DOE/OE Transmission Reliability Program
June 2017 Advanced Applications Peer Review

Meeting Summary

Modernizing America's electricity infrastructure is one of the U.S. Department of Energy's top priorities. The DOE Strategic Plan[1] states that today's electric grid needs to be more efficient, reliable, and secure. A modern, smarter electric grid may save consumers money, help our economy run more efficiently, allow rapid growth in renewable energy sources, and enhance energy reliability. The Department's research into a variety of tools that will improve advanced system monitoring, visualization, control, operations, and market structure will ultimately modernize the electricity transmission infrastructure to ease congestion, allow for increases in demand, and provide a greater degree of security.

The Department's Transmission Reliability research focuses on developing and prototyping software tools that will ultimately enable the electricity grid to function as a smart, automatic, switchable network. These tools seek to:

- Improve understanding of the impacts of competitive market forces on the management of system reliability
- Provide real-time data and support information that enables operators to quickly grasp and analyze system status and respond effectively
- Allow operators to measure, monitor, assess, and predict the performance of the system and the behavior of market participants
- Allow rapid incorporation of the latest sensing, data communication, visualization, and algorithmic technologies

The Department's research in this area is based on the recognition that off-line, engineering-based modeling and analysis of system performance is no longer adequate because markets—rather than centralized engineering decision making—now determine how the transmission system is used. As a result, new tools are needed to identify in real time the critical resource deficiencies that could endanger system reliability, and to reliably and efficiently match customer demands with supplies of electricity. We are currently focused on three main areas of research:

- *Technical Support to North American Synchrophasor Initiative*
  DOE researchers are focused on a variety of technical support, R&D, and pre-commercialization activities involving industry-led initiatives on the deployment of high time-resolution and time-synchronized grid monitoring technologies ("synchrophasors") to enhance grid reliability and economics.
- *Advanced Applications Research & Development*
  This set of activities is focused on the development and demonstration of advanced grid applications and tools to enhance grid reliability and economics.
- *Reliability Metrics and Monitoring*
  Development of new reliability performance metrics that provide the basis for development of new prototype monitoring tools that then track and analyze grid performance in real time.

[1] See http://energy.gov/downloads/2011-strategic-plan

This work is reviewed annually by the U.S. Department of Energy's Office of Electricity Delivery & Reliability, and review materials are posted to the DOE website.[2]

2017 Peer Review Meeting

The 2017 meeting was held on June 13, 2017 in Washington, D.C. Attendees included research performers from participating national labs and research institutions. The meeting included 15 presentations, each with a research talk and a question-and-answer period. Presenters were asked to summarize progress to date, and to describe future activities for the coming fiscal year.

Peer Reviewers

The reviewers participating in the 2017 Program Review were: David Bertagnolli, of ISO New England; Vikram Budhraja, of Electric Power Group (EPG); Bob Cummings, of the North American Electric Reliability Corporation (NERC); Jeff Dagle, of Pacific Northwest National Laboratory (PNNL); Matt Gardner, of Dominion Power; Allen Goldstein, of the National Institute of Standards and Technology (NIST); Gordon Matthews, of Bonneville Power Administration (BPA); and Dejan Sobajic, an independent consultant.

Reviewers were chosen based on their research and industry knowledge. Reviewers with personal involvement with individual specific projects were recused from scoring those projects.

Reviewer Scoring

Reviewers were asked two questions:

1. How valuable is the research for DOE's R&D program?
2. What (if anything) should be done to improve this research activity?

In response to the first question, reviewers were asked to score each project on a scale of 1-5, with 1 being 'low value' and 5 being 'highest value.' The average score for each presentation is included in the summary section below. Following the meeting, each presenter was provided with their scores and the summary comments provided by the reviewers.

