PHASOR TECHNOLOGY RESEARCH ROADMAP FOR THE GRID OF THE FUTURE

Eastern Interconnection Phasor Project Executive Steering Group

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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EXECUTIVE SUMMARY

In 2002, Department of Energy and Consortium for Electric Reliability Technology Solutions[1] (CERTS) initiated a project on utilization of phasor technologies in the Eastern Interconnection. The goal was to research application of phasor technologies for grid monitoring, control and reliability management. This research effort enjoyed early support of industry stakeholders, including MISO, NYISO, Tennessee Valley Authority, New York Power Authority, American Electric Power, Entergy, and North American Electric Reliability Council. This initiative was called the Eastern Interconnection Phasor Project (EIPP).

On August 14, 2003, the Eastern Interconnection suffered a major blackout that resulted in the loss of 60,000 MW of power affecting 50 million people. Investigations of the blackout concluded with key findings and recommendations that included need for:

- Improved situational awareness;
- Real time visibility of system conditions over wide areas;
- Better real time tools for operators and reliability coordinators;
- Utilization of wide area time-synchronized data for grid management and systems dynamics monitoring; and,
- Improved voltage management and system modeling to define system state.

The EIPP became a focal point of DOE and industry collaboration to address the recommendations above. In the 2.5 years since the August 2003 blackout, the EIPP has:

- 50 Phasor Measurement Units (PMUs) across the interconnect and 7 Phasor Data Concentrators (PDCs);
- Expanded participation from the initial set of utilities and independent system operators (ISOs) to broaden coverage and reach;
- Established an initial network linking 34 PMUs and transmitting data to a central data repository at Tennessee Valley Authority;
- Implemented a central data repository for retrieval and use of phasor data to monitor and analyze system performance during normal, emergency, and post-disturbance periods;

[1] CERTS is currently conducting research with funding from the U.S. Department of Energy (DOE) Transmission Reliability Program and the California Energy Commission. CERTS is working with electric power industry organizations, including ISOs, RTOs, NERC, and utilities. CERTS members include Electric Power Group, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Power Systems Engineering Research Center (PSERC) – consortium of 13 universities, and Sandia National Laboratories.

- Attracted the vendor community to accelerate development and commercialization of phasor technology hardware and upgrade EMS/analysis software; and,

- Identified research opportunities for utilization of phasor data to improve modeling, analysis, operations, monitoring, control, visualization, system dynamics, and other areas.

EIPP's success has encouraged utilities to fund investments in more phasor measurement units, network infrastructure and data collection. This has produced (and continues to produce) system data that opens up research that addresses the larger public interest; the R&D payoff goes well beyond individual utilities and control areas.

Phasor data provides insights for the management and operation of the power system which were previously not possible. The industry standard has been 2 or 4 second resolution SCADA data, designed for viewing the local control area. Phasors provide time-synchronized data, wide area coverage and finer resolution from sample rates of up to 60 data points per second. Phasors are the equivalent of "MRI of the power grid", while SCADA is the "x-rays".

Industry has taken the lead on installing PMUs and deploying phasor infrastructure as part of the EIPP. The research needs now shift to actual utilization of phasor data to developing applications and solving problems, i.e., improving system reliability, facilitating market operations, improving grid security, and supporting policymaking. Specific areas that need to be addressed include:

- Analyzing, processing, and presenting operational data to system operators that is clear and actionable (i.e. focus on human factors)

- Understanding dynamic behavior of systems beyond their control area (wide area visualization).

- Using phasor data to better understand grid dynamics and detect vulnerabilities in real time.

- Using phasor data to define safe and reliable operating zones in real time.

- Addressing the challenges of data collection, transmission, synchronization, archiving, management, and retrieval of phasor data to assure data security and data quality.

- Using phasor data to improve system modeling.

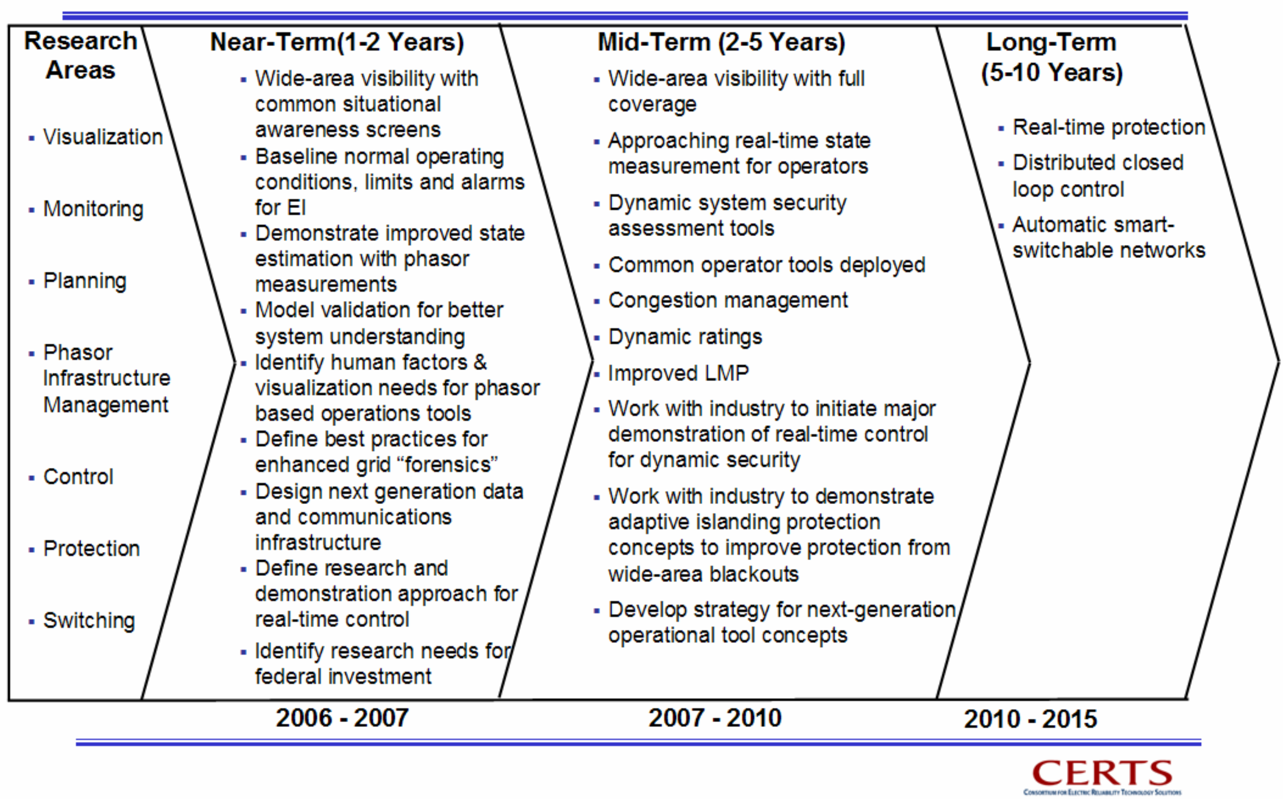
- Using phasor data for dynamic line ratings and real time stability assessments.

- Using phasor data to improve state estimation.

These important research topics clearly extend beyond the reach of individual utilities and industry stakeholders. Consequently, DOE's sustained leadership and funding of R&D to leverage phasor data is critical to addressing public interest needs.

This research roadmap outlines needs, roles, responsibilities, and milestones – near-, mid-, and long-term – for leveraging phasor data. A summary of research milestones and goals is presented in Figure 1.

Figure 1: Summary of Research Goals and Milestones



1. INTRODUCTION

The North American power grid was built and operated as a vertically integrated system under the control of local utilities. This system has been undergoing significant transformation over the last 50 years with formation of utility control areas, interconnections among neighboring utilities, formation of ISOs/RTOs (independent system operators/regional transmission organizations), and development of regional grids and markets.

The fundamental elements and principles of power system operation and control were established before the 1960's to serve the vertically integrated utilities. Electric power grid operating systems all use System Control and Data Acquisition (SCADA) to collect real time data to monitor and control the power system. These SCADA systems all have a local focus to serve the vertically integrated utility control area. SCADA system infrastructure has evolved over the years to take advantage of new control, communications, and computing technology. Wide area grid monitoring and management using SCADA systems, however, presents significant challenges. It is costly, time consuming and impractical to try and use these systems to encompass a wide area. Additionally, the field RTUs used in these systems communicates information with time scales ranging from every few seconds to as long as several minutes – these rates are inadequate for observing power system dynamics.

