements within the grid and the regions most affected by potential voltage problems,
- A real-time dispatcher's dashboard-type of display providing information about voltage problems at the normal look-ahead operating conditions and for the worst-case contingencies (contingencies with large severity ranks) that may appear in the future.

Acceptance by CA ISO of a final functional specification for a production-quality VSA software tool is the principal evidence that this overall technical objective has been met.

The objective of Task 2.0 in support of this overall technical objective is to develop and conduct the first-ever demonstration of the first of two prototype real-time software tools for CA ISO (Task 3.0 is to conduct parallel work on the second of these prototype tools).

The specific objectives of Task 2.0 are to:

- Perform a technical assessment of algorithms: 1) for voltage security margin, the distance to instability determined for a selected loading of stress direction, and 2) to identify weak elements;
- Develop and test an initial VSA prototype software tool incorporating these features, and conduct a technical assessment of the continuation power flow algorithm; and
- Provide a functional specification for a next VSA prototype software tool to CA ISO that includes enhancements to these algorithms, among other features, such as contingency ranking. The actual development and testing of this prototype is being conducted under a separate contract #500−02−004, MR−041, Real Time System Operations (RTSO) 2006–2007.

1.3 Task Approach

The task approach involved research on each of the first phases of the three project tracks identified in Figure 1: (1) implementation and validation of suitable algorithms; (2) integration with CA ISO energy management system (EMS); and (3) creation of a platform for validating the tool through its development.

The project team conducted an extensive review of existing VSA approaches, and identified and selected a state-of-the-art combination of approaches and computational engines for implementation in this project. Key elements of the task approach are the use of 1) parameter continuation, 2) direct methods, and 3) hyperplane approximation of the voltage stability boundary.

1) Parameter continuation is also known as the predictor-corrector method. It involves finding a continuum of power flow solutions starting at some base load and leading to the steady state voltage stability limit (critical point) of the system. This method is quite robust and useful since it overcomes several mathematical obstacles.

2) Finding the exact critical point or the point of collapse using parameter continuation technique might require several iterations especially while operating close to the critical point. With the help of the direct method algorithm, one can avoid such multiple iterations and obtain the exact solution point directly. However, this method can only be applied when the operating point is in the vicinity of the point of collapse. Hence, VSA utilizes a parameter continuation-direct method hybrid approach to quickly find the point of collapse.

3) Hyperplane is a linear geometry in multi-dimensional space. In 1, 2, and 3 dimensions this happens to be a point, a line and a plane respectively. In power systems, a 2-dimensional security region constructed by hyperplane approximation describes a region of safe operation (aka operating nomograms).

These elements were first approved by a panel of leading experts during the course of the survey described above. The elements were also verified in the course of face-to-face personal meetings with well-known university professors, industry experts, and software developers, and included email discussions, telephone exchanges, and feedback from industrial advisors and brainstorm meetings with the projects' consultants.

CERTS industrial advisors reviewed these developments during two Technical Advisory Committee (TAC) meetings conducted in 2005. The TAC, consisting of representatives from the CA ISO, California utilities, Bonneville Power Authority (BPA), DOE and other organizations, provided strategic guidance for this Real-Time Operations RD&D program to foster rapid adoption of RD&D results. At the TAC meetings, the California utilities shared their plans on various applications of phasor measurements such as local remedial control interests by SCE, state estimation improvements by SDG&E, and critical path monitoring by PG&E.

And, finally, CA ISO staff was consulted extensively throughout the project.

The approach is based on the following principles and algorithms:

- Concepts of local voltage problem areas and descriptive variables influencing the voltage stability problem were used in each area. Information about the known voltage problem areas was utilized, and formal screening procedures to periodically discover new potential problem areas and their description parameters, were developed
- The voltage stability boundary was calculated and approximated. The approximated voltage security conditions in real time for a fast VSA, and hyperplanes to approximate the voltage stability boundary were used.
- To calculate the approximating hyperplanes, and reactive margins, the project team used the parameter continuation techniques and introduced a sufficient additional security margin to account for inaccuracies of approximation and uncertainties of the power flow parameters.
- A list of abnormal reductions in nodal voltages that highlighted the elements and regions most affected by potential voltage problems was compiled.
- The parameter continuation predictor corrector methods were implemented by identifying and developing necessary improvements.
- Motivated by survey results, the project team used the PSERC parameter continuation program and MATLAB programming language as a basis for building the VSA prototype functional specifications.

The project team prototyped the proposed algorithms on a platform developed by the team for validating the tool and tested it with a CA ISO-provided test case. The project team validated the VSA algorithm results through numerous meetings and correspondence with CA ISO staff, who helped identified test cases and appropriate stressing directions. The project team used the GE PSLF power flow tool (a well-accepted off-line planning tool currently used by CA ISO) to simulate the VSA algorithms and compare output results, and the CA ISO system planning model (in GE PSLF form).

1.4 Task Outcomes

The project team completed research on each of the first phases of the three project tracks identified in Figure 1: (1) implementation and validation of suitable algorithms; (2) integration with CA ISO energy management system (EMS); and (3) creation of a platform for validating the tool through its development.

With respect to the project objectives, the project team:

- Performed a technical assessment of algorithms: (1) for voltage security margin, the distance to instability determined for a selected loading of stress direction, and (2) to identify weak elements.
- Developed and tested an initial VSA prototype software tool incorporating these features, and conduct a technical assessment of the continuation power flow algorithm and the hyperplane approach.
- Provided a functional specification for a next VSA prototype software tool to CA ISO that includes enhancements to these algorithms, among other features, such as contingency ranking. The actual development and testing of this prototype is being conducted under a separate contract #500−02−004, MR−041, Real Time System Operations (RTSO) 2006–2007.

What follows in this sub-section is a summary of the task accomplishments and research findings. A complete discussion of the research findings is contained in Appendix B, CA ISO Real-Time Voltage Security Assessment Summary Report.

The proposed algorithm was successfully implemented on the VSA platform and tested on the Humboldt and San Diego areas. The efficacy of using hyperplanes to approximate the voltage stability boundaries, as well as identifying the associated weak elements and the 'controllable' elements for these boundaries were corroborated.

The approximated voltage stability boundary was compared to results obtained from the GE PSLF program which is commonly used in the Western Interconnection. The results of the comparison of the approximated voltage stability boundary to the results obtained from the GE PSLF program were within a few percent of each other. The main contributing factor to these discrepancies was the CA ISO state estimator model, which had deficiencies that required manual modifications to get it to solve. The GE PSLF handles such scenarios differently, and these differences show up in the stability boundary calculations. The project team expects that, with improvements to the CA ISO state estimator model, these differences will disappear.

A first prototype was developed and tested. Among other features, it incorporated a contingency ranking feature that had been previously requested by CA ISO, the continuation power flow algorithm as recommended by the academic experts, and the hyperplane concept. The release was preceded by factory testing, and presentation of results to CA ISO.

