Sensing and Measurement

Portfolio Overview

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April 18, 2017
Arlington, VA

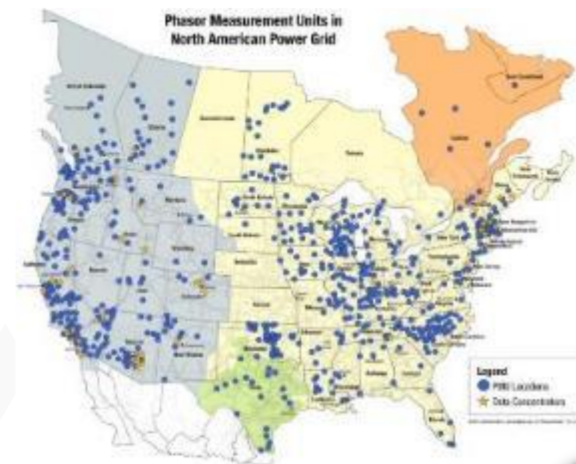
U.S. DEPARTMENT OF ENERGY

Sensing and Measurements

Objective: Sensor development and deployment strategies to provide complete grid system visibility for system resilience and predictive control

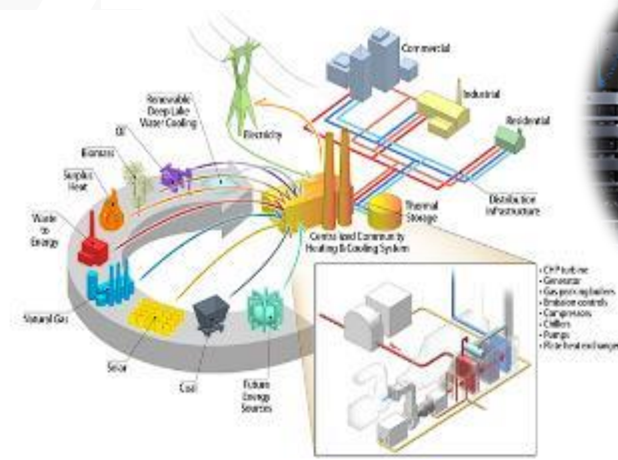
Expected Outcomes

- ► Advance and integrate novel, low-cost sensors to provide system visibility
- ► Develop real-time data management and data exchange frameworks that enable analytics to improve prediction and reduce uncertainty
- ► Develop next-generation sensors that are accurate through disturbances to enable closed-loop controls and improved system resilience



Federal Role

- ► Common approach across labs and industry test-beds for effective validation of emerging technologies
- ► Develop common interoperability and interconnection standards and test procedures for industry / vendor community



Grid Sensing & Measurement Activities & Technical Achievements

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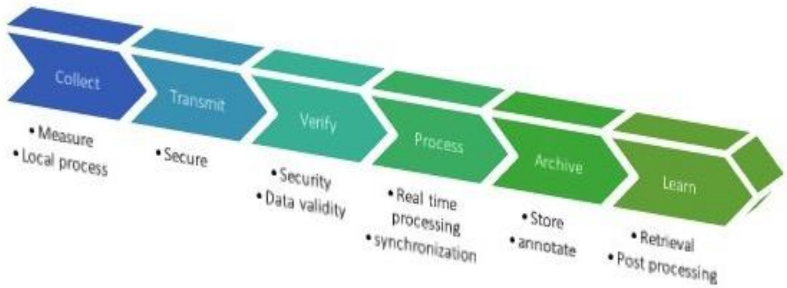
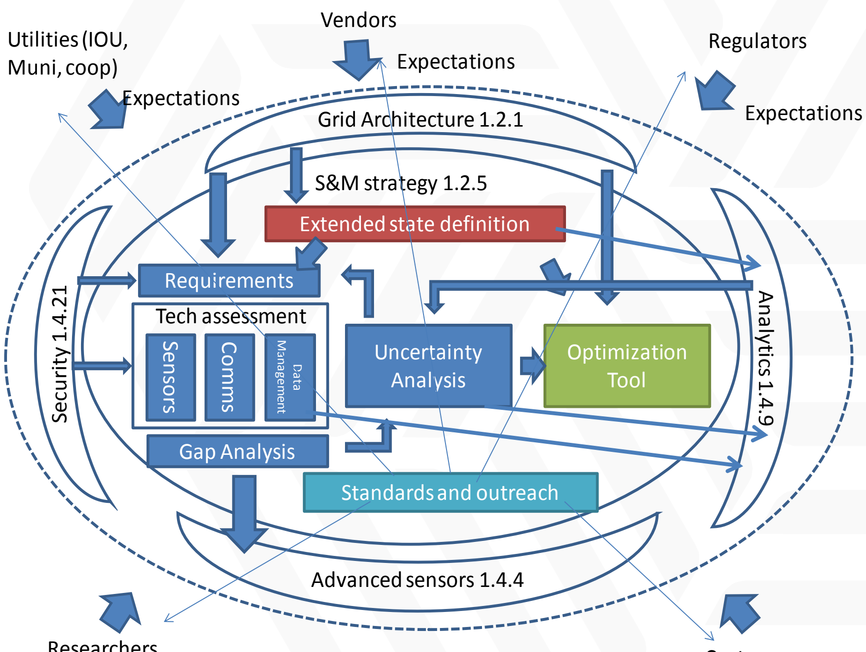
MYPP Activities	Technical Achievements by 2020
Improve Sensing for Buildings & End-users	Develop low cost sensors (under $10 per sensor) for enhanced controls of smart building loads and distributed energy resources to be "grid friendly" in provision of ancillary services such as regulation and spinning reserve while helping consumers understand benefits of energy options.
Enhance Sensing for Distribution System	Develop low cost sensors (under $100 per sensor) and ability to effectively deploy these technologies to operate in normal and off-normal operations Develop visualization techniques and tools for visibility strategy to help define sensor type, number, location, and data management. Optimize sensor allocation for up to 1,000 non-meter sensing points per feeder.
Enhance Sensing for the Bulk Power System: Develop Agile Prognostics and Diagnostics for Reliability & Asset Management	Develop advanced synchrophasor technology that is reliable during transient events as well as steady state measurement. Develop low cost sensors to monitor real-time condition of electric grid components. Using novel, innovative manufacturing concepts, develop low-cost sensors to monitor electric grid assets
Develop Data Analytic and Visualization Techniques	Provide real-time data management for the ultra-high velocities and volumes of grid data from T&D systems. Enable 100% visibility of generation, loads and system dynamics across the electric system through the development of visualization techniques and software tools Develop measurement and modeling techniques for estimating and forecasting renewable generation both for centralized and distributed generation for optimizing buildings, transmission, storage and distribution systems.
Demonstrate unified grid-communications network	Create a secure, scalable communication framework with a coherent IT-friendly architecture that serves as a backbone for information and data exchange between stakeholders and decision makers.