Projects Presented for Review in June 2017

Project: **Real-Time Applications Using Linear State Estimation Technology (FOA 1492)**
Presenter: **Ken Martin/Lin Zhang**
Avg. Score: **3.75**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
		xx	x	x

The objective of this project is to design, develop, implement, and demonstrate real-time security applications using synchrophasor data and linear state estimation (LSE) technology to provide operators with actionable intelligence on contingencies, voltage margins, and phase angle limits. The intelligence will enable utilities and Independent System Operators (ISOs) to meet the challenges of increasing renewables in the changing energy resource mix, the limitations of current state estimation technology to solve during contingency situations, and improving overall real-time assessment of grid voltage and

[2] See http://energy.gov/oe/services/technology-development/transmission-reiability

phase angle. The applications will be demonstrated at host utility site(s) for validation and acceptance as a step toward application commercialization.

EPG will leverage significant investments in synchrophasor technologies, from the electric power industry, to develop a tool that utilizes this data for expanded grid visibility, real-time assessment of the steady state system, and actionable intelligence on contingencies, voltage stability margins, phase angle limits, and consequence evaluations for present state system in terms of thermal and min-max voltage violations. The tool, called Real Time Applications using Linear State Estimation (RTA/LSE), will be a combination of three separate LSE driven applications. LSE has been developed to solve the real-time steady state system model using synchrophasor data to reduce state estimation to a linear problem. This allows detecting all error types, including those introduced by the phasor measurement unit (PMU), data communication, and the potential transformer/current transformer (PT/CT) transformation. The three applications included in RTA/LSE are as follows:

1. An Enhanced Real Time Contingency Analysis (ERTCA) to provide information to characterize steady state conditions in real-time and under contingencies.
2. Area Angle Limit Monitoring Application for a defined area is an indicator of stress for the region and takes into account current system state. This approach takes into account multiple contingencies in the selected area or region and provides operators with the intelligence necessary to take corrective actions to reduce area angles for stability.
3. Voltage Stability Application to calculate a voltage stability index for selected transmission corridors and provide a voltage stability margin in real-time.

Selected Reviewer Comments:

- Incorporation of angle separation is important next step for RTCA. Direct use of PMU measurements on angle separation great next use.
- Very central to the goals/objectives of the program, well organized and executed with strong partners. Also a great set of advisors. This work is poised to provide long-term benefit to the nation's electric power system. The performance enhancement of the eLSE is impressive. The methodology for evaluating accuracy, albeit somewhat ad-hoc, seemed reasonable.
- RTCA is an important application and is at a relatively high TRL. The RTAP will help with other RT applications to come to market more quickly.

Project: **Substation Secondary Asset Health Monitoring and Management System (FOA 1492)**
Presenter: **Kevin Chen and Lin Zhang**
Avg. Score: **3.6**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
		xxx	xxxx	

The Electric Power Group, LLC (EPG) will design, develop, and demonstrate a real-time software application to monitor and manage the health of substation equipment including instrument transformers (ITs) and intelligent electronic devices (IEDs). This Substation Secondary Asset Health Monitoring and Management System will leverage synchrophasor data and three-phase linear state estimation (LSE) technology to detect equipment malfunction and alert utility personnel in real time to diagnose the malfunction and take appropriate actions for asset management to prevent equipment

failure, customer outages, and injury. The software application will also help avoid relay system mis-operation, equipment damage, forced outages, and safety hazards, and support calibration of ITs and IEDs.

The goals and objectives of this project are to:

- Collect three-phase measurements from critical substation secondary equipment
- Process PMU, relay, digital fault recorder (DFR), and IT data to derive synchrophasor equivalents and run a three-phase substation LSE (SLSE) in real time
- Monitor and characterize equipment data signatures
- Detect signature anomalies
- Alert end-users and provide equipment signatures for forensic analysis
- Enable end users to take needed proactive actions of calibration, repairs, and replacement

Selected Reviewer Comments:

- This project is meeting an important need that is currently lagging behind commercially available tools using prevalent data that is now available. Partnering with AEP is very valuable. The project plan seems to include all of the necessary elements to ensure success, and is organized into a project plan that looks reasonable and comprehensive. Nice leveraging of the NASPI white paper.
- We may find that 'so called secondary' uses of PMU data may prove more important than primary uses. It is very important to continue to champion safety-related applications.
- Distributed intelligence (moving processing to substation) is the new opportunity that we should be exploring.

