Sensing & Measurement Strategy

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

National Labs: ORNL, NETL, ANL, INL, LANL, LBNL, LLNL, NREL, PNNL, SNL
Industry Partners: ComEd, Dominion, Entergy, EPB, EPRI, NASPI, NIST, OSIsoft, Southern Co., TVA

Project Description

The Electric Grid is undergoing a major transformation (integration of new devices, major shift in generation mix, aging infrastructure, added risk of extreme grid events) which presents new and greater challenges for effective grid operation and management requiring greater grid visibility through sensing and measurement. A Sensing & Measurement Strategy (measurement parameters, devices for making measurements, communications to transfer data, and data analytics to manage data) is needed to allocate and turn grid measurements into actionable information.

Expected Outcomes

- Creation of an Extended Grid State Reference Model to identify the information needed to understand how to instrument the modern grid with conventional sources/loads and renewables, storage, EVs, etc.
- Development of a Technology Roadmap to identify the state of sensors and to determine sensor R&D needs/priorities needed to measure grid measurements and to provide actionable information.
- Development of a Sensor Placement Optimization Tool (SPOT) to assist utilities in deciding what sensing & measurement technologies to use and how to allocate them to achieve effective grid observability.
- Outreach to technical groups to coordinate with industry needs/priorities and identify new standards and enhancements needed.
- Value Proposition: A cohesive strategy for sensing & measurement will provide what is needed to characterize the state of the grid at much higher fidelity/resolution to maintain system resiliency, reliability, and security.

SIGNIFICANT MILESTONES	STATUS	DATE
SM CY1 – Development of Technology Roadmap	*Completed draft with industry feedback and submitted to DOE*	4/1/2017
CY2 Roadmap – Fully compiled report outlining roadmap and gap analysis to DOE	*On track*	10/102017
SM CY2 – Development of prototype optimization tool	*On track*	4/1/2018
CY3 Outreach – facilitate the creation of a PAR, task forces or working groups for standards to respond to new sensor and measurement requirements	*On track*	4/1/2019
SM CY3 – Validated framework of optimization tool based on field test of utility stakeholders	*On track*	4/1/2019

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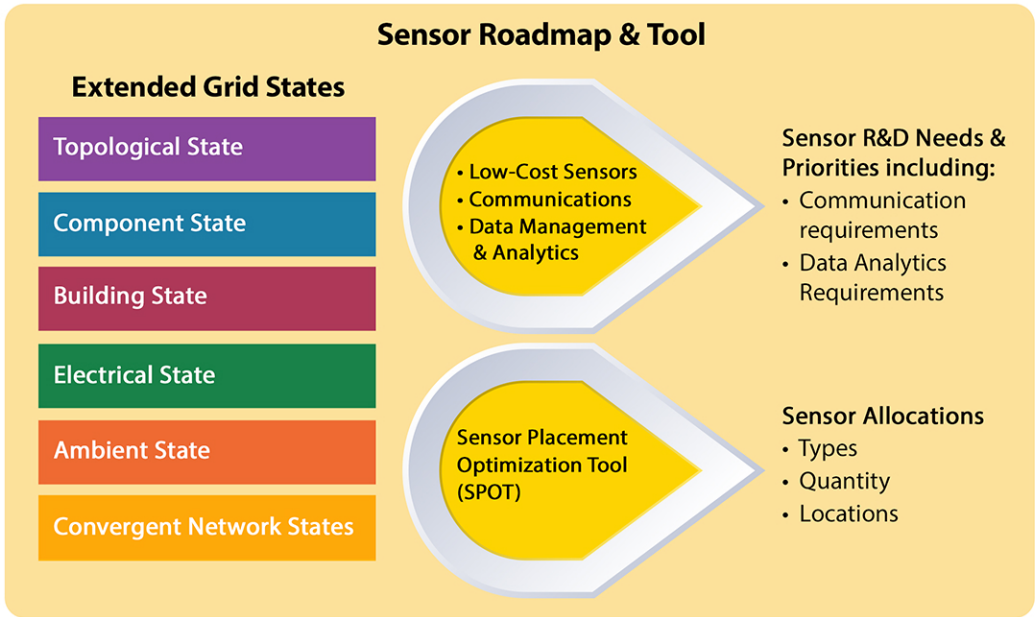

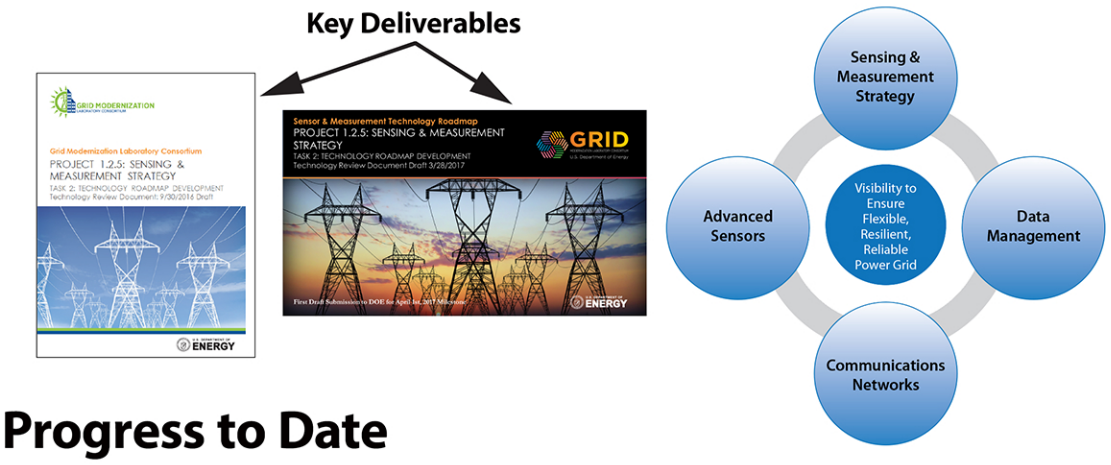

Progress to Date

- Industry meeting (Sep. 20, 2016) hosted with EPB (Chattanooga, TN) to share draft project results with industry partners/stakeholders and gain knowledge of EPB's distribution system sensor and communications activities
- Draft Extended Grid State Framework and Definitions (Sep. 30, 2016)
- Draft Sensing Technology State-of-the-Art Review (Sep. 30, 2016) submitted to DOE
- Webinars on Extended Grid State with industry partners and stakeholders (Fall 2016)
- Webinars on Roadmap with industry partners and stakeholders (Winter 2017)
- Draft Sensor Optimization Placement Tool development and implementation plans (Feb. 1, 2017)
- Industry meeting (Feb. 9-10, 2017) hosted with ComEd (Oak Brook, IL) to share project activities of this and two related GMLC projects and to gather feedback from a broader audience of industry partners and stakeholders
- Development of sensor placement optimization tool or SPOT initiated (Mar. 30, 2017)
- Draft Sensing & Measurement Technology Roadmap (Mar. 31, 2017) with industry feedback and matrix categorization of R&D thrusts submitted to DOE

ORNL 2017-G00384/tcc

Advanced Sensor Development

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Project Description

Focus on key challenges previously identified in industry roadmaps and DOE programs that are critical to increased visibility throughout the energy system. The project is organized around three major segments: end-use, transmission and distribution (T&D), and asset monitoring.

Expected Outcomes

End-use: (1) develop low-cost sensors, exploiting additive manufacturing techniques, to monitor the building environment and electrical characteristics of HVAC equipment, and (2) develop algorithms to use building-level data to provide utility-scale visibility of grid reliability and localized weather monitoring.