Foundational Projects

- Sensing & Measurement Strategy
- Advanced Sensor Development
  - End-use devices
  - Transmission & Distribution
  - Asset Monitoring
- Integrated Multi Scale Data Analytics and Machine Learning for the Grid

Project - Sensing & Measurement Strategy



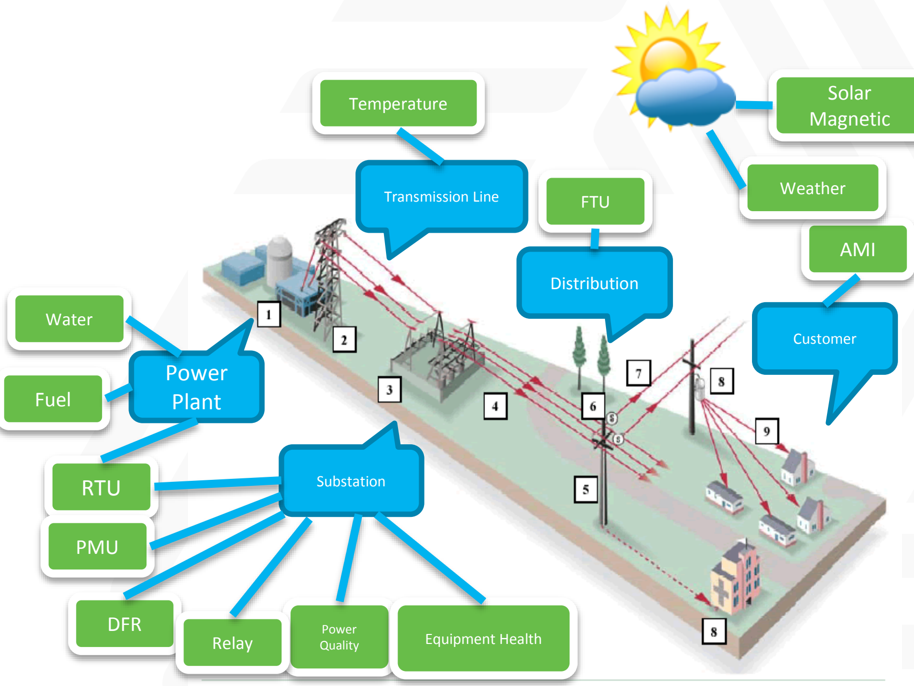


Identify measurement requirements along with associated data management and communication systems to achieve the MYPP goals. *Without an understanding of the true state of the system, these goals will never be realized.* This methodology includes: 1) defining the grid state, 2) developing a roadmap and 3) framework to determine sensor allocation for optimal results.

Labs: ORNL, PNNL, NETL, LLNL, ANL, NREL, SNL, LBNL, LANL

Partners: EPRI, Southern Co, EPB, Entergy, OSIsoft, Dominion, TVA, CommEd, NASPI

Project – Advanced Sensor Development



Modified from Duke Energy
https://www.progress-energy.com/florida/home/safety-information/storm-safety-tips/restoration.page?

Increase visibility throughout the energy system including transmission, distribution and end-use by developing low-cost, accurate sensors. Additionally, next generation asset monitoring devices will help determine state of grid components prior to failure.

Labs: ORNL, PNNL, NETL, NREL, SNL, LBNL

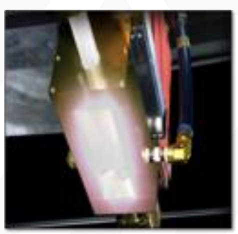
Partners: EPRI, University Tennessee, Southern Co, EPB, Entergy, Eaton, SmartSense, National Instruments, Dominion, TVA, ComEd, NASPI

Low Cost Sensors & Controls – Technology Platform

Thin Film Deposition

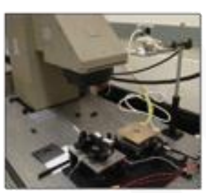
- **Inkjet Printing**
- **Ultrasonic Spray**
- **Sputtering**
- **E-beam Evaporation**

Low Temperature Photonic Curing



- **PulseForge 3300**
- **Vortek-300**
- **Vortek-500**

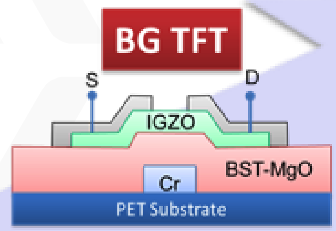
Materials and Device Characterization

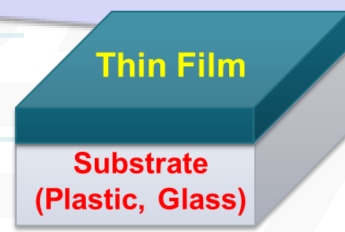


- **CNMS**
- **CATS Lab**
- **NSTL**
- **EMC2**
- **RF-Clean Room**
- **RF Test Setups**