Project: **Operationalizing Synchrophasors for Enhanced Electric Grid Reliability and Asset Utilization (FOA 1492)**
Presenter: **Chaitanya Baone**
Avg. Score: **3.0**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
x	xx	xx	xx	x

The objective of this project is to develop, deploy, and field test next generation applications that utilize synchrophasor infrastructure to enhance grid reliability and asset utilization from two perspectives: (a) improved component and system level dynamic and steady state models for better modeling accuracy in planning and operations applications; and (b) hybrid Phasor Measurement Unit (PMU) "measurement" + system topology "model" based approach to monitor, predict and provide corrective control actions for improving grid stability. The project is distributed into broadly three phases: Technology Development, Factory Acceptance Testing, and Field Demonstration.

The four major tasks to be completed on this two-year project include: (1) Development of a software application to validate and calibrate system and component level static as well as dynamic models utilizing synchrophasor and operational data which would be in compliance with North American Electric Reliability Corporation (NERC) standards; (2) Development of a software application that leverages synchrophasor data along with the real-time system topology model to monitor and predict

grid stress using an innovative angle-based approach; (3) A hybrid Wide Area Measurement System (WAMS) + real-time topology based approach for black start and restoration, and disturbance management for the current as well as any N-1 contingency conditions; and (4) Demonstration of the developed production-grade applications in the field at various utility partner locations.

In the first phase (technology development), the algorithms governing the software applications will be developed using simulation test systems. In the second phase (factory acceptance testing), the developed applications will be tested and further improved upon in the factory using models and data that closely resemble actual field data. Finally, in the third phase (field demonstration), the software applications will be tested and demonstrated in the field at various utility host sites using actual field data and utility models.

Selected Reviewer Comments:

- This is a needed technology evolution to commercialize a series of technologies that have been previously developed by academia and National Labs. The partners will provide a solid basis for providing something of value to the industry. An important conduit for implementing things that have been going on.
- NERC has identified that, historically, model validation has been lacking. We need this.
- This work is <u>really</u> important, with huge implications for enhancing the reliability of the BES – starting with alleviating introductions of forced oscillations by badly tuned generators. Also opens rationale for requiring RT PMUs on each generator.

Project: **Advanced Synchrophasor Protocol (ASP) Development and Demonstration (FOA 1492)**
Presenter: **Ritchie Carroll**
Avg. Score: **4.5**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
		x	xx	xxxxx

The objective of this project is to create a phasor data communication protocol that improves upon the presently used Institute of Electronical and Electronics Engineers (IEEE) C37.118 protocol. This project will result in the Advanced Synchrophasor Protocol (ASP), a new phasor data publish/subscribe protocol, and a collection of tools to support it. ASP will be a well-tested, thoroughly vetted, production-grade communication solution that will be ready for broad deployment. The open source ASP Tool Kit will include a test harness that will allow developers outside the project to test and validate the protocol in their systems and include application programming interfaces (APIs) in at least three programming languages – C#, C++, and Java – to allow quick native deployment of ASP in multiple systems.

The project is divided into two Phases: (I) Design and Development and (II) Demonstration. During Phase I of the project, the Recipient will create an ASP specification document and develop pre-production versions of the protocol's APIs as well as an API Tool Kit. GPA will build the ASP Tool Kit based on its open source Grid Solutions Framework (GSF) and their secure Gateway Exchange Protocol (GEP) originally developed as part of GPA's SIEGate project (DOE-OE000536). During Phase II of the project, GPA will deploy and evaluate ASP at multiple utilities. GPA will refine the ASP specification and the software that implements it prior to the production release of this software at the end of the

project. Following the project demonstrations, the ASP specification will be published and offered to the standards community.