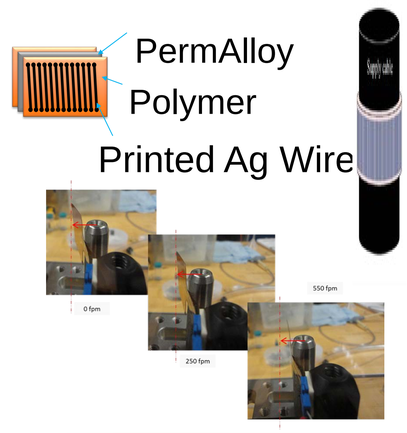
T&D: extend the resolution of transmission grid visibility orders of magnitude higher than current technologies. Focus is on dynamic response and data resolution as well as innovative ways to estimate electrical parameters from optical sources.

Asset Monitoring: sensing platforms with attributes that are best-suited for broad applicability across the entire grid asset monitoring application areas. Focus is on very low cost gas and current sensors for asset monitoring.

Significant Milestones	Date
(1) Draft requirements specification document. (2) Develop Ultra-PMU Algorithms for Transient Capture and Prediction, including adaptive zero-crossing algorithm and phase-locked loop algorithm. (3) Develop Optical CT/PT Integrated PMU Monitoring System: Tailor ORNL high-accuracy phasor and frequency measurement algorithms for optical CT/PT. (4) Develop CoFe electrodeposition process for integrated biasing magnets.	**11/30/2016**
(1) Draft specification of sensor development to measure airflow at an accuracy > 90% and current at >95% accuracy.	**2/28/2017**
(1) Document describing an algorithm to identify power outages based on Internet disconnects. Demonstrate >90% recognition accuracy of power outages based on real streams of Internet communications from typical homes. (2) Develop Ultra-PMU Algorithms for Transient Capture and Prediction: Experiment with adaptive window size for optimal performance. Ensure the algorithms be able to detect the transients in one cycle or less. (3) Validation of repeatable electrodeposition process which is capable of providing repeatable material stack of required thickness (variable thickness range for detecting currents in the 1A - 1000A range , while current state-of-the-art solutions detect currents on the order of 10A).	**5/31/17**
(1) Draft design document for physical and data-driven sensors incorporating functional and deployment requirements. The document will describe the sensor designs, in particular, airflow measurement at >90% accuracy, current at >95% accuracy, and outage detection >90% accuracy	**8/30/17**

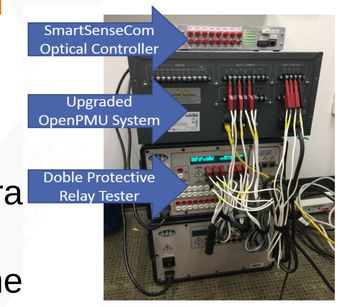
End-Use

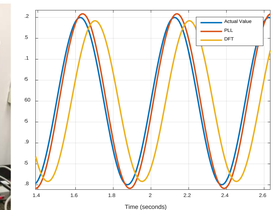
- A thin film low-cost sensor for improving building energy efficiency.
- Data-driven outage map in partnership with a network company.
- Open-source package in R for load shape estimation and forecasting

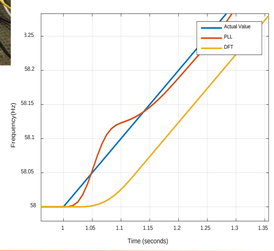


T&D: Ultra PMU and optical sensors

- Built PMU testing system.
- Developed multiple ultra fast PMU algorithms.
- Ultra fast response time of one cycle. (Compared to 6 cycles DFT algorithm)





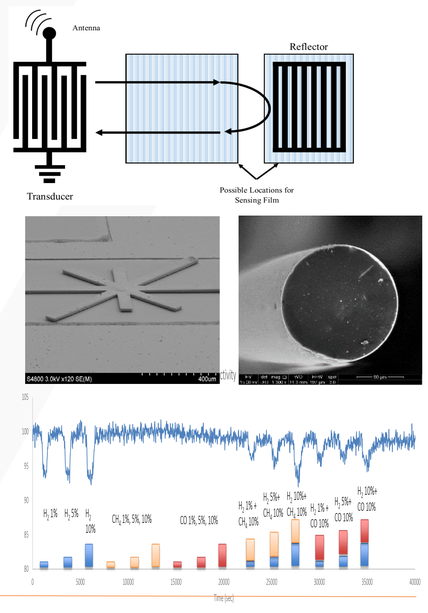


Asset Health Monitoring

Magneto-elastic sensor (MagSense): a first-of-its-kind ECD CoFe alloy with a high degree of magnetostriction.

Surface-Acoustic Wave (SAW) sensor: for methane detection. promising selectivity and sensitivity.

Nano-Enabled Optical Fiber sensor: for selective H2 chemical sensing. demonstrated temperature monitoring for transformer core.



Progress to Date

All milestones completed
3 Patent applications
3 Patent disclosures
2 Journal Papers under review

- Utilization of Optical Sensors for Phasor Measurements Units, IEEE Power Energy Society (PES) letter
- Clustering of Residential Load Patterns Based on an Improved Gravitational Search Algorithm, IEEE Transactions on Smart Grid

Integrated Multi Scale Data Analytics and Machine Learning

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Develop and demonstrate distributed analytics solutions to building-grid challenges, leveraging multi-scale data sets, from both sides of the meter. Evaluate and demonstrate the application of machine learning techniques to create actionable information for grid and building operators, and derive customer benefits from disparate data

Enabling the transition from data to actionable information at the building to grid interface

Outcomes

- Enable local nodal information exchange and high-performance, distributed algorithmic analysis
- Deploy local analytics integration at the grid edge, with a bridge to supervisory grid layers
- State-of-the-art distributed analytics strategies to thrive in an evolving distribution system

