Western Electricity Coordinating Council

WECC SYNCHRO-PHASOR PROJECT WHITEPAPER

Proposed Scope

Version 3.0

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VERSION	DATE	AUTHOR	CHANGE DESCRIPTION
0.5	Jun 10, 2009	VanZandt	Initial Draft.
0.6	Jun 15, 2009	VanZandt	Additional details on proposed applications. Distinction between deployment proposals and demonstration proposals made.
0.7	Jun 24, 2009	VanZandt	Editorial clean-up.
0.9	Jun 29, 2009	S-P Team Edits, Ashbaker, VanZandt	Recognizes final FOAs for demonstration and investments. Shifts application to a single project under FOA-0000058 as synchro-phasors are featured there. Clarification of applications, NASPInet connection, movement of process management from an objective to a means to achieve infrastructure and application objectives.
1.0	July 10,2009	S-P Team Edits, Parashar, Kosterev, VanZandt	Clarifies tasks, fills in missing information, identifies NASPInet Class Service Levels, adds project timeline and preliminary costs and FOA references in appendices.
1.1	7-13-09	Bob Applegate	Editing for readability. Formatting consistency. Proofreading.

VERSION	DATE	AUTHOR	CHANGE DESCRIPTION
2.0	7-14-09	Davies/VanZandt Kosterev/S-P Team Edits	Added PMU locations for wind and other major generating sites, Added appendix with existing and desired PMU/PDC locations. Application Cost Estimate Updates.
		Budhraja	Match Project Plan to Task Descriptions, separate real-time from off-line applications' cost projections.
3.0	7-15-09	Mittelstadt/Kosterev	Added Equilibrium State Control application.

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Synchro-Phasor Investment Program

Executive Summary

On June 25, 2009, the US Department of Energy issued Funding Opportunity Announcement 0000058 to facilitate investment in “Smart Grid” technologies. Smart Grid capabilities are designed to enhance grid reliability, increase the transmission system’s ability to withstand disturbances, and integrate a fleet of regional renewable resources. This technology will be a cornerstone of the US Department of Energy’s (DOE) efforts to carry out the American Recovery and Reinvestment Act of 2009.

The staff of the Western Electricity Coordinating Council (WECC) is actively working with both public and private partners to submit a grant application in the sum of approximately $100 million. Proposals are due on August 6, 2009. Projects will be awarded by September 30, 2009 and provide for a three-year period of performance.

WECC’s application will call for investment in Phasor Measurement Unit technology. A Phasor Measurement Unit (PMU) measures the electrical waves on an electricity grid to determine the health of the system. PMUs that are time-synchronized are commonly referred to as synchro-phasors.

The value of the existing Synchro-Phasor Network – some of which is more than 30 years old – has been to time-synchronize power system disturbance data that can then be analyzed to improve generator, transmission, and load modeling and to understand abnormal power system behavior in the stability-limited Western Interconnection. Historically, power system oscillations have been detected and analyzed off-line, leading to better understanding of power system dynamics and modest improvements in operational standing orders and transfer path operating limits.

The Synchro-Phasor Project would install new and upgrade older PMUs; creating the communications system necessary to collect the data into a new system of data concentrators needed to deliver interconnection-wide networking and the applications to help manage the operation of the interconnection. Such a system would:

- Create a more reliable transmission system
- Help integrate renewable resources (which have intermittent output characteristics)
- Improve the operator’s situational awareness of the status and vulnerabilities of the system in real-time
- Develop and implement real-time controls
- Provide for better understanding and modeling of the power system’s dynamic nature
- Unlock latent capacity in the existing transmission system

Specifically, the Synchro-Phasor Project will address three objectives:

1. Infrastructure improvement and network expansion for full WECC interconnection coverage and data management (collection, archiving, and inter-utility exchange) to promote reliable and economic grid operations.

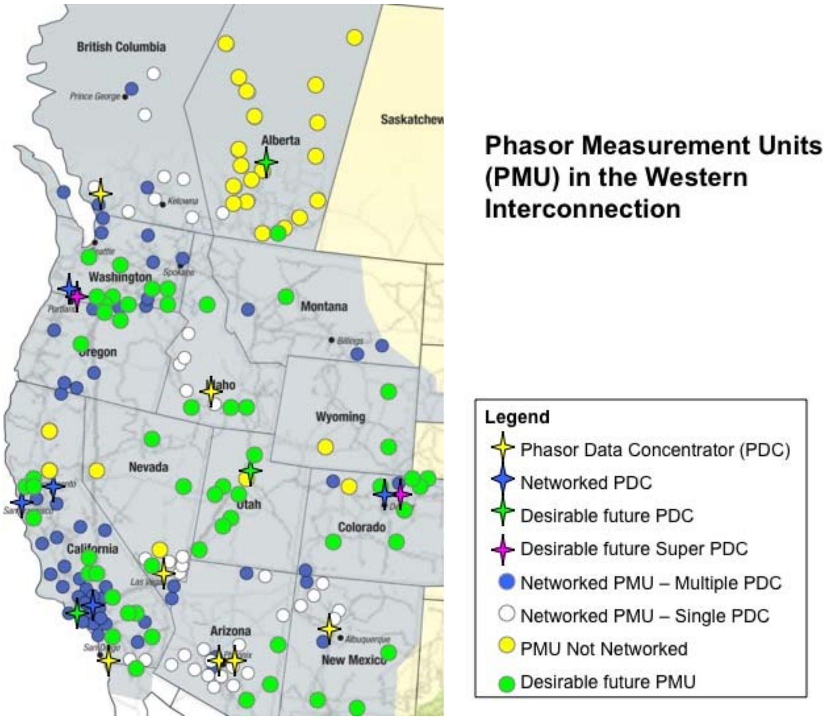
2. Development, implementation, and testing of real-time synchro-phasor applications for situational awareness and wide-area controls.

3. Development of off-line applications and analysis for model validation and system performance and event analysis.

WECC is working with the following potential partners: Southern California Edison, The Bonneville Power Administration, Pacific Gas & Electric, the California Independent System Operator, the California Energy Commission, Areva, Quanta, Salt River Project, PacifiCorp, and Idaho Power Company.

WECC believes the promise of synchro-phasor technology is huge, the opportunity immense. It is time to take a significant leap forward in developing the myriad uses of this technology and stand on the shoulders of the research and demonstration of the utility, government and academic visionaries over the past 30 years to implement a better, more flexible, and more resilient grid.

The following map depicts the existing and proposed synchro-phasor infrastructure:



Section 1: History and Background

The American Recovery and Reinvestment Act of 2009 (ARRA) goals are to stimulate the economy, and to create and retain jobs. A robust and sustainable energy structure is key to these goals. Smart Grid capabilities designed to enhance grid reliability and increase the transmission system's ability to withstand disturbances and integrate a fleet of regional renewable resources will be a cornerstone of the US Department of Energy's (DOE) efforts to carry out the ARRA.

The DOE has issued Funding Opportunity Announcement (DE-FOA-000058) in final form. The DOE will evaluate proposals and select the entities that will receive funding to perform Smart Grid investments within the interconnections. WECC intends to apply for this funding to further its pursuit of synchro-phasor infrastructure and applications in the west. This project proposes installing phasor measurement units (PMU), collecting the data from individual systems or utility/RTO phasor data concentrators (PDC), and putting that data into super phasor data concentrators (Super PDC) to deliver interconnection-wide networking, situational awareness, event analysis, model validation, and real-time controls on a wide-area basis. This West-wide project will significantly further the pursuit of a reliable and economic power delivery system in the Western United States with the capability to integrate an increasingly renewable generation fleet.

The Western Interconnection has a long history of using synchro-phasor technology to understand the behavior of the Western power system, especially under abnormal conditions. The value of the existing Synchro-Phasor Network — some of which is more than 30 years old — has been to time-synchronize power system disturbance data that can then be analyzed it to improve generator, transmission, and load modeling and to understand abnormal power system behavior in the stability-limited Western Interconnection. Power system oscillations have been detected and analyzed off-line, leading to a better understanding of power system dynamics and modest improvements in operational standing orders and transfer path operating limits. This technology should be enhanced and more broadly used in order to:

- Integrate renewable resources (which have intermittent output characteristics)
- Improve the operator's situational awareness of the status and vulnerabilities of the system in real-time
- Develop and implement real-time control — a self-healing grid concept

The following is an excellent example of the value of PMU technology:

On January 26, 2008, transformation was lost at Bonneville Power Administration's Big Eddy substation, near the northern terminus of the 3100 MW DC Intertie. Control center operators in the West observed oscillations and, after the power on the DC Intertie was reduced by 500 MW, it appeared that the oscillations had ceased. However, the oscillations had only been reduced by 50 percent, which is below the observable level by dispatchers using their main tool — the Energy Management Systems in the control centers. However, in the California Independent System Operator's control room, synchro-phasor data was available and presented to power system dispatchers. They were able to see the reduced, but still present, system oscillations. When the DC Intertie flow was reduced to zero MW, the oscillations stopped. To quote Terry Boston of PYM, "It's like going from an X-ray to an MRI of the grid." Providing better situational awareness tools to operators of the system will enable them to see power system vulnerabilities much better and prevent such a vulnerability from ever becoming a disturbance or blackout.

Phasor measurement unit technology can be used to other valuable ends. The technology will provide the ability to see and manage the intermittent nature of renewable resources, and to deploy the ancillary services needed to solidify the changing nature of the West's generation fleet. Additionally, developing real-time controls to automatically take corrective actions will significantly increase the reliability of the interconnection and should release latent transmission capacity at very low cost.

The promise of PMU technology is huge, the opportunity immense. It is time to take a significant leap forward in developing the myriad uses of this technology and stand on the shoulders of the research and demonstration of the utility, government, and academic visionaries over the past 30 years to implement a better, more flexible, and more resilient grid.

1.1 Synchro-Phasor Project Scope

The scope of the Western Electricity Coordinating Council's (WECC) Synchro-Phasor Project is to meet the following objectives:

- Infrastructure improvement and network expansion for full WECC interconnection coverage and data management (collection, archiving, and inter-utility exchange) to promote reliable and economic grid operations.
- Development, implementation, and testing of real-time synchro-phasor applications for situational awareness and wide-area controls.
- Off-line applications and analysis for model validation and system performance and event analysis.

1.2 Proposal Organization

To meet these objectives, the proposal is organized into the following tasks:

Task 1: Infrastructure Improvement, Network Expansion, and Data Management

This task will upgrade the existing research network to a secure, reliable, production grade Synchro-Phasor Network with sufficient reach to provide full coverage for the Western Interconnection.

Task 1a. Upgrade existing phasor network.
Task 1b. Build out the existing network.

Task 1c. Develop architecture for integrating Synchro-Phasor Network in control centers.
Task 1d. Implement historical archive for synchro-phasor data.
Task 1e. Prototype and field test NASPInet phasor gateway and data bus concepts.

Figure 1 below depicts the Western Interconnection's current and desired deployment of PMUs and PDCs and Super PDCs. While the West currently employs significant phasor infrastructure, much remains to be done.