Selected Reviewer Comments:

- This will eliminate many of the issues that make the current technology difficult to live with and make it easier for utilities to adopt PMU technology.
- The large number of participants is excellent. The project is well founded and is poised for success. This will be very important to the future. STTP building on GEP is a good approach. Open source approach is good. Building some functionality, e.g., security, is a good requirement. Meta data exchange is great.
- Promising step change in control-center level data exchange. Good support from vendors.

Project: **Eastern Interconnection Situation Awareness Monitoring System (ESAMS) Prototype**
Presenter: **Joe Eto**
Avg. Score: **4.5**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
			xxx	xxx

The objective of this project is to demonstrate a PMU-based system that provides a common view of interconnection-wide operating conditions—focusing on conditions not currently visible with existing systems. The goal is to introduce a common, high-level interconnection-wide view based on synchrophasor information in order to foster discussion within and among Eastern Interconnection operating entities. Key elements of the initial high-level view will include:

1. Detect and identify forced and natural oscillations
2. Monitor phase angle pairs and identify when values are outside of normal operating ranges
3. Detect atypical behavior from an ensemble of measurements and identify which ones are contributing to the atypicality

Information will be delivered (by subscription) via two methods, including:

1. Near real-time text message
2. Emailed reports (daily, weekly, monthly)

Selected Reviewer Comments:

- This project may be the only use of PMU data for very wide area monitoring and provides a foundation for wide area control. Common View will be important for system operators.
- Executive buy-in at PJM is key. Good mention of that effort. Appears to be appropriately sized. Good coordination with EIDSN.
- Transitional project: now that PMUs are coming in service with appropriate maintenance & calibration, how do we leverage technology to grasp large areas. This is really important for operators: something is going is… is it in my system or outside of it?

Project: **Discovery through Situational Awareness (DTSA) [GM0070]**
Presenter: **Brett Amidan**
Avg. Score: **3.6**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
		xxxx	xx	x

This effort will produce an interactive situational awareness tool with the following capabilities:

- Process Phasor Measurement Unit (PMU) data, including data-quality cleaning
- Investigate and implement anomaly and event detection algorithms in near real-time
- Provide informative data visualizations
- Provide insight into equipment failure or misoperation
- Investigate the effect of other data streams (e.g., net interchange, pricing, load, climate/weather, etc.) to determine which ones are accessible and could possibly provide additional insight
- Apply machine-learning models and algorithms to characterize patterns found in the data and begin initial look at event precursor behavior.

This tool will apply statistical and machine-learning algorithms in the context of big data analytics to address the area of transmission reliability. The tool will be developed through iterative interactions with system engineers from our industry partners to help steer the data-driven results into practically useful results and visualizations. This effort is in direct response to the Grid Modernization Initiative, specifically the DOE Major Technical Achievement area of "Advanced Modern Grid Planning an Analytics Platform" (see MYPP Tasks 3.4.1 and 3.4.2). This work addresses the technology activity area of "Sensing and Measurements" in which analytic and visualization techniques are developed to assess the health of the grid in real time, predict its behavior, and give the information necessary to improve response to system events.

Situational awareness tools are lacking in the power grid community and this tool advances the state of the art toward closing this gap. The key abilities and capabilities necessary to accomplish this include (1) analytical expertise, (2) computing resources, and (3) access to data.

This project will deliver a prototypical situational awareness tool, installed at selected power grid entities (our previously mentioned industry partners), and a technical report explaining the methodologies and results from this effort.