TFT Development

- PTP Curing
- Multilayer Structure
- Characterization

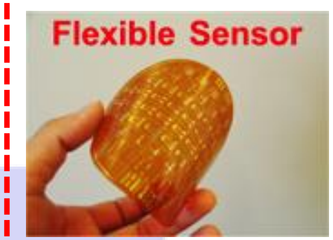




Plastic Integrated Thin Films

- Metal
- Semiconductor
- Dielectric

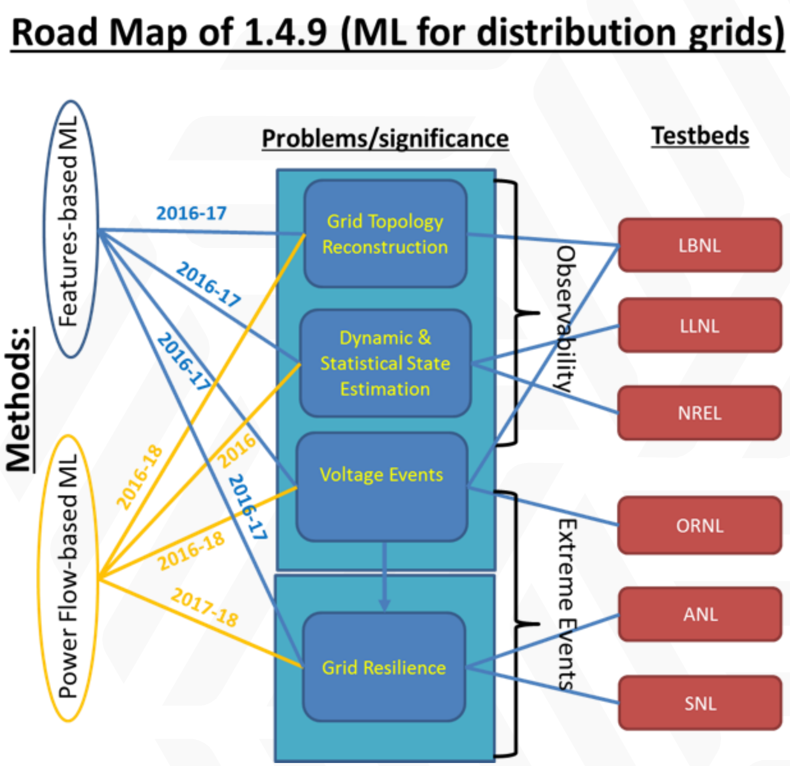
Development Target



Target Technologies

- **Sensors** (Electricity, Temperature, Environment, Mechanical)
- **Optoelectronics** (Phosphor, OLED, Display)
- **Batteries** (CNT, Nanoparticles, C-fiber)
- **RF Electronics** (Energy Harvesting, RF Tags)
- **Photovoltaics** (a-Si, CIGS, CZTS, Polymer)
- **Organic Electronics** (PV, Sensor, TFTs, RF)

Project – Distributed Analytics



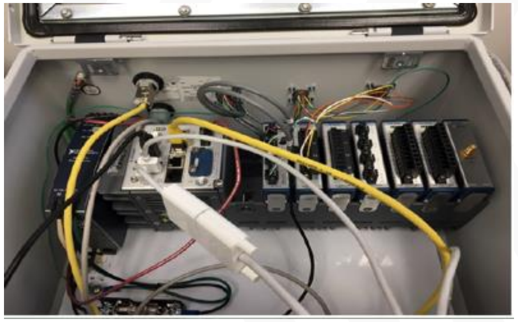
Developing a low cost scalable infrastructure for integrating disparate high fidelity data sources. Machine learning methodologies will be used to assist in transforming data into actionable intelligence. This platform will allow multiple entities to collaborate on data utilization.

Labs: LANL, SNL, LBNL, ORNL, LLNL, NREL, ANL

Partners: OSIsoft, National Instruments, PJM, EPB, Entergy, CommEd

Regional Project: Southeast Consortium

"Sensor Suite" for IoT monitoring



Step Distance Impedance Protection Using Optical Sensors

Establish a regional partnership that will increase utility clean energy portfolios and improve power system network resiliency to ensure increased reliability along with improved responsiveness under extreme conditions by eliminating outages or enabling faster restoration of power to critical loads

- Developed and Deploying Low Cost Sensor Suite
- Evaluated Time Sensitive Network within Utility
- Step Distance Impedance Protection Using Optical Sensors

Labs: ORNL, SRNL

Partners: University Tennessee, EPB, Southern Company, TVA, UNC-Charlotte, Duke Energy, Santee Cooper, Clemson

Connections and Collaborations

Foundational and Program Projects

13 Partnership Projects between National Labs – Industry – Universities

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MYPP Area	Foundational Projects	Program-Specific Projects
Develop Low-cost advanced sensors	1.2.5 Sensing & Measurement Strategy 1.4.4 Advanced Sensor Project	GM0073 - HVDC and Load Modulation for Improved Dynamic Response using Phasor Measurements
Data Management & Analytics & Visualization	1.4.9 Distributed analytics	GM0070 - Discovery through Situational Awareness (DTSA) GM0072 - Suite of open-source applications and models for advanced synchrophasor analysis GM0077- Advanced Machine Learning for Synchrophasor Technology SI-1728 - Solar Resource Calibration, Measurement and Dissemination SI-1758 - Frequency Response Assessment and Improvement of Three Major North American Interconnections due to High Penetrations of Photovoltaic Generation WGRID-59 - WindView: An Open Platform for Wind Energy Forecast Visualization
Communications	1.2.5 Sensing & Measurement Strategy 1.3.5 SE Regional Project	SI-1586 - Opportunistic Hybrid Communications Systems for Distributed PV Coordination

Accomplishments and Emerging Opportunities

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Accomplishment

- 1.2.5 Draft Extended Grid State framework and definitions incorporating industry feedback. Draft Technology Roadmap (including key use cases) with industry feedback submitted to DOE
- 1.4.4 End-use & Asset Monitoring sensor development has four invention disclosures & 2 patent applications; Developed algorithm for improved PMU under transient conditions;
- 1.4.9 Completed White Papers : What is machine learning and why do we need it from two perspectives building/grid and data science

Path Forward

- 1.2.5 Continue EGS and Roadmap efforts. Optimization Tool (SPOT Tool) development is underway; 1st application is a distribution state estimator
- 1.4.4 Evaluate performance of developed sensors; continue research on promising approaches;
- 1.4.9 Structure for testing and benefits assessment of the existing state of the art is identified and initial application will be demonstrated in early July

Thank you

For More Information

http://energy.gov/under-secretary-science-and-energy/grid-modernization-initiative

U.S. DEPARTMENT OF ENERGY

GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.2.5 – Sensing & Measurement Strategy

PAUL OHODNICKI, NETL (PLUS ONE)
PI: D. TOM RIZY, ORNL

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

Sensing & Measurement Strategy

High Level Summary

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Project Description

- A cohesive strategy to develop and deploy sensing & measurement technologies is lacking.
- Project focuses on strategy to define measurement parameters, devices for making measurements, communications to transfer data, and data analytics to manage data and turn it into actionable information.