Figure 1 – Existing and desired phasor measurement units and phasor data concentrators in the Western Interconnection

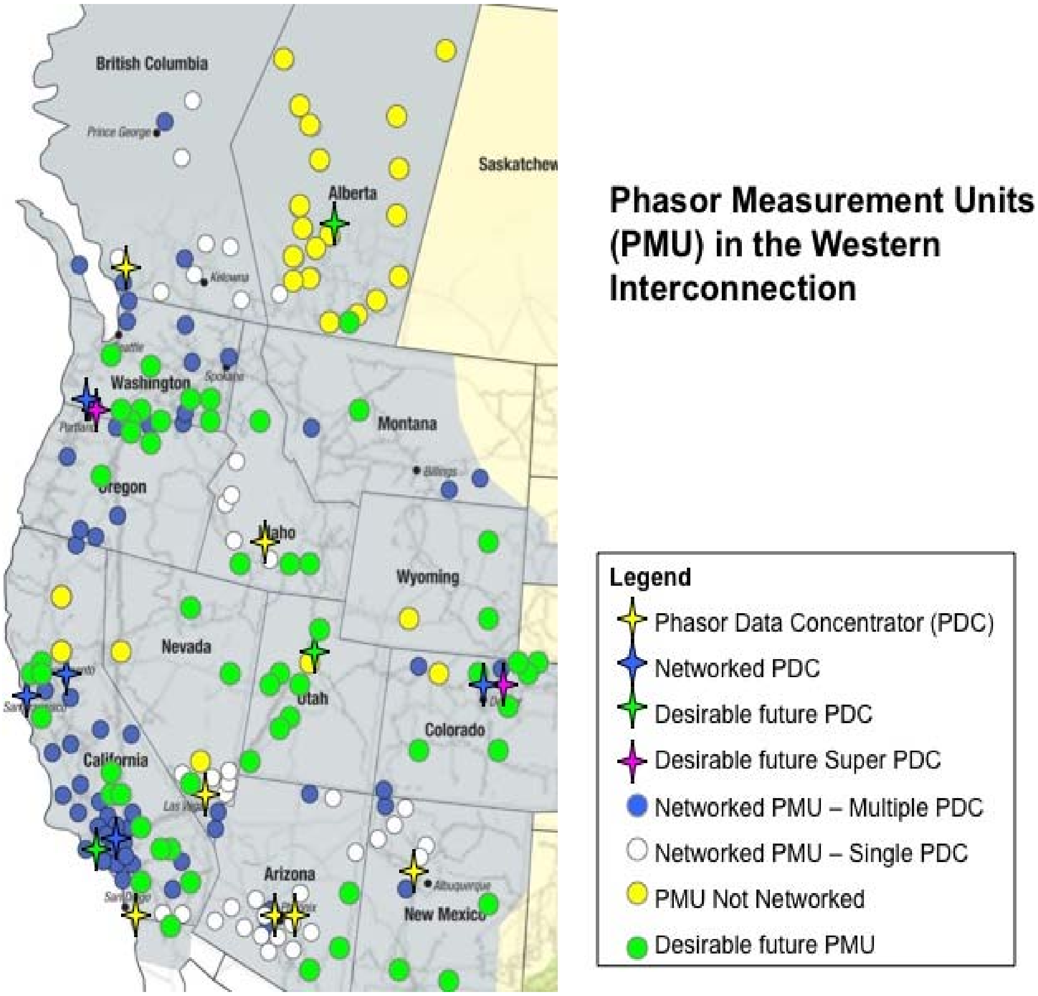
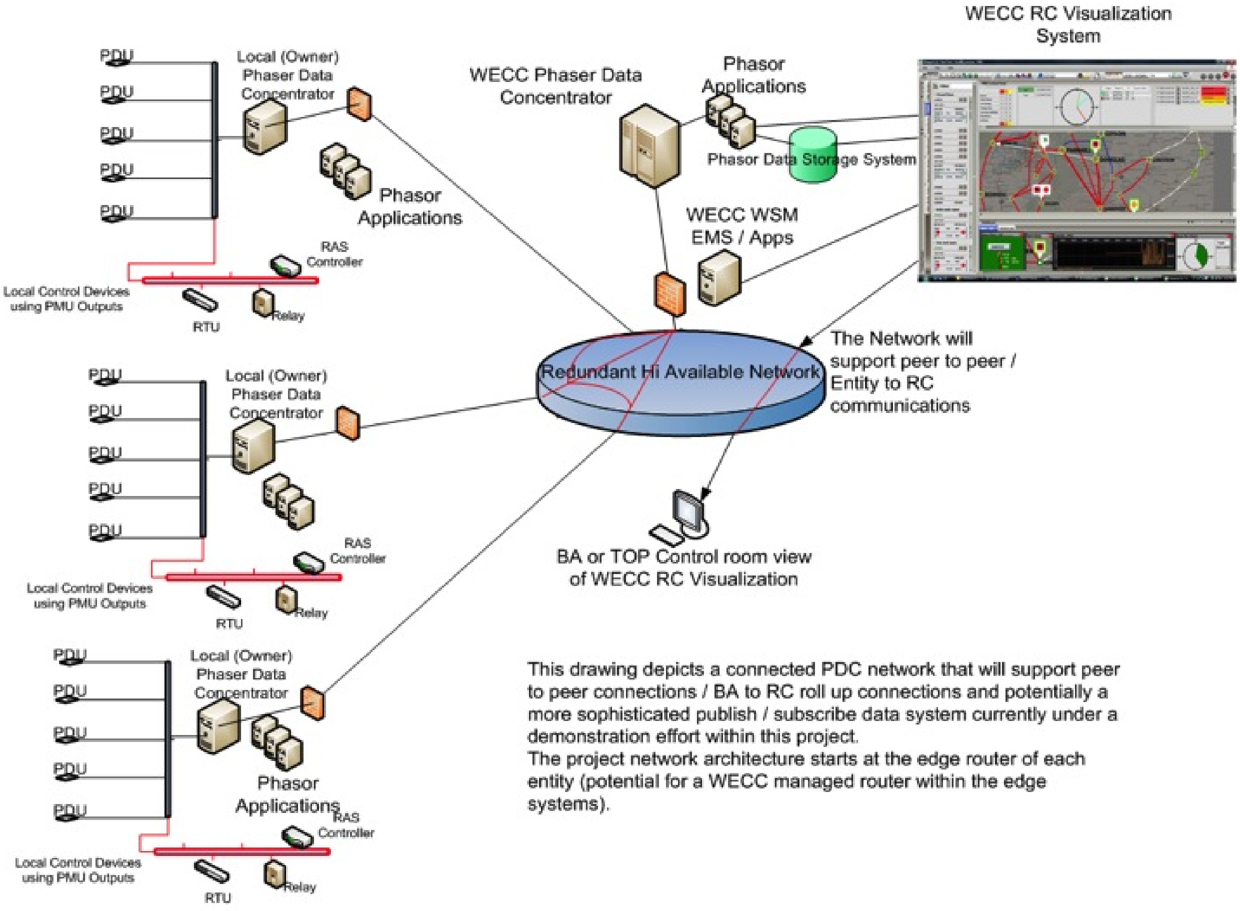


Figure 2 below depicts the proposal's overall communications architecture.

Figure 2 – Conceptual phasor communications architecture



This drawing depicts a connected PDC network that will support peer to peer connections / BA to RC roll up connections and potentially a more sophisticated publish / subscribe data system currently under a demonstration effort within this project.
The project network architecture starts at the edge router of each entity (potential for a WECC managed router within the edge systems).

Task 2: Deployment of Real-Time Synchro-Phasor Situational Awareness Applications across WECC

Task 2a. Implement trending measurements including frequency, voltages, phase angles, path flows, and oscillation energy.
Task 2b. Implement synchro-phasor-based alarming on phase angles, reactive reserves, and oscillation energy.
Task 2c. Implement displays and alarms on advanced metrics (voltage instability predictor, mode meter, etc.) and pre-determined operator actions.

Task 3: Implementation of Regional Control Schemes Using Synchro-Phasor Data

Task 3a. Research benefits and feasibility of wide-area control applications.
Task 3b. Implement regional controls that take pre-determined discrete actions based on wide-area measurements.
Task 3c. Implement regional continuous feedback controls.

Task 4: Deployment of Tools and Processes for Disturbance Event Analysis and System Performance Baselining

- Task 4a. Implement tools and establish processes within WECC for using synchronized wide-area data for disturbance analysis.
- Task 4b. Implement tools and develop a baseline understanding of power system performance through the wide-area visibility of the phasor network.
- Task 4c. Utilize baseline findings to establish meaningful alarming limits and thresholds within the real-time situational awareness tools.

Task 5: Standardized Tools and Best Practices for Equipment and System-Wide Model Validation

- Task 5a. Implement tools and establish processes within WECC for equipment model validation (power plants, HVDC systems, SVCs).
- Task 5b. Implement tools and establish processes within WECC for system-wide model validation (loads, overall system).
- Task 5c. Conduct model parameter identification in real time

Task 6: Project Management, Interoperability and Cyber Security Assurances

Task 6 will focus on project management, project coordination, outreach, knowledge sharing, technology transfer, and interface with industry activities such as North American Synchro-Phasor Initiative (NASPI). Interoperability and cyber security requirements and monitoring will be addressed under this task.

The proposed WECC Synchro-Phasor Project framework and tasks are summarized in Table 1, and are organized based on the maturity model and an application lifecycle process that includes the following phases: Research, Prototyping, Shakeout, Demonstration, and Operations and Maintenance. Level 1 represents the lowest level of maturity and readiness and Level 4 represents the highest.

Table 1: Proposed Synchro-Phasor Project Elements

	Infrastructure	**Situational Awareness** NASPI Class B & C Service Level	**Wide Area Controls** NASPI Class A Service Level	**Model Validation** NASPI Class D Service Level	**System Performance and Event Analysis** NASPI Class D Service Level
Level 4		*Intelligent alarms and grid optimizers	*Inter-area continuous feedback and discrete controls		
Level 3	* NASPInet Phasor Gateway & Data Bus proof-of-concept demonstrations	*Alarms that use wide-area measurements to calculate system stability margins and pre-determined operator actions (voltage instability predictor, mode meter, etc)	*Regional "defense in depth" control systems that take proportionate actions based on wide-area measurements; *Regional continuous feedback controls	* Model parameter identification from real-time data	
Level 2	*Build out the existing network *Develop architecture for integrating Synchro-Phasor Network in the control centers *Implement historical archive for synchro-phasor data	Phase Angle Alarms; *Reactive Reserve Alarms *Wind Generation State Awareness	*Regional controls that take pre-determined discrete actions based on wide-area measurements; *Arming existing RAS based on wide-area measurements; *Reactive power management controls	*Processes and tools for system-wide model validation in time and frequency domain	*Tools for data mining and data management *Processes and tools for using synchronized phasor measurements for system performance analysis (e.g. oscillation damping, mode shapes, participation factors)
Level 1	*Upgrade the existing Synchro-Phasor Network	*Trending high-speed wide-area measurements - frequency, voltages, path flows, and phase angles	*Research benefits and feasibility of wide-area control applications	*Processes and tools for equipment model verification (power plants, including wind, HVDC systems, SVCs, etc)	*Processes and tools for using synchronized wide-area data for disturbance event analysis *Compliance with NERC Disturbance Monitoring Standard PRC-002
	INFRASTRUCTURE	REAL-TIME		OFF-LINE	

Section 2: Guiding Principles

The WECC Synchro-Phasor Deployment Project proposal is guided by the following principles:

- The Operating Committee (OC) and Planning Coordination Committee (PCC) will provide expertise and guidance on the elements, timing, and priorities of the funding proposal content through a newly chartered work group, the Joint OC/PCC Synchro-Phasor Work Group. The OC and PCC Chairs will alternate as chair and vice-chair of the Work Group.