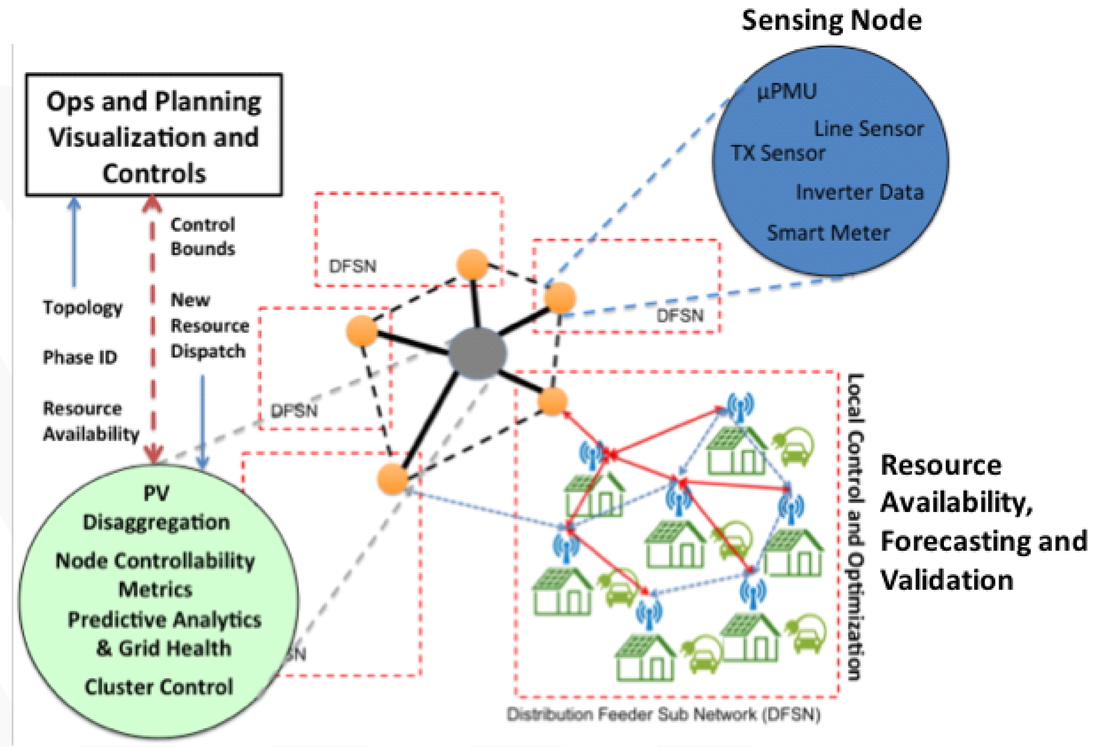
Benefits

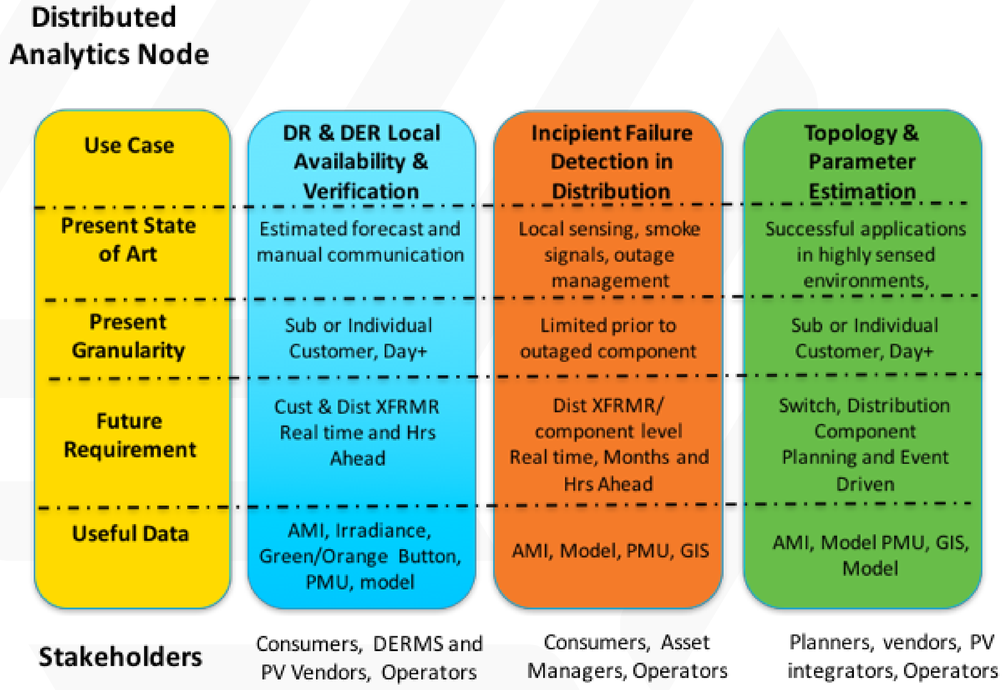
- Consumers will have increased revenue streams for utilization of resources
- Grid operators and planners can proactively and efficiently manage assets
- Improved grid health and data utilization

Significant Milestones	Date
Task 1: White paper delivery and review	9/1/16
Task 2: Workshop & Use Case Review	2/1/17
Task 4: Benchtop application demo	7/1/17
Task 6: Framework Presentation	6/1/18

Team

- LLNL, LBNL, LANL, ANL, NREL, SNL
- Industrial Partners: RPU, Pecan St, PG&E, PSL, Sentient, Duke Energy, SGIP, OSISoft





Progress

- Use case review at stakeholder workshop
- Evaluated state of the art in ML, and selected platform
- Two white papers delivered, and being published
- Coordinated with synergistic activities across programmatic boundaries

Discovery through Situational Awareness

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Create a tool that applies statistical and machine-learning algorithms in context of big data analytics to identify and investigate data-driven anomalies and oscillations in near real-time

Expected Outcomes

- Initial investigation using neural networks to identify events
- Prototypical situational awareness tool deployed at the EIOC (streaming WECC PMU data housed at PNNL) focused on anomaly and oscillation detection
- Integrate these algorithms into a demonstrational tool focused on the Eastern Interconnect and wide-area phase angle pairs (tool developed with EPG)
- Technical report discussing the algorithms and results when applied to PMU data

Significant Milestones	Date
First draft technical report to industry partners	7/28/2017
Investigation results to industry partners	8/25/2017
Technical report final	10/27/2017
Prototypical Situational Awareness Tool	12/29/2017

Progress to Date

- Key stakeholders from the Eastern Interconnect have been identified and the initial plan developed
- Applied initial anomaly detection and machine-learning algorithms to 6 months of PMU data (1.2 TB) accessed from the EIOC at PNNL
- Presented at the GMLC Industry workshop (Feb 2017) and recent NASPI workshop (March 2017)
- Lead in organizing the upcoming NASPI white paper – *"Data Mining Techniques and Tools for Synchrophasor Data"*

GMLC-0072: Suite of Open-Source Applications and Models for Advanced Synchrophasor Analysis

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

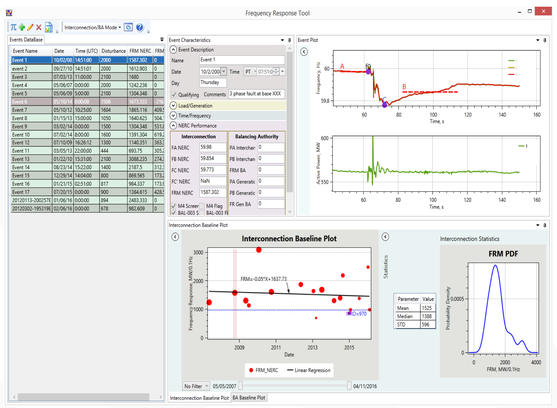
The goal of this research is to develop and advance applications of phasor measurement units (PMUs) and synchrophasor data for power system planning, modeling, and analysis.

Expected Outcomes

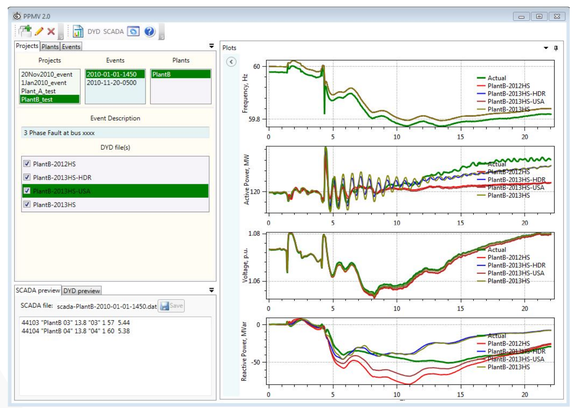
- Industry-grade, open-source power system analytical tools and software modules.
- Common open platform and data format structures.
- Building blocks and solutions for future and third-party applications.
- Addressing oscillation analysis, frequency response, model validation and calibration, load modeling, and other important power-grid-related issues.
- Enabling adoption of PMU technology by a wider range of electrical utilities.