The VSA prototype functional specifications (Appendix C) included:

- Expansion of VAR Management application to include contingency simulation and ranking capabilities.
- Calculation of sensitivity factors of the security margin with respect to dispatchable and non-dispatchable parameters in order to determine the reasons for potential instability and to identify the best actions to increase the security margin.
- Findings from the analysis of algorithms for assessing voltage security margins.
- Findings from the analysis of algorithms for weak elements calculation.
- Execution results from field test of prototype voltage security software.
- Displays of the most limiting overloads and voltage deviations restricting the current and future operating conditions.
- Remedial actions pre-calculated for the worst contingencies in order to effectively support the real-time dispatcher's need to respond quickly to dangerous contingencies once they occur.

Our research suggests that while the continuation method worked well in reaching the proximity of the collapse point in a particular stressing direction, several iterations of the algorithm and associated step-halving within the vicinity of the point-of-collapse were required to obtain the functions needed to extract accurate information about the hyperplane boundaries, weak elements and control elements.

The project team discovered the advantage of applying the direct method at this point is that it is a one step approach of finding the collapse point within a predefined tolerance, and therefore overcomes accuracy limitation in the continuation method. Once having accurately reached a point on the stability boundary, it is also theoretically feasible to apply the underlying continuation method framework to the direct method equations (as apposed to the powerflow equations as in the traditional continuation powerflow) and systematically trace the voltage stability boundary (i.e. Boundary Orbiting Method). This adaptation is believed to further reduce the computational time because there is no longer a need to return back to the operating point and move in a different stress direction to find a second point on the stability boundary. These enhancements will be incorporated into the VSA platform and this overall hybrid algorithmic approach will be validated under the follow-on contract.

Additionally, the efficacy of using hyperplanes (i.e., linear planes defined in multidimensional space) to approximate the voltage stability boundaries as well as identifying the controllable elements in the space of power injections was corroborated. In particular, the project team demonstrated that the attributes of hyperplanes (i.e. coefficients of the hyperplane) can be interpreted as the parametric sensitivities of the margin to power injections and therefore are particularly useful in ranking the most appropriate corrective actions to steer away from the stability boundary. Similarly, the participation factors at the various buses in the voltage collapse also fall out of the proposed methodology and aid in identifying the various weak areas with the worst degradation in voltages during a voltage collapse situation.

In summary, the validation process confirmed that: 1) these hyperplanes, or piecewise linear approximations, can be extracted from the solution at the point of collapse in a particular stressing direction, 2) using piecewise linear approximations for the stability boundary are in fact appropriate, 3) the properties of these boundaries (e.g. the orientation of the hyperplanes) also offered valuable information on the 'control' elements which represent the optimal points in the system for corrective action to steer away from a dangerous condition, or the weak elements which are the areas where the impact of the voltage collapse phenomenon is the most severe. The findings also suggested that the continuum power flow algorithm on its own lacked the accuracy and speed required for a real time security assessment tool, and a hybrid approach, wherein the continuum power flow algorithm augmented with direct methods, could meet these performance requirements.

1.5 Conclusions and Recommendations

1.5.1 Conclusions

The project team concluded that the continuation powerflow had limitations. It was not able to achieve the execution speed and accuracy required from a real time voltage security assessment tool to provide the level of detailed information required by CA ISO. However, the project team established that a hybrid approach, wherein the continuation powerflow is augmented by other algorithms such as the direct method, which are more suitable for calculating these margins near the voltage collapse point, could meet the desired performance requirements for a real time tool.

1.5.2 Recommendations

The project team recommends additional work to enhance the functionality of the VSA Real-Time tool by conducting RD&D on algorithms, such as the direct methods, which have the potential to overcome the limitations of the continuation powerflow, validating these methods on the CA ISO system, and finally providing a functional specification for a production-quality VSA tool to CA ISO.

This additional functionality and the projection quality functional specifications are being developed under the subsequent Work Authorization, Contract #500−02−004, MR−041, RTSO 2006–2007.

1.5.3 Benefits to California

The benefit to California is the enhanced reliability of the CA ISO and interconnected Western Interconnection by providing reliability coordinators and control area operators at CA ISO, California's major utilities, and Bonneville Power Administration (BPA) with the latest technology in VAR management tools. Most of the voltage security assessment tools that are currently available commercially are well-suited for the planning environment, where they are used in an offline mode to conduct studies and define safe operating regions and margins (or nomograms). However, these nomograms, which are utilized to operate the grid in real time, tend to be conservative in order to accommodate unforeseen uncertainties, worst case conditions, and any discrepancies between the real time operating conditions and those used in the offline planning studies. Therefore, the ability to dynamically adjust the voltage security regions to changing system conditions, and compute margins in real time that accurately reflect the true system conditions, will have the following benefits to CA ISO and the California utilities:

- CA ISO will immediately benefit from increased reliability;
- Improved voltage monitoring may also improve the accuracy of locational marginal pricing (LMP) calculations that will accompany the roll-out of CA ISO's Market Redesign Technology Update (MRTU) initiative. MRTU will address problems in California's electricity markets that contributed to the market disruptions experienced in 2000 and 2001, and translate into better management, potentially at lower cost, of congestion on the CA ISO system. It builds on three foundational designs – a full

network model of the electricity grid, an integrated day ahead forward market and LMP. The LMP is the result of the integrated forward market which provides nodal prices so that all market participants know the cost of generating power, serving load and resolving congestion at each location on the system. LMPs reflect physical constraints under all load and system conditions and offer better economic measures and signals with which to manage the system. These pricing patterns also indicate where additional generation and transmission upgrades are needed in the future; and

- A successful demonstration at the CA ISO will likely accelerate market acceptance of this and similar operating tools by the industry, leading to a promulgation of these first two benefits to other regions of the country.

2.0 Task 3.0: Real-Time Applications of Phasors for Monitoring, Alarming and Control

2.1 Executive Summary

Electric industry restructuring in California has led to the formation of larger control areas with correspondingly larger areas of reliability oversight, as well as increased energy transactions over long, region-wide transmission paths. These developments have introduced greater uncertainty into real-time grid operations, which, in turn, has led to the need for better real-time information on actual conditions that can supplement traditional operating guidelines based on off-line studies. Currently, control areas depend on static nomograms produced from off-line simulations conducted several months in advance of the operating season to manage power flows on critical transmission paths. Because actual operating conditions may differ significantly from those assumed in preparing the off-line simulations, the California Independent System Operator (CA ISO) system may be operated (unknowingly) without adequate reliability margins. This project is the second phase of a multi-year program of research in which CERTS is conducting research on and developing prototypes for real-time applications of phasors for monitoring, alarming and control to accelerate the adoption and foster greater use of new, more accurate, time-synchronized phasor measurements by CA ISO reliability coordinators and control area operators, as well as by California and WECC utility transmission dispatchers. The project significantly leverages companion efforts, also managed by CERTS for the U.S. Department of Energy (DOE), to promote the use of phasor measurements nationally. For this project, version 3 of the CERTS Real-Time Dynamics Monitoring System (RTDMS) was developed and delivered for testing and feedback from the CA ISO. Version 3 includes real-time alarming and event detection, and event archiving and playback. In addition, training on the use of the tool was provided along with a user guide. Version 3 incorporated visualization concepts that were developed initially under DOE funding for the prototype RTDMS that has been released for evaluation by reliability coordinators in the Eastern Interconnection. Ultimately, research in this area will lead to the development of functional specifications for a production quality system that would be acquired by CA ISO and other entities with operating reliability responsibilities in the Western Interconnection.