- Should the funding proposal be successful and funds awarded, the costs and benefits of carrying out this project should be allocated in such a way that Western end-use consumers are treated equitably.

- Benefits of the deployment of synchro-phasors in the West should be determined on a societal basis for purposes of DOE reporting.

- Synchro-phasor expertise should reside long-term in dedicated WECC staff.

- Synchro-phasor data and tools should be available to Reliability Coordination Office operators and engineers in order to best carry out their interconnection reliability responsibilities.

- Allow all reliability entities that follow Federal Energy Regulatory Commission (FERC) Standards of Conduct to have access to all available PMU data subject to NDA restricting the use of the data to operating personnel. Conversely, asset owners will provide phasor data to reliability personnel who need it to carry out their responsibilities.

- Synchro-phasors should be deployed to facilitate the reliable integration of renewable resources.

- The Synchro-phasor system should meet all interoperability and cyber security requirements.

Section 3: Project Specific Elements and Background

The section describes a plan to move from the existing research network to a secure, reliable, production-grade synchro-phasor network that will provide the foundation for real-time applications such as situational awareness and situational controls.

3.1 Challenges and Opportunities Moving Forward

The existing synchro-phasor network is viewed as a research-grade system that is suitable primarily for off-line applications such as system performance analysis, model validation, and prototyping of research ideas. The network does not currently meet reliability and cyber-security requirements of real-time applications such as real-time controls and situational awareness. It is not justifiable to continue expansion of the existing synchro-phasor network without planning a conversion to a production-grade system capable of supporting real-time applications.

3.2 Task 1: Infrastructure Improvement, Network Expansion, and Data Management

Regulatory Issues

North American Electric Reliability Corporation’s (NERC) PRC-002 Standard will require many entities to increase the number of Disturbance Data Recorders on their systems, a function likely to be met by the installation of PMUs. To remain compliant with mandatory reliability standards as they evolve, a multi-year PMU deployment plan must be developed independent of this funding opportunity

Technology

Reliability of the existing synchro-phasor network has been one of the major reasons for the slow pace of synchro-phasor adoption for real-time applications. Data drop-outs are frequent from key locations, particularly from inter-utility data exchanges. The failures are mostly attributed to the radio communications used with original PMU installations more than 30 years ago.

Phasor Measurement Units

Phasor Measurement Unit technology has reached a mature state. There are a number of large relay manufacturers that offer commercial-grade PMUs. Institute of Electrical and Electronic Engineers (IEEE) standards are developed to cover PMU steady state performance and inter-operability, and requirements have been further expanded to cover PMU dynamic performance. Due to a variety of PMU filter settings, the project intends to test and certify PMUs before they are installed in the field.

Many western utilities need to start a replacement program for many of their original PMUs. These units are no longer supported by vendors and are non-compliant with IEEE C37.118 inter-operability standards and dynamic performance requirements. Replacement will be also accelerated by compliance with the NERC PRC-002 standard.

Phasor Data Concentrators and Data Management

Commercial Phasor Data Concentrators (PDC) are also available to enable synchro-phasor networks. WECC members are testing and evaluating several commercial PDCs. Both a hierarchical and distributed architecture of PDCs needs to be evaluated. With huge volumes of synchro-phasor data anticipated, data management tools are a priority of this project. Quality of Service (QoS) and performance of the synchro-phasor network needs to be monitored and statistics made available on network availability, signal latency, and data dropouts. The Reliability Coordinators will perform the Synchro-Phasor Network monitoring function.

Historical Data Archive and Access Management

Currently within WECC, each of the member utilities archives data that is locally collected through their own intra-utility phasor network. The most common mechanism for this is using contiguous five-minute binary files in the PhasorFile format. The process for sharing intra-utility data files during a major disturbance is a manual process and is done through a secure FTP site. Commercial technologies have matured sufficiently to implement an automated WECC-wide data archival and access management system that will greatly streamline the archival and data mining process in support of off-line applications.

Telecommunications

Most of the data dropout issues are related to analog communications used with early PMU installations. Most entities have moved, or are moving to, a digital communications infrastructure that can better support PMU networking. Digital communications, mainly fiber-optics, will be used with a production-grade synchro-phasor network. The needs for additional fiber will be identified.

Inter-Utility Data Exchange

Utilities, independent system operators, and reliability coordinators jointly operate the interconnection and need to exchange real-time synchro-phasor data with their interconnected partners. This proposal includes an inter-utility synchro-phasor data exchange network to enable wide-area situational awareness applications. The DOE has a research project, NASPInet, that may facilitate such data exchange. NASPInet is still a research project and it is not clear whether it will be suitable for real-time applications in the timeframe of this proposal (deliverables in two to five years).

However, WECC intends to include NASPInet in the current proposal as a pilot of NASPI’s newly developed specifications, and will plan for migration to NASPInet in the future as its development matures. In the meantime, direct PDC-to-PDC communications are possible and currently used for the inter-utility data exchange.

Reliability of communications remains the major issue because of the use of analog radios. Improvement of the telecommunication infrastructure is needed to improve the quality and reliability of data exchange.

Integration of Synchro-Phasor Information into Existing Business Practices

The integration of PMU-generated information into existing business practices is critical to the implementation of synchro-phasor applications. This can only be accomplished by a WECC-wide training requirement to educate control center personnel on the use of the information in operations and the development of the standard operating procedures for the use of the data. This will require “baselining” of the normal operations of the WECC grid.

Summary of Task 1:

Task 1a:	**Upgrade the Existing Network –** Upgrade the existing synchro-phasor network — phasor measurement units (PMU), phasor data concentrators (PDC), and telecommunications — to a production-grade system capable of meeting cyber-security requirements and the reliability and availability needs of real-time controls and situational awareness applications.
Task 1b:	**Build Out the Existing Network –** Build out the existing network by adding PMUs and telecommunications to support the acquisition and exchange of needed data at sites within the interconnection.
Task 1c:	**Integrate Synchro-Phasor Information –** Integrate synchro-phasor information into control center operations by creating an environment that allows development, prototyping, and deployment of synchro-phasor applications. This should include training on the understanding and use of synchro-phasor applications for operators, and operations and planning engineers.
Task 1d:	**Implement Historical Archive and Access Management System –** Implement an end-to-end phasor data archival and access management system within WECC with configuration, administration, redundancy, and trust management mechanisms in place.
Task 1e:	**NASPInet Phasor Gateway and Data Bus Pilot** – Conduct proof-of-concept field demonstrations on various aspects of the NASPInet architecture and its functional components (naming convention, assignment and enforcement process, device registration, update and removal mechanism, error logging, cyber security capability, etc.).

3.3 Task 2: Implementation of Synchro-Phasor Situational Awareness Applications across WECC

Over the years, a significant amount of research has been done on how synchronized, wide-area measurements could improve power system operations and release latent transmission capacity for commercial use. A large number of synchro-phasor applications have been discussed and are now well understood. The availability of robust digital communications and satellite-synchronized transducers means the time is right for implementation of various real-time controls, situational awareness, and system performance analysis applications.

Synchronized wide-area measurements are expected to dramatically improve operator’s situational awareness as demonstrated by the January 26, 2008 event described earlier. In addition, large scale integration of renewable resources will present a new challenge to the system operators. Initial operational experience shows that large and fast changes in wind generation can be expected, such as 50 percent ramping of the wind generation fleet in the Pacific Northwest within an hour, and individual projects as much as 100 percent ramping in 10 minutes. Operators need real-time tools to anticipate and react to the fast changes in generation patterns.

It is useful to separate dispatcher tools from those used by operations engineering staff. Dispatcher tools are more action-driven, while the engineering staff tools can include capabilities for more in-depth system performance or event analysis.

A. Implement trending of real-time measurements

Providing operators a continuous trend of key power system measurements (trending tools) is the first essential application.

1. Trending Interconnection Frequency

The average frequency is the same at any point in an interconnection. System frequency is an indicator of system integrity. Bus frequencies are reliable indicators of power system islands and system separation points.

Frequency information is also very important during the blackstart and system restoration following break-ups, as demonstrated by Entergy's experience following hurricane Gustav.

Frequency is a great indicator of the generation and load outages in the interconnection. PMU frequency plots provide a good indication of lost generation.

A frequency drop of 0.1 Hz is typical in WECC for 800 MW of generation loss. Also, the propagation of the frequency drop can indicate where the generation drop occurred.

Frequency difference can also be a good indicator of inter-area oscillations.

WECC proposes continuous trending of frequencies at the following locations in the Western Interconnection:

- At least two frequency monitoring sites within each potential island
- El Paso
- Colorado, within Public Service of CO/Western Area Power Administration systems
- Oregon/Washington
- Idaho
- California, north and south of Path 15
- East of River
- Phoenix
- Western Montana
- British Columbia

- Alberta.

All trends will have a fixed scale from 59.95 to 60.05 Hz. The display frame will be “green” as long as the system frequency is within range. When any frequency moves outside the limits, an autoscale function is enabled and the display frame will turn to “red.” An operator can override the autoscale function.

A frequency trend of five minutes is adequate for visibility of system governor response. A shorter frequency trend of 30 seconds is needed for oscillation visibility. Frequency trending is ready for deployment.

2. Trending System Voltages at Key Load Center and Bulk Transmission Busses

- Low voltages are indicators of low reactive support. If regional voltages are out of normal limits, the operators can insert shunt capacitors to improve reactive support.

- Oscillations can also be observed in voltages.

- The display frame will remain “green” as long as voltages stay within the corresponding limits. When the voltage moves outside the limits, an autoscale function will be enabled and the display frame turned “red.” An operator will have an option to disable the autoscale function and return to the pre-set limits.

- Long-term voltage trend duration is one hour. Long-term voltage trend is already provided by SCADA. Short-term voltage trend duration is one minute. The need for short-term voltage trends needs to be considered further.

- If the PMU drops data, the reported voltage is zero and can cause false alarm and plot autoscale. The voltage display must have an intelligent pre-processor to recognize the data drop-outs.

- Voltage trending is ready for the prototyping phase.

3. Trending of Path Loading

- Real and reactive power flows on the major paths currently monitored by the Reliability Coordinators will be trended.

- Path flows are very sensitive to data drop-outs, particularly if several line-flows that make up a transfer path are added. Data reliability will be evaluated and redundant measurements may be needed for key paths. Benefits of breaker status information will be considered.