Value Proposition

✓ Grid is undergoing a major transformation (integration of new devices, major shift in generation mix, aging infrastructure, added risk of extreme system events).

✓ There is a need to characterize state of the grid at much higher fidelity/resolution to maintain system reliability and security.

Project Objectives

✓ **Creation of an extended grid state reference model**: identifies the information needed to understand how to instrument the extended electric grid.

✓ **Development of a technology roadmap**: develop technologies to measure electric grid parameters.

✓ **Development of a sensor observability optimization tool (SPOT)**: develop approaches to place the technology to measure these parameters.

✓ **Outreach to technical groups**: coordinate with industry to ensure industry acceptance and to identify standards (new & enhancements).

Sensing & Measurement Strategy

Project Team

Project Participants and Roles

Ten National Laboratories make up the project team:

- ✓ ORNL, PI and Task 3 & 4 Lead
- ✓ NETL , Plus One and Task 2 Lead
- ✓ PNNL, Task 1 Lead
- ✓ Total of ten labs involved in Task 1-4
- ✓ Others include: NREL, SNL, ANL, LBNL, LLNL, LANL, INL

- ✓ Industry members include: Utilities, EPRI, IEEE, NASPI Task Team members, NIST, Standards Organizations, Vendors

- ✓ Multiple other organizations are serving as stakeholders and attended our webinars and Feb industry meeting.

PROJECT FUNDING

Lab	FY16 $	FY17$	FY18 $
ORNL	350	375	425
PNNL	150	200	100
NREL	100	100	150
NETL	100	100	100
SNL	50	40	40
ANL	100	30	30
LBNL	50	40	40
LLNL	100	75	75
LANL	0	40	40
TOTAL	1,000	1,000	1,000

Sensing & Measurement Strategy

Relationship to Grid Modernization MYPP

- **Project focuses on a strategy for sensing & measurement technologies to:**
  - ✓ Meet the challenges of integrating new technologies, such as renewable sources and storage
  - ✓ Provide the visibility needed to operate the modern grid to deliver resilient, reliable, flexible, secure and sustainable electricity.
  - ✓ Identify sensor R&D needs, priorities, and sensor allocation

- **Project is a crosscutting effort of the three thrusts of the MYPP including**:
  - ✓ Technology – identifies grid states that need measurements, roadmap of sensor R&D needs, and how to allocate sensors in the system.
  - ✓ Modeling and analysis – identifies communications and data analytics requirements for sensing and measurement.
  - ✓ Institutional and business – working with industry to identify needs and priorities and with technical organizations to identify enhancement and new standards needed.

Sensing & Measurement Strategy

Relationship to Grid Modernization MYPP
(Links to Sensing & Measurement Areas are shown below)

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Sensing & Measurement

- **Enhance Sensing for Transmission Systems**
  - 3.3.1 Develop advanced synchrophasors reliable during transient events
  - 3.3.2 Examine Sensor placement strategies as well as measurement accuracy requirements
  - 3.3.3: Develop novel inexpensive sensors for component health monitoring and low-cost grid state monitors.
  - 3.3.4 Develop diagnostic and prognostic algorithms based on computationally efficient methods that interface with and use a suite of sensors
- **Enhance Sensing for Distribution System**
  - 3.2.1 Extended Grid State Framework
  - 3.2.2 Validated Visibility Strategy and Sensor Allocation Software Tool
  - 3.2.4 New, Low-Cost Sensors for Distribution-Level Electrical State and Asset Condition Monitoring
  - 3.2.5 Demonstrate low-cost synchronized voltage and current sensors
- **Improve Sensing for Buildings and End-Users**
  - 3.1.1 Advanced Sensors
  - 3.1.2 New Methods for Secure Wireless Sensor Communications
- **Develop Data Analytics and Visualization Techniques**
  - 3.4.3: Develop & demonstrate a tool for acquiring heterogeneous sensor data/ populating extended grid state
  - 3.4.1: Develop real-time streaming analytics & machine learning paradigms for grid visibility, control, resilience, and security

Sensing & Measurement Strategy

Approach

- **The project will create an overall sensing and measurement strategy that will:**
  - ✓ Bring together various stakeholders to define the "extended grid state"
  - ✓ Create technical roadmaps for sensors and measurement technology, communications requirements, data management and analytics requirements
  - ✓ While at the same time considering MYPP goals (i.e., reliability, security, etc.) in the overall design.

- **Tasks are:**
  1. **Extended Grid State (EGS)** – to define the EGS reference model, drive extensions in standards, support development of strategy frameworks, and enhance interoperability.
  2. **Technology Roadmap** – to identify technical objectives, sensor functionality, measurement requirements, and associated data management/analytics and communication requirements.
  3. **Optimization Tool** – to provide tool for optimal sensor allocation and placement and to enable creation of individual frameworks by utility stakeholders.
  4. **Outreach** – to work and coordinate with technical and standards development organizations and industry to incorporate ESG framework/definitions and sensing/measurement requirements in domestic and international standards. Also to identify roadmap gaps and prioritize roadmap R&D objectives and to ensure the usefulness of the optimization tool for industry.

Sensing & Measurement Strategy

Approach (graphic)

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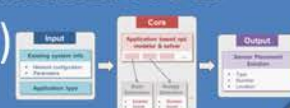
Sensor Roadmap & Tool

Extended Grid States

- Convergent Network States
- Ambient State
- Electrical State
- Building State
- Component State
- Topological State

✓ Low-Cost Sensors
✓ Communications
✓ Data Management & Analytics

✓ Sensor Placement Optimization Tool (SPOT)



Sensor R&D Needs & Priorities including:

- Communication Requirements
- Data Analytics Requirements

Sensor Allocations

- Types
- Quantity
- Locations

Sensing & Measurement Strategy

Key Project Milestones (CY1, completed)