Operators look at potential problems by using contingency analysis, driven from state estimation that is fed by data collected by the SCADA system. Although, state estimation fills in the observability gaps within the utility or control area, the slower time scales associated with this process (typically every 5 minutes) restricts the monitoring and any downstream analysis capability to steady-state conditions while most stability limits are rooted in the dynamic phenomena. Furthermore, not all control areas use state estimators. Those control areas that do have state-estimates, may not use its output in real-time contingency analysis tools, but rather run these tools on demand following potentially significant system events.

Presently, intelligence with the electric power grid is restricted to either protection systems applied locally at the substation or centrally at the control center through the SCADA/EMS systems. The only wide-area control in common use today is AGC for frequency control partially because of the type of phenomena it addresses allows for slow control. During emergencies, although there are fast acting remedial action schemes in place, these are very localized. Much of the wide-area coordination across the power grid still happens telephonically between the system operators at the various utilities on a much slower time scale.

2. INDUSTRY CHALLENGES

Electric grid operators are faced with significant operating challenges to assure reliable, secure and efficient market operations. These challenges include:

- utilizing the power grid as a regional network while its design is based on local control;
- reliance on market signals for energy supplies, reserves and ancillary services as opposed to direct control;
- atypical and changing load and power flow patterns based on market economics as opposed to engineering algorithms;
- economic and market pressures to accommodate all transactions which may result in "unstudied" flow patterns and loadings;
- limited wide area visibility and monitoring tools;
- increase in number of players and transactions;
- separation of operating and market functions; and,
- shift in grid control, management and market operation decisions from local utilities and control areas to ISOs/RTOs.
- lack of user-friendly tools to allow operators to effectively manage new system complexities.
- lack of an early detection system for low probability but high impact system conditions

Furthermore, America's electric system is aging. Much of the infrastructure was built in the 60's and 70's and needs new investments and technologies to meet the needs of the future grid. In the coming decades, electricity's share of total energy is expected to continue growing. Transmission load is projected to grow in the next ten years by 22-25%; the grid, however, is expected to grow less than 4%. Utilities are less willing to make investments in transmission reliability that does not increase revenues. The lack of transmission expansion and environmental constraints makes reliable system operation a more challenging task.

At the same time, there are increased interdependencies among certain infrastructures such as electric power, transportation, communications, and finance infrastructures which are critical for the well being of modern society. Grid failures which propagate across these critical infrastructures come at enormous human and economic cost, so the demand for higher reliability and better security and protection has never been greater.

Recent task force studies show evidence of degrading reliability performance over the years. For example, the Frequency Response Characteristic (FRC), which is a measure of the Interconnection's primary frequency control to significant change in load-generation balance and the initial defense towards arresting its decline and supporting the system frequency, is at a decline. FRC survey results gathered for the observed frequency deviations over various outages indicate that the Eastern Interconnection's Frequency Response has declined from about -3,750 MW/0.1Hz in 1994 to less than -3,200 MW/0.1Hz in 2002 (i.e., an 18% decline) while load and generation grew nearly 20% over the same period (Figure 2). A similar decline has also been observed in the Western Interconnection's Frequency Response. Theoretically, Frequency Response should have increased proportionally with generation and load. In the past many control areas carried full reserves for their individual largest contingency and some for multiple contingencies. However, competitive pressures and greater reliance on reserve sharing groups (RSG) have reduced reserves and safety margins. If these trends continue, they may jeopardize the interconnection's ability to withstand large disturbances and move the system closer to automatic under frequency load shedding.

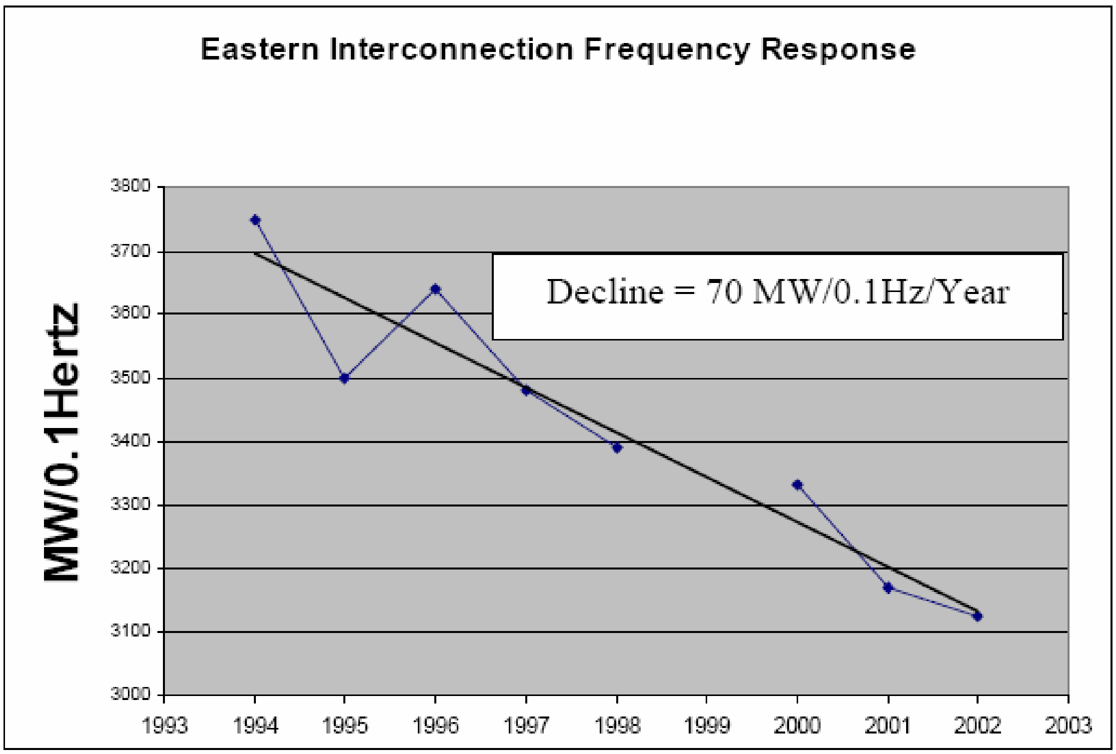


Figure 2: Trend in Eastern Interconnection Frequency Response[2]

Some of the secondary effects of such a decline include the incapability of self restoration during islanding and black-start conditions, poorly damped system, and inaccurate stability transfer limits. Additionally, NERC resources subcommittee also noted a similar degradation in secondary control (i.e. control area's ability to continuously maintain its generation-demand balance and system frequency) where control areas failed to match

[2] Source: North American Electric Reliability Council (NERC), "Frequency Response Standard Whitepaper", April 6, 2004.

their scheduled and actual interchange or provide their frequency bias obligation. An increase in frequency control deviation within the Eastern Interconnection has also been observed. Variations in the power system frequency indicate perturbations that signal risk to the grid. Without appropriate monitoring infrastructure, measures or requirements, increasing demand will likely continue to drive such a decline in performance.

This mismatch between the growing power system reliability needs and the eroding spare capacity and performance, coupled with the rising impact of outages on the nations vital infrastructures highlight the necessity for redefining the current power system operation and planning practices, and to look towards new tools and technologies to meet the challenges and the needs in this new competitive era. Critical challenges faced by power grid managers include:

- High congestion costs – estimated at billions of dollars annually across the U.S.
- The need for additional transmission transfer capacity
- Limited post disturbance assessment capability
- Inaccurate power system models

3. AUGUST 14, 2003 BLACKOUT RECOMMENDATIONS

Reliable electricity supply is becoming increasingly more essential for society, and blackouts are becoming increasingly more costly. In recent years, there has been an increase in the frequency and severity of blackouts in North America and Europe which underscores the grid's increasing vulnerability. The most recent major blackout occurred on August 14, 2003 and impacted 50 million people in the Eastern Interconnection. Investigation of the blackout carried out by the US-Canada Power System Outage Task Force indicated several causes or contributory factors in common with the earlier outages, including:

- Inadequate situational awareness and regional-scale visibility over the bulk power system
- Inability of system operators or coordinators to visualize events on the entire system
- Failure to ensure operation within secure limits
- Failure to identify emergency conditions and communicate that status to neighboring systems
- Inadequate training of operating personnel

The bi-national investigation recommendations to reduce the possibility and scope of future outages included:

- Need for wide-area visibility and situational awareness to address problems before they propagate
- Adopt better real-time tools for operators and reliability coordinators
- Require use of time-synchronized data recorders
- Improve system modeling, data quality and data exchange practices
- Strengthen reactive power and voltage management practices
- Expand research programs on reliability-related tools and technologies

The Eastern Interconnection Phasor Project, and DOE's continued support of R&D activities, directly addresses these recommendations.