Selected Reviewer Comments:

- This project brings modern "big data" techniques to PMU data (machine learning, pattern recognition, etc).
- PMU data will continue to increase. Data analytics is important to find the 'nuggets' from the haystack that are useable in reliability management.
- Really promising—and essential. Reaching the PMU maturity level where we have lots of PMUs installed and maintained and generating reams of data. Now—how do we get what we need: INFORMATION. This is a good approach, with the right folks to make progress.

Project:	**Update on PMU-Related Standards Activities**
Presenter:	**Ken Martin**
Avg. Score:	**This project was not scored**

This project provides direct technical support for industry-led activities, conducted through the IEEE and IEC, to develop consensus standards for the technologies involved in synchrophasor grid monitoring systems—such as the means for describing the performance of phasor measurement units.

Project:	**Open-Source Applications & Models for Advanced Synchrophasor Analysis [GM0072]**
Presenter:	**Pavel Etingov**
Avg. Score:	**3.3**
Distribution:	**(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	xx	x	xx	x

The goal of this research is to develop and advance applications of phasor measurement units (PMUs) and synchrophasor data for power system planning, modeling, and analysis. The Pacific Northwest National Laboratory (PNNL) and Lawrence Berkeley National Laboratory (LBNL) are partnering to develop a suite of software applications and libraries for PMU measurements analysis. The research and software development activities will be coordinated with industry partners and universities, including: Bonneville Power Administration (BPA), Western Electricity Coordinating Council (WECC), North American Electric Reliability Corporation (NERC), University of Wyoming, Binghamton University (SUNY), Montana Tech, and University of Wisconsin-Madison. All applications will be based on the common open platform concept, have a common data format structure, and be released under an open-source license.

This project proposes to address oscillation detection, frequency response, model validation and calibration, equipment misoperations, and other important power-grid-related issues. These topics are directly related to Foundation Topic 2 in the Grid Modernization Lab Call (Advanced synchrophasor technology research). Free and open-source applications developed in the proposed project will help the power industry adopt PMU measurements applications for a wider range of tasks (e.g., model validation, model parameter calibration, oscillation analysis, and baselining). Better and more accurate models of power system elements (e.g., synchronous generators, wind plants, and electrical loads, as advanced PMU-based analytical applications) are key factors in enhancing electrical grid reliability and efficiency. The open-source nature of this platform is especially suited for enabling adoption of such PMU-based capabilities at smaller utilities that may not have the resources to fully utilize their PMU investment.

The proposed work expands the feasibility and usefulness of synchrophasor-based applications by leveraging existing work to increase functionality and improve overall technology readiness levels to allow utilities to benefit from their investment in, and deployment of, various synchrophasor technologies. The proposed work also creates a unified application and capabilities suite to consolidate tools and algorithms leveraging synchrophasor data. Because the framework is open source, any developer can contribute to the application set either by modifying existing software or by creating new applications. In addition, third-party organizations and vendors can build commercial products based on the open-source code developed under the proposed project.

Selected Reviewer Comments:

- Incredibly responsive to improving tools; operations engineering/situational awareness eng.
- A good effort that should be continued. Glad to hear PPMV supports PSS/E.
- These tools are important. They have been available while still in development.

Project: **Advanced Machine Learning for Synchrophasor Technology [GM0077]**
Presenter: **Michael Chertkov**
Avg. Score: **2.7**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	xxx	xx	x	

The main goal of this project is to develop a suite of new Machine Learning (ML) tools to monitor stochastic and dynamic state of the transmission grid during its **normal operations** (task 1) and also localize significant frequency events in seconds after they occur (task 2).

To achieve this ambitious goal, the interdisciplinary three labs (LANL, LBNL & PNNL) and a Columbia University team supported by industry Bonneville Power Administration (BPA) will focus on combining a number of technical ideas to design a Grid-Modeling aware ML toolbox that utilizes and develops (a) advanced optimization and computation methods and algorithms for ML and data analytics; (b) the state-of-the-art, industry-grade frequency monitoring software; (c) phasor measurement unit (PMU) measurements at the transmission level; (d) aggregated micro-synchrophasors (uPMU) measurements at the distribution level; and (e) modern map-visualization tools and approaches.