Milestone (FY16-FY18)	Status	Due Date
EGS – Schedule initial workshop	√ Held webinars and industry meeting at EPB in Chattanooga	10/1/ 2016
Roadmap – draft of roadmap	√ Technology Review Report Draft submitted to DOE	10/1/ 2016
Optimization Tool – determine objectives & functional requirements	√ Development Plan completed and initiated tool development in March	2/1/2017
Outreach – identify technical and standards organizations	√ Developed contacts with industry and they participated in webinars and meetings.	2/1/2017
EGS – Initial workshop report	√ EGS framework/definitions includes industry input	4/1/2017
SM – Development of Technology Roadmap	√ Draft Roadmap (& use cases from industry feedback) submitted to DOE	4/1/2017

Sensing & Measurement Strategy

Key Future Project Milestones (CY2 & CY3)

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Milestone (FY16-FY18)	Status	Due Date
Roadmap (CY2) – Fully compiled report outlining roadmap and gap analysis to DOE	**On track**	**10/1/2017**
Optimization Tool (CY2) – deliver draft report on requirements and draft strategy plan to DOE	On track	10/1/2017
Outreach (CY2) – survey results of IEEE PES Working Groups regarding EGS requirements	**On track**	**10/1/2017**
Optimization Tool (CY3) – deliver report on case studies and results of applying tool	On track	4/1/2019
Outreach (CY3) – 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**

Sensing & Measurement Strategy

Accomplishments to Date

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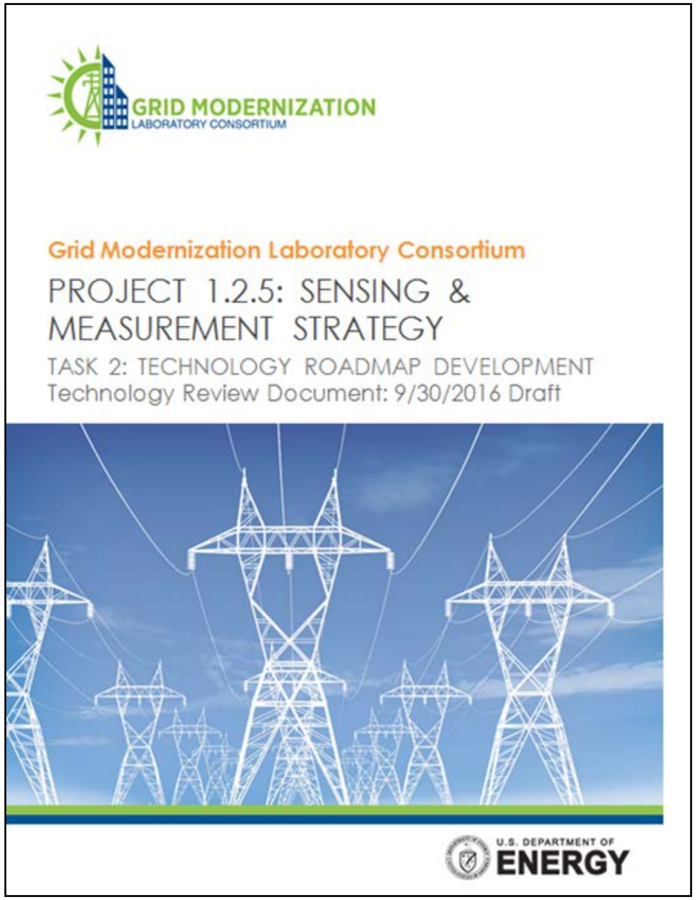
2016

- ✓ Meetings with industry both online and at EPB in Chattanooga. Well attended online meetings of EGS and Roadmap presentations.
- ✓ Produced draft reports – (1) EGS framework and definitions and (2) Sensor Technology Assessment, precursor to full technology roadmap.

2017

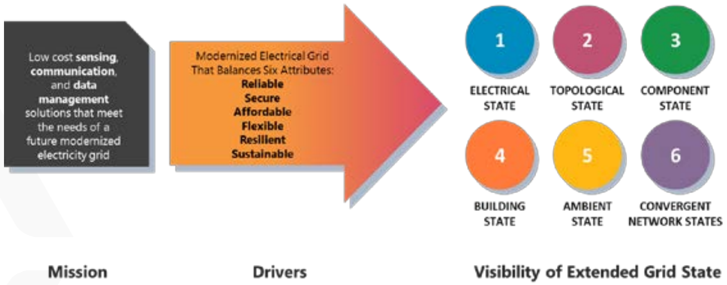
- ✓ Feb, Oak Brook, IL Industry Meeting (included Sensing & Measurement, Advanced Sensors and Data Analytics & Machine Learning) hosted by ComEd with over 50 attendees from various industry organizations.
- ✓ Draft Extended Grid State framework and definitions incorporating industry feedback.
- ✓ Draft Technology Roadmap (including key use cases) with industry feedback submitted to DOE

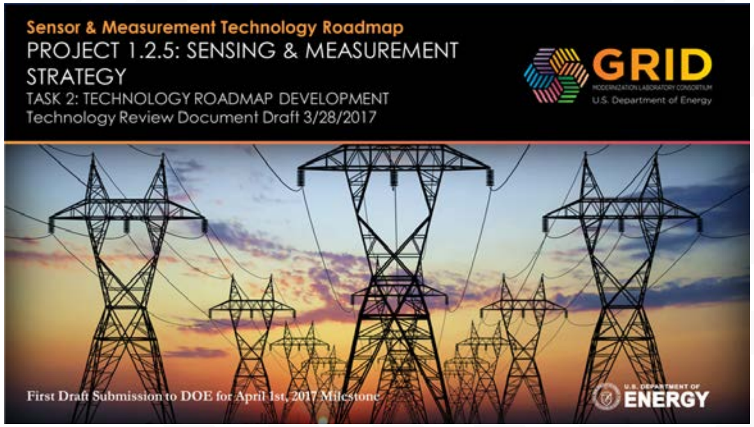


Sensor & Measurement Roadmap*

Focus Areas Include: **Devices, Communications, and Data Management & Analytics**

LINKAGES TO DRIVERS & EGS





TYPES OF R&D EFFORTS TO BE PURSUED

- **Scope the problem including stakeholder engagements**
- **Literature review on state-of-the-art and emerging technologies**
- **Develop computer models and computational methods**
- **Apply computer models and computational methods**
- **Develop new software technologies at TRL 1-3**
- **Develop new software technologies at TRL 3-5**
- **Develop new hardware technologies at TRL 1-3**
- **Develop new hardware technologies at TRL 3-5**
- **Computational modeling TRL 1-3**
- **Computational modeling—data analytics at TRL 3-5**
- **Demonstrate technologies in field environment at TRL 5-7**
- **Transition technologies to industry for commercialization at TRL 7+**
- **Working with organizations to define interoperability standards**