4. PHASOR TECHNOLOGY OVERVIEW

Phasor technology[3] is one of the key promising technologies on the horizon that could help improve the Nation's electric delivery system reliability and security, relieve transmission congestion, and address some of the above mentioned problems in system planning and operations. Phasor technology complements existing SCADA systems by providing the high sub-second resolution and global visibility to address the new emerging need for wide area grid monitoring, while continuing to use existing SCADA infrastructure for local monitoring and control.

Recent advances in the field of phasor technologies offer new possibilities in providing the industry with new tools and applications to address the blackout recommendations and to tackle reliability management and operational challenges faced by system operators and reliability coordinators. In particular:

- Phasor technology provides time synchronized sub-second data which is applicable for wide area monitoring; real time dynamics and stability monitoring; dynamic system ratings to operating power system closer to the margin to reduce congestion costs and increasing asset utilization; and improvements in state estimation, protection, and controls.
- Phasor measurement equipment, algorithms and applications have been successfully prototyped in the lab and in test environments. They are mature enough to transition into operational environments.
- Technical developments in communication technologies and measurement synchronization have made the design of wide area monitoring, protection and control systems realizable.

[3] Phasor technology is considered to be one of the most important measurement technologies in the future of power systems due to its unique ability to sample analog voltage and current data in synchronism with a GPS-clock and compute the corresponding phasor quantities (i.e. complex numbers representing the magnitude and phase angle of a 60 Hz sinusoidal waveform) from widely dispersed locations

- Traditional SCADA/EMS systems are based on steady state power flow analysis, and therefore cannot observe the dynamic characteristics of the power system – phasor technology is the "MRI of the power system" industry providing the high sub-second visibility required for studying dynamic behavior and, therefore, overcoming the limitations of the old "x-ray" quality visibility that traditional SCADA-based systems offer.
- The precise timing of phasor data makes it useful beyond the local bus where the measurement was taken, i.e. the technology offers wide area visibility. This, in turn, facilitates the capability for distributed sensing and coordinated control action.
- Phasor measurements improve post disturbance assessment capability using high-resolution time-synchronized data.
- The high data rates and low latency associated with phasor acquisition systems provide the desired agility to respond to abnormal conditions.

The utilization of real-time phasor measurements in the fields of visualization, monitoring, protection, and control is expected to revolutionize the way in which the power grid of the future will respond to contingencies.

5. EASTERN INTERCONNECTION PHASOR PROJECT (EIPP)

The Eastern Interconnection Phasor Project (EIPP) was started in 2002 by Department of Energy (DOE) and Consortium for Electric Reliability Technology Solutions (CERTS). DOE has served as a catalyst for collaboration among utilities, ISOs/RTOs, NERC transmission companies, researchers and vendors to demonstrate phasor technology to the Eastern Interconnection (EI) participants.

The EIPP gained momentum as a result of the August 14, 2003 blackout. EIPP targets many of the recommendations of the blackout investigations. Specifically, the project addresses several (5) requirements in the NERC V0 Standard for Planning and many (6) NERC blackout recommendations.

The mission statement of the EIPP, "to create a robust widely available and secure synchronized data measurement infrastructure over the eastern interconnection with associated analysis monitoring tools for better planning and operation, and improved reliability," has been and continues to be supported by the industry and government officials at the highest level. The project participants are drawn from a broad array of stakeholders including utilities, operating/reliability organizations, academia, research institutions and government laboratories, manufacturers, IEEE and other standards bodies and more.

To achieve its objectives, the EIPP Work Group has organized six Task Teams, each lead by an industry member and supported by a DOE-funded CERTS team member, to address different aspects of the project (Figure 3):

- Equipment Placement Task Team – The responsibilities of the Equipment Placement Task Team include planning, coordinating and managing the placement of phasor measurement devices across the EI and identifying possible observability gaps across the system.

- Real-Time Applications Task Team – The scope of the Real-Time Applications Task Team is to define, prototype and deploy monitoring tools for dispatchers, reliability coordinators and others responsible for maintaining grid reliability, to effectively monitor and assess the real-time operations of the power grid.

- Offline Applications Task Team – The scope of the Offline Applications Task Team is to define, prototype and deploy tools for planners, analysts and others, to assess system performance, model validation and to enhance decision making related to bulk grid reliability.

- Business Management Task Team – The responsibilities of the Business Management Team include coordinating and resolving matters related to agreements between the involved parties (e.g. non-disclosure agreements).

- Data Management Task Team – The responsibilities of the Data Management Task Team include architecting and managing the phasor data storage and retrieval system.

- Performance Requirements Task Team – The responsibilities of the Performance Requirements Task Team include evaluating performance of phasor measurement devices and components, define satisfactory performance guidelines and protocols, and acting as liaison to the standards efforts in the phasor technology area.

The Task Team leaders along with NERC, CERTS and DOE representation form a Leadership Committee to facilitate communication and coordination between the activities of the different Teams. There is also an Executive Steering Group (ESG) comprised of senior executives from different utilities and organizations to establish liaison with the external organizations and to provide leadership and guidance towards increased PMU deployment, expand organizations installing PMUs, and planned transition to utility-led EIPP.

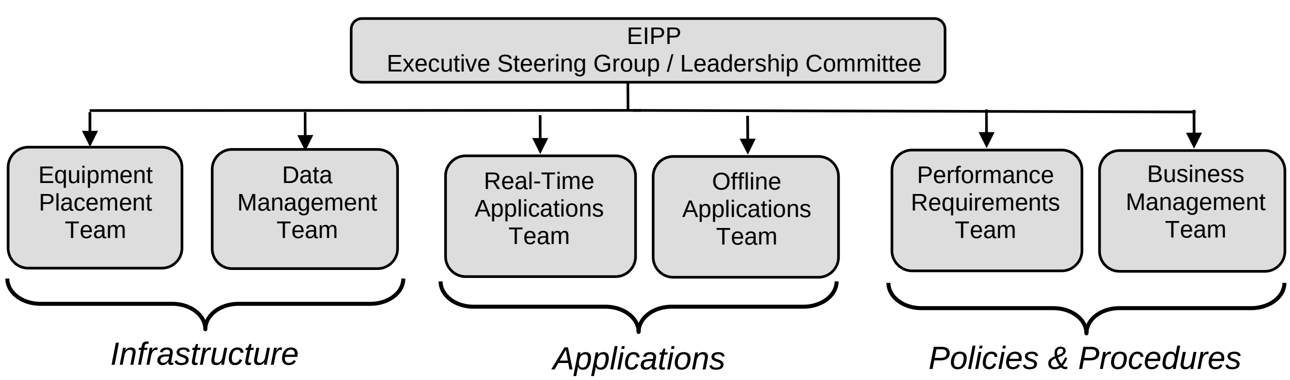


Figure 3: The EIPP Organizational Structure and Responsibilities

DOE's facilitation of the Eastern Interconnection Phasor Project (EIPP) and initiative to fund the initial research and demonstration activities has been invaluable. This is evident both in terms of the growing involvement and contribution by industry participants as well as the project's major accomplishments to date. The EIPP Work Group consists of over 220 interested stakeholders working together to advance the state of the art in power system monitoring and to share information deemed valuable in enhancing the reliability of the bulk grid. Industry has also stepped up to fund investments in deployment of phasor measurement devices, network infrastructure, and data collection, and vendors are stepping up their investments to bring new phasor based hardware and software to the market.

Under the auspices of the EIPP, the initial demonstration of a starter phasor network connecting 34 existing Phasor Measurement Units within the Eastern Interconnection from multiple utilities and providing real-time wide area visibility is complete and fully operational. The additional firm commitments for new installations before March 2006 demonstrates industry's continued commitment in moving this initial demonstration forward and supporting the project. Additionally, at least 12 vendors now supply instruments with phasor measurement capabilities. It is expected that while DOE will continue to seed such proof of concept efforts, the utilities and manufacturer and vendor community shall continue to expand the underlying infrastructure into a commercial production quality system and take ownership of the maintenance and support.

6. EIPP ACCOMPLISHMENTS

The EIPP project has made several accomplishments over a very short time span. Some of the major achievements of the project are summarized below.