2.2 Introduction

Electric industry restructuring in California has led to the formation of larger control areas with correspondingly larger areas of reliability oversight, as well as increased energy transactions over long, region-wide transmission paths. These developments have introduced greater uncertainty into real-time grid operations, which, in turn, has led to the need for better real-time information on actual conditions that can supplement traditional operating guidelines based on off-line studies. Currently, control areas depend on static nomograms produced from off-line simulations conducted several months in advance of the operating season to manage power flows on critical transmission paths. Because actual operating conditions may differ significantly from those assumed in preparing the off-line simulations, the CA ISO system may be operated (unknowingly) without adequate reliability margins. CERTS is conducting research on real-time applications of phasors for monitoring, alarming and control to accelerate the adoption and foster greater use of new, more accurate, time-synchronized phasor measurements by CA ISO reliability coordinators and control area operators, as well as by California and WECC utility transmission dispatchers.

Applications based on phasor measurements will provide the real-time operating staff with the previously unavailable, yet greatly needed, tools to avoid voltage and dynamic instability, and monitor generator response to abnormal significant system frequency excursions. Perhaps of equal or greater importance, in the near term, the measurement infrastructure will provide CA ISO with an alternate, independent real-time monitoring system that could act as an end-of-line backup for failures affecting CA ISO's current Supervisory Control and Data Acquisition/Energy Management System (SCADA/EMS). In the long term, the infrastructure is expected to become a key element of CA ISO's next generation monitoring system for advanced real time control.

- SCADA is a category of software application program for process control, the gathering of data in real time from remote locations in order to control equipment and conditions. SCADA systems include hardware and software components. The hardware (sensors) gathers and feeds data into a computer that has SCADA software installed. The computer then processes this data and presents it in a timely manner. SCADA also records and logs all events into a file stored on a hard disk or sends them to a printer. SCADA warns when conditions become hazardous by sounding alarms.

- EMS is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. The monitor and control functions are known as SCADA; the optimization packages are often referred to as "advanced applications."

This project is the second phase of an ongoing RD&D activity coordinated by CERTS for the Energy Commission's PIER Transmission Research Program. Earlier phases of this research were sponsored by PIER through a RD&D contract with LBNL (Contract #150−99−003) and through several task orders funded through the California Institute for Energy and Environment (BOA#20). Additional funding, through a separate subsequent work authorization, Contract #500−02−004: MR−041, has already been provided to continue the work initiated in this task (see Figure 2, Multi Year Research Roadmap for CA ISO Phasor Project).

2.2.1 Background and Overview

Currently, the CA ISO and other WECC control areas depend on static nomograms to manage power flows on critical transmission paths. These nomograms are produced from off-line simulations that are conducted several months in advance of the operating season. Because actual operating conditions may differ significantly from those assumed in preparing the off-line simulations and because the simulations, themselves, may be based on incorrect models (which is the topic addressed in Task 4.0), the CA ISO system may be operated (unknowingly) without adequate reliability margins.

Due to the long-distance nature of transmission in the west, there is a special need to ensure the dynamic stability of the grid. The information required to assess reliability margins in real-time must be: a) collected over a wide area; b) sampled at high frequency (30 times or more per second, compared to traditional monitoring at once every 4 seconds); and, most important of all, c) precisely time-stamped so that information collected from different locations can be synchronized with each other. Phasor measurement units are a leading example of the new generation of advanced measurement technology that has these capabilities. Currently, there is reasonable deployment of these units throughout the west; however, to date, they have only been used to support off-line applications, such as model validation and post-disturbance analysis.

The first research grade demonstration of phasor technologies was undertaken by Department of Energy (DOE), Electric Power Research Institute (EPRI), Bonneville Power Administration (BPA), and Western Area Power Administration (WAPA) in the early 1990s. The investment was paid in full when data recorded by the system was effectively used to investigate causes of the major 1996 west coast blackouts. DOE has continued to support outreach for these technologies and has provided technical support to the WECC committees that rely on these data for off-line and model validation reliability studies.