**format adapted from EPRI Transmission & Substation Roadmap*

Sensing & Measurement Strategy

Accomplishments to Date (Roadmap Example and Structure)

Suggested Focus Area with Description

Phasor Measurement Units for Grid State and Power Flow

The transmission and distribution (T&D) systems of the power grid are used to transfer electric power from the generation sites to loads. To ensure this power transferring task is accomplished in a reliable, secure, and efficient manner, the system operator must know the states of the systems at all times during the operation. That knowledge requires a number of system states and parameters, which describe different physical characteristics of the systems, to be measured and monitored accordingly.

Power flow includes the information of the amount and direction of the real and reactive power flowing in the T&D networks. It is one of the key grid states that are crucial to the grid operation and must be continuously monitored and controlled over the entire grid to achieve optimal operation of the systems. The generation and consumption of real power have to be balanced at any given time in the grid to maintain a stable system and stable frequency. Reactive power is due to energy which is stored in the electric and magnetic fields in the whole systems (generators, T&D, and loads) and does not do actual work, but it enables the transfer of real power in the grid.

With the maturation of the technology of Phasor Measurement Units (PMU), the phasor measurement capability is widely enabled in modern power systems to measure and time-stamp basic electrical parameters.

Key Parameters

Key measurement parameters: Voltage, current, frequency, phase angle, real and reactive power

Individual Research Thrusts

Research Thrust #1

Improve the dynamic response of PMU technologies in order to significantly improve dynamic grid state measurement and enable high-speed, real-time control applications. This research area seeks to provide a 1 to 2 order of magnitude performance improvement over the current state of the art.

Key measurement parameters: voltage and current phasors

Metrics Goal = Quantitative

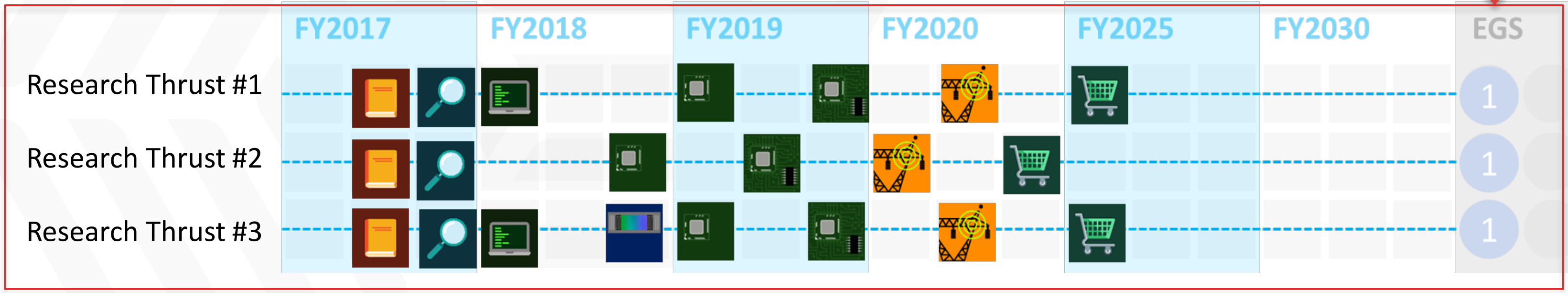
Key metrics:
Current spec: 5-6 cycles time window
Target spec: < one cycle time delay

Drivers: Resiliency, Flexibility
EGS Level: Electrical State

Direct Links to GMI MYPP and EGS

Scope of Activity: Develop robust, cost-effective PMU with fast dynamic response with pilot scale deployment and testing by FY2020.

Graphical Timelines with Icons



Sensing & Measurement Strategy

Accomplishments to Date

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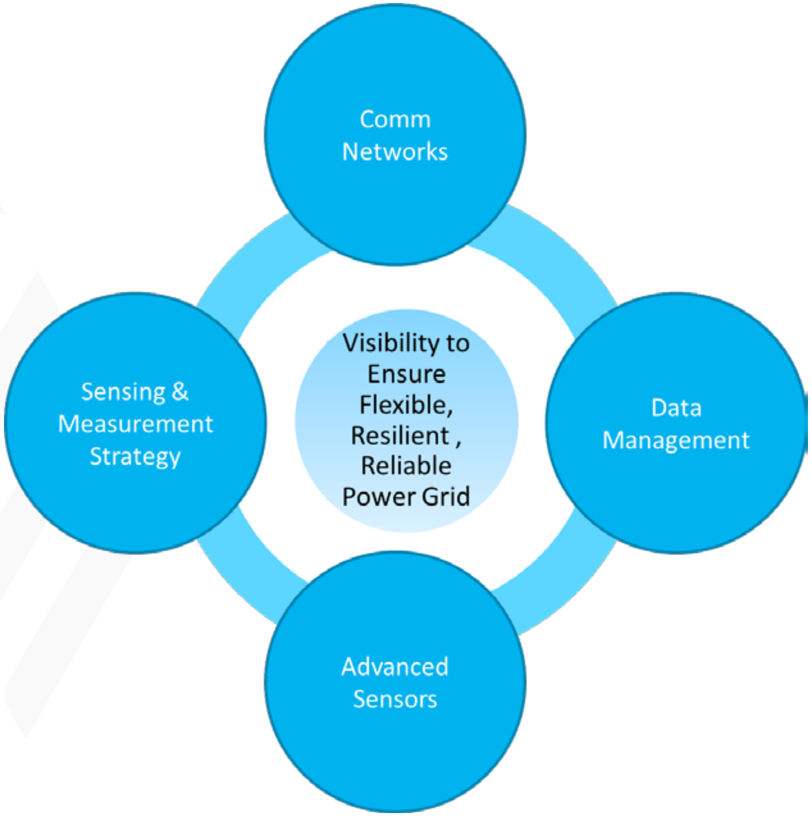
Lessons Learned