- Path flow information provides important information regarding power oscillations. A short-term (30 second) plot may be used with the long-term path flow trend.

- Path trending is one of the highest priority project elements.

4. Trending of phase angles

- Phase Angles between major load centers and generation sites will be trended and phase angle differences monitored. The proposed sites consist of Malin (California-Oregon Border), Grand Coulee, Palo Verde, Four Corners, major load centers, and generation centers.

- Relative phase angles are very sensitive to data drop-outs. This problem was one of the reasons the Phase Angle Alarm was disconnected in some control centers. Data reliability needs to be evaluated and redundant measurements may be needed for key paths.

- Phase angle limits must be also provided with the trending tool.

- Phase angle trending is a high-priority project element.

5. Trending oscillation energy

- The energy of power oscillations indicates whether an oscillation is growing or dissipating. Any build-up in energy signals oscillatory activity can alert an operator to check with the other indicators described above.

- Oscillation energy plots are recommended for:

    - North-South oscillation
    - Montana-Northwest oscillation
    - Desert Southwest – Southern California
    - Alberta
    - Kemano (British Columbia)

Oscillation energy trending is a high-priority project element.

B. Implement Synchro-Phasor Based Alarming

1. Phase Angle Displays and Alarms

The value of relative phase angle information became obvious during analysis of the August 10, 1996 outage. As the angular separation between Grand Coulee and Malin was increasing, the damping of the oscillation was decreasing. Phase angle information, if available, could have helped prevent the August 14, 2003 East Coast blackout.

Studies of disturbances have shown that relative phase angles in the West strongly correlate with overall system stress and the system susceptibility to inter-area oscillations. When phase angles exceed critical limits, operators will be presented options to increase reactive power reserves, insert series capacitors, or reduce path flows.

The same angles identified in 1-d will to be monitored and alarmed.

2. Phase Angle Baselining

Studies will be performed to provide baselines for the phase angles. A two-step approach will be used. First; historic phase angle data will be used to correlate system performance to the measured angular separation. Second; power system simulations will be done to predict how system performance relates to the phase angles under large disturbance events. Phase angle alarm settings will be proposed based on the studies. This effort is currently supported by NASPI.

Phase-angle alarming is a high-priority project element.

C. Implement Reactive Reserve Monitors

These alarms will process real-time data to alert dispatchers when system stability is at risk.

Many parts of the WECC transmission system are voltage-stability limited, and voltage collapse can happen very quickly if stability limits are reached. Voltage instability occurs when either the system has inadequate reactive reserves, or the transmission system cannot deliver reactive power from the source to where it is needed.

1. Voltage Instability Prediction

Early indication of voltage instability vulnerability would be an important operational tool and can be partially addressed by reactive reserve monitors and voltage instability predictors.

Reactive Reserve Monitors

Early detection of voltage instability vulnerability is an important operational tool and can be partially addressed by reactive reserve monitors and voltage instability predictors.

Synchronous generators (operating in voltage control mode) and static VAR compensators provide primary reactive power reserves in the interconnection. Appropriate alarms will be set when the reactive reserves are low. Corrective actions include deploying synchronous condensers, adding shunt capacitors, requesting additional reactive support from the generation fleet, and reducing flows on transfer paths.

With rapid penetration of wind-turbine generation, reactive reserves measurement has become a challenge. Additional synchro-phasor measurements at wind sites is necessary and infrastructure will be added to ensure system operators know how much reserve is primary and how much is secondary, as well as to ensure the deliverability of the reserves during a disturbance.

Determination of required reactive supply providing voltage support to major metro areas and transmission paths in the West will be accomplished as well as determination of the alarm thresholds when reactive reserves become low.

Implement Voltage Instability Predictors

Methods have been researched to use wide-area measurements to determine whether a transmission corridor is adequate to provide reactive support to a load center. The methods need to be reviewed and applied to the following major load centers: Seattle, Portland, San Francisco Bay Area, LA Basin, Phoenix, Denver, and Albuquerque.

Recent operational issues with voltage control of wind power plants make the implementation of voltage stability indicators particularly critical, since WECC cannot rely on models to anticipate such operational issues.

The following will be accomplished:

a) observability – sets of synchronized measurements to detect the voltage stability limits
b) algorithm – how to translate these measurements into information
c) controllability – how the information is translated into operator actions

2. Implement Oscillation Detection Alarm

Oscillation detection methods calculate the damping of a ring-down during a system disturbance. The method was perfected by Dr. John Hauer over the past 20 years and used extensively for off-line analysis of power oscillations.

BPA (Bill Mittelstadt) coordinates efforts in the area of oscillation damping analysis. The team includes Montana Tech University, Pacific Northwest National Laboratory, Washington State University, Electric Power Group and University of Wyoming. The DOE, BPA, and California Energy Commission fund a portfolio of projects.

Oscillation Damping Alarms are high-priority elements of this project.

3. Implement Mode Meter

Mode meters promise to provide early detection of damping in the system. As an example, system studies show that system damping decreases by four percent during a specific severe contingency. It would be necessary to maintain the normal system damping higher than four percent at all times to protect for this contingency. Mode meters measure normal system damping from “ambient” data. This is, however, a very challenging signal processing problem as the signal-to-noise ratio is very low.

Pacific Northwest National Laboratory, Montana Tech, University of Wyoming, and BPA are in process of testing mode meter algorithms for production deployment.

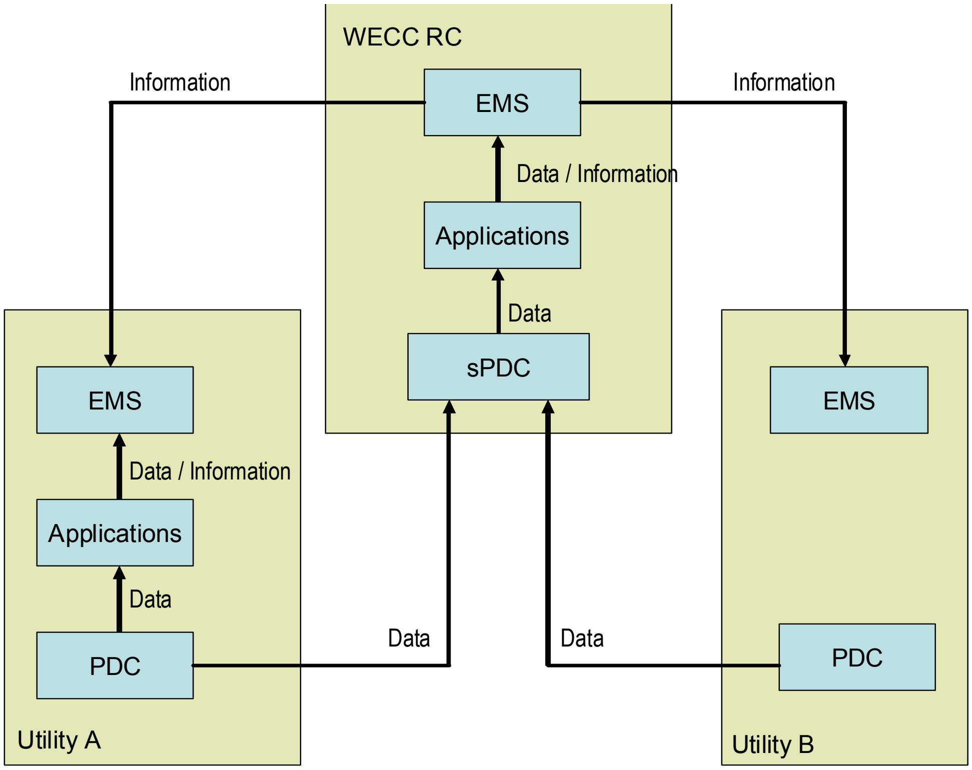
Mode meters are very attractive “early warning” tools. Oscillation energy will be used to determine when energy is sufficient to activate the mode meter.

Situational Awareness Application Integration

Figures 2 and 3 show integration of the situational awareness applications

Reliability entities collect synchro-phasor data in their Phasor Data Concentrators. The data is rolled up to the Super Data Concentrators at WECC RCOs. The synchronized data is passed to the “Application” layer which hosts applications identified above (trending tools, phase angle alarms, reactive reserve alarms, voltage stability indicators, mode meter). Applications will send information, including alarms, to the “Visualization” layer residing within the EMS. The operational information can be shared by WECC among other Balancing Authorities and transmission owners within WECC. An individual utility (Utility A in the figure) can deploy these common applications to gain economies of scale. Unique applications could also be deployed utilizing common visualization tools.

Figure 3: Integration of Situational Awareness Applications



Risks to Mitigate for Situational Awareness Tools

The risks to mitigate for situational awareness tools fall into three areas: network architecture, applications, and project management. Specifically, those risks are:

Network Architecture:

- Overall Synchro-Phasor Network reliability and availability.
- PMU data dropouts. Data “sanity checks” will be developed to ensure that PMU data is credible.
- PMU calibration and maintenance.

Applications:

- Developed applications and displays must be informative and actionable for system operators and reliability coordinators.
- Developed tools may have problems with data processing algorithms and provide misleading information. Nuisance alarms would eventually lead to loss of credibility.

Project Management:

- The ability to innovate must not exceed the capacity to manage. It is imperative to proceed at an aggressive but measured pace with stage gate enforcement.

Summary of Task 2:

Task 2a: **Implement trending measurements** including frequency, voltages, phase angles, path flows, and oscillation energy.
Task 2b: **Implement synchro-phasor based alarming** on phase angles, reactive reserves, and oscillation energy.
Task 2c: **Implement displays and alarms on advanced metrics** (voltage instability predictor, mode meter, etc.) and pre-determined operator actions.

The specific deliverables planned as part of Task 2 are listed below:

1. **WECC-wide area reliability monitoring function** – located at reliability coordinator locations (WECC Phasor Monitoring Center).

2. **WECC-wide area situational awareness and visualization for the entire interconnection** – common interconnection level displays for Reliability Coordinators, Balancing Authorities, and Transmission Owners. Situational Awareness tools including actionable on-line tools for real-time human operation of the power system to include trending information on frequency, phase angle, reactive reserves, key path flows, and oscillation energy with appropriate alarming to focus the operator's attention.

3.4 Task 3: Implementation of Regional Control Schemes Using Synchro-Phasor Data.

Wide-area synchronized measurements will provide a foundation for the next generation of real-time controls. Stability controls often face two conflicting requirements: reliability and selectivity. It is desirable to take actions early when needed (reliability) and to avoid taking actions when they are unnecessary or detrimental (selectivity). Experience shows that using local measurements alone may not achieve the required balance between reliability and selectivity. Wide-area measurements provide better observability of the system state and ultimately lead to better control decisions.

When discussing power system controls, it is useful to draw a distinction between primary and secondary controls. The primary control actions are taken in sub-second time frames to ensure that the system survives a severe disturbance. The secondary control actions are taken within several minutes to help system recovery and position the system best to withstand the next disturbance. Many of the West's disturbances are very severe and primary control actions are often necessary for system stabilization. To release latent transmission capacity, primary control actions will be more prevalent and synchro-phasor applications will be the only means to take them.