Establish Starter Network – DOE's early leadership through the EIPP project has enabled the industry to coalesce around a common goal to establish the starter network and demonstrate and validate the potential of phasor technology for the public benefit. The initial EI phasor network connecting 34 PMUs dispersed across various EI utilities is in place and is fully operational. This starter phasor network uses point-to-point VPN links for real-time data transfer between utilities with existing PMU installations (i.e., Ameren, AEP, NYISO and Entergy) and Tennessee Valley Authority (TVA) which currently serves as the central host site for synchronizing this phasor data. In support of this EIPP endeavor, TVA has made substantial contribution in developing a central data store, called the "Super Phasor Data Concentrator" (or "Super PDC"). The phasor measurements sent to TVA are integrated and aligned across utilities by the Super PDC to provide a precise Interconnection-wide snapshot, as well as simultaneously archived into TVA's DatAWare data repository for long-term storage. Comparisons of high sub-second snapshots enable real-time monitoring and tracking of grid dynamics and stress. TVA's real-time data output stream and central archive supports industry standard protocols such as BPA PDCStream for real-time streaming data and OLE for Process Control (OPC) and XML for historical data.

Provide Real-Time Wide Area Visibility – The August 14 blackout pointed to a need for operating tools that provide wide area views of the grid state and also time-synchronized history following an event. The DOE funded Real-Time Dynamics Monitoring System

(RTDMS) is currently the prototype tool in place for providing this type of wide area viewing across the Eastern Interconnection phasor data in real-time (Figure 4). To allow convenient access to the data in real-time and at multiple locations, RTDMS uses secure web connections to retrieve data from TVA's Super PDC, cleanse the data and distribute this data to its many remote visualization terminals. These multiple RTDMS visualization applications use various geographic and graphic displays to provide operators and reliability coordinators both near real-time and time series information on:

- Interconnection and local frequencies at key monitoring points across the EI. Changes in frequency are mapped to precise generation-load imbalances within the Interconnection. The local frequency measurements can be used to assess stress under normal operating conditions, as well as to estimate the points of deceleration and acceleration during a disturbance.
- Phase angle differences across different utilities with respect to alarming thresholds. Thresholds can be defined by offline analysis and operator experience to assess the static stress across the system and its proximity to instability.
- Wide area view of system voltage angle and magnitude profiles to identify the sources and sinks of power, and the high and low voltage regions within the grid.
- Monitor and track the MW and MVAR values across key transmission lines and flowgates with respect to predefined thresholds.

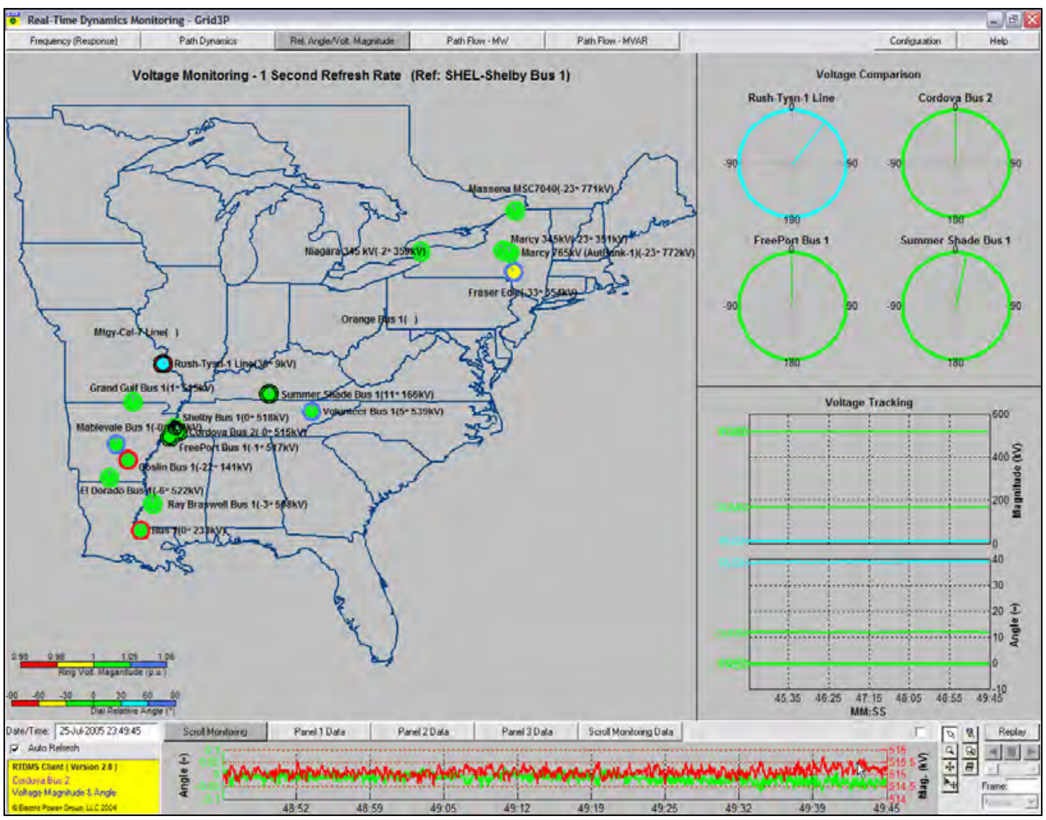


Figure 4: The Sample RTDMS Visualization Display

This system offers flexibility in terms of it being designed as an open and scalable platform with the ability of other vendor applications to access data using its available Web Service.

The RTDMS application had been deployed to the 7 operations centers and 11 reliability coordinators within the Eastern Interconnection. Some of the other early visualization tools provided by vendors like Powerworld and OSISoft are also installed at a few of the EI utilities.

Improved State Estimation – The EIPP Real-Time Task Team is providing coordination and support to a demonstration project currently under way by energy management system (EMS) vendors in collaboration with utilities to utilize phasor measurements in the state estimation process. Phasor measurement devices directly measure the system state with high precision and are therefore believed to improve state estimation. There are many alternatives available for using phasor measurements in the state estimation: some are non-invasive to the conventional state estimation process but rather use the output of these traditional state estimators in conjunction with the phasor measurements, while others use the phasor measurements along with SCADA data as direct inputs in a hybrid state estimation process. Preliminary research has shown that as little as 10% coverage by strategically placed PMUs dramatically improves the accuracy and processing speed of state estimation. Such improved accuracies in state estimation process will be reflected in economics operations (e.g. LMP computations), contingency analysis, and security margin estimates which utilize the state estimation results as inputs in their computations. The results from the state estimation activity are expected to be made available further down the road. This exercise will reveal some of the underlying challenges in fulfilling this activity such as unobservability, data rate incompatibility, etc.

Establish Performance Guidelines – The Performance Requirements Task Team is currently investigating several key areas of interest for EIPP stakeholders with the plan to document findings in a series of “requirements documents”. The requirements documents are intended to be used by utility engineers or suppliers who wish to gather information that will help them participate in the project. The team has prepared a document on the raw phasor data utilization which covers various relevant topics such as data accuracy, minimum performance requirements phasor network components, characterization of synchronized measurement devices and instrumentation channels, etc. In addition, the team is also pursuing requirements documents for PMU testing/interoperability/calibration, PMU/PDC installation/commissioning, state estimation using synchrophasors, phase angle reference for PMU measurements, phase inconsistency in PMU measurement’s, naming conventions, etc. The National Institute of Standards and Technology (NIST) recently created a SynchroMetrology Laboratory to support this EIPP activity and other industries that make use of synchrophasors. As phasor technology and associated applications become commercial, many of these performance guidelines may eventually be incorporated into industry standards.

Project Advocacy – Perhaps the greatest testament to the value of the EIPP project is the overwhelming industry involvement and support it has received, and the fast pace EI utilities are deploying of these new devices. A key focus of the Real-Time Applications Task Team activities has been to involve the Reliability Coordinators and other system operators, to introduce them to this new technology and applications, and especially get their feedback in the definition and development of these early monitoring tools. To encourage increased stakeholder involvement in the EIPP project, the team has also distributed a generic Business Plan which interested parties may use to justify participation in the project.

Resolve Data Confidentiality Issues – One of the major obstacles in the sharing of this high resolution phasor data has been protecting the confidentiality of this data. In the short-term, to expedite the sharing process, the Business Management Team put in place an "Interim Data Confidentiality Agreement" that was signed by each of the initial EIPP data contributors and protected the data confidentiality and its misuse. Working with NERC, the NERC "*Confidentiality Agreement for Electric System Security Data*" has now been modified to include time-synchronized phasor measurement data. All signatories of this new NERC non-disclosure agreement now have access to this real-time data.

DOE leadership and funding has been critical in galvanizing the industry behind demonstration of the phasor technology. Now the R&D focus shifts from validating the fundamental technology to applying phasor data to improve grid reliability, security, efficiency as part of meeting DOE's vision for the grid of the future.