- ✓ The industry is very interested in all aspects of the project and a strategy for placing sensors is recognized as lacking.
- ✓ Industry recognizes the need for R&D priorities for sensor technology with the grid transformation.
- ✓ In addition to R&D needed, the industry also sees the need for support with mining of large sets of existing data such as synchrophasor data.
- ✓ There is a concern about resiliency of sensors to EMI type events as well as cybersecurity
- ✓ Sensing & Measurement is also an area of interest to non-US entities such as the UK per a UK-US grid modernization collaboration workshop



Sensing & Measurement Strategy

Accomplishments to Date

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Market Impact

- ✓ Attendees of Feb Industry Meeting (30 from industry) see important connection with the three projects (**sensing & measurement strategy, advanced sensors and data analytics and machine learning**) and that this should continue. Feedback led to matrix development for roadmap.
- ✓ Industry partners/stakeholders continue to grow: now include ComEd, Duke Power, NIST.
- ✓ At Feb Meeting, ComEd both hosted and co-presented on their activities/plans. They seek more involvement.
- ✓ Industry feedback at Feb Meeting and follow-up meetings with EPB and TVA provided several key use cases for the roadmap.
- ✓ EPB has become a strong "distribution system" partner providing input on the roadmap and willing to host advanced sensors and provide data to test/verify the SPOT tool

Matrix – How R&D Thrusts Impact High Level Objectives

Research Thrusts for Sensing & Measurement Devices

Attributes of a Modern Electrical Grid	Harsh Environment Sensing for Real-Time Monitoring	Advanced Electromagnetic Diagnostic Techniques	Electrical Parameter Measurements for More Flexible Centralized Generation Controls	Electrical Parameter & Topological Measurements for Distributed Generation Controls	Large Power Transformer Health Performance Monitoring	Distribution Grid Asset Health Performance Monitoring	Transmission and Distribution Substation Health Monitoring	Transmission Line Health Monitoring	Centralized Thermal Generator Health Monitoring	Distributed Generation and Energy Storage Monitoring	Broadband Frequency-Selective Sensors	Derivative Sensors	Sensors for Next Generation Power Electr	Low Cost Sensors for PMU Mont	Rapid Abnormality Detec	Integration of Se	Optimiz	In
Reliability			■	■	■	■	■	■	■	■								
Security					■	■	■	■										
Affordability																	■	■
Flexibility	■	■	■	■							■	■	■	■	■	■		■
Resiliency	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■
Sustainability	■	■	■	■														

Sensing & Measurement Strategy

Response to December 2016 Program Review

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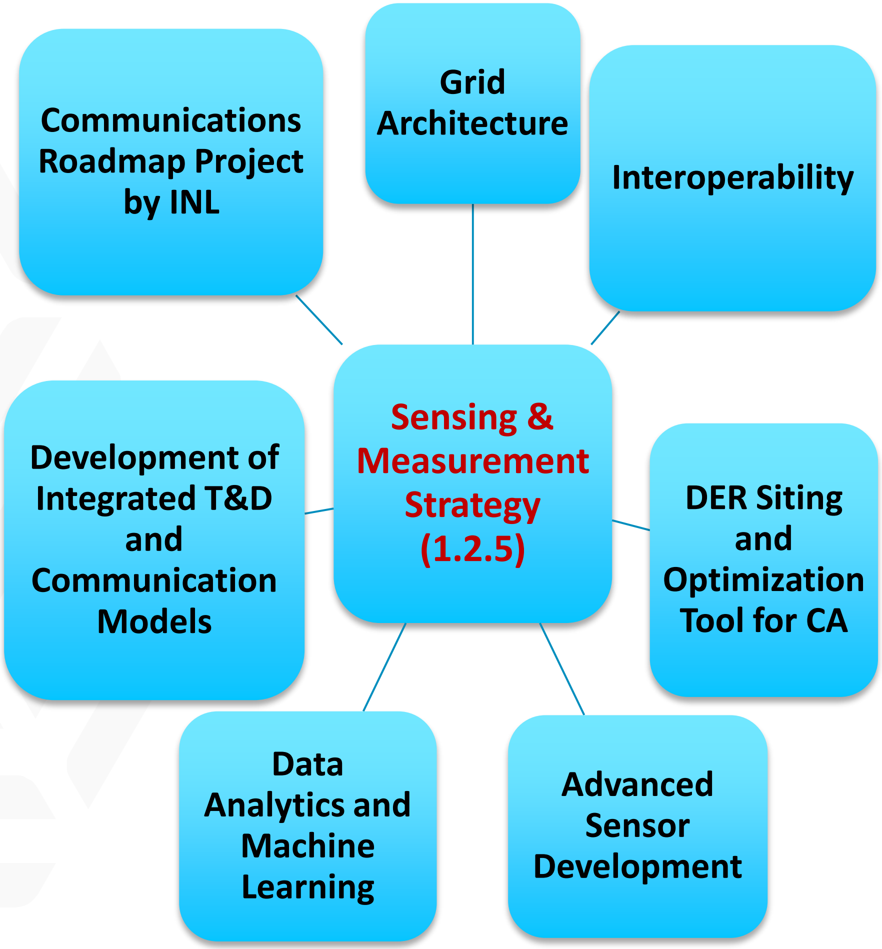
Recommendations	Responses
Please share the draft technology roadmap with program managers to get their feedback on the document	**Shared with them both at the Feb Meeting and prior to this meeting which includes industry feedback**
Please invite DOE program managers to the February 2017 workshop in Chicago	**Both program managers attended the meeting.**
Schedule a webinar for DOE program managers so they can understand how this project directly applies to their work.	**Hold monthly meetings and a follow-up meeting to the Feb industry meeting was held.**
Please coordinate this with projects 1.2.1 and 1.2.2 since they will also be providing similar webinars on their work.	**Tom Rizy is the liaison with 1.2.1 (interoperability) and Jeff Taft (and Emma Stewart) are the liaisons with 1.2.2 (grid architecture)**
During the meeting in Chicago, please work with stakeholders to identify and prioritize a portfolio of use cases that the sensing and measurement roadmap will address.	**Use cases were presented at the meeting and follow-up meetings were held with EPB and TVA. A meeting with ComEd is still pending. High value use cases were incorporated into the draft roadmap.**

Sensing & Measurement Strategy

Project Integration and Collaboration (within GMLC)

- **Grid Architecture (1.2.1)** – coordinate to determine what needs to be incorporated into the ESG development.
- **Interoperability (1.2.2)** – Coordinate to determine sensor & measurement system interoperability needs & requirements.
- **DER Siting and Optimization Tool for CA (1.3.5)** – coordinate to determine if any approaches, methods or lessons learned may be helpful to accelerate development of optimization tool.
- **Advanced Sensor Development (1.4.4)** – coordinate to incorporate new functionality of advanced sensors.
- **Data Analytics and Machine Learning (1.4.9)** – coordinate on the data analytics needed for sensing and measurement.
- **Development of Integrated T&D and Communication Models (1.4.15)** – coordinate on communication models needed for sensing and measurement.
- **Communications Roadmap Project by INL** – INL has completed a draft report and participates in our team meetings.