Another control distinction is between discrete remedial action scheme switching actions (control set-point activation) and continuous feedback controls. WECC expects that discrete controls can be implemented first, with feedback controls following thereafter. While feedback controls are more complex their benefit is also greater in terms of enhanced grid capability.

A. Research Benefits and Feasibility of Wide-Area Control Applications

The West has extensive expertise and experience in designing, implementing, and operating complex Remedial Action Schemes (RAS). A vast majority of existing RAS are event-driven. However, event-driven RAS do not protect against disturbances initiated by external events, nor are they effective for dealing with complex events. NERC event analysis reports point to increasing disturbance complexity. Event-driven RAS have also been known for excessive and unnecessary operations.

Early research has shown the benefits of fast-reactive switching and generator dropping for improving California-Oregon Intertie (COI) transient stability. Recent voltage and transient stability studies have been conducted to quantify the benefits of response-based fast-reactive switching of shunt capacitors.

B. Implement Regional Controls That Take Pre-determined Discrete Actions Based on Wide-area Measurements

1. Secondary Voltage Controls

Synchronous generators (in voltage control mode) and Static VAR Compensators (SVC) provide reactive power reserves that can be deployed during disturbances.

2. Wind Site Voltage Controls

On-line wind generating capacity is increasing quickly and the West wishes to ease this transition in support of renewable generation. It is critical to ensure that replacing conventional generation with wind does not degrade grid reliability.

Voltage control is one area of particular concern Synchronous generators currently provide primary voltage response during grid disturbances. The ability of wind power plants to provide reactive power support depends on the wind generation technology used. The earlier wind-turbine generators were induction generators and had no reactive capability. Supplementary reactive controls such as switched capacitors and dynamic VAR devices are required for voltage support. Newer technologies, such as doubly-fed asynchronous generators and full-converter interface generators, are capable of reactive power control and can provide voltage control, if appropriate control systems are installed.

Western Interconnection reliability standards require that generators with Automatic Voltage Regulators (AVR) be in voltage control mode to provide reactive support. However, time synchronized measurements at wind plants are needed to know the quantity of reactive reserves supplied. Reactive power deliverability is another issue to be resolved. Due to the distributed nature of wind power plants, voltage rise in the collector system may prevent wind turbine generators from providing full reactive support. Unlike conventional generators, wind generators have virtually no short-term overload capabilities, a function that may be needed to provide voltage support during severe transient swings.

Studies will be done to determine the primary and total reactive power requirements for wind power plants. Coordinated control of wind power plants may be needed to optimize availability of reactive reserves and to ensure stable reactive power sharing among individual wind power units.

Phasor Measurement Units will be installed at wind facilities to record substation voltage and substation transformer current.

3. Primary Transient Stability Control

The Bonneville Power Administration (BPA) has developed a response-based controller that arms a fast-reactive switching scheme when a severe voltage swing is detected. Wide-area voltage measurements and two uncorrelated algorithms are required to make the control decisions. Wide-area measurements are needed to ensure both fast control activation and selective operation.

BPA's transient controller is in its implementation phase. This project anticipates additional control deployment in the West.

4. Equilibrium State Control

Equilibrium State Control (ESC) as used here is to assure that the system has a stable equilibrium (target state) to return to following a disturbance event. The more secure the target state, the more likely the system oscillation will be damped and the less strong oscillation control will be needed. In effect, the network and transfer demands are brought into balance to assure that there is a stable equilibrium (power flow) condition.

Common forms of ESC used today include the Fort Rock Series Capacitor insertion for loss of a parallel line, and generator tripping for loss of two COI lines. This is most commonly treated as a part of the RAS. Equilibrium State Control may be used to rebalance flow among a set of lines (series capacitor application) or to reduce the flow across a weakened transmission path (generator tripping for COI), and is generally in the form of a one-time discrete (switched) action.

Indicators of need for control action include:

- Measured phase angles between areas or buses (beyond understood limits)
- Measured line or path flow above understood limits (nomograms)
- Developing angle instability (increasing angle and collapsing voltage)

As an example, this project proposes insertion of the Fort Rock series capacitors and Malin Substation shunt capacitors for a large NW/SW angle. This could be the result of a developing disturbance that weakened the system but would not be picked up by normal RAS control functions. Other applications within the interconnection are anticipated.

C: Implement Regional Continuous Feedback Controls

The ever increasing complexity of grid disturbances requires developing "defense in depth" control systems that protect the grid's stability for the rare but disruptive events.

1. Regional Voltage Stability Controls

Voltage stability of large metropolitan areas that make up the interconnection's load centers has been attracting new attention recently. Advances in load modeling suggest that changes in load composition from resistive to electronic and inductive motor load represent new reliability risks. No new generation is planned near load centers, to provide voltage support. Wind generation is remote and its ability to provide and deliver reactive support may not be as flexible and abundant as that provided by traditional resources with significant mass. Wind generation may replace any remaining thermal generation around load centers. Summer studies indicate that large load centers are susceptible to Fault-Induced Delayed Voltage Recovery. The meshed transmission and sub-transmission network creates a path for wide propagation of such a disturbance in the grid.

Regional voltage stability controls will encompass both primary and secondary control time-frames. The secondary control will adjust and position the system to maximize the controllability and availability of dynamic reactive reserves. The primary control will respond to major grid disturbances.

2. Inter-Area Oscillation Damping Controls

Modulation of the Pacific Direct Current Intertie (PDCI — a 3,100-MW transmission facility between The Dalles, Oregon to Los Angeles, California) shows significant promise for damping of North-South oscillations. Following disturbances in the West in 1996, analysis showed the PDCI was a major contributor to the 1996 oscillation, when the DC controls tried to maintain the power order even as the Celilo voltage was collapsing. BPA has implemented an AC Voltage Dependent Control Limiter (AC-VDCOL) function in PDCI controls to limit DC current for low voltage conditions at Celilo. The control limiter has also provided benefit for transient damping.

Excessive oscillatory activity was observed during the 2006 summer heat wave. This provided additional incentive to revisit the feasibility of oscillation damping controls. Stability controls, because of their wide-area impact, must be particularly secure as well as reliable. Attention must be paid to the robustness and scalability of the controls as well as ensuring there are no unintended consequences.

Oscillation damping feasibility studies were completed and addressed the following questions:

- what types of devices can be deployed for damping of inter-area oscillations
- where are the effective locations for oscillation damping

- what is the quantity of control action and the appropriate controller gain needed to dampen oscillation
- which disturbances are these control actions effective for

The answers to these questions are in hand:

Absorbing and supplying real power during a power swing can effectively damp inter-area oscillations. A relatively small braking action (250 MW) or a power flow controller can very effectively dampen the North-South oscillation and protect the interconnection for the loss of two generating units at Palo Verde near Phoenix. The best locations for the damping controllers are at the ends of the oscillatory mode (British Columbia, Canada, and Washington State in the North; Southern California and the Desert Southwest in the South).

The control is shown to be robust and scalable. High controller gain of 700 to 1,000 MW per 0.1 Hz of oscillation is required.

The feasibility of DC modulation controls is currently under study at BPA. While simulations show a dramatic damping improvement, this demonstration project is needed to prove that the simulated benefits can actually be achieved. The PDCI is proposed for use as a test bed. PDCI probing tests are planned for model verification and for identification of the system transfer function within the controller algorithm. In parallel, equipment stress analysis will be performed to determine whether there are any interactions between modulation signal and generator torsional modes that would harm the generator shafts.

Risks Addressed for Wide-Area Controls

The fundamental principle for wide-area controls is to “Do No Harm.” During the control assessment not only controller benefits, but also controller risks will be evaluated very carefully. The controller fault tolerance must be addressed to ensure that the control system can function (both reliable and secure) with partial loss of PMUs and network failures. Synchro-phasor network Cyber Security issues will also be addressed.

Summary of Task 3:

Task 3a: Research benefits and feasibility of wide-area control applications.
Task 3b: Implement regional controls that take pre-determined discrete actions based on wide-area measurements.
Task 3c: Implement regional continuous feedback controls.

The specific deliverables that are planned as part of Task 3 are listed below:

1. **Local or Sub-Regional Advanced Applications** – Development, testing, and deployment of response-based (as opposed to event-based) real-time automatic controls, focused on reactive supply and voltage controls at wind resource sites, and transient stability controls (e.g., Tehachapi, CA; Oregon; and Wyoming).

2. **Regional Control Applications for Increased Asset Utilization** – Development and demonstration of ‘defense in depth’ regional voltage stability and inter-area oscillation damping controls that protect the interconnection from rare but very severe events (e.g., loss of Pacific Intertie or multiple generators).

3.5 Task 4: Deployment of Tools and Processes for Disturbance Event Analysis and System Performance Baselining

Post-disturbance event analysis includes reconstructions of the sequence of events, and evaluation of protection and control operation, as well as analysis of power system performance. Complex disturbances typically involve many switching actions within a second and therefore, synchronized measurements are extremely valuable in the event reconstruction and analysis.

NERC Standard PRC-002 recognizes the value of time-synchronized measurements for disturbance analysis. The standard requires time- synchronized, continuous Dynamic Disturbance Recordings (DDR) be made at substations with voltage levels above 200 kV that have seven or more transmission elements. PMUs are seen as a way of meeting the DDR function.

A. Event Analysis

Deploy processes and tools using wide-area synchronized recordings for event analysis, compliant with NERC disturbance monitoring standards.

B. Power System Performance Analysis

Deploy processes and tools using wide-area synchronized recordings for power system performance analysis.

After event analysis, the next step is the analysis of power system performance; the behavior of the grid even in the absence of a disturbance. The analysis of inter-area oscillation damping is of particular interest. The Western Interconnection has many inter-area oscillation modes. The following modes have shown risks to interconnection stability:

- North-South oscillation involves generators in the Pacific Northwest and Canada oscillating against generators in Desert Southwest and California. The oscillation frequency ranges from 0.25 to 0.33 Hz. This oscillation affects operations of the COI and is more pronounced during on-peak hours with heavy transfers from North to South.

- East-West oscillation involves Eastern Montana oscillating against the Pacific Northwest. The oscillation frequency ranges from 0.6 to 0.7 Hz.

This oscillation is more active during off-peak hours with heavy power imports from Montana.

- The Alberta mode is complex and includes at least two cut-planes; one between Alberta and the West, and the second between Oregon and California. The oscillation frequency ranges from 0.38 to 0.5 Hz. This mode interacts with the North-South mode, affecting its frequency and damping.

A number of system tests have been performed, including the insertion of the 1,400 MW Chief Joseph braking resistor and PDCI probing signal tests, to gain better insight in the analysis of power system oscillations. The PMU network expansion to date across the Western Interconnection led to better understanding of the oscillatory modes and the participation factors of various areas in the oscillations. Such knowledge is paramount in determining operational and control solutions to oscillation damping as well as provision of system model verification.

Summary of Task 4:

Task 4a: Implement tools and establish processes within WECC for using synchronized wide-area data for disturbance analysis.
Task 4b: Implement tools and develop a baseline understanding of power system performance through the wide-area visibility of the phasor network.
Task 4c: Establish meaningful alarming limits and thresholds within the real-time situational awareness tools utilizing the baseline findings.