7. OVERVIEW OF PHASOR TECHNOLOGY VISION AND RESEARCH ROADMAP

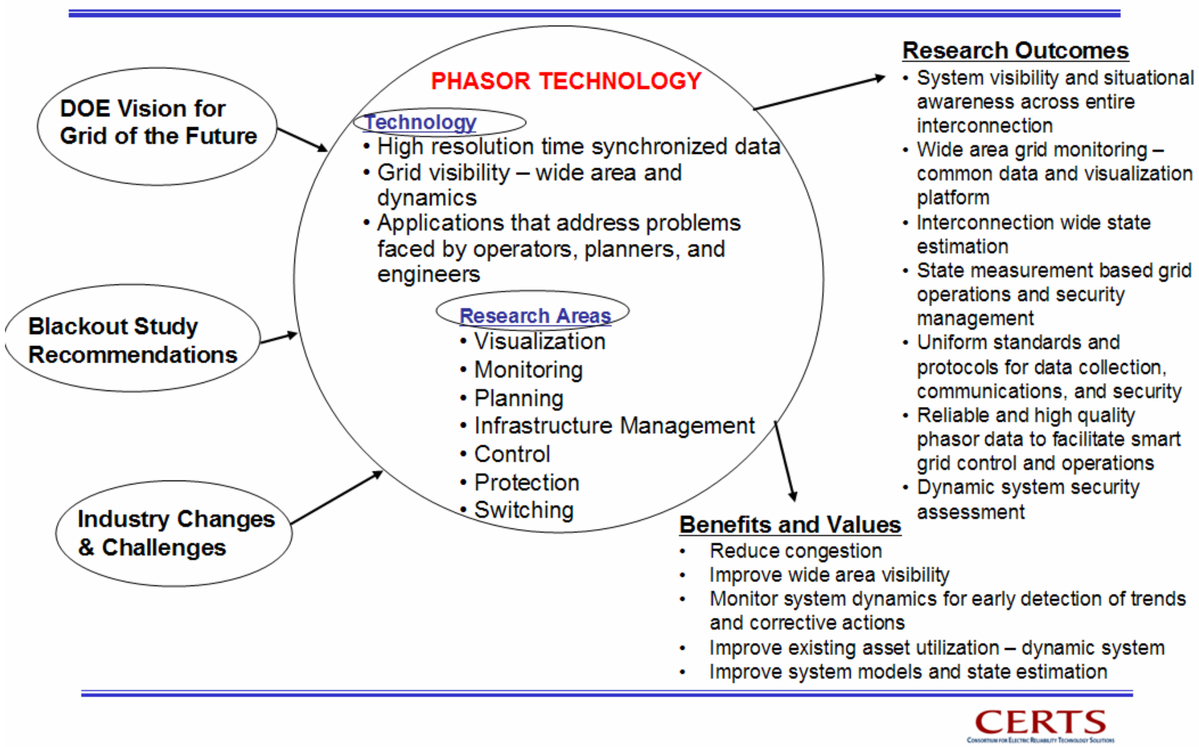
With the EI starter phasor network in place gathering real-time phasor data across the Interconnection, the stage is set to begin utilizing this data for research, prototyping, and demonstration of new phasor technology based applications for the operating and planning environments. DOE's role has been instrumental in the successful demonstration and validation of the basic technology to the EI participants who have begun embracing it, and EIPP is now poised for the next phase of research and demonstrations. It is equally vital for the sustained success of the project that DOE continue to provide leadership, coordination and direction though these initial research and demonstration stages of using this technology to enhance reliability, promote market efficiency, and set the path for tomorrow's smart, automatic switchable network.

The research needs, technology vision and research roadmap are the result of inputs from EIPP Leadership Team and direction from the EIPP Executive Steering Group. The EIPP Leadership team met on October 13, 2005 in Arlington, Virginia to discuss and define the vision for the grid of the future, research goals and milestones, future path of the EIPP, and roles and responsibilities for the DOE and industry stakeholders. On October 31, 2005, the EIPP Executive Steering Group met in Princeton, NJ to review the framework for the Phasor Technology Research Roadmap.

There is consensus on the need to modernize the power grid and develop and deploy advanced technologies to move the power industry from the traditional electro-mechanically controlled grid into the digital age of an electronically controlled network. The vision of the Nation's power system is a one that functions in a new operating paradigm that integrates reliable and secure grid operations along with efficient market operations. The power grid of the future is built on a smart-switchable and automatically self correcting infrastructure with intelligence distributed across each of its components to adapt, reconfigure and respond in a coordinated fashion to achieve an optimal operating state and steer away from an impending catastrophic event under a broader array of destabilizing disturbances.

Phasor technology, in conjunction with other communication and computation technologies and high-power electronic devices, offers a vision that is beyond the conventional local protection systems or central control systems and closer to a fully distributed intelligent system and a truly smart grid. In addition, the research focus needs to be responsive to DOE's Vision of the Grid of the Future, to Blackout Study Recommendations, and Industry Challenges. An Overview of the Phasor Technology Vision and Roadmap is provided in Figure 5.

Figure 5: Phasor Technology Vision and Roadmap - Overview



8. RESEARCH NEEDS, GOALS AND MILESTONES

The EIPP Leadership has identified the following seven key research areas that need to be targeted by the Work Group members: Visualization, Monitoring, Planning, Phasor Infrastructure Management, Control, Protection, and Switching.

To develop the Phasor Technology Research Roadmap, each of the research areas were mapped with problems faced by the industry to define Research Needs. A summary of the Industry Problems, Research Areas, and Research Needs is presented in Table 1.

Table 1: Industry Problems and Research Needs

Areas		Problems	Research Needs
Visualization	Wide Area Visibility	- Lack of knowledge beyond Control Area - Limited dynamics monitoring capability restricted to offline analysis	- Define real-time Interconnection-wide visualization system for operators and RCs - Research new performance metrics for dynamics and phasor information
	Display Management	- Lack of common displays across EI - Fast growing phasor network resulting in display clutter and overwhelming streaming data	- Define standardized situational awareness screens for communication across EI - Involve human factors experts to address visualization needs for phasor based tools - Define summary displays to present relevant information in an integrated fashion
Monitoring	Real-Time Alarming and Reporting	- Undefined alarming criteria on high resolution data and wide-area monitoring - Lack of automated reporting capabilities on system conditions, trends and analysis	- Identify alarming thresholds based on trends, simulations and operator experience - Define reporting requirements and procedures for early warning, threat analysis, etc.
	Interconnection Wide State Estimation	- Currently limited to utility jurisdiction - Convergence problems - Inaccurate system status/modeling - Data sources with inconsistent data rates	- Define optimal PMU placement - Validate traditional SE results with phasor data - Integrate phasor and SCADA data for SE (Hybrid SE) - Improve system topology info. with PMU data - Use of PMU data for boundary equivalents/model reduction - Resolving seams related issues for interconnection wide state estimation
	Measurement Based Sensitivities	Traditionally based on steady-state analysis using models	- Define monitoring points/parameters used in sensitivity computation (e.g. P-V, δ-P)
	Security Assessment	- Traditionally based on offline analysis and there fore conservative	- Dynamic line rating (thermal monitoring, volt. stability margins, damping monitoring) - Validate/improve nomograms using dynamic information - Develop new angle based nomograms
Planning	Post-Disturbance Analysis	Unsynchronized data from multiple sources	- Baseline normal operating conditions and limits - Set guidelines for cleaning/aligning data for offline analysis - Define procedures for enhanced grid "forensics" (e.g. Prony Analysis)
	Model Validation	Outdated dynamic models not representive of true field equipment characteristics	Fine-tune models based on simulations and real-time dynamics information Suggest active/passive ringdown signals appropriate for analysis
	Freq. Response	Require high resolution data	Assess system stiffness from frequency response observations
	Trending/Pattern Recognition	Dynamic/transient signatures require high resolution data	- Perform trending with time of day, season, peak load, major line outages, etc - Identify key signatures of events/system changes for event/topology change classification
Infrastructure Management	Phasor Devices	- Lack of common standards for different phasor devices (PMUs, DFRs, Relays)	- Benchmark existing devices with phasor measurement capabilities - Define performance standards for devices
	Data Quality	- Calibration errors - Transmission losses/corruption	- Determine errors sources and failure modes of PMU data - Suggest diagnostic techniques and recommend appropriate fixes - Define performance standards for different applications
	Communication Networking	- Communication latencies/Transmission losses	- Define communication/networking requirements for different types of applications - Plan for transition to production network
	Data Management	Inconsistent data rates/signal types	Define data requirements for different applications
Control	Regional Voltage Control	Voltage instability can be solved locally only to a limited extent	Recommend schemes for using wide-area measurements for load shedding or capacitor/reactor bank switching
	Small Signal Stability Control	Traditionally based on local measurements (Power System Stabilizers) which may be unsatisfactory against inter-area oscillations	- Determine mode shapes to define mode observability for control signals - Research modulation of HVDC lines, or use of FACTS devices to control oscillations - PSS tuning
	Transient Stability Control	- Limited ability to mitigate transient stability based on real-time information	- Research techniques for first swing instability classification - Recommend control actions such as load shedding or supervised islanding
Protection Switching	Remedial Action Schemes	Manual arming/disarming based on criteria determined by offline studies	Research and define phasor measurement based thresholds for arming/disarming points and RAS tripping requirements
	FACTS Transmission Control	Power transfers governed by engineering laws with limited control capability	Research the use of FACTS devices with coordinated wide-area control (TCSCs, static compensators, UPFCs) to increase the controllability of power transfers under steady-state operation.