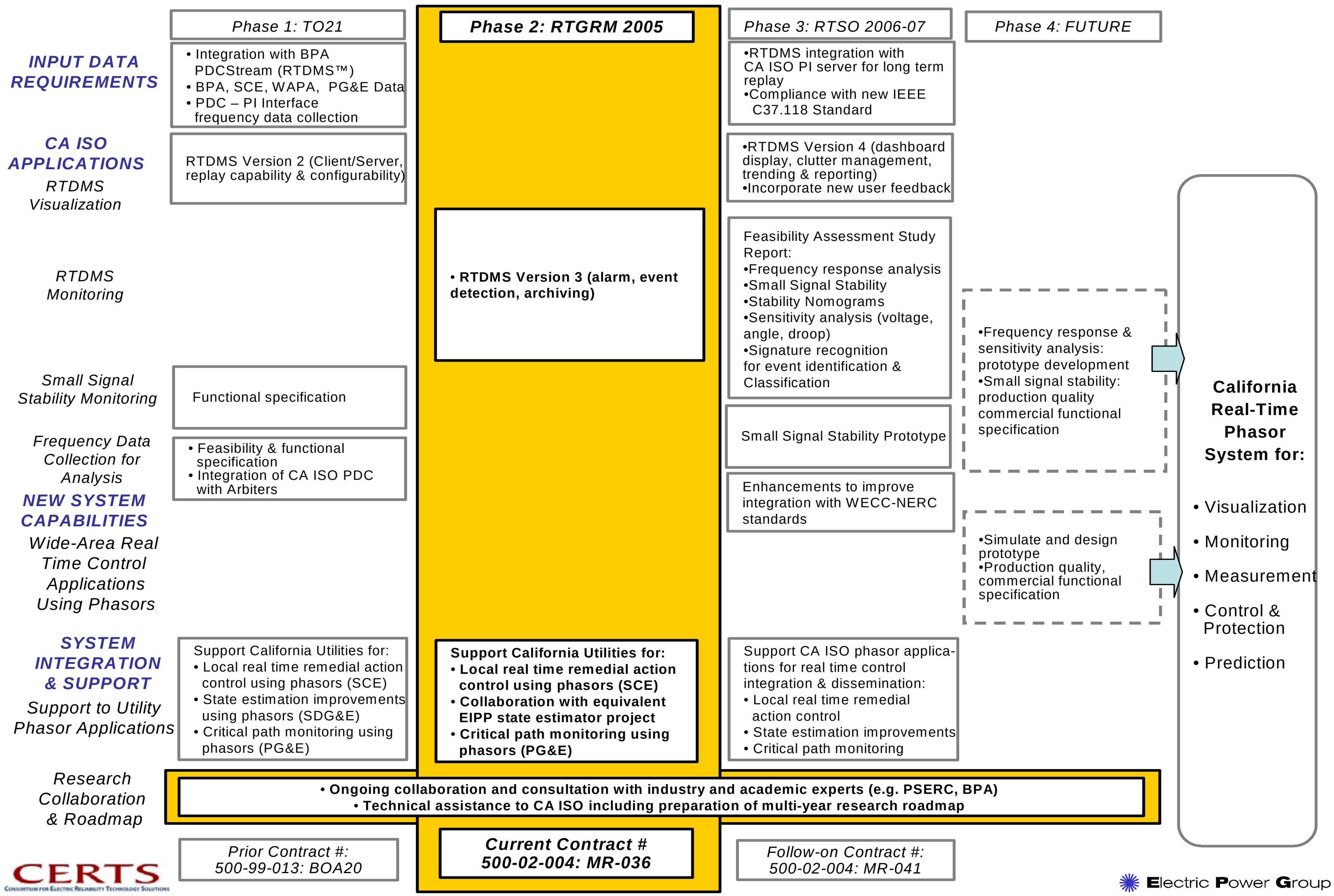

Figure 2. Task 3.0 Multi Year Research Roadmap for CA ISO Phasor Project

PIER, through CERTS, supported installation of an initial data connection and workstation to support offline analysis by CA ISO staff in 2002. In 2003 and 2004, PIER, through CERTS, supported the deployment of a real-time application, using phasor technology, to monitor actual grid conditions, a phasor-data link to BPA and WAPA for real-time data.

In July of 2004, the TRP Program Review Committee recommended that the Energy Commission and CA ISO continue the research, development and application of this technology including research to determine what phase angles and rates of change of phase angles are appropriate for various locations in system, what actions should be taken by operators or automatic control equipment, if there are major deviations, and the desired location for additional phasor monitoring equipment around the WECC. The proposed approach, developed in conjunction with CA ISO staff, represents a phased approach toward addressing these issues, centered around introducing phasor information to operators and working closely with them to modify and enhance the applications (including training) to increase their confidence in relying on this information to support their day-to-day activities.

During 2004 and 2005, the CERTS Real-Time Dynamics Monitoring System (RTDMS) phasor visualization prototype, which was initially developed as a stand-alone application, was transformed into a phasor technology development platform with the underlying functionalities to support a longer-term goal to use phasor technology for wide-area monitoring, alarming and control. In particular, the RTDMS platform now supports a server-client architecture with the central server responsible for data management functions (such as data acquisition, filtering and caching), and multiple client applications installed on different machines can simultaneously access data from the central server.

In July of 2005, CERTS worked with CA ISO in developing an RD&D Roadmap to guide the Phasor Applications technology research and development effort. Figure 2 is the Multi Year Research Roadmap for CA ISO Phasor Projects. It outlines the research and development plans by the various task activities that need attention, as well as through the various phases of the development cycle including research, development, demonstration, and technology transfer, and the intermediate milestones and deliverables. Potential applications include the use of phasor measurements for wide-area visibility, real-time monitoring and alarming, small-signal stability assessment, frequency data collection, nomogram validation and improvements, improved state estimation, and real-time control.

These applications will provide the operators with the previously unavailable, yet greatly needed, tools to avoid voltage and dynamic instability, and monitor generator response to abnormal significant system frequency excursions. Perhaps of equal or greater importance, in the near term, the measurement infrastructure will provide CA ISO with an alternate, independent real-time monitoring system that could act as an end-of-line backup for failures affecting CA ISO's current SCADA/EMS. In the long term, this infrastructure a key element of CA ISO's next generation monitoring system for advanced real time control.

The project significantly leverages companion efforts, also managed by CERTS for the U.S. Department of Energy (DOE), to promote the use of phasor measurements nationally. Starting in 2003, DOE has tasked CERTS to provide technical support to the industry-led development of a phasor-based measurement network in the Eastern Interconnection. CERTS has provided technical support for the creation of a phasor data concentrator hosted by Tennessee Valley Authority and developed a prototype platform and visualization application for evaluation by reliability coordinators in the east. The experience and concepts developed through these DOE-supported activities contributes directly to the research undertaken in this task.

2.2.2 Task Objectives

The overall technical objective is to accelerate the adoption and foster greater use of new, more accurate, time-synchronized phasor measurements by CA ISO reliability coordinators and control area operators as well as by California and WECC utility transmission dispatchers. The research required includes:

- Providing real-time operators with new tools that provide previously unavailable wide-area visibility and information on the dynamic stability of the grid;
- Designing the conceptual look of operator displays for phasor applications;
- Defining functional specifications such that, upon completion, the tools can be transferred to a vendor (selected by CA ISO) for implementation as a production-grade operating tools; and
- Providing technical support to and assist in coordinating phasor applications being researched and developed by CA utilities.

The objective of Task 3.0 in support of this overall technical objective is to develop and conduct the first-ever demonstration of the second of two prototype real-time software tools for CA ISO (Task 2.0 is to conduct parallel work on the first of these prototype tools).

Delivery of the RTDMS Version 3, the user guide, and CA ISO staff training is the principal evidence that this objective has been met.

2.3 Task Approach

The task approach involved research on the first phases of each of the four project tracks identified in Figure 2: a) input data requirements; b) CA ISO applications; c) new system capabilities, and d) system integration and support.

CERTS utilized and expanded the current WECC and CA ISO phasor infrastructure as the input data source for the real-time applications.

CERTS conducted a survey to reach out to experts in the field for their comments, suggestions, and recommendations on wide area security assessment. The survey was sent to 51 academic and power industry experts worldwide with sixteen responses received; eight of the respondents were from the power industry and eight from academia. The consensus from the joint CERTS-CA ISO survey (Appendix A. Summary of Survey Results on Methodologies for use in Real-Time Voltage Security Assessment) was that the use of phasor measurements for modal estimation to assess small signal stability was an ideal initial step towards achieving the CA ISO's objectives for wide area security assessment with phasors.

As a result of the survey, the project team began to collaborate with Bonneville Power Administration (BPA) and others to develop a small signal stability application on the RTDMS platform. The small signal stability application and the proposed visualization solution are being implemented on the RTDMS platform under Contract #500−02−004: MR−041.

The project team developed a phasor technology platform for research and prototyping new tools, called the Real-Time Dynamics Monitoring System (RTDMS). The project team developed RTDMS with a server-client architecture to accommodate the high data rates associated with phasor measurements. This is a system design where the data management (i.e. RTDMS Server) and the algorithmic and visualization components (i.e. RTDMS Clients) are separate and independent functions in order to ensure that the computational burden of algorithms does not affect real time data management and flow, and cause data loss. The server-client architecture also offers the flexibility of having a single central data server, and multiple monitoring clients which could then simultaneously access the same central server and present the corresponding results within their individual visualization displays.

CERTS also provided assistance and support to California utilities in their efforts to use phasor measurements for local remedial action control (SCE), state estimation improvement (SDG&E), and critical path monitoring (PG&E). CERTS provided technical assistance to CA ISO in preparing their multi-year research roadmap, which included activities such as WECC-EIPP collaboration and knowledge exchange, and collaboration with industry and academic experts.

Throughout this task, the work built upon both off-line analysis and research conducted by CA ISO staff, as well as feedback from operators on the usability and usefulness of the information provided by the network and the means developed to present it. These interactive processes continued in parallel directly with the delivery of specific functionalities and prototype displays.