Significant Milestones	Date
Prototype of the Oscillation Analysis and Baselining Tool (OBAT)	12/15/2016
New version of the Power Plant Model Validation (PPMV) with Siemens/PTI PSSE support	3/15/2017
OBAT released under an open source license	5/1/2017

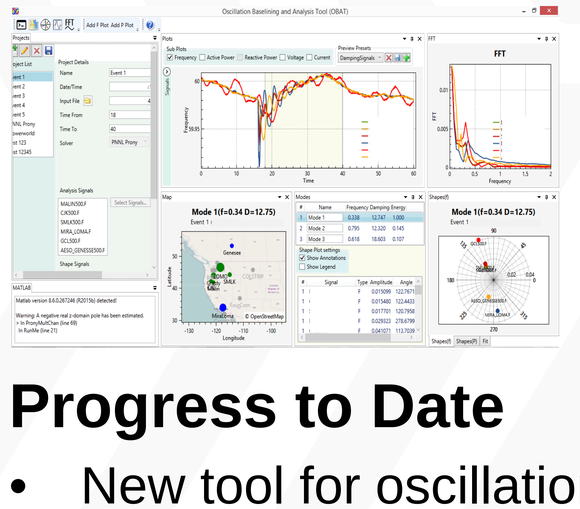
Frequency Response Analysis Tool (FRAT 2.0)



Power Plant Model Validation Tool (PPMV 2.0)



Oscillation Baselining and Analysis Tool (OBAT)



Load model Data Tool (LMDT 2.0)

Progress to Date

- New tool for oscillation analysis and baselining has been developed.
- New versions of the FRAT, PPMV and LMDT tools with enhanced capabilities have been released.
- Tools used by multiple leading electrical organizations, including NERC, WECC, BPA, SCE, PG&E, and many more.
- Tools presented at multiple events, including NASPI, NERC and WECC working groups meetings.
- Published one journal paper and two conference papers. Submitted one journal paper and one conference paper.

GM0073: HVDC and Load Modulation for Improved Dynamic Response using Phasor Measurements

PNNL: *J. Lian(PI), S. Wang, M. Elizondo, J. Hansen, R. Fan, L. Marinovici, R. Huang*;
SNL: *D. Schoenwald*; ASU: *V. Vittal*; PSU: *M. Zhu*

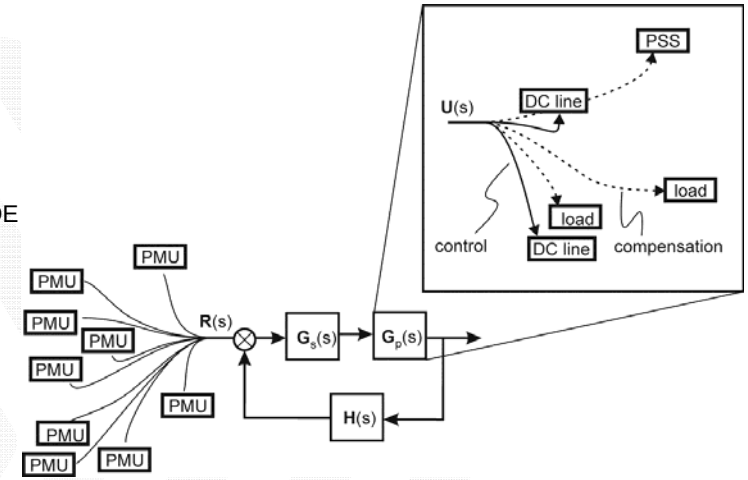
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

The focus of this project is to investigate ways of using the information available from phasor measurement units (PMUs), and the widespread availability of controllable devices, to design novel control strategies for damping inter-area oscillations. This effort directly supports Advanced Synchrophasor Technology Research (ASTeR) to develop and advance the applications of PMUs and synchrophasor data as part of the DOE OE Transmission Reliability program.

The specific objectives of this project are to:

- Develop a mode decoupling approach based on wide-area measurements from PMUs
- Design damping control strategies with HVDC networks based on decoupled modulation
- Investigate the applicability of controllable loads for oscillation damping control



Block diagram of wide area control for inter-area oscillation mitigation

Expected Outcomes

- Greater understanding of the impact of wide-area data transmission limitations on damping control performance
- Specifying upper bounds of PMU network latencies to preserve stable and reliable damping-control operation
- Improving damping of electromechanical modes of oscillation, thereby allowing the system to operate closer to reserve margins
- Creating a level playing field for end-user loads with traditional generating assets for providing oscillation damping

Significant Milestones	Date
Completed the design of decoupled modulation algorithms	04/30/2017
Completed the initial design of damping control strategy for three or more HVDC lines	07/31/2017
Complete the design of damping control strategy based on end-user load modulation	07/31/2017
Completed the proof-of-concept testing of proposed damping control strategies	07/31/2017

Progress to Date

- Completed selection of signals for oscillation mode decomposition and the initial design of decoupled modulation algorithms
- Completed the design of a base case with two or more HVDC lines in MinniWECC system
- Examined the controllability options for HVDC network in MinniWECC system
- Finalized aggregated model development and initial control design for residential end-user loads
- Documented available large-scale test system models and available modeling approaches for HVDC and loads in MATLAB
- Presented a paper at “2017 ACEEE Hot Water Forum”
- Delivered a letter report on literature survey of HVDC lines and network modeling, and existing WECC transmission planning including proposed HVDC lines
- Planned 3 conference papers and 4 journal papers

Advanced Machine Learning for Synchrophasor Technology (GM0077)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- Transmission systems are becoming more dynamic as distribution grid loads participate in control and intermittent renewable generation affects power flows
- PMUs provide data that may enhanced the system situational awareness and decision support
- Operators do not have sufficient tools to convert PMU data into actionable information
- Operators need:
  - Fast algorithms to convert PMU data into a transmission system-wide model of dynamics
  - Fast algorithms that leverage these models and PMU data to detect, characterize and localize anomalies
  - Advanced visualization to support decision making and situational awareness

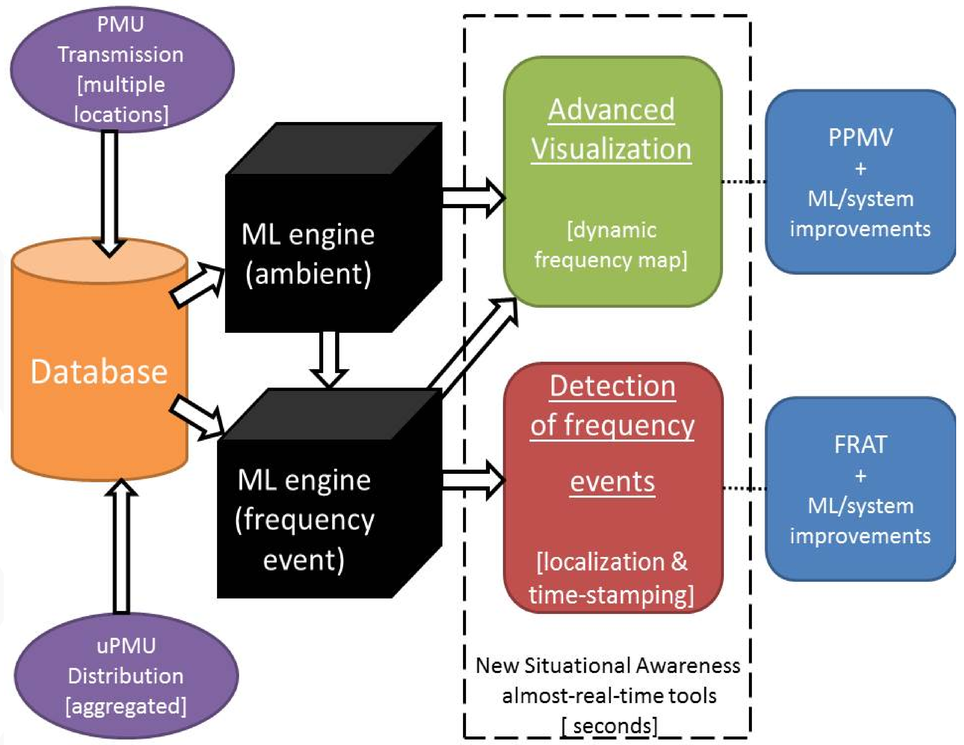
Challenges

- Online streaming data processing methods are needed to process high bandwidth PMU data
- Real-time decision support for control demands computationally efficient machine learning algorithms
- PMU data is sparse—machine learning algorithms should accurately reconstruct system properties using partial observations
- Machine learning algorithms should be robust to noisy and corrupted PMU data
- Machine learning outputs will still be spatially complex and require computationally efficient real-time visualization tools to depict large scale events in the grid.