As part of the Research Roadmap development, EIPP has developed research milestones and goals. These have been organized in three timeframes – near-term, mid-term, and long-term. This framework is important to:

- meet the needs of industry stakeholders who want near-term results to improve reliability management and develop cost justification for continued investment;
- respond to DOE and industry need to guide research activities within the framework of a long-term vision and plan; and,
- help define roles and responsibilities for DOE and industry.

To address these research needs, research activities and milestones have been developed as discussed in the following sections.

Near-Term Milestones (1-2 Years)

Wide-Area Visibility with Common Situational Awareness Screens –Visualization tools to help operators gain a more holistic understanding of the current state of the bulk power grid. Through consistent screens and displays for better communication among operators from different control areas, system operators can be provided with a "wide area" view of the state of the grid, and over time will gain a better understanding of the factors both within and outside their own control area that affect the reliability of the bulk grid. The displays shall utilize simple color codes and graphics on various monitored metrics to provide alerts and cues for operators and engineers. In the future, these phasor measurements could be time synchronized with the traditional SCADA measurements and integrated into common operator displays to provide a more comprehensive view of the power system behavior. Additional performance metrics for real-time reliability monitoring would be integrated into the operator displays as they are defined and verified. Examples of such performance metrics include sensitivity computation such as voltage sensitivities at load buses or angle sensitivities at generator buses. DOE would fund the initial research towards defining and validating these new performance metrics, which the utilities could then take to the vendor community to transition into their commercial offerings.

Baseline Normal Operating Conditions Limits and Alarms for EI – The August 2003 blackout recommended the need to "establish clear definitions for normal, alert, and emergency operational system conditions." One of the early hurdles in presenting real-time phasor related information to the initial users has been in identifying appropriate alarming thresholds for the Interconnection that are of relevance from a wide-area monitoring point-of-view. For the near-term, one approach is to study the observed profiles over an extended period of time to ascertain their behavior under normal system conditions, and to use these long-term trends to define either hard limits (i.e. fixed limits) or soft limits (i.e. statistical bounds) for these metrics. Phasor measurements captured from different geographic locations under normal operating conditions can be compared and correlated with time of day, season, peak load, major line outages, etc. to better understand the typical system behavior. DOE's role here is to facilitate a coordinated effort by the utilities towards a global Interconnection-wide system understanding.

Demonstrate Improved State Estimation with Phasor Measurements – Incorporation of measured angles into the state estimator. Various utilities are working with their vendors in demonstrating this Capability. The many ways in which phasor measurements can improve accuracy, robustness and speed of the state estimation process include:

- Validate traditional state estimation results with real-time accurate phasor measurements for observability analysis and bad data identification.
- Calibrate network models to more accurately represent system performance.
- Use phasor measurements at system boundaries to accurately represent boundary conditions, thereby reducing the dependency on large network models or the use of simplistic boundary equivalents, which may be inaccurate, and expediting the estimation process.
- Incorporate phasor measurements as input measurements in the state estimation algorithm to improve the convergence and the estimation accuracy (Hybrid State Estimator).

To assess and compare these different approaches, the workgroup participants are working towards defining metrics that quantify the benefits of phasor measurements to the state estimation process in terms of performance, accuracy, robustness, completeness, etc. The DOE role is well served in coordinating these comparable demonstrations towards a longer term vision of an Interconnection wide state estimator.

Model Validation for Better System Understanding – The Western Interconnection has successfully used phasor measurements to improve dynamic models. Phasor technology has the ability to observe transient and dynamic behavior. By comparing the numerical simulations (which use the dynamic models) to the PMU observations, the phasor technology offers a means to calibrate and fine-tune these planning models. In the WECC power system, planned tests are coordinated by the Validation Work Group to compare and calibrate their models. Some of the input signals for the test include ambient noise within the system reflecting small fluctuations due to random load switching, staged generator trips with automatic generation control (AGC) and other controls suspended, dynamic brake insertions, mid and low-level probing through HVDC modulation. The measured system response, when compared to simulation studies using similar input signals, provides feedback information to calibrate and fine-tune these planning models. DOE's assistance in the near-term R&D needed to leverage this expertise and experience to improve EI models could greatly expedite this information transfer process.

Identify Human Factors & Visualization Needs for Phasor Based Operations Tools – Visualization is not just presentation of graphics. It is both a presentation and discovery process to gain understanding and insight of the underlying information and of the system performance the information represents. It is crucial that the visualization tools provide meaningful and actionable information for operators and reliability coordinators in a concise fashion. Human factors experts would need to be involved in identifying the visualization needs and proposing suitable visualization solutions.

Define Procedures for Enhanced Grid "Forensics" – The August 2003 blackout brought to light the challenges associated with performing forensic analysis including synchronization, data quality, and calibration issues. Fortunately, the high sub-second resolution and accuracy of these phasor measurements, which is well suited to observe transient behavior, make these measurements highly valuable for post disturbance analysis. However, there is still a need to "establish requirements for collecting and reporting of data needed for post-blackout analysis". Furthermore, although there is a great deal of information that can be extracted from time-synchronized measurements taken from multiple locations (e.g. disturbance recognition or location identification such as short-circuit fault, line or generator tripping, load increase, reactive source switched in etc), there also a need to have well-define analysis procedures in place and a good understanding of the data characteristics to fully and efficiently extract this information. R&D support is needed to develop analysis techniques including techniques to identify and characterize low frequency modes in the system, and to assess the EI frequency response performance. There have to be established practices for pre-processing the data to remove any instrumentation induced inaccuracies and communication failures prior to performing such analysis.

Design Next Generation Data and Communications Infrastructure – The starter phasor network uses point-to-point VPN links to transmit phasor data in real-time to the central TVA host site. While VPN links are adequate for this initial demonstration with the small set of PMU devices and for monitoring purposes, the bandwidth of this communication channel will not be adequate when many more such devices come online or for control applications where latency is a concern. High bandwidth data links along with local processing of data into information to reduce communication would be required. It is also recommended that the system migrate to a network based communication infrastructure for redundancy. Additionally, as the amount of data gathered by the network grows, it could be impractical to collect and archive the data at a single central location. Distributed data storage and management architectures may be needed to ensure efficient data management and guarantee redundancy. DOE's role is well suited towards supporting the research in architecting such an interconnection-wide infrastructure that the utilities could proceed to implement in coordination with the vendor community. It is important that this infrastructure support industry standard protocols for seamless integration with both commercial hardware devices within the field and the next generation of software applications.

Define Research and Demonstration Approach for Real-Time Control – While most of the power system controls are localized, the precise time synchronization and high resolution of these measurements make them ideal feedback signals in wide area control schemes to improve the overall reliability and stability of the power system. The common premise is that a coordinated wide-area control approach would be more efficient in achieving a globally optimal operating state and in steering away from a potentially dangerous situation. The workgroup will collectively need to define a research and demonstration framework to reveal the potential benefits of using these phasor measurements in real-time wide-area control schemes. Such a collaborative effort fits well into DOE's traditional role of supporting long-term research.

Mid-Term Milestones (2-5 Years)

Wide Area Visibility with Full Coverage – The number of PMU installations within the EI is growing at a fast rate. Moreover, many relay and disturbance fault recorder vendors now offer phasor measurement and continuous recording capabilities, some of which may easily be attained through firmware upgrades to existing equipment already in the field. As these additional devices are integrated into the phasor network, it is conceivable that they could provide complete wide area visibility and make state-measurement a reality within the next 2-5 year time span. Present R&D activities are looking into Decision Tree methods for optimal placement of new PMU devices for adequately monitoring multiple power system phenomena (angular instability, oscillation, etc.). The utilities could work with their vendors to close these monitoring gaps.