2.4 Task Outcomes

CERTS produced task outcomes for each of the first phases of three of the four project tracks identified in Figure 2: a) input data requirements; b) CA ISO applications; c) new system capabilities, and d) system integration and support.

What follows in this sub-section is a summary of the task accomplishments and research findings. A complete discussion of the research findings is contained in Appendix D, CA ISO Phasor Applications Summary Report.

Initially the phasor network consisted of only 14 Phasor Measurement Units (PMUs) that gathered data at the sub-second resolution (30 samples/second) from two utilities and sent it in real time to CA ISO. Through this project, the network grew to 42 PMUs with expanded coverage including Western Area Power Administration (WAPA) and PG&E regions. Presently, CA ISO Phasor Data Concentrator (PDC) receives data from PMUs in geographically distributed locations via the WECC Wide Area Network (WAN) which connects utilities' PDCs with the PDC at CA ISO. PMUs feed into their corresponding PDCs, and this data is further transmitted in real-time to the CA ISO PDC. Figure 3 shows the current synchronized data communication network and proposed expansions.

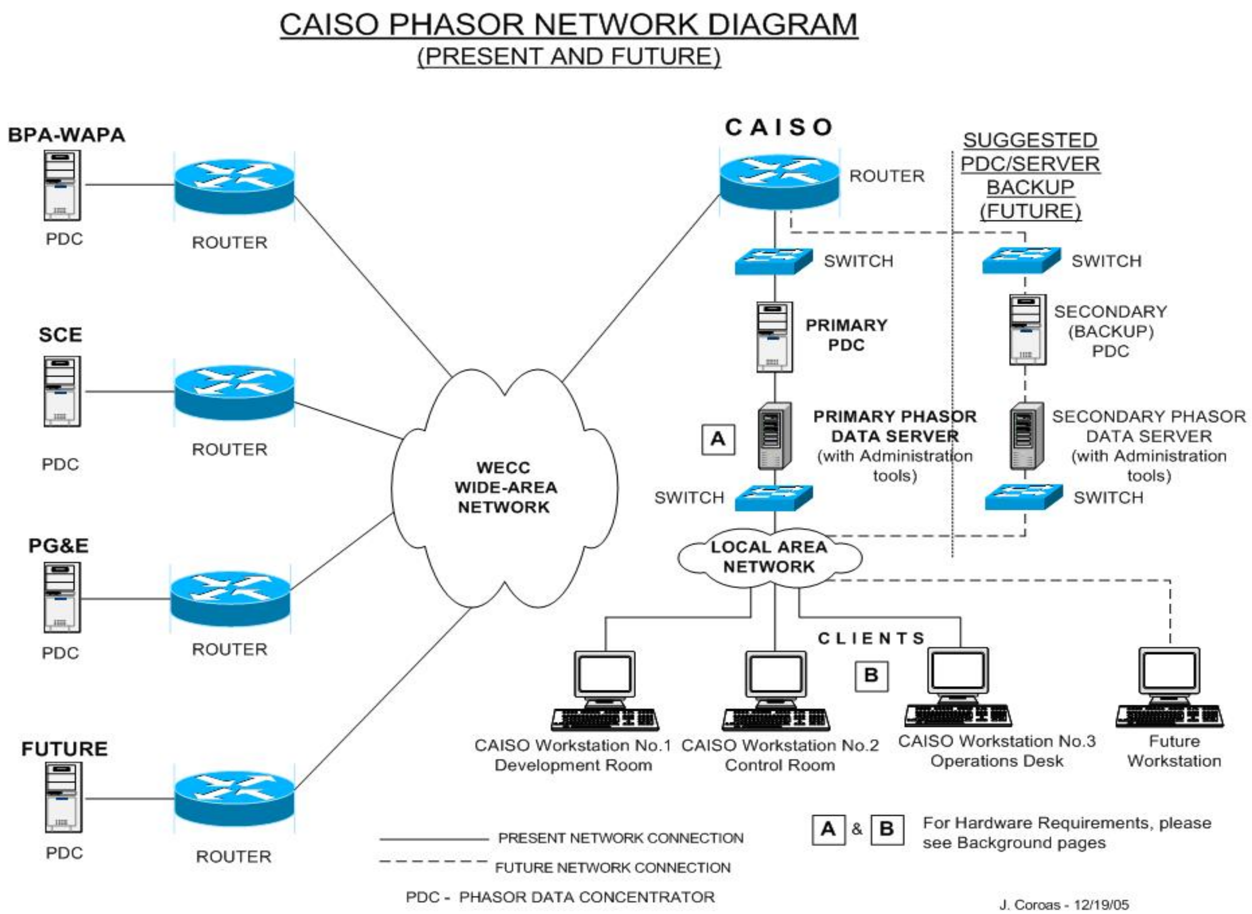

Figure 3: CA ISO Phasor Network Diagram

CERTS developed and delivered RTDMS version 3 to CA ISO operators and reliability coordinators as a stand-alone application for real time monitoring. Version 3 includes applications for real-time alarming and event detection, and event archiving and playback. CERTS also provided training to CA ISO staff (Appendix E) and a users guide (Appendix F).

The current RTDMS application, version 3, at CA ISO reads the collective set of phasor data output from the CA ISO PDC and displays it in real-time. This complete set of time-synchronized high-resolution data provides the desired wide-area visibility across the western interconnection required for security monitoring by dispatchers including dynamic performance assessment and post disturbance analysis. See Figure 3: CA ISO Phasor Network Diagram.

Another initial application that was developed on the RTDMS platform includes the collection and archiving of sub-second frequency data from PMUs to meet new North American Electric Reliability Council (NERC)-WECC Western Interconnection frequency data collection requirements.

The RTDMS platform and visualization application tool is undergoing active evaluation by CA ISO operations staff. Operational versions of the prototype are located at both the CA ISO control room and operations desk. See Figure 3. Feedback from staff has been incorporated into specifications for future prototype releases and new avenues of basic research that is enabled by the availability of phasor measurement data in real-time.

The consensus from the joint CERTS-CA ISO survey was that the use of phasor measurements for modal estimation to assess small signal stability was an ideal initial step towards achieving the CA ISO's objectives for wide area security assessment with phasors. As noted earlier, the project team began conducting collaborative research with BPA and others in the Northwest to explore this application. Our initial research in this project concludes that it is possible to characterize the stability of the power system in real time and under ambient system conditions with respect to the low frequency oscillations that exist in the system. As a result, the project team began work to develop an application to monitor small signal oscillations in real time, and alert operators when the system is experiencing poor damping. CERTS began developing visualization enhancements to deal with the rapid growth in the numbers of PMUs within the WECC phasor network and the associated clutter. The small signal stability application and the proposed visualization solution are being implemented on the RTDMS platform under Contract #500−02−004: MR−041, Real Time System Operations 2006−2007.

A wide-area research need that extended beyond the CA ISO, the use of phasor measurements for real-time wide-area control, was also addressed. As a first step towards achieving new system capabilities (see roadmap), the project team researched methods for utilizing phasor measurement to validate and possibly improve stability nomograms. This work is also continuing under Contract #500−02−004: MR−041, Real Time System Operations 2006−2007.