Expected Outcomes

- A grid physics-aware, Machine Learning and Analytics (MLA) toolbox to monitor stochastic and dynamic state of the transmission grid during **normal operations** and to **localize significant frequency events** in seconds after they occur. The MLA will also enable or improve:
  - System-wide estimation of dynamic model parameters
  - Dynamic and stochastic modeling of controlled and uncontrolled resources

- The MLA toolbox integrated into an industry-grade situational awareness platform interfaced with existing tools that is able to
  - Receive real-time PMU and system state information
  - Detect system events, critical system states and other operational abnormalities
  - Perform system analysis within the seconds timeframe
  - Visualize the analysis results for decision support



Progress to Date

- Static Graphical Model Reconstruction for Load-Fluctuations Models: The algorithm SLICE is able to reconstruct probability distributions from minimal amount of observations and is robust with respect to highly-correlated data [1].
- Static Streaming Reconstruction: An online algorithm for retrieving leading principal components or leading correlations in very large dataset. It extracts relevant signals from noise in large PMU dataset in real-time [2].
- Topology Learning in Loopy Power Grids: developed algorithm that uses time-series of nodal phase angle/frequency fluctuations to arrive at the exact loopy topology [3].
- State estimation using partial information: developed methods for state estimation inside an impacted area using only partial or imperfect information e.g., PMU measurements only from outside the area [4].
- Synthetic power grid networks: developed methods to generate realistic large networks that will be used to evaluate the team's algorithms [5].
- Contingency analysis: assessed the impact of the differences between the AC and DC models on contingency analysis [6].
- Grid partitioning: obtained theoretical results for grid partitioning & islanding [7].

Publications

[1] S. Misra, M. Vuffray, A. Lokhov, M. Chertkov "Towards Optimal Sparse Inverse Covariance Selection through Non-Convex Optimization," submitted to ICML, 2017
[2] S. Yun, "Noisy Power Method with and without Spectral Gap", in preparation, 2017
[3] S. Talukdar, D. Deka, M. Chertkov, M. Salapaka, "Learning Exact Topology of a Loopy Power Grid from Ambient Dynamics", ACM e-energy 2017.
[4] S. Soltan, M. Yannakakis, G. Zussman, "Power grid state estimation following a joint cyber and physical attack," IEEE Trans. Control of Network Systems (to appear), 2017.
[5] S. Soltan, A. Loh, G. Zussman, "On the Reproducibility of the Structural and Spatial Characteristics of Power Grids," submitted, 2017.
[6] H. Cetinay, S. Soltan, F. Kuipers, G. Zussman, P. Van Mieghem, "Comparing the Effects of Failures in Power Grids under the AC and DC Power Flow Models," under revision in IEEE Trans. Network Science and Engineering, 2017.
[7] S. Soltan, M. Yannakakis, G. Zussman, "Doubly Balanced Connected Graph Partitioning," Proc. ACM-SIAM SODA'17, Jan. 2017.

Opportunistic Hybrid Communications Systems for Distributed PV Coordination

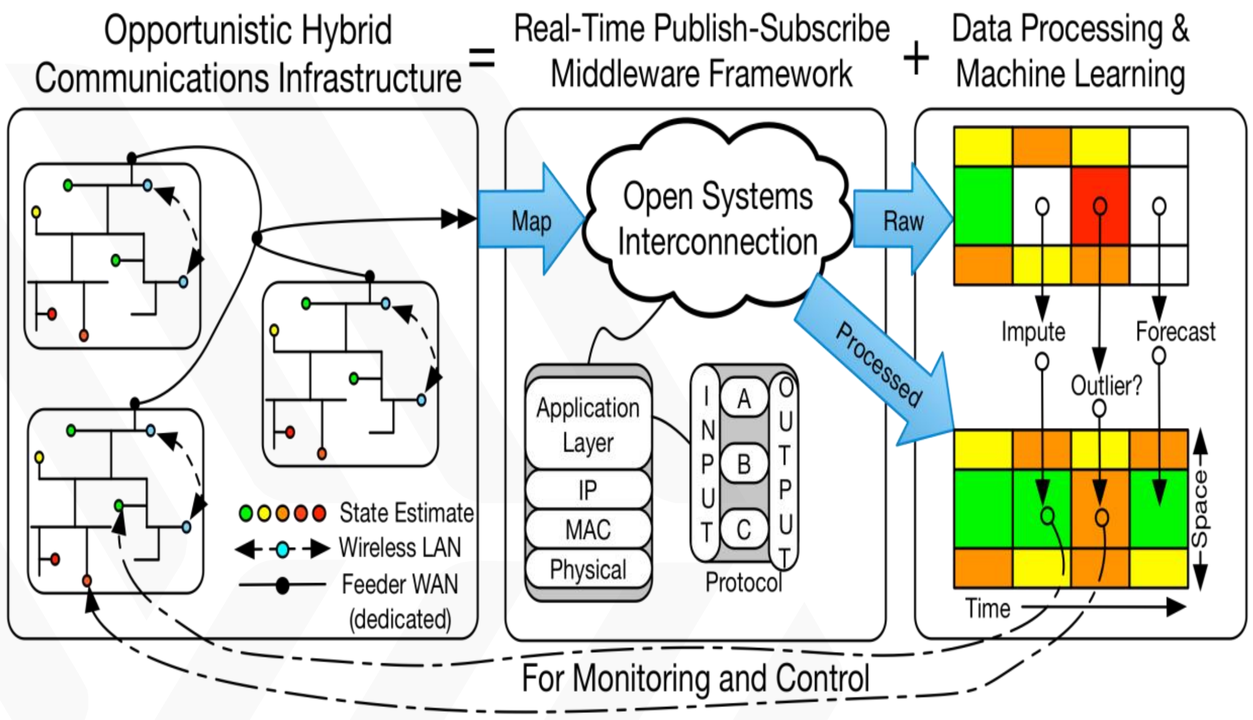
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

This project aims to develop an innovative opportunistic hybrid communication infrastructure that allows for the use of existing infrastructure and actionable information about distributed PV generation that can be utilized at both distribution and transmission system operator (DSO and TSO, respectively) levels.

Expected Outcomes

- ✧ A new design of opportunistic hybrid communication infrastructure.
- ✧ Advanced distributed QoS-resilient middleware architecture extending the utilization level of existing communication systems.
- ✧ New distributed steady and dynamic state estimation techniques for both PV generations and multiple levels of the power grid.
- ✧ Validation and robustification of the proposed hybrid communication infrastructure and distributed state estimation techniques through both IGMS-based co-simulations and HIL experiments.