The specific deliverable that is planned as part of Task 4 is stated below:

> **Off-line Analysis and Assessment Tools** - Development and demonstration of off-line tools to support interactive post-event analysis.

3.6 Task 5: Standardized Tools and Best Practices for Equipment and System-Wide Model Validation

Grid planning and operating decisions rely on simulations of the dynamic behavior of the power system. The technical and commercial segments of the industry must both be confident that the dynamic simulation models and databases are accurate and up to date. Optimistic models can result in unsafe operating conditions and widespread power outages, as indicated by the events in the summer of 1996 in the Western Interconnection. Pessimistic models and assumptions can result in overly-conservative grid operation and underutilization of transmission capacity leading to adverse economic results. Having accurate models is essential to reliable and economic power system operation.

Two major disturbances occurred in the Western Interconnection in summer of 1996, July 2 and August 10 respectively. When engineers attempted to reproduce both events in dynamic simulations, there were significant differences between the simulated events and actual disturbance recordings. The August 10, 1996 sequence of events resulted in unstable power oscillations and eventual system break up. However, the modeled response was stable and well damped. The failure of the simulations to correlate, even remotely, with the actual disturbance data was very concerning for utilities and grid operators in the West, since the models were used for setting System Operating Limits. Following the disturbance, the West undertook a number of long-term modeling initiatives including generator testing, HVDC modeling, load modeling, and system-wide model validation. This project proposes to further this work.

A. Equipment Model Verification

Processes and tools using disturbance recordings for equipment model verification (power plant models, including wind generation plants, HVDC systems, and load models)

B. Generator Model Verification

Following the 1996 outage, testing of all generators larger than 10 MW was required to verify their models. While testing has been very beneficial, it has been insufficient to create and maintain a satisfactory simulation database. Some research has been done to find methods of independent verification of generator models and dynamic performance using disturbance data. For instance, a load flow study program has implemented a “playback” capability that enabled injection of recorded bus voltage and frequency into dynamic simulations. Some in the West have been using the playback function for periodic model verification of many power plants. When WECC developed a Generating Unit Model Validation Policy in 2006, model verification by a disturbance playback was included as an acceptable method. The methods are also included in the draft of NERC generator verification standards.

In recent years, some have begun automating generator model verification processes, but this project proposes additional sophistication to resolve known model limitations. For instance, automatic generation control changes to a plant’s voltage and power schedules are not currently addressed.

Large-scale integration of wind power plants represents a new challenge for modeling accuracy.

Generator Model verification is mixed. Some needed improvements are in production phase while others are in research phase.

C. Pacific HVDC Intertie

Pacific HVDC Intertie (PDCI) is a major path in the West connecting the Pacific Northwest (Celilo) and Los Angeles basin (Sylmar). PDCI is rated at 3,100 MW. PDCI was a main contributor to the negatively damped oscillations developed on August 10, 1996.

PMUs were installed at BPA's Big Eddy 500-kV and 230-kV substations monitoring bus voltage and Celilo line currents after the 1996 outages; however, they need replacement due to performance issues. A higher sampling rate (120 samples per second) is needed. There is also a PMU at Sylmar; however, additional quantities need to be monitored for complete visibility of the southern terminus. Additional PMUs are needed at Celilo to monitor DC power order, voltages, currents, and DC current orders synchronized with AC measurements.

D. Load Modeling

Loads are playing a larger role in power system stability due to evolving changes in load composition: the proportion of compressor (air-conditioning and heat pump) and electronic loads is growing, and the proportion of resistive loads (incandescent lighting, space, and water heating) is shrinking. Resistive-type loads were energy inefficient but had favorable voltage characteristics: the power is reduced proportional to voltage squared. Compressor motor and electronic loads behave as constant power loads with respect to voltage and therefore maintain their demand when the electrical grid is in trouble.

Single-phase residential air-conditioners can stall during a fault, basically becoming a high-impedance locked rotor fault with very detrimental impact to the ability of the grid to recover. Recent events of Fault-Induced Delayed Voltage Recovery (FIDVR) have been observed in California and the Southeast. NERC has recently published a white paper on the FIDVR issue. The risk of fast voltage collapse in large metro areas is increasing as a result of the changes in load composition and as reactive support to combat it is moving further from the load centers in the West (as generation sources become more remote).

The need for better load modeling is apparent. WECC's Load Modeling Task Force is in the final stages of implementing a new composite load model structure in grid simulators. The Synchro-Phasor Project furthers that effort. Load model data remains a challenge as load composition changes seasonally, hourly, and by feeder. This project proposes derivation of model data using a bottom-up approach and then to validate model performance using synchro-phasor disturbance recordings.

E. System Model Verification

Overall system verification is an ultimate step in ensuring simulation models reasonably match reality. This project proposal addresses three issues:

1. How to verify system-wide model verification. This has been a major obstacle in developing a validation base case. The recent West-Wide System Model development promises great improvements in the speed of creating validation base cases.

2. How to judge model performance. Apart from the rare case in which there is a complete disagreement between the model and reality, most cases have some similarities and some disagreements between the real and simulated behavior of loads. More sophisticated tools beyond those using time-domain

methods are proposed to distinguish between accurate and inaccurate element models.

3. What to do when the model and reality do not match. A process needs to be formalized to reconcile differences between a model and reality. This project proposes tool development and demonstration for guiding model adjustments to achieve a better agreement between models and actual recordings.

Note: WECC's Model Validation Work Group (MVWG), NERC, and the North American Synchro-Phasor Initiative (NASPI) are jointly preparing a white paper on system model validation. The specific elements of the proposed project action plan will be further developed based on the white paper recommendations.

Summary of activities of Task 5:

Task 5a: Implement tools and establish processes within WECC for equipment model validation (power plants, HVDC systems, SVCs).
Task 5b: Implement tools and establish processes within WECC for system-wide model validation.
Task 5c: Conduct model parameter identification in real time.

The specific deliverable planned as part of Task 5 is stated below:

> Development and deployment of off-line tools to support equipment and system model validation.

3.7 Task 6: Process and Project Management, Interoperability, and Cyber Security Assurances

The project contemplates a number of situational awareness and real-time controls using synchro-phasors as well as a process for evaluating feasibility and timing of these applications. WECC intends to employ a maturity model and application lifecycle as tools to manage risks and realize benefits as quickly as practical. It is also imperative that interoperability and cyber security objectives are met as the functional requirements are deployed.

A maturity model describes how the project will grow hierarchically. A maturity model greatly minimizes project risks, as maturity levels become stage gates for expanding the project complexity. A maturity model provides visibility as to the readiness of the interconnection in technology and application demonstration and is expected to lead to appropriate timing and efficient allocation of resources and capital.

Each application will be managed through its lifecycle, which includes the following phases:

1. **Research**. Ideas are generated and “proof of concept” research is conducted. It is important to generate a wide range of ideas during this phase without excessive criticism. Diverse ideas can be achieved by either providing “seed” funding to multiple independent researchers, or by collaboration through an expert panel. The WECC project team expects to facilitate and direct the researchers.

2. **Prototyping**. The most promising approaches are prototyped and tested in monitoring mode. Feasibility analysis is also completed at this phase. If possible, several competing approaches may be prototyped. Close collaboration between researchers and the WECC project team will be employed.

3. **Shakeout**. Prototypes will be tested extensively, and the necessary design modifications made. Project risk analysis is conducted and benefits are evaluated at this phase. Commercialization versus customization is also decided. The WECC team leads this phase.

4. **Demonstration**. The final design is completed; the scheme is implemented and released to operations. It is critical to understand how the innovation will fit the existing business processes. The WECC team leads this phase.

5. **Operation and maintenance, upgrades**. Appropriate resource commitments must be made to operate and maintain the applications. At this phase, WECC members (control room applications) and WECC staff (Reliability Coordinator applications) operate and maintain an application. Feedback is encouraged. Application upgrades are made as required.

Summary of Task 6:

Manage the process of implementing the individual elements of the synchro-phasor project utilizing a maturity model to mitigate risks and derive optimal benefit as quickly as possible. Interoperability and cyber-security objectives are assured under this task.

Section 4: Appendices and References

Appendix 1: Project Plan and Timeline
Appendix 2: Project Participants
Appendix 3: Pertinent FOA References
Appendix 4: Existing and Future PMUs and PDCs
Appendix 5: Glossary of Terms

Appendix 1: Synchro-Phasor Project Plan – Version 1.0

7/10/2009

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
PROJECT MANAGEMENT & COORDINATION; TECH TRANSFER; INDUSTRY INTERFACE, INTEROPERABILITY AND CYBER SECURITY ASSURANCES	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	--→X
PLANNING (Infrastructure)												
Finalize new RTU Locations and Measured Quantities (Consistent with evolving NERC standard PRC-002)	→X											
Determine PMU Replacement Locations and Changes to Measured Quantities	-→X											
Determine PDC Locations	→X											
Determine SuperPDC Requirements	--→X											
Determine Functional and Performance Requirements for Network – Inter-utility Data Exchange (IUDE)	--→X											

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
Determine NASPInet pilot requirements – prototype and field test phasor gateway, data bus concepts, and cyber security capability	-------	--→X										
Determine Control Center Interface Requirements	-------	→X										
Determine Cyber-Security Requirements/Coordination with NERC & NASPI	-------	→X										
DESIGN (Infrastructure)												
Specify PMU Major Materials	-------	→X										
Acquire PMUs		→X										
Acceptance Test, Calibrate & Certify PMUs	-------	--→X										
Design PMU Substation and Power Plant Installations		----	--→X									
Design Telecommunication Installations and F/O or Radio Channel Assignments (including alternate routing requirements)		---	--→X									
Specify PDC Major Materials	--	--→X										
Acquire PDCs		--	--→X									
Acceptance Test and Certify PDCs			--	--→X								
Design Control Center Installations			--	-→X								
Acquire SuperPDCs				--	--→X							

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
Acceptance Test and Certify SuperPDCs				--	--→X							
Design Reliability Center Simulator Installations			--	-------	--→X							
Design Reliability Center Control Room Installations			--	-------	-------	-------	→X					
Design Historical Archiving Implementation			--	-------	-------	-------	→X					
CAPITAL CONSTRUCTION												
Phase 1 PMU Installation		--	-------	→X								
Phase 2 PMU Installation				---	-------	→X						
Phase 3 PMU Installation						---	-------	--→X				
Phase 1 PMU Replacement		-----	-------	→X								
Phase 2 PMU Replacement				-----	-------	→X						
Phase 3 PMU Replacement						---	-------	--→X				
Phase 1 PDC Installation				-----	-------	--→X						
Phase 2 PDC Installation						---	-------	--→X				
Phase 1 IUDE Network Installation		-----	-------	→X								
Phase 2 IUDE Network Installation				---	-------	-→X						
Phase 3 IUDE Network Installation						….---	-------	--→X				
Historical Archiving Implementation			----	-------	-------	-------	-------	--→X				