Figure 4 provides a conceptual overview of the system hardware and software architecture for RTDMS Version 3. The RTDMS platform now supports a server-client architecture with the central RTDMS server responsible for data management functions such as data acquisition, filtering, data processing and caching, and a thin client layer where multiple RTDMS client applications installed on different machines can simultaneously access data from the central server. By centralizing the data management process, this architecture minimizes the necessary performance requirements for all client machines, which translates to a reduction in hardware cost. Finally, any new client applications that are developed in the future will be able to connect to the common RTDMS server for data access and retrieval.

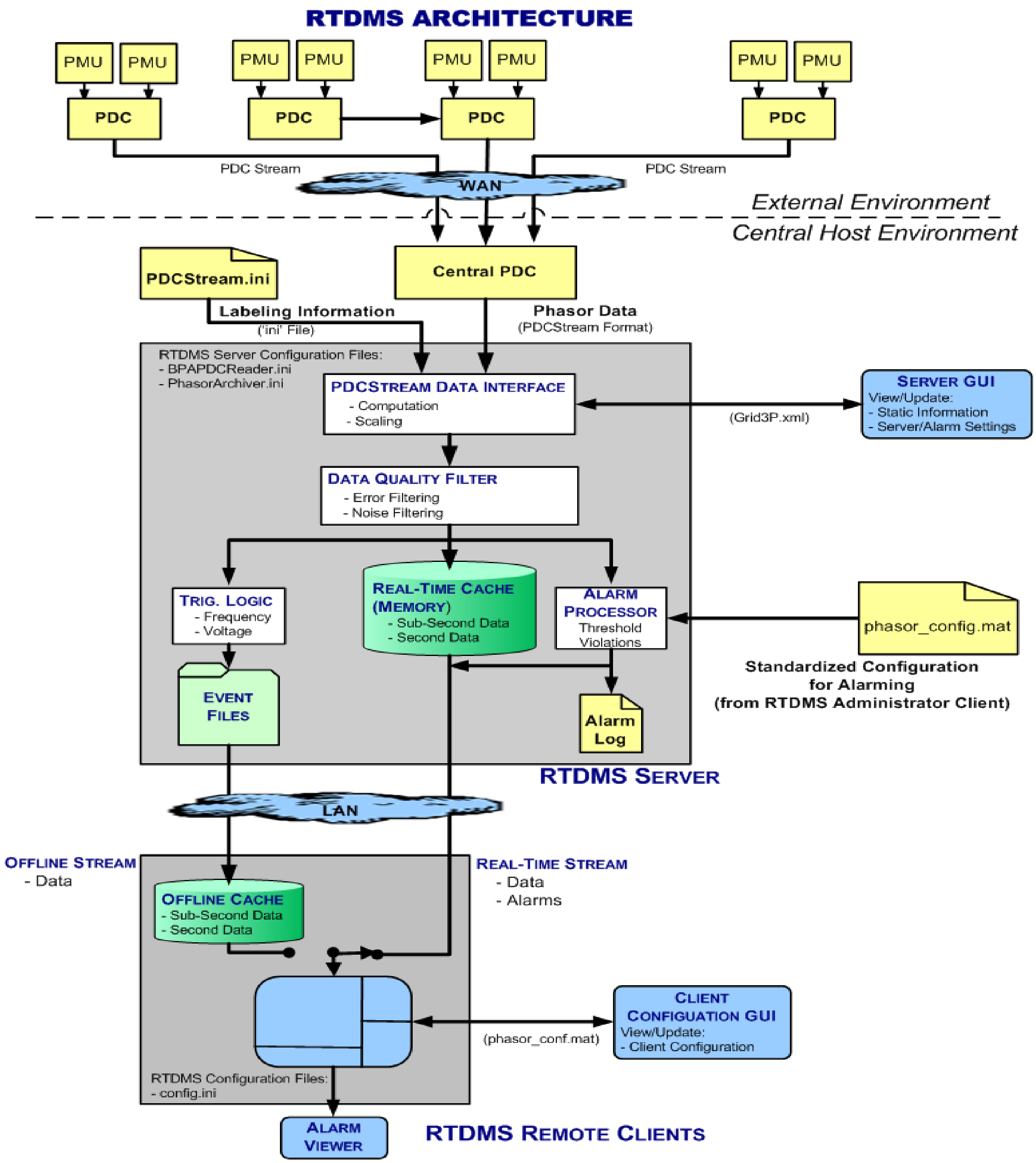

Figure 4: RTDMS Version 3 System Architecture

CERTS provided system integration and technical support and assisted as needed in coordinating phasor applications being researched and developed by CA utilities (e.g. local remedial action controls with phasors at SCE, state estimation using phasor measurements at SDG&E, and critical path monitoring by PG&E) as well as WECC-EIPP collaboration and knowledge exchange, and collaboration with industry and academic experts. CERTS prepared and delivered a PMU Measurement Unit Installation and Cost Estimates document to SDG&E, and have offered RTDMS to PG&E to meet their respective objectives.

2.5 Conclusions and Recommendations

2.5.1 Conclusions

The development and testing of a prototype RTDMS with CA ISO system operators has accelerated the adoption and use of time-synchronized phasor measurements for real-time applications in the Western Interconnection. Eventually, this wide-area, common view will allow operators to evaluate stability margins across critical transmission paths, detect potential system instability in real time, and, in the future, take manual or initiate automatic actions to mitigate or dampen these potential problems. It will also enable CA ISO, California and WECC utilities to explore closely related issues, such as use of phasor data to improve state estimation, to determine the optimal location of additional phasor measurements, and to gain the experience with the technology required to develop these advanced real-time control applications. Finally, it will facilitate technical exchange, collaboration, and resource leveraging with companion phasor measurement-based activities supported by the operating entities and DOE throughout North America.

2.5.2 Recommendations

CERTS recommend continued research and development of prototype applications that, ultimately, will provide the technical basis for preparation of functional specifications for a production-quality system that can be used by CA ISO to select a commercial vendor for the system. CERTS also recommend continued efforts through the WECC to expand and link phasor measurement units across the entire Western Interconnection.

Aspects of the additional RD&D required have already begun under Contract #500−02−004, MR−041, Real Time System Operations 2006–2007.

2.5.3 Benefits to California

The benefit to California is the enhanced reliability of the CA ISO and interconnected Western Interconnection by providing reliability coordinators and control area operators at CA ISO and California's major utilities with the latest advances in phasor measurement applications. Ultimately, system operators will be able to evaluate stability margins across critical transmission paths, detect potential system instability (pattern recognition) in real time, and then provide control signal(s) to devices or controls that will mitigate or dampen the instability. The wide-area, common view will also allow operators to detect unanticipated system limitations in real-time, even when the grid is operating within perceived safe portions of the existing operating nomograms. Thus, the system will serve a dual purpose to both improve transmission loadability from the point of view of transient stability and help operate the system within safe regions.