The Full-scale and Operational Implementation Framework of Opportunistic Hybrid Communications Systems

Impacts:

- ❖ The proposed project will significantly contribute to maintain system economic efficiency and reliability with increased distributed PV penetration by combining unique communication infrastructure, intelligent communication middleware and distributed state estimation techniques.
- ❖ The new design framework of opportunistic hybrid communications systems we develop in this project will be open-sourced to all DOE labs and be licensed to U.S. utilities and ISOs per their requests.

Significant Milestones	Date
Development of QoS-resilient middleware architecture	3/31/2016
Design distributed ladder iterative state estimation algorithm	9/30/2016
Development of distributed PV state estimation algorithm	3/31/2017
Development and Co-simulation of hybrid communication system models	9/30/2017
Robustification and integration of the proposed distributed state estimation algorithms	3/31/2018
Hardware-In-Loop validation of opportunistic hybrid communication infrastructure	9/30/2018

Progress to Date

- ➢ Developed distributed QoS-resilient middleware architecture.
- ➢ Finished the design framework of opportunistic hybrid communications systems including communication node optimal placement and hybrid communication system simulation models.
- ➢ Developed distributed state estimation algorithms for both PV generations and multiple levels of the power grid.
- ➢ Peer-reviewed articles
  - 2 conference papers on attack-resilient middleware architecture on IEEE CPSCom Dec., 2016 and IEEE ICC May, 2017
  - 1 conference paper on automatic regionalization algorithm on IEEE Global SIP 2016
  - 1 journal paper on distributed ladder iterative state estimation (in preparation)
  - 1 journal paper on multi-rate and event-driven Kalman Kriging filter (in preparation)
  - 1 conference paper on hybrid communication system design (in preparation)

U.S. DEPARTMENT OF ENERGY

P.I.: Bri-Mathias Hodge, National Renewable Energy Laboratory
Team members: Anthony R. Florita, S M Shafiul Alam, Jianhua Zhang and Tarek Elgindy (NREL)
External Partners: Colorado State University and University of Akron

Solar Resource Calibration, Measurement and Dissemination

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

NREL develops and disseminates foundational solar resource data and products, best practices, and national standards. This project reduces the cost of developing, financing, integrating, and operating solar energy projects.

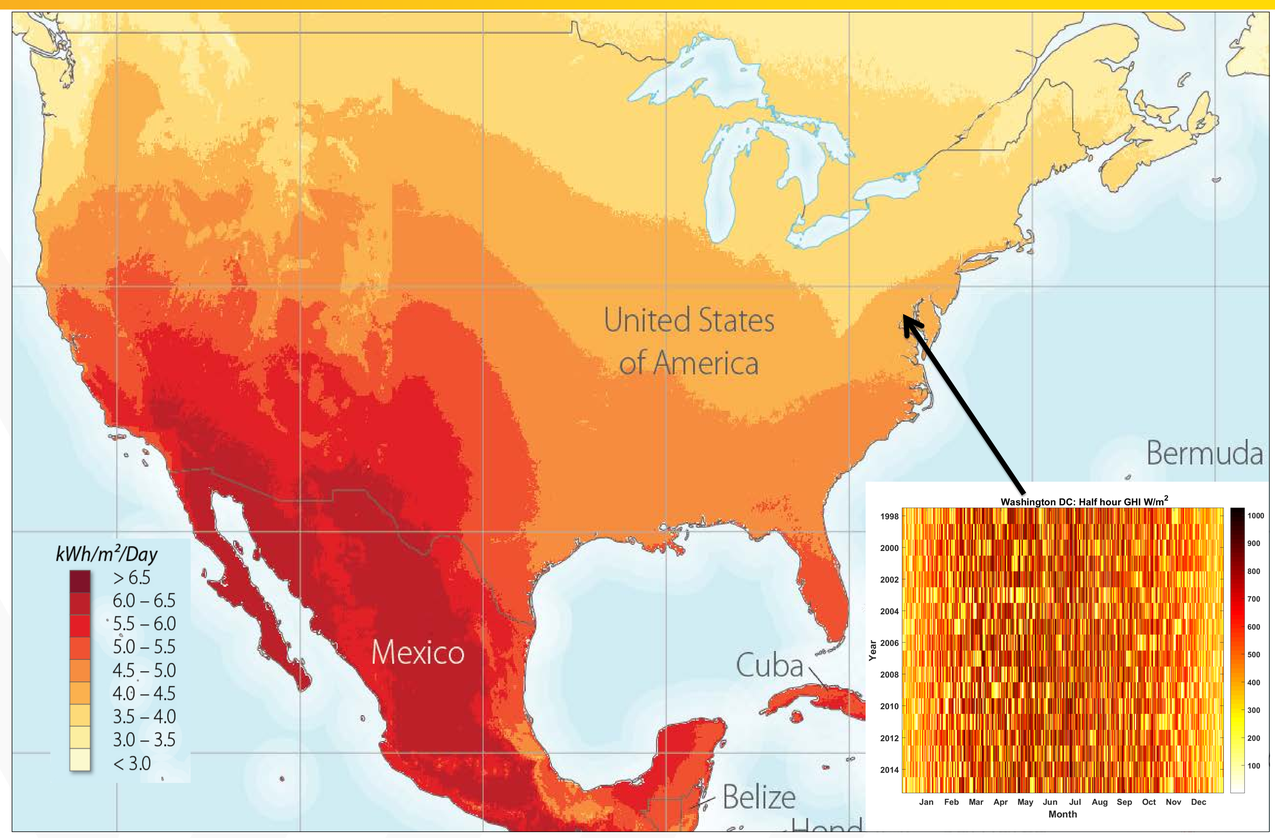
Expected Outcomes

Easy access to high quality, low uncertainty, solar resource data increases solar energy deployment and reduces project development and integration costs.

To achieve these goals, this project:

- Creates high quality long-term solar resource and meteorological data for the U.S. and distributes it through the **National Solar Radiation Database (NSRDB)**.
- Researches and develops **accurate, robust and low-cost solar radiation instrumentation and methods**.
- Uses new knowledge and technology to develop **consensus national standards and best practices** for solar energy.
- Provides **solar measurement reference to all instruments in the US** through the annual NREL Pyrheliometer Comparison conducted by the Solar Radiation Research Laboratory (SRRL).

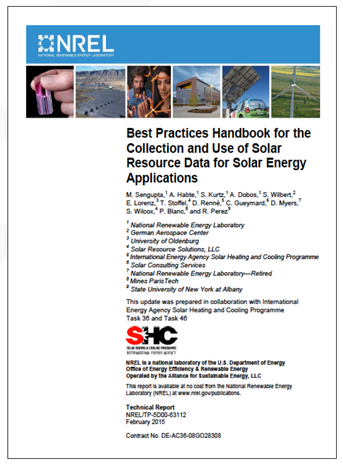
Significant Milestones	Date
Produced and delivered solar radiation data for 1998-2015 through the NSRDB	September 2016
Transferred world radiation standard to 23 national and international calibration providers	October 2016
Lead the writing of the “Best Practices Handbook of Solar Resources for Solar Energy Applications”	June 2017
Working concept for next-generation of low-cost high-accuracy irradiance sensors.	June 2018



The freely-available data from the NSRDB is critical for solar energy development and integration across the US

Progress to Date

- Since 2016, the NSRDB data have been available as a free download to the public from https://nsrdb.nrel.gov, which now has over **3,000 users per month**. External users include Southern Company and First Solar. Major projects include the System Advisor Model (SAM) and the North American Regional Integration Study (NARIS).
- NREL developed the Fast Atmospheric Radiation Model, leading to faster and more accurate solar assessment and forecasting.
- Together with industry and the American Society for Testing of Materials, NREL led the **development of new standards** that reduce the uncertainty and cost of solar energy projects.