To learn ambient/normal behavior of the grid (task 1), the LANL and Columbia University team members will "invert" the recently developed dynamic modeling approach to advance the inverse (ML) problems of interest. We will pose a typical normal operation inverse/learning problem will be posed as a network optimization consistent with dynamic and synchronized PMU measurements from practical transmission systems (available through PNNL & BPA collaboration) and also complemented by uPMU measurements aggregated over the distribution system (available through LBNL test-beds, hardware, and software development).We will then build new ML software, tested and validated first as a research code, to provide situational awareness (almost real time), computational, and map-visualization extensions of the PNNL & BPA Power Plant Model Validation (PPMV) software. Our methodology for localization and time-stamping of frequency events (task 2) is similar: we will first pose, analyze, and test the problem through a research grade code (LANL) and then transformed into an industry-grade code providing the situational awareness extension of another PNNL & BPA code - frequency response analysis tool (FRAT).

Selected Reviewer Comments:

- Very good exploratory work on network sensing – longer term.
- Important to the future of real-time operations and closed loop control.
- This could be a home-run, but requires discipline.

Project: **HVDC and Load Modulation for Improved Dynamic Response using Phasor Measurements [GM0073]**
Presenter: **Jianming Lian**
Avg. Score: **3.6**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	x	xx	xxx	x

Active damping has been successfully demonstrated to improve the electricity system response to inter-area oscillations, which in turn improves system reliability. Power system stabilizers (PSSs) have proven to be effective in damping local modes. However, PSSs, which are based on local information, have limited effect on inter-area oscillations unless they are carefully coordinated. The proposed work will investigate ways to use the information available from phasor measurement units (PMU), and the widespread availability of controllable loads, to design a novel control strategy for inter-area damping. The objective of the first part of the proposed work is to develop a decoupled modulation control approach that provides an easier way to design and more effective damping control with less interference among different oscillation modes in the system. The second part of the proposed research explores how HVDC networks and a sufficient proportion of the loads could be used to enhance the decoupled modulation control approach developed in the first part. Methods to enhance measurement redundancy and control in case of PMU communication failure will also be developed, thereby overcoming one of the major technical barriers preventing PMU-based controls from being applied in today's control centers.

The proposed effort directly supports Advanced Synchrophasor Technology Research (ASTeR) to develop and advance applications of PMUs and synchrophasor data as part of the DOE OE Transmission Reliability program. The project will satisfy the goal identified on p. 35 of the Lab Call of "using real-time synchrophasor data to actively control electricity system response so as to maintain reliability and/or system efficiency". The proposed work directly supports DOE Major Achievement 1 in the MYPP of substantially reducing the amount of system reserve capacity (generation and delivery), thereby substantially improving the economic productivity of the modernized grid. Large-scale commercial tools will be used to validate the proposed control strategy against local and regional reliability and cost performance criteria for the Western Interconnection first (FY 16-FY 18), and then for the Eastern Interconnection and ERCOT in subsequent years (FY 17 and beyond).

Selected Reviewer Comments:

- Important area for real time wide area controls.
- Very important for forward-looking system stability.
- When it comes to real-time control, this is the most important project to come out of this DOE program!

Project: **Powerline Conductor Accelerated Testing (PCAT)**
Presenter: **Terry Jones**
Avg. Score: **3.25**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	x	xxxx	xxx	

The Powerline Conductor Accelerated Testing (PCAT) Facility is part of the National Transmission Technology Research Center and is a high-current test facility used to test high-current, low-sag conductors, and other transmission line equipment. PCAT will be utilized for testing the performance of new conductor technologies. The system was initially commissioned in late 2002 and has tested a variety of conductor and sensor technologies since its commissioning. During the 10+ years of operation, the system at PCAT has aged and is in need of an upgrade for controls and data acquisition to maintain minimum required functionality. These necessary upgrades have allowed for testing of new conductor technologies and new transmission line monitoring devices.