As a result, this research, ultimately, will have the following benefits for CA ISO and the California utilities:

- CA ISO will immediately benefit from increased reliability;
- Improved voltage monitoring may also improve the accuracy of locational marginal pricing (LMP) calculations that will accompany the roll-out of CA ISO's Market

Redesign Technology Update (MRTU) initiative. MRTU will address problems in California's electricity markets that contributed to the market disruptions experienced in 2000 and 2001, and translate into better management, potentially at lower cost, of congestion on the CA ISO system. MRTU builds on three foundational designs – a full network model of the electricity grid, an integrated day ahead forward market and LMP. The LMP is the result of the integrated forward market which provides nodal prices so that all market participants know the cost of generating power, serving load and resolving congestion at each location on the system. LMPs reflect physical constraints under all load and system conditions and offer better economic measures and signals with which to manage the system. These pricing patterns also indicate where additional generation and transmission upgrades are needed in the future; and

- A successful demonstration at the CA ISO will likely accelerate market acceptance of this and similar operating tools by the industry, leading to a promulgation of these first two benefits to other regions of the country.

3.0 Task 4.0: Improving Dynamic Load and Generator Response Performance Tools

3.1 Executive Summary

Secure operation of the electric grid relies on planning studies, conducted off-line, typically months in advance, that consider whether the grid is capable of withstanding credible contingencies (such as the unplanned loss of major generating plants or transmission inter-ties). These anticipatory (or what if) studies are used to establish operating limits for secure operation following criteria established by North American Electric Reliability Council (NERC) and Western Electricity Coordinating Council (WECC). The dynamic load models currently relied on to prepare these studies are known to be inadequate. They were first developed over 20 years ago and have rarely been updated to capture the dramatic changes that have taken place in the underlying composition of load (for example, increased saturation of power electronic devices, induction motors, etc). Similarly, dynamic models for governor frequency response control, until recently, have not kept pace with industry changes. Blackout risks, exacerbated by inaccurate models, were clearly illustrated in the August 10, 1996 blackout, when simulations, using these models, were unable to replicate blackout events. Recent disturbances in Southern California displaying delayed voltage recovery, and lightly damped oscillations on the California-Oregon Intertie are not captured by simulations using current models. This project prepared a scoping study to identify the research required to improve dynamic load and generator response models. The study was based on literature reviews of current state-of-the-art load modeling, active participation in the WECC Load Modeling Task Force, and discussions with leading researchers and practitioners. The project has already led to formal sponsorship by WECC of a follow-on, cost-shared PIER project to conduct research on the highest priorities identified in the scoping study.

3.2 Introduction

Secure operation of the electric grid relies on planning studies, conducted off-line, typically months in advance, that consider whether the grid is capable of withstanding credible contingencies (such as the unplanned loss of major generating plants or transmission inter-ties). These anticipatory (or what if) studies are used to establish operating limits for secure operation following criteria established by NERC and WECC. The dynamic load models currently relied on to prepare these studies are known to be inadequate. They were first developed over 20 years ago and have rarely been updated to capture the dramatic changes that have taken place in the underlying composition of load (for example, increased saturation of power electronic devices, induction motors, etc). Similarly, dynamic models for governor frequency response control, until recently, have not kept pace with industry changes. Blackout risks, exacerbated by inaccurate models, were clearly illustrated in the August 10, 1996 blackout, when simulations, using these models, were unable to replicate blackout events.

This project is the first phase of an ongoing RD&D activity coordinated by CERTS for the Energy Commission's PIER TRP. The purpose of this initial phase is to prepare a scoping study that identifies needed research to improve these dynamic models. The research identified in this scoping study is being conducted through a separate TRP contract #500−02−004: MR−049, WECC Load Modeling Research Project.

3.2.1 Background and Overview

To study transient events, such as the sudden, unplanned loss of a major transmission line or generator, dynamic computer simulation models are used to predict the response of the grid in the first few cycles and seconds following an event. CA ISO and others have reported that these simulations are inaccurate and, sometimes, do not adequately predict the actual, observed response of the system to events, especially when the grid is under stressed conditions. A comparison of observed voltage and frequency transients to simulated responses suggests that there are inaccuracies both in load models and in generation plant control models used in these simulations.

The load models in use today were first developed over 20 years ago and have rarely been updated to capture the dramatic changes that have taken place in the underlying composition of load (for example, increased saturation of power electronic devices, induction motors, etc.). Moreover, the forms of the load models that are used are unrealistic because they are based on the estimated composition of loads during the summer peak period, while they are also used for studies of other time periods (such as other seasons and other times of day).

Similarly, until recently, the models for governor frequency response control have not kept pace with changes in the industry. CA ISO staff have noted decreased frequency response after large outages, and NERC has documented a persistent decline in frequency response in both the Eastern and Western Interconnections. As a result of restructuring, the actual settings on generator controls are not as well-known as they used to be by the transmission system operators because different firms now operate the generators. Previously, the same firm operated both the transmission system and the majority of generators, so information sharing on settings was easier. Newer generation technologies, especially, have plant controls that are believed to override the automatic governor controls on the generators. Yet, transmission operators have traditionally assumed that these controls are operating in order to ensure system reliability. Better information is required on the actual settings for these controls, as well as on the plant control systems than may override them. Recent WECC modeling work has resulted in new plant control models that should improve the simulations of plant response.

3.2.2 Task Objectives

The overall technical objective is to conduct research that will improve the accuracy of the dynamic models used in WECC to set reliability limits, retrospectively evaluate significant disturbances, and conduct additional planning studies.

Incorporation of research results into the models used by WECC to conduct these studies is the principal measure of success for this program of research.

The specific technical objective of Task 4.0 is to prepare a scoping study that identifies and prioritizes the research activities needed to improve the performance of computer-simulation models.

Follow-on work, which has been awarded through a separate TRP contract #500−02−004: MR−049, WECC Load Modeling Research Project, to conduct the research identified in this scoping study, is the principal measure of success for this project.

3.3 Task Approach

The task approach involved gathering information through literature reviews of current state-of-the-art load modeling, phone and electronic consultations with experts, and active participation in meetings of the WECC Load Modeling Task Force (LMTF).

The draft report of research findings and recommendations was submitted for review to a panel of seasoned and knowledgeable industry experts, including: Bob Cummings (NERC), Dimitry Kosterev (BPA), Irina Green (CA ISO), Anatoliy Meklin (PG&E), Gary Chinn (SCE), Abraham Ellis (PNM), Henry Huang (PNNL), Donald Davies (WECC), David Hawkins (CA ISO); and Baj Agrawal (APS). In addition, presentations were made to the WECC LMTF, CA ISO, PIER and TRP.

A final report, Improving Dynamic Load and Generator Response Performance Tools, that responds to these reviewers was prepared and submitted to TRP/PIER/CIEE. (Appendix G. Scoping Study Report on Improving Load and Generator Response Models.)

3.4 Task Outcomes

The literature reviews and interviews with staff in the West, documented the need for improved load generator governor modeling. CERTS paid special attention to WECC modeling activities, including the work of both the Model Validation Working Group and the Load Modeling Task Force. As a result, the project team learned that WECC research had neared completion of a project to improve models for generator governor controls, but that more work is required in the area of dynamic load modeling. Accordingly, the project team focused our efforts on RD&D needs to improve dynamic load models.

The project team developed 16 recommendations to improve dynamic load models. See Table 1. The recommendations are grouped into three general areas (Policy, Load Modeling, Measurement and Validation, etc.), by level of effort, including time required, the need for/role of PIER support, and our assessment of the overall significance of each recommendation with respect to the others.