NREL sets standards for government agencies, academia, and industry, ensuring high-quality measurements in the U.S. (left). NREL’s 35 years of experience is shared through best practices (right), standards, collaborations, and training.

Frequency Response Assessment and Improvement of Three Major North American Interconnections due to High Penetrations of Photovoltaic Generation

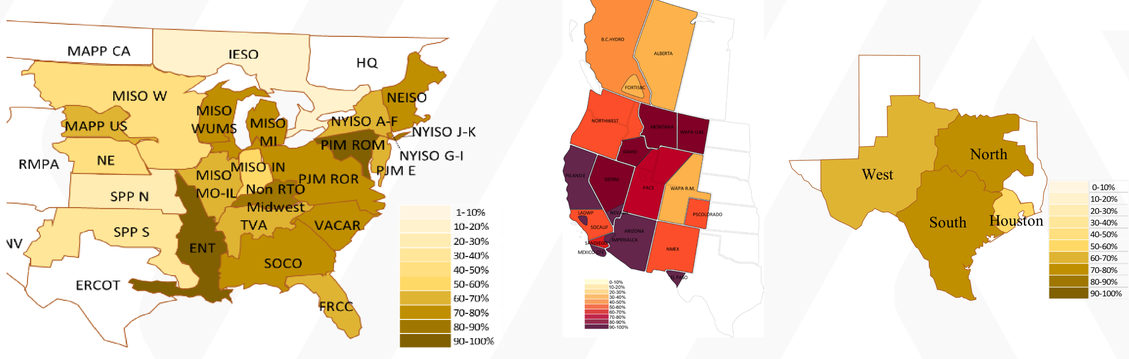
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

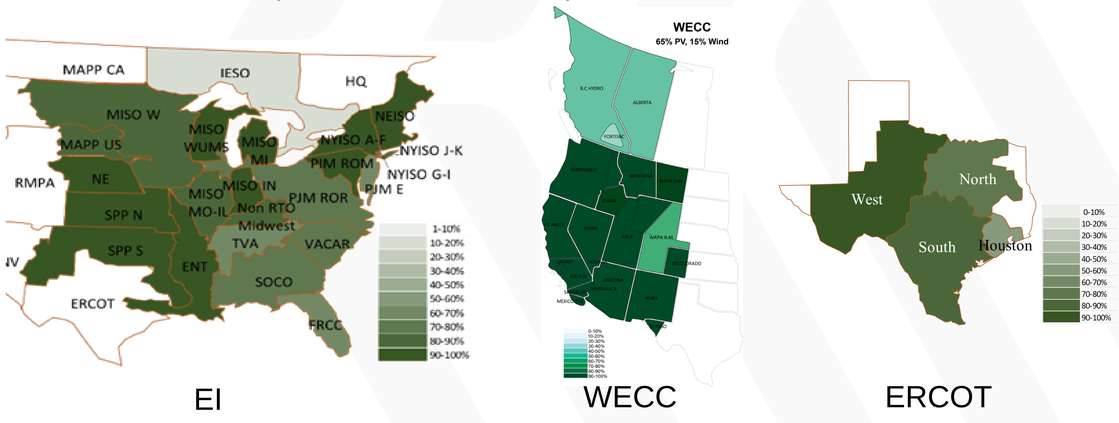
- The project will produce a family of high solar PV penetration scenarios from detailed, validated models of all three U.S. interconnections so that the effects of increased solar PV generation on frequency response can be fully quantified.
- Mitigation strategies will be developed and validated using both software and hardware test beds for a final recommended portfolio from available options.

Significant Milestones	Date
Develop a wide range of high PV penetration scenarios based on previously measurement-validated interconnection models and realistic PV distribution projections for each interconnection. √	12/31/2016
Quantify increased solar PV generation's impact on each North American interconnection's frequency response. √	09/30/2017
Quantify the local frequency response change due to an over 100% PV penetration at the BA level.	12/31/2017
Design remedial schemes for the negative frequency response impacts of high PV generation under the developed multiple PV penetration scenarios.	09/30/2018
Implement artificial inertia/governor/AGC schemes on a GE's utility-scale PV inverter product (Brilliance series) and test their effectiveness in GE's RTDS laboratory.	12/31/2018

PV distribution (65% PV scenario):

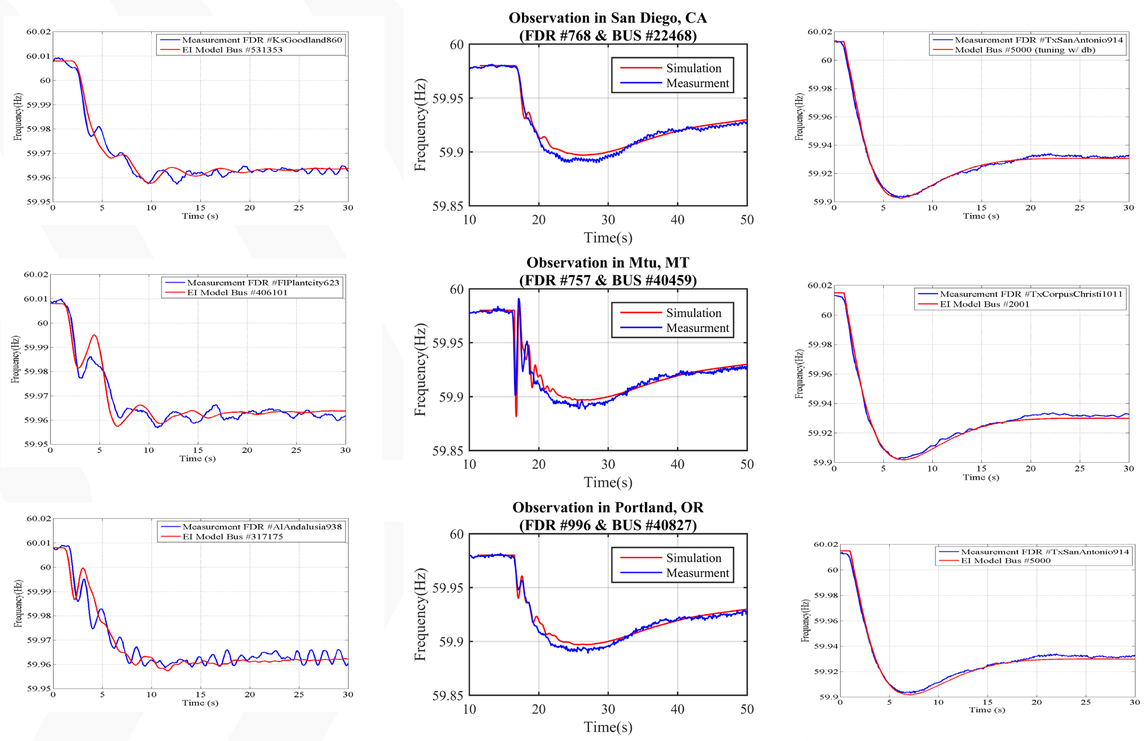


Renewable distribution (65% PV + 15% Wind):