Dynamic Line Ratings and Security Assessment Tools – Transmission rating can be based on thermal limits as well as voltage and transient (angular) stability limits. Conventionally, these ratings are the product of a set of offline studies. Various phasor measurements based techniques have been proposed that offer the ability to dynamically assess the security margins (voltage stability, small signal stability, thermal margins, etc) across key transmission lines/corridors in real-time. In particular, with phasor data it is possible to calculate critical metrics for the grid that quantify the health of the system with respect to stability limits, as well as the ability to precisely monitor the conductor's true temperature. By continuously tracking these phasor measurements through a sliding time window of predetermined duration, it is possible to estimate certain load, generator and/or network parameters that provide the most accurate up-to-date assessment of these limits. For example, thermal limits on transmission lines are usually very conservative as they assume high ambient temperatures and no wind conditions. Phasor measurements offer the ability to monitor the actual line temperature and therefore determine the true transfer limits. A main advantage of such methodologies is that they do not rely on offline studies for its assessment, nor does it rely on comprehensive system models, which can be plagued by inaccuracies. These advanced security assessment concepts need further validation in the field.

Common Operator Tools Deployed & Next Generation Tools – There is a need to have standardized displays across the interconnection to facilitate communication across utilities and for consistency between operator and reliability coordinator displays. There is also the desire to allow each utility to customize its displays to meet the utility's monitoring needs. The Real-Time Applications Task Team proposes to utilize a tiered visualization architecture in the prototype RTDMS system with drill-down capabilities from centrally configured and standardized "global" displays for wide-area viewing at the Interconnection and Reliability Coordinator levels, to "local" end-user customized displays at the utility level. The different tiers proposed by the Team include:

- *Summary Dashboard Display* – It uses simplistic "traffic light" type visuals and gauges to provide information on a set of predefined metrics that characterize the overall system status.

- The *Eastern Interconnection Displays* – A set of standardized displays, providing key information at the Interconnection level that are centrally maintained/configured and are common to all EI Operators and Reliability coordinators.

- *Reliability Coordinator Displays* – For each, Reliability Coordinator region, a set of standardized displays providing key information within the corresponding Reliability Coordinator Region, that are centrally maintained/configured and are also common to all EI Operators and Reliability Coordinators,

- *Local Displays* – A set of displays that the end users will be able to define and customize to their own utility needs.

Working with the operators and reliability coordinators, the team will need to identify the required research to define that next generation of tools that would be well-suited for the new operating paradigm. These and other advanced application should rely on industry standard protocols for seamless integration with the supporting phasor infrastructure and accessing the underlying data. These tools, once defined, would be incorporated into commercial offerings.

Improved LMP Computations – PMU measurements and consequent improvements in the state estimation process offer high potential for immediate value in both grid and market operations. In particular all downstream applications such as contingency analysis, security constrained unit dispatch, etc that use state estimator results as input data would gain from the accuracy and speed improvements in these results and the upshot would be better and faster security margin and LMP computations.

Demonstration Projects in Protection and Control – The various teams shall work with the industry to initiate the proof-of-concept demonstration projects for:
- fast coordinated control responses based on wide-area infrastructure and system dynamics visibility to control the evolution of large disturbances and ensure dynamic security.
- adaptive islanding concepts to intentionally separate the system across weak couplings into sustainable islands as a last resort to limit the damage and prevent wide-area blackouts, and load/generation shedding schemes based on frequency changes to balance generation-load resources within these islands.

DOE's role is well served in coordinating some of these research and demonstration activities and technology transfer across the Interconnection.

Long-Term Milestones (5-10 Years)

Real-Time Protection and Control – Some of the ways in which phasor measurements may be used for real-time protection and control schemes against well-known stability problems include:

- Wide area voltage control: This use of measurements for providing system wide-voltage control is of interest since the phenomenon of voltage instability can be solved locally only to a limited extent. Load tripping based on low voltage and/or high generator reactive power output would be the main control actions. As an example, Bonneville Power Administration is developing a Wide Area stability and voltage Control System (WACS) that uses voltage measurements and generator reactive power measurements taken by PMUs at several stations, and combines those using fuzzy logic to provide voltage support thought single discontinuous stabilization action such as capacitor/reactor bank switching or generator tripping.

- Small signal stability control: Small signal instability occurs when small system disturbances excite a natural oscillatory mode of the power system. The main technique to guard against this instability are controllers on the generators such as Power System Stabilizers which act on local bus measurements such as local bus voltage, generator speed or rotor angle. While these local controls are effective against local oscillatory modes, they are found to be unsatisfactory against inter-area oscillations. New controllers that utilize remote phasor measurement inputs would be more effective in mitigating these inter-area oscillations. Alternately, real-time monitoring of the power oscillation modes can be used for adaptive on-line tuning of PSS set points to achieve the best performance reacting to the actual conditions in the network. Other techniques for controlling low frequency oscillations include special modulation controls for HVDC links.

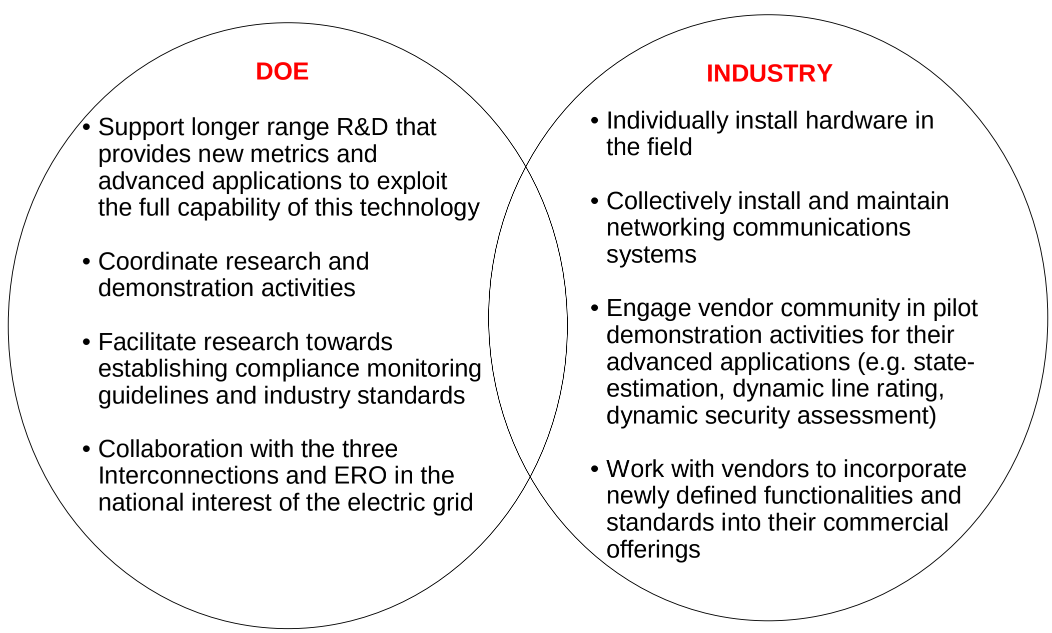
- Transient stability control: The development of such a control scheme is by far the most difficult because of short timeframe available to control the event. For first swing transient stability, control action must be taken prior to the peak of the forward inter-area angle swing (i.e. 1.0 – 1.5 seconds). Some of the possible approaches to guard against such instability are to automatically adjust existing protective schemes with on-line calculation or to directly operate the control actions after the disturbance occurs. Phasor measurements can accurately trace the progression of a transient in real time and could be used to classify the swing as stable or unstable depending on the resulting outcome. In the event that instability is predicted, appropriate control action can be taken such as disconnecting of the affected generator from the power grid. Such phasor measurement based control action can be taken within 0.3 seconds. The delay time associated phasor measurement, fiber optic communications, phasor data concentrator throughput, transfer trip, and circuit breaker tripping/closing are approximately 3, 2, 2, 1, and 2/5 60 Hz cycles respectively, or around 10 cycles for tripping and 13 cycles for closing (167 and 217 ms).

Smart-Switchable Networks – This is the ultimate goal for the project. Research and demonstration activities are required in using FACTs devices along with coordinated wide-area sensing and control (TCSCs, static compensators, UPFCs) to increase the controllability of power transfers under steady-state operation.