As part of the review process for the scoping study, the project team vetted its recommendations with the aforementioned WECC Working Group and Task Force. They were well-received. While the scoping study was in its final stages of development, the WECC Load Modeling Task Force sponsored a research project to implement the highest priority recommendations from the scoping study. The study is being cost-shared by industry participants and PIER.

Table 1: Summary of Research Recommendations

Recommendation	Level of Effort	Time Required	PIER Support	Significan-ce
Load Model Development and Policies				
Develop seasonal models.	Low	1-year	Low	Moderate
Validate with state estimator models.	Low	1-year	Low	Moderate
Review reliability criteria.	Low	Multi-year	Low	High
Load Modeling				
Study motor mechanical load characteristics and impact.	Moderate	1-year	Moderate	High
Study impact of single-phase and three-phase motors.	Moderate	1-year	High	High
Model motor load shedding and Low-voltage conditions.	Moderate	1-year	Moderate	Low
Improve Low-voltage protection.	Low	1-year	Low	High
Measurement and Validation				
$10K load monitor	Low	1-year	Low	High
Scoping study: research needs for automatic validation and dynamic state estimation.	Moderate	1-year	Moderate	Moderate
Load Monitoring				
Estimate load composition from measurements.	High	Multi-year	High	High
Characterize model uncertainties using measurements.	Moderate	Multi-year	High	High
Use harmonic information in measurements to enhance load composition estimates.	Moderate	Multi-year	High	unknown
Measurement-Only (Black Box) Models				
FolLow research activities in this area.	Low	Multi-year	Low	Low
Uncertainty Analysis				
Develop methods to assess the impact of load model uncertainties on system studies.	High	Multi-year	High	High
Generator Governor Models				
Support WECC activities to implement best model and maintain data for generator characteristics.	Low	Multi-year	Low	High
Develop tools to monitor individual generator frequency response.	High	Multi-year	High	Moderate

3.5 Conclusions and Recommendations

3.5.1 Conclusions

CERTS corroborated industry sentiment that dynamic load models are the least accurate of all of the components in current dynamic system models. CERTS also develop support for the contention that air conditioner models, as a prominent class of dynamic load models, represent the most important area for improvements.

Alarmingly, evidence suggests that generator response to disturbances has been steadily decreasing. Studies conducted using traditional dynamic models do not reproduce these findings. A recent WECC project, however, has already produced an improved model that better represents actual generator governor behavior. Hence, additional, fundamental research is not required, as these efforts are already well-underway. Nevertheless, maintenance of the databases of generator characteristics remains important. In the future, there may be a need for tools to monitor generator frequency response, which is not a modeling issue, per se.

3.5.2 Recommendations

As noted in Table 1, above, the project team makes 16 recommendations to improve dynamic load models (Appendix G. pages 16−41). The recommendations are by general area (Policy, Load Modeling, Measurement and Validation, etc.), level of effort, time required, need for PIER support, and significance. CERTS recommend pursuit of research on these topics in a follow-on project.

CERTS also strongly recommend that this program of research be conducted in close collaboration with and, ideally, with support from the WECC Load Modeling Task Force. WECC already has a standing committee structure whose sole purpose is to review these models and seek to improve them as needed. Working directly with WECC is essential for ensuring that the results of this research can be implemented readily.

Note: based on the results of this task, a formal load modeling research program has been approved by the PIER TRP under Contract #500−02−004: MR−049, WECC Load Modeling Research Project.

3.5.3 Benefits to California

California will benefit from improved dynamic models in several ways. First, improved models and a better understanding of the likely impacts of remaining uncertainties in these models will increase the reliability of grid operations by allowing operators to more accurately study system voltage problems and the dynamic stability response of the system to disturbances.

Second, improved models will increase operator confidence in operational limits and operator controls. Secure operation of the grid is maintained through planning for credible contingencies, including the specification of path ratings and the deployment of remedial action schemes. Improved models may identify the need to curb optimistic ratings or may allow increases for overly conservative ratings. In either case, confidence in grid security will increase. Confidence for operator actions will also increase with the ability to accurately predict system responses to events and actions.

Third, in the longer-term, improved models will benefit the decision process for capital investments, which must account for how operational limits value the benefit of a proposed resource. For example, load modeling studies will lead to better informed investments in components for remedial action schemes. Similarly since the models are used to set operational path ratings, they will impact decisions for transmission and generation investment.

References

Electric Power Research Institute and PNM. 2002. *Advanced Load Modeling*. TR-1007318. Palo Alto, CA: September.

LaCommare, K. H., and J. H. Eto. 2006. "Understanding the Cost of Power Interruptions to U.S. Electricity Customers." *Energy: The International Journal*, 31 (12), 1509-1519.

U.S.-Canada Power System Outage Task Force. 2004. Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations. April. 238 pages.

Glossary

Acronym	Definition
APS	Arizona Public Service
BPA	Bonneville Power Administration
CA ISO	California Independent System Operator
CERTS	Consortium for Electric Reliability Technology Solutions
CIEE	California Institute for Energy and Environment
DOE	Department of Energy
EIPP	Eastern Interconnection Phasor Project
EMS	Energy Management System
EPG	Electric Power Group
EPRI	Electric Power Research Institute
LBNL	Lawrence Berkeley National Laboratory
LMP	Locational Marginal Pricing
LMTF	Load Modeling Task Force
MRTU	Market Redesign and Technology Update
NERC	North American Electric Reliability Council
PDC	Phasor Data Concentrator
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research
PMUs	Phasor Measurement Units
PNM	Public Service Company of New Mexico
PNNL	Pacific Northwest National Laboratory
PSE	Puget Sound Energy
PSERC	Power Systems Engineering Research Center
PSLF	Positive Sequence Load Flow
RD&D	Research Development & Demonstration
RTDMS	Real Time Dynamics Monitoring System
RTSO	Real Time System Operations
SCADA/EMS	Supervisory Control and Data Acquisition/Energy Management System
SCE	Southern California Edison

SDG&E	San Diego Gas and Electric
TAC	Technical Advisory Committee
TRP	Transmission Research Program
VAR	Volt-Ampere Reactive
VSA	Voltage Security Assessment
WAN	Wide Area Network
WAPA	Western Area Power Administration
WECC	Western Electricity Coordinating Council

Appendix A
Task 2.0 CA ISO Real Time Voltage Security Assessment (VSA) Project: Summary of Survey Results on Methodologies for use in Real-Time Voltage Security Assessment

Appendix B
Deliverable Task 2.0 CA ISO Real-Time Voltage Security Assessment Summary Report

Appendix C
Deliverable Task 2.0 CA ISO Voltage Security Assessment (VSA) Prototype Functional Specifications/Prototype Development

Appendix D
Task 3.0 CA ISO Phasor Applications Summary Report

Appendix E
Task 3.0 Prototype Phasor-Based Real-Time Monitoring Software Tool – Training Presentation

Appendix F
Task 3.0 Prototype Phasor-Based Real-Time Monitoring Software Tool – Users Guide

Appendix G
Deliverable Task 4.0 Scoping Study Report on Improving Load and Generator Response Models