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
NASPInet Prototype & Field Test Installation, Cyber Security Capability			----	-------	-------	-------	-------	-------	--→X			
PLANNING (Applications)												
Situational Awareness												
Real-time Trending												
Frequency	→X											
System Voltages	--→X											
Path Loading	--→X											
Oscillation Energy	-------	→X										
Phase Angle Displays/Alarms												
Phase Angle Baselining	-------	→X										
Phase Angle Trending	-------	--→X										
Alarms w/ Data Preprocessing												
Voltage Instability Predictor	-------	--→X										
Reactive Reserve Monitor	------	→X										
Oscillation Detection	------	-------	→X									
Mode Meter	------	-------	-------	--→X								
Off-Line Tools												
Event Analysis	------	→X										
Power System Performance Analysis	------	-------	→X									

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
System Model Validation												
Equipment	------	→X										
Generator	------	→X										
HVDC Intertie	------	-------	→X									
Loads	------	-------	-------	→X								
Wide-Area Controls												
Response-Based Wide Area Controls Feasibility & Benefits Study	------	--→X										
Secondary Controls & Primary Control Arming	------	-------	-------	--→X								
Secondary Voltage Controls	------	-------	→X									
Wind Site Voltage Controls	------	-------	-------	--→X								
Primary Transient Stability Control	------	-------	-------	-------	-------	→X						
Regional Stability Controls	------	-------	-------	-------	-------	→X						
Regional Voltage Stability Controls	------	-------	-------	-------	-------	→X						
Equilibrium State Control	-------	-------	-------	--→X								
Inter-Area Oscillation Damping Controls	------	-------	-------	-------	--→X							
ALGORITHM & DISPLAY DEVELOPMENT (Applications)												
Situational Awareness												
Real-time Trending												
Frequency	-------	--→X										

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
System Voltages	-------	-------	→X									
Path Loading	-------	-------	→X									
Oscillation Energy	-------	-------	-------	→X								
Phase Angle Displays/Alarms												
Phase Angle Trending	-------	-------	→X									
Alarms w/ Data Preprocessing												
Voltage Instability Predictor	------	-------	-------	-------	--→X							
Reactive Reserve Monitor	------	-------	--→X									
Oscillation Detection	------	-------	-------	-------	--→X							
Mode Meter	------	-------	-------	-------	-------	-------	→X					
Off-Line Tools:												
Event Analysis	------	-------	-------	-------	-------	-------	------	-------	-------	-------	-------	--→X
Power System Performance Analysis	------	-------	-------	-------	-------	-------	------	-------	-------	-------	-------	--→X
System Model Validation												
Equipment	-------	-------	-------	→X								
Generator	-------	-------	-------	→X								
HVDC Intertie	------	-------	-------	-------	-------	→X						
Loads	------	-------	-------	-------	-------	-------	→X					
Wide-Area Controls												
Secondary Controls & Primary Control Arming	------	-------	-------	-------	-------	→X						

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
Secondary Voltage Controls	------	-------	-------	-------	--→X							
Wind Site Voltage Controls	------	-------	-------	-------	-------	→X						
Primary Transient Stability Control	------	-------	-------	-------	-------	→X						
Regional Stability Controls												
Regional Voltage Stability Controls	------	-------	-------	-------	-------	-------	------	--→X				
Equilibrium State Control	-------	-------	-------	-------	-------	-------	-------	--→X				
Inter-Area Oscillation Damping Control	------	-------	-------	-------	-------	-------	------	-------	--→X			
APPLICATION SIMULATOR DEPLOYMENT & TESTING												
Situational Awareness												
Real-time Trending												
Frequency			-------	--→X								
System Voltages				----	-------	--→X						
Path Loading				----	-------	--→X						
Oscillation Energy					----	-------	-------	→X				
Phase Angle Displays/Alarms												
Phase Angle Trending				----	-------	--→X						
Alarms w/ Data Preprocessing												
Voltage Instability Predictor						---	-------	→X				
Reactive Reserve Monitor				---	-------	→X						

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
Oscillation Detection						---	-------	→X				
Mode Meter							---	-------	→X			
Wide-Area Controls												
Secondary Controls & Primary Control Arming												
Secondary Voltage Controls						----	-------	-------	→X			
Wind Site Voltage Controls						-------	-------	-------	→X			
Primary Transient Stability Control						-------	-------	-------	→X			
Regional Stability Controls												
Regional Voltage Stability Controls								-------	-------	--→X		
Equilibrium State Control								-------	-------	--→X		
Inter-Area Oscillation Damping Controls										---	--→X	
CONTROL CENTER AND RELIABILITY COORDINATOR APPLICATION INTEGRATION												
Situational Awareness												
Real-time Trending												
Frequency				---	-------	→X						
System Voltages						---	-------	→X				
Path Loading						---	-------	→X				
Oscillation Energy								---	-------	--→X		
Phase Angle Displays/Alarms												

	Year 1 Q1	Year 1 Q2	Year 1 Q3	Year 1 Q4	Year 2 Q1	Year 2 Q2	Year 2 Q3	Year 2 Q4	Year 3 Q1	Year 3 Q2	Year 3 Q3	Year 3 Q4
Phase Angle Trending						---	-------	→X				
Alarms w/ Data Preprocessing												
Voltage Instability Predictor								---	-------	-→X		
Reactive Reserve Monitor						--	-------	→X				
Oscillation Detection								---	-------	-→X		
Mode Meter									----	-------	→X	
Deployment of Situational Awareness Tools Across Interconnection				---	-------	-------	-------	-------	-------	-------	→X	
Wide-Area Controls												
Secondary Controls & Primary Control Arming												
Secondary Voltage Controls						-------	-------	-------	--→X			
Wind Site Voltage Controls						---	-------	-------	-------	--→X		
Primary Transient Stability Control						---	-------	-------	-------	--→X		
Regional Stability Controls												
Regional Voltage Stability Controls									-------	-------	-------	→X
Equilibrium State Control									-------	-------	-------	→X
Inter-Area Oscillation Damping Controls										-------	-------	--→X

Preliminary Project Cost Projection

Project Element	Total	Year 1	Year 2	Year 3
Infrastructure:				
Planning	$ 5.0M	$ 5.0M		
Design/Materials	$ 42.0M	$ 25.0M	$ 12.0M	$ 5.0M
Construction	$ 29.2M	$ 12.1M	$ 12.1M	$ 5.0M
Applications:				
Situational Awareness:				
Planning	$ 1.8M	$ 1.8M		
Development/Deployment	$ 1.2M	$ 1.2M		
Controls:				
Planning	$ 2.1M	$ 1.5M	$ 0.6M	
Development	$ 1.3M	$ 0.8M	$ 0.4M	$ 0.1M
Deployment	$ 15.0M	$ 2.0M	$ 10.0M	$ 3.0M
Off-Line Tools:				
Development	$ 0.6M	$ 0.6M		
Deployment	$ 1.8M	$ 1.2M	$ 0.6M	
Total:	$ 100.0M	$ 51.2M	$ 35.7M	$ 13.1M

Appendix 2: Current Project Participants

Areva
Bonneville Power Administration
California ISO
California Energy Commission
Electric Power Group
Pacific Gas and Electric
Quanta
Salt River Project
SISCO
Southern California Edison
WECC

Appendix 3: Smart Grid Investment Grant Program

Pertinent FOA – 000058 References

- Purpose of Smart Grid Investment Grant (SGIG) Program is to…modernize the nation's electric transmission….systems and promote investments…which increase flexibility, functionality, interoperability, cyber security, situational awareness, and operational efficiency.

- Preference to activities that can be started and completed expeditiously

- Measureable improvements are desired in:
  - Reliability
  - Electric power system costs
  - Environmental impacts
  - Clean energy development
  - Economic opportunities for businesses and new jobs for workers

- SGIG Goals that this projects should address include:
  - Optimizing asset utilization and operating efficiency
  - Anticipating and responding to system disturbances
  - Operating resiliently to attacks and natural disasters
  - Improvements in: Outage detection, equipment maintenance, asset deferral, cost-effectively integrating renewables, advanced control methods, and decision support (visualization tools, simulation modeling, and power systems analysis)

- SGIG desires projects for design, acquisition, installation, commissioning, and training for PMUs. Projects can include hardware, software that process, manage, store, transmit, receive, or deliver PMU measurement data. Projects can also include applications that utilize PMU data for enhancing the reliability and operational efficiency of the Nation's power system.

- Transmission-Level Metrics are the number of installation points and percentage and magnitude of total load covered by:
    - PMUs
    - PDCs that share data with other parties in support of reliability management
    - Real-time management and visualization systems receiving data from PMUs and PDCs
    - Automated electric transmission systems or possessing advanced measurements
  - This project proposes advances in each of these metrics

- Critical goal is to expand the number and coverage of PMUs in each interconnection that feed their output into a network that … [can] detect and mitigate wide-area disturbances.

- Grants are to support the manufacturing, purchasing and installation of smart grid devices for immediate use

- NASPI and NASPInet are featured:

  - ‘Additional items to consider in the application include: A description of efforts involving NASPInet and phasor gateways for sharing data outside of the project’s service territory or geographic boundaries.’
  - ‘For those projects that involve deployment of PMUs and related devices on electric transmission or distribution systems, there is an opportunity to earn progressively higher technical merit ratings for applications that include the following features: Connecting with organizations such as NASPInet to allow for the sharing of relevant data with external parties in support of reliability management.’

- Funding is $3.4 Billion with 40% to smaller projects ($330K-$20M) and 60% to larger projects ($20M - $200M)

- 50% of total project costs must be matched

- Performance period is 3 years

- Coordinating councils are eligible applicants, Power Marketing Agencies are eligible for supporting roles, but not prime roles, and national laboratories are not eligible. Other eligible applicants include electric power companies, states and local agencies, universities and colleges, electricity consumers, manufacturers, IPPs, energy service providers, marketers, and others.