9. RESEARCH ROADMAP PRIORITIES, GOALS, & ROLES

EIPP has been a very successful DOE-industry collaborative project. It has opened the path to a broader research initiative to understand, interpret, and utilize phasor data to further the public interest. Fundamental research and technology demonstrations are needed to see how this data could be utilized to improve reliability management, market operations, grid security, system modeling, and policy making in support of the grid of the future. With industry taking the leadership on the phasor technology infrastructure, the DOE can now transition to its traditional role of coordinating and supporting longer range research and demonstration activities to accelerate the "technology readiness" for adoption by industry. Individual utilities would provide the necessary expertise and know-how needed for the initial research and act as test beds for these demonstrations. As the technologies and applications are validated, the vendor community would incorporate and/or migrate the prototypes into commercial grade systems to serve the industry needs. The key DOE and Industry roles and the separation of responsibilities are summarized in Figure 6.

Figure 6: ***Roles and Responsibilities***



DOE's sustained commitment and funding of research and demonstrations to utilize phasor technologies is critical to address the needs of the future grid, and EPACT requirements for monitoring and ERO formation. Through collaborative development and coordination with researchers, vendors, and utilities, the project will avoid duplications and increase the value of research investments. A summary of the Phasor Technology Research Roadmap is presented in Table 2.

Table 2: Phasor Technology Research Roadmap Priorities, Goals, and Roles

	Areas	Current Situation	Near Term Priorities	Long Term Goals	Industry Role	DOE Role
Visualization	Wide Area Visibility	- Sparse PMU coverage - Potential for expansion using existing devices - Limited experience with PMU data in operations	- Identify monitoring holes - Deploy real-time tools in operations environment - Operator education & training	- Situational awareness - Improved reliability	- Installation and maintenance of devices - Serve as testers for new prototype - Provide feedback	- Support human factors research towards defining common situational awareness screens - Facilitate research towards defining and validating new performance metrics.
	Display Management	- Inconsistency in operator displays - Display clutter due to growing installations	- Define standardized operator displays - Define visualization interplay between local and wide-area monitoring screens	- Common operator tools deployed - Develop strategy for next generation operational tool concepts	- Work with vendors to implement standardized operator displays	
Monitoring	Real-Time Alarming and Reporting	- Lack of real-time alarming criteria on grid dynamics - Absence of automated reporting processes	- Define new alarming criteria based on wide-area dynamics visibility - Define automated reporting procedures	- Establish real-time alarming, reporting and emergency response practices	- Put in place real-time alarming and reporting systems	- Facilitate research for new compliance monitoring guidelines using dynamics visibility
	Interconnection Wide State Estimation	Early research suggests that 10% strategically placed PMU coverage is adequate to improve SE	- Identify and resolve data quality issues - Perform hybrid SE demo & quantify benefit	- Better security assessment - Improved asset utilization and LMP calculation	Incorporate phasor measurements into their state estimators	Coordinate and support utility demonstration efforts towards interconnection wide state estimation
	Measurement Based Sensitivities	- Promising concepts & initial results - Requires further evaluation for reliable assessment capability	Demonstrate feasibility of reliable sensitivity calc. from phasor measurements	Improved reliability	- Define key monitoring points - Undertake demonstration projects	Support research and validation activities towards advanced applications for better reliability and security assessment tools
	Security Assessment		Define stability indices for: - Voltage stability monitoring - Small signal monitoring	Dynamic Security Margins		
Planning	Post-Disturbance Analysis	- Limited wide-area understanding of EI system dynamics - Sync. data available from EIPP starter network will facilitate this process	Baseline normal EI system operation by: - selecting events/outages of interest for analysis - coordinate analysis efforts	Enhanced grid 'forensics"	- Provide data & expertise for collaborative effort	Coordinate EI research efforts towards improved system understanding & modeling
	Trending		Perform trending with time of day, season, peak load, major line outages, etc	Improved system modeling		
Infrastructure Management	Phasor Devices	- Initial starter system in it's infancy; requires assessment - Early standards definition activities in progress	- Benchmark existing devices - Define new performance standards	Establish industry standards for performance & protocols	Install, maintain, & upgrade phasor acquisition/management systems as needed to meet application needs, and evolving performance guidelines and industry standards.	Facilitate standards development & system design towards a fully reliable and redundant phasor system
	Data Quality		- Evaluate performance assessment of current EI phasor network & propose fixes	Performance standards for reliable, secure, redundant network		
	Data Management/ Communication Networking		Research & define communication/data management architectures to support current/future application needs	- Guidelines for phasor data acquisition, archiving & retrieval - Redundant data management		
Protection Control Switching	Voltage / Transient / Small Signal Stability Control	Limited experience in this area within EI	Work with individual utilities to identify demonstration pilot projects on the use of phasor measurements for protection & control	- Automated remedial action schemes - Improve reliability & asset utilization	Undertake demonstration projects to address utility specific problems	- Support utility sponsored research and demonstration projects - Facility information sharing and technology transfer
	Remedial Action Schemes					

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10. RESEARCH & DEVELOPMENT FRAMEWORK

To successfully achieve the research objectives, demonstrate value, and continually monitor progress along the way, the following implementation approach is planned for each of the above mentioned research areas:

- Define Research Target – The Executive Steering Group shall provide direction on what research problems need to be addressed and what the research expectations.
- Project Definition – The Leadership Committee shall define what research needs to be performed, coordinate the project definition, and delegate responsibilities across the various Task Teams based on the Team's scope.
- Research and Analysis – Each of the Task Teams shall provide technical expertise and perform the research that it has been delegated.
- Development – The Task Teams will work closely with the developers (utility, vendor, and research institution) to define and develop the prototype system required for proof-of-concept.
- Test and Demonstration – The Task Teams will work with the appropriate utility or utilities to test and demonstrate the prototype system in the field, and document the results of this demonstration activity.
- Deployment and Commercialization – The utilities shall leverage off the prototype demonstration findings and work closely with the vendor and manufacturer community to migrate the prototype capabilities into a production quality commercial system.

11. NEXT STEPS

The recommended next steps in moving the project are as follows:

Infrastructure Build-Out

- Expand deployment of PMUs across the EI.
- Expand phasor system to include other devices with phasor monitoring capability (e.g. phasor relays, digital fault recorders, frequency monitors, etc).
- Identify key monitoring holes for PMU placement.

Network Management

- Benchmark existing system performance, identify bottlenecks and propose fixes.
- Resolve data quality and calibration issues.
- Expand initial phasor communications to a network infrastructure.
- Define communication and data management infrastructure to support network expansion.

Industry is taking on the responsibility for infrastructure build-out and network management. As more devices are installed, the DOE research focus needs to shift from hardware validation, development and deployment to research on utilization of phasor data to develop applications, tools, and models, algorithms for grid reliability, security, monitoring, visualization and efficient market operations. Some examples of next areas of research include:

- Define new alarming criteria based on phasor measurement data and wide-area dynamics visibility.
- Standardize operator displays across the Eastern Interconnection.
- Demonstrate state-estimation improvements using phasor measurements and quantify benefits.
- Research, define and validate advanced monitoring metrics for reliability monitoring
- Baseline normal EI system operation
- Perform long-term trending analysis with time-of-day, season, peak load, major outages, etc.

A summary of the Research Goals and Milestones is presented in Figure 7.

Figure 7: *Summary of Research Goals and Milestones*

Research Areas

- Visualization
- Monitoring
- Planning
- Phasor Infrastructure Management
- Control
- Protection
- Switching

Near-Term(1-2 Years)

- Wide-area visibility with common situational awareness screens
- Baseline normal operating conditions, limits and alarms for EI
- Demonstrate improved state estimation with phasor measurements
- Model validation for better system understanding
- Identify human factors & visualization needs for phasor based operations tools
- Define best practices for enhanced grid "forensics"
- Design next generation data and communications infrastructure
- Define research and demonstration approach for real-time control
- Identify research needs for federal investment

2006 - 2007

Mid-Term (2-5 Years)

- Wide-area visibility with full coverage
- Approaching real-time state measurement for operators
- Dynamic system security assessment tools
- Common operator tools deployed
- Congestion management
- Dynamic ratings
- Improved LMP
- Work with industry to initiate major demonstration of real-time control for dynamic security
- Work with industry to demonstrate adaptive islanding protection concepts to improve protection from wide-area blackouts
- Develop strategy for next-generation operational tool concepts

2007 - 2010

Long-Term (5-10 Years)

- Real-time protection
- Distributed closed loop control
- Automatic smart-switchable networks

2010 - 2015

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