Selected Reviewer Comments:

- Unique facility; provides good value to industry.
- Great service for advancement of conductor service.
- A well-equipped outdoor test facility for conductor testing. Enables testing of advanced technologies--providing good value. Keeping the capability intact is important, and should be maintained. Also—there is value in having a credible, unbiased party doing the testing.

Project: **Application of VARPRO Ambient Mode Estimation**
Presenter: **Bernie Lesieutre**
Avg. Score: **3.75**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	xx		xxxx	xx

Research into the application of a VARPRO-based approach to modal analysis of ambient data from the power grid may improve on existing methods to estimate system damping. This would increase situational awareness of potential system instabilities. Initial exploratory work has involved a first pass at recently acquired data, which shows promising results that warrant further investigation. Direct application of VARPRO curve-fitting provides excellent results compared to brake-test ringdown. The research will need to address practical issues with automating the algorithm with a goal of real-time implementation.

Specific research tasks include:

1. Investigate fundamentals of sample correlation signals with a view to automation. The important outcome of this is to automatically determine a window size to use for the VARPRO curve-fitting algorithm, and then to apply the algorithm. Parameters include the length of the original signal, the effective number of modes in the signal, and practical issues associated with rejection of low-frequency shaping functions.

2. Perform automated VARPRO fit, applying window from #1, and order limit to be investigated. Investigate the use of multiple signals, their sample auto-correlations, and sample cross-correlations.
3. Determine if and how to use information in the long-term correlation functions. Initial analysis suggests that the statistics depend on modal damping.
4. Working with BPA on a second stage implementation.

Selected Reviewer Comments:

- Good innovative approach. Has potential to link to operating guidelines in control centers.
- This is a solid project that has a good foundation. Good rigor and providing good value. I also like the technology transfer aspects of this where they brought in something used in a different application to power system applications.
- Bernie's work underwrites a lot of the progress in characterizing and analyzing oscillatory behavior observed with PMUs. Continued support of his work is an excellent DOE investment to providing operators a definitive number indicating level of risk.

Project: **Wide-Area Damping Control Proof-of-Concept Demonstration**
Presenter: **David Schoenwald**
Avg. Score: **4.25**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	x		xxx	xxxx

The primary focus for phase II of the project (FY16–FY17) will be the development and initiation of a phased closed-loop testing plan for the deployment of the prototype PDCI control system. This plan will be developed and refined under the jurisdiction of the JSIS MOU currently used for PDCI probe testing. This will help address institutional barriers to closed-loop testing of the prototype. We will continue the verification & validation of the prototype controller via open-loop testing, already in progress, to facilitate closed-loop deployment. We will address PMU data quality concerns by monitoring latencies and creating identification & mitigation strategies for bad data.

During phase II, we will also focus on further refinement of the supervisory system that ensures the controller is operating as intended and causing no harm to the grid. Additional tasks for phase II include analysis of 2016 and 2017 PDCI probe testing results, model development and simulation studies to support the closed-loop testing plan, and evaluation of approaches to enhance control system interface with BPA Operations. To support the DOE Energy Storage Program, a provider of project matching funds, we will design and evaluate control strategies, both at the simulation level and the architectural level, that incorporate distributed energy storage to damp wide-area oscillations.

Engagement with the utility community will be coordinated through WECC/JSIS and Peak RC, which will serve as forums for briefings, discussion, and stakeholder input on closed-loop testing plans, results, and analysis. Communication will be in the form of reports, slides, telecons, and in-person meetings at WECC, Peak RC, and/or BPA facilities.

The content of this communication will consist of:

1. Analysis results from most recent closed-loop tests.
2. Briefing on prototype status, such as any recent or planned software or design changes.
3. Discussion of existing plans for upcoming closed-loop tests.