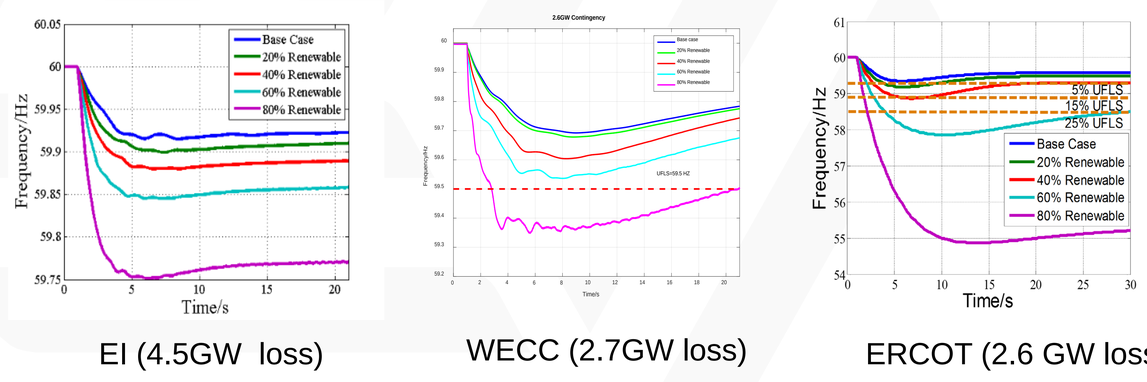
EI WECC ERCOT

Model validation at various locations:



EI WECC ERCOT

Frequency response of the largest resource event:



EI (4.5GW loss) WECC (2.7GW loss) ERCOT (2.6 GW loss)

Progress to Date

- All BP1 and BP2 Q1 milestones completed
- 1 face-to-face meeting and 2 teleconferences with technical review team, 1 presentation to NERC
- 1 technical report: Frequency Response Assessment and Improvement of Three Major North American Interconnections due to High Penetrations of Photovoltaic Generation — Phase 1. 2017
- 1 journal paper published, 2 conference paper accepted, 5 papers in review/revision

WindView: An Open Platform for Wind Energy Forecast Visualization

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Jie Zhang (University of Texas at Dallas)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

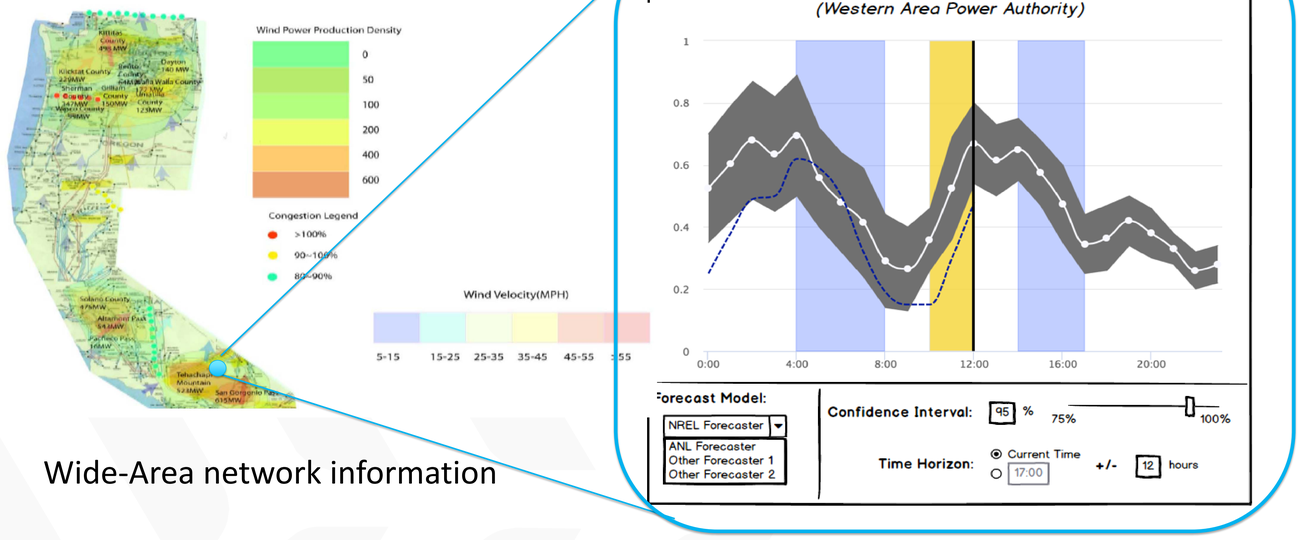
Project Description

WindView is an open source situational awareness and decision support visualization platform for wind energy. It will be capable of visualizing probabilistic wind power forecasts with ramp detection capability at different horizons on a dynamic and interactive map to display the uncertainty information in an easy to understand manner.

Expected Outcomes

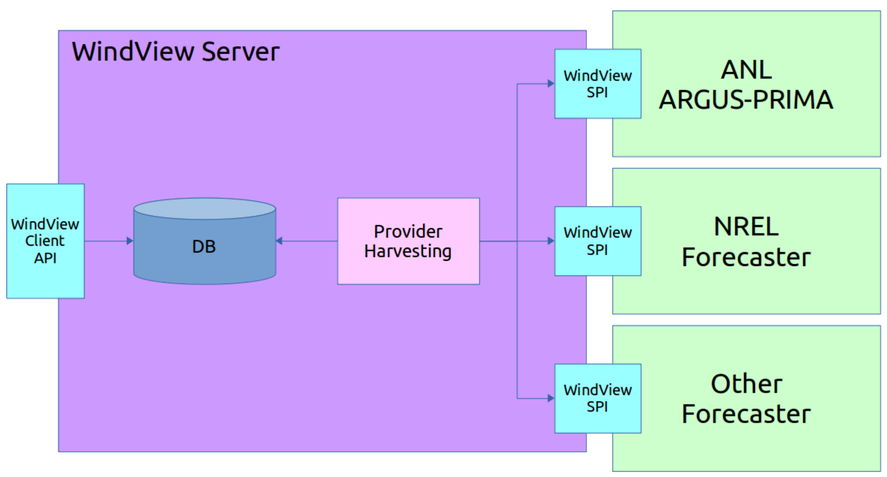
- Visualization of probabilistic wind forecasts with different horizons, temporal and spatial correlations of wind power forecasts, ramp forecasting, and condensed view of uncertainties
- Dynamic map with zoom to swap between wide-area information and specific plant details
- Aid the operators to manage wind forecast uncertainty and variability and thereby enhancing system reliability, having better management of system reserves and reducing power outages
- Will increase power system operators' situational awareness and allow wider integration of wind power advancing the Wind & Water Power Technologies Office objectives
- Develop a production-level version of WindView for the Western Area Power Administration's network
- Publically available for industry and academic researchers

Significant Milestones	Date
Survey available map-based layout options and choose the most suitable platform for WindView	06/30/2016
Finalize initial design and architecture based on industry feedback	12/31/2016
Design application interface for forecasting tools	03/31/2017
Initial feature implementation, including wind forecast displays and wind uncertainty representation	06/30/2017
Hold a demonstration of the WindView visualization system for a power system operators class at WAPA's EPTC facility and receive industry feedback on additional design features desired.	09/30/2017



Wide-Area network information

Mockup of a probabilistic forecast chart under development.



Platform Architecture

Progress to Date

- Collated industry feedback including presenting the WindView plan over webinar to a technical review committee including the Western Area Power Administration and an in-person visit to Excel Energy.
- Presented progress of WindView to system operators at the Western Area Power Administration.
- Created forecast visualization client interface mockup and exploratory implementation.
- Defined WindView platform architecture and preliminary programmer interfaces, i.e. client application (API) and forecast service provider (SPI).
- Created prototype WindView server implementation.
- Discussed hosting WindView at PNNL's EIOC center to support the GMLC project Multi-scale Integration of Control Systems