- Merit Review Criteria:

    - Adequacy of Technical Approach for enabling Smart Grid Function (40%)
    - Adequacy of Plan for Project Tasks, Schedule, Management, Qualifications, and Risks (25%)
    - Adequacy of Technical Approach for Addressing Interoperability and Cyber-Security (20%)
    - Adequacy of Plan for Data collection and Analysis of Project Costs and Benefits (15%)

- Letter of Intent to Apply due July 16, 2009

- Application (40 pages + appendices) due August 6, 2009

- Anticipated awards in October, 2009

Appendix 4: Existing and Future PMUs

Existing PMUs

Location	Organization	Networked
1. Grand Coulee	BPA	Yes
2. John Day	BPA	Yes
3. Malin	BPA	Yes
4. Colstrip	NWE	Yes
5. Big Eddy 230	BPA	Yes
6. Big Eddy 500	BPA	Yes
7. Sylmar - LDWP	LDWP	Yes
8. Maple Valley	BPA	Yes
9. Keeler	BPA	Yes
10. Captain Jack	BPA	Yes
11. Summer Lake	BPA	Yes
12. Slatt	BPA	Yes
13. SCE Devers	SCE	Yes
14. SCE Vincent	SCE	Yes
15. McNary 230	BPA	Yes
16. McNary 500	BPA	Yes
17. Ashe 500	BPA	Yes
18. Bell 500	BPA	Yes
19. Bell 230A	BPA	Yes
20. Bell 230B	BPA	Yes
21. Chief Joseph 500	BPA	Yes
22. Chief Joseph 230A	BPA	Yes
23. Chief Joseph 230B	BPA	Yes
24. Custer 500	BPA	Yes
25. Custer 230	BPA	Yes
26. Garrison 500	BPA	Yes
27. Garrison 230	BPA	Yes
28. Ault 345 - WAPA LC	WAPA	Yes
29. Bears Ears 345 - WAPA LC	WAPA	Yes
30. Shiprock 345 - WAPA LC	WAPA	Yes
31. Yellow Tail - WAPA LC	WAPA	Yes
32. Mead 230	SCE	Yes
33. Vincent	SCE	Yes
34. Mohave G S	SCE	Yes
35. Devers	SCE	Yes
36. Big Creek 3	SCE	Yes
37. Alamitos G S	SCE	Yes
38. San Onofre Switchyard	SCE	Yes
39. Kramer	SCE	Yes

Existing PMUs

Location	Organization	Networked
40. Devers 115	SCE	Yes
41. Antelope 66	SCE	Yes
42. Valley 115	SCE	Yes
43. Magunden	SCE	Yes
44. Eldorado	SCE	Yes
45. Lugo	SCE	Yes
46. Control	SCE	Yes
47. Mira Loma	SCE	Yes
48. Serrano	SCE	Yes
49. Rector 230	SCE	Yes
50. Rector 66	SCE	Yes
51. Midway 500	PG&E	Yes
52. Diablo Canyon	PG&E	Yes
53. Tesla 500	PG&E	Yes
54. Moss Landing	PG&E	Yes
55. Pittsburg 230	PG&E	Yes
56. Los Banos 500	PG&E	Yes
57. Round Mtn. 500	PG&E	No
58. Table Mtn. 500	PG&E	No
59. Four Corners 500 kV Yard	APS	No
60. Four Corners 345 yard	APS	No
61. Navajo G.S.	APS	No
62. Palo Verde G.S.	SRP	No
63. Pinnacle Peak	APS	No
64. Westwing	APS	No
65. Hassayampa	SRP	No
66. Coronado G.S.	SRP	No
67. Kyrene	SRP	No
68. Ingledow	BCH	No
69. Dunsmuir	BCH	No
70. Nicola	BCH	No
71. Williston	BCH	No
72. Selkirk	BCH	No
73. Minette	BCH	No
74. Revelstoke	BCH	No
75. Mica	BCH	No
76. GMS	BCH	No
77. GMS	BCH	No
78. Langdon	Altalink	No
79. Sylmar	LADWP	Yes
80. B-A	PNM	No
81. San Juan	PNM	No
82. West Mesa (Albuquerque West)	PNM	No

Existing PMUs

Location	Organization	Networked
83. Guadalupe (West of Santa Rosa)	PNM	No
84. Rogers Thunderstore	SRP	No
85. Santan Thunderstore	SRP	No
86. Thunderstore Rogers	SRP	No
87. Thunderstore Santan	SRP	No
88. Agua Fria - White Tanks 230Kv	SRP	No
89. Anderson-Orme 230Kv	SRP	No
90. Brandow-innacle Peak 230Kv	SRP	No
91. Palo Verde-Westwing 500Kv	SRP	No
92. Pinal West - Hassayampa 500Kv	SRP	No
93. Brownlee-Oxbow #2	IPCO	No
94. Calldwell-Locust	IPCO	No
95. Locust-Cadwell	IPCO	No
96. Midpoint-Hunt	IPCO	No
97. BoiseBench-wee	IPCO	No
98. Miguel 230	SDGE	No
99. Miguel 500	SDGE	No
100. Mission 230	SDGE	No
101. Mission 500	SDGE	No
102. Sycamore Canyon 230	SDGE	No
103. Anderson 1	AESO	No
104. Anderson 2	AESO	No
105. Anderson 3	AESO	No
106. Bear Creek	AESO	No
107. Benalto	AESO	No
108. Chin Chute	AESO	No
109. Calpine	AESO	No
110. Cordel 1	AESO	No
111. Cordel 2	AESO	No
112. Cordel 3	AESO	No
113. Empress	AESO	No
114. Kettles	AESO	No
115. Langdon	AESO	No
116. Magrath	AESO	No
117. McBride Lake	AESO	No
118. Balzac	AESO	No
119. Cavalier	AESO	No
120. Ruth Lake	AESO	No
121. Sundance	AESO	No
122. Soderglen	AESO	No
123. Summerview	AESO	No
124. Taber	AESO	No
125. Carseland	AESO	No

Existing PMUs

Location	Organization	Networked
126. Whitefish	AESO	No
127. Genessee 1	AESO	No
128. Genessee 2	AESO	No
129. Crystal	NEVP	No
130. Apex	NEVP	No
131. Mead	NEVP	No
132. SilverHawk	NEVP	No
133. Lenzie 1	NEVP	No
134. Lenzie 2	NEVP	No
135. Camp Williams	PAC	No
136. Jim Bridger	PAC	No
137. Valmy	SPR	No

Suggested PMUs

Location	Organization	Suggested by	Visibility of?
1. Adelanto	LDWP	DMWG	DC
2. Intermountain	LDWP	DMWG/NERC	DC
3. Marketplace	LDWP	DMWG	SVC
4. Adelanto	LDWP	DMWG	SVC
5. Paul	BPA	DMWG	Generation
6. Imperial Valley	SDGE	DMWG	Generation
7. Sylmar	LDWP	DMWG	DC
8. Toluca	LDWP	DMWG	Load
9. Dworshak	BPA	DMWG	Generation
10. Lower Granite	BPA	DMWG	Generation
11. Lower Monumental	BPA	DMWG	Generation
12. Little Goose	BPA	DMWG	Generation
13. Grizzly	BPA	DMWG	Transmission
14. Midpoint	IPCO	DMWG	Transmission
15. Mona	PAC	DMWG	Transmission
16. Libby	BPA	DMWG	Transmission
17. Borah	IPCO	DMWG	Transmission
18. Kinport	IPCO	DMWG	Transmission
19. Great Falls	NWMT	DMWG	Transmission
20. MATL	ALTALINK	DMWG	Transmission
21. Luna	EPE	NERC	Transmission
22. Newman	EPE	NERC	Generation
23. Greenlee	TEP	NERC	Transmission
24. Vail	TEP	NERC	Transmission
25. Springerville	TEP	NERC	Generation
26. Tracy	SPR	NERC	Transmission
27. Gonder	SPR	NERC	Transmission
28. Ben Lomond	PAC	NERC	Transmission
29. Mona	PAC	NERC	Transmission
30. Sigurd	PAC	NERC	Transmission
31. Red Butte	PAC	NERC	Transmission
32. Laramie River Station	TSGT	NERC	Generation
33. Wyodak	PAC	NERC	Transmission
34. Craig	WAPA	NERC	Generation
35. Midway	PSCO	NERC	Transmission
36. Curecanti	WAPA	NERC	Transmission
37. Ault	PRPA	NERC	Transmission
38. Ft. St. Vrain	PSCO	NERC	Generation
39. Antelope Wind	SCE	Proposal Team	Wind Site
40. Arlington W1	BPA	Proposal Team	Wind Site
41. Big Horn	BPA	Proposal Team	Wind Site

Suggested PMUs

Location	Organization	Suggested by	Visibility of?
42. Contra Costa Wind	PG&E	Proposal Team	Wind Site
43. Devers Wind	SCE	Proposal Team	Wind Site
44. ES Juarez W1	SDGE	Proposal Team	Wind Site
45. Golden Hills W1	BPA	Proposal Team	Wind Site
46. Klondike W3-A	BPA	Proposal Team	Wind Site
47. Leaning Juniper W2	BPA	Proposal Team	Wind Site
48. Little Goose W1	BPA	Proposal Team	Wind Site
49. Milford Wind	LDWP	Proposal Team	Wind Site
50. NM Wind_EC1	PNM	Proposal Team	Wind Site
51. PTZLOGN1	PSCO	Proposal Team	Wind Site
52. PTZLOGN2	PSCO	Proposal Team	Wind Site
53. Shepherds_Flat W1	BPA	Proposal Team	Wind Site
54. Shepherds_Flat W2	BPA	Proposal Team	Wind Site
55. Shepherds_Flat W3	BPA	Proposal Team	Wind Site
56. Shiloh III	PG&E	Proposal Team	Wind Site
57. Tehachapi_24252	SCE	Proposal Team	Wind Site
58. Tehachapi_24254	SCE	Proposal Team	Wind Site
59. Tesla Wind	PG&E	Proposal Team	Wind Site
60. Twin Butte	PSCO	Proposal Team	Wind Site
61. White Creek	BPA	Proposal Team	Wind Site
62. Wild Horse	PSE	Proposal Team	Wind Site

Appendix 5: Glossary of Terms

AC	Alternating Current
ARRA	American Recovery and Reinvestment Act of 2009
BA	Balancing Authority
COI	California-Oregon Intertie – a 4800 MW AC Intertie System
DOE	US Department of Energy
EMS	Energy Management System – A control room operator's primary tool
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronic Engineers
FERC	Federal Energy Regulatory Commission
FIDVR	Fault Induced Delayed Voltage Recovery – referring to adverse grid condition caused by stalling of air-conditioners
FOA	Funding Opportunity Announcement
MVWG	WECC's Model Validation Work Group
NASPI	North American Synchro-Phasor Initiative
NASPInet Data Classifications	An architecture designed for interconnection-wide phasor data sharing. It is intended to support multiple on-line and off-line phasor data applications. Services classes supported, with quality of service guarantees for each class are: Class A – high performance feedback control

	Class B – feed forward control (state estimation) Class C – operator visualization Class D – event analysis and off-line queries Class E – test and research
NERC	North American Electric Reliability Corporation
NDA	Non-disclosure agreement
NOC	Network Operations Center
PDC	Phasor Data Concentrator
PDCI	Pacific Direct Current Intertie – referring to the ± 500 kV, 3100 MW Intertie between Celilo (on the Washington – Oregon Border) and Sylmar (in Los Angeles)
PMU	Phasor Measurement Unit
Primary Controls	Automatic controls taken in less than 1 second in response to a changing system condition or system disturbance
QoS	Quality of Service
RAS	Remedial Action Scheme – a special protective control scheme to preserve reliable operation
RC	Reliability Coordinator – Located at WECC's Reliability Coordination Offices in Vancouver, Washington and Loveland, Colorado
RCO	Reliability Coordination Office
SCADA	Supervisory Control and Data Acquisition
Secondary Controls	Control actions taken within several minutes to help the system recover and to position the system best

	to withstand the next disturbance. May be manual control actions.
Super PDC	Collecting and concentrating data from PDCs — located at the RCs and some Major BAs
SVC	Static Var Compensator – a device used to provide dynamic reactive power for voltage support to the grid
VAR	Volt-Ampere Reactive – a measure of reactive or imaginary power useful in supporting healthy voltages on the grid
WECC	Western Electricity Coordinating Council