Feedback from the utility community will be gathered and incorporated into potential modifications to any upcoming closed-loop testing plans and/or design refinements to the controller itself.

Selected Reviewer Comments:

- Very important to establish confidence in use of PMUs for control.
- This is a solid project that has been around for a while. Good team, good plan, good project objectives. A very deliberate schedule with rigorous testing. This is a very important project to pave the way toward more wide area control projects. Gaining confidence in doing this will pay dividends.
- High profile, high potential return; enhanced reliability potential is undamped oscillatory behavior can be cancelled.

Project: **NERC-DOE Special Reliability Assessment: Oscillation Analysis**
Presenter: **Mani Venkatasubramanian**
Avg. Score: **3.4**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
	xxx	x	xx	xx

This project represents a joint effort between NERC and DOE to characterize, better understand, and assess the inter-area oscillatory modes of the Eastern, Western, and ERCOT Interconnections. NERC and the NERC Synchronized Measurement Subcommittee (SMS) will lead the technical analysis and data collection. The project PI, an expert in the area of inter-area and forced oscillation modes, will help NERC improve its analytical capabilities and perform the initial analysis to characterize the system modes in each of the interconnections.

NERC will facilitate data transfer and ensure sufficient measures are in place to ensure the Oscillation Expert has appropriate access collected data whilst maintaining confidentiality issues.

The work will support NERC's efforts to bring value to the electric utility industry through advanced analytics. Deliverables include:

1. Abstract Report of inter-area oscillatory modes in the NERC Interconnections (for broader consumption);
2. Detailed Report of oscillatory modes in the NERC Interconnections; and
3. IEEE technical publication highlighting oscillation analysis and synchrophasor data.

This Analysis is expected be completed over the course of approximately one (1) to one and a half (1.5) calendar years. The analysis will look at recurring data requested from industry for major grid events where inter-area oscillations are exhibited.

Selected Reviewer Comments:

- Sorely needed to develop understanding of EI Oscillatory behavior.
- Supporting the NERC SMS is important. Raising awareness of oscillatory behavior among industry stakeholders is good. Understanding the limitations of data availability/formatting is good to know about. Having rigor on the mathematics and eigenvalues/eigenvectors is important.
- This project already demonstrating significant ROI. While we used to believe Eastern Grid was quiescent—now we know better. Still much to be done to understand the Eastern Grid at the peril of a significant event.

Project: **Measurement-Based Stability Assessment**
Presenter: **Dan Trudnowski**
Avg. Score: **4.1**
Distribution: **(See Table)**

Low Value (1)	Somewhat Valuable (2)	Valuable (3)	Very Valuable (4)	Highest Value (5)
		x	xxxxx	xx

Real-time PMUs provide significant opportunity for real-time monitoring of a grid's stability state (often termed situational awareness). Such monitoring is enabling new stability-based control systems that allow for reliable increased transmission flows over paths that are today stability limited. The research proposed here is aimed at the development of understanding and algorithms that form the basis for real-time operations and control. The proposed foci are:

- Conduct research with the goal of developing PMU-based signal-processing algorithms that: (1) distinguishing between a transient oscillations and a forced oscillation; and (2) locate the source of a forced oscillation. Oscillations in the electromechanical frequency range that can be accurately measured by a PMU will be considered.
- Conduct a detailed comparison and certification of the most recent mode-meter estimation algorithms, including those that estimate modes in the presence of forced oscillations.

Selected Reviewer Comments:

- This project performs fundamental research into processing PMU data and identifying oscillations. Very thorough analysis of various techniques. Monte Carlo approach is very powerful.
- Moving the ball forward on understanding forced plus known oscillation behavior.
- A very qualified team—world class experts. Solving and important problem that is necessary to rely on accurate mode meter algorithms. Because of the importance of mode meters to oscillations (a key synchrophasor application area), this is an important area.