Sensing & Measurement Strategy

Project Integration and Collaboration (within GMLC)

Relationship with Advanced Sensors and Data Analytics

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Sensing & Measurement Strategy

- ✓ Overall strategy for sensing & measurement including grid states, sensors, communication requirements and data management and analytics needs.
- ✓ Identify gaps and priorities in sensor R&D and optimizes sensor placement.

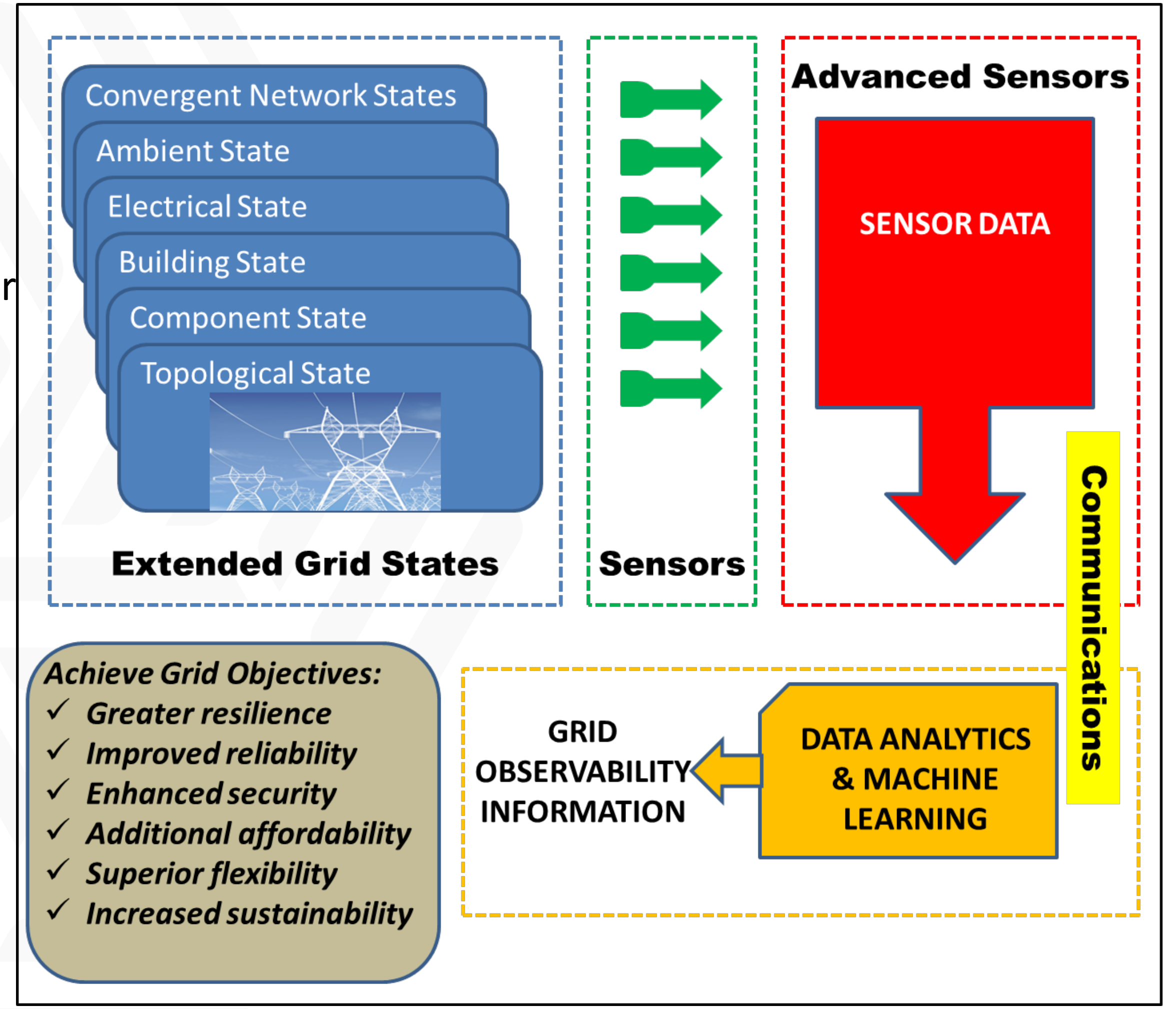
Advanced Sensors

- ✓ Developing new sensors to fill the gap in sensors needed for the modern grid.

Data Analytics & Machine Learning

- ✓ Identify gaps in data analytics for the modern grid and develop machine learning algorithms.
- ✓ Turn sensor data into useful information to meet modern grid objectives.

Sensing & Measurement Strategy



Sensing & Measurement Strategy

Project Integration and Collaboration (Industry Outreach)

Utility Industry, EPRI, & NASPI

- ✓ Two industry meetings hosted by EPB and ComEd; 30 industry reps attended most recent meeting in Oak Brook, IL in Feb.
- ✓ AEP, Ameren, CAISO, Duke Energy, Dominion, Entergy, EPB, ComEd, ISO-NE, National Grid, NRECA, MISO, PacificCorp, PJM, SMUD, Southern Co., Southern California Edison
- ✓ EPB has offered to provide data for the optimization tool development
- ✓ EPRI – provided update on their current sensor activities
- ✓ NASPI Synchrophasor Task Teams: Performance, Standards & Verification, Distribution Systems

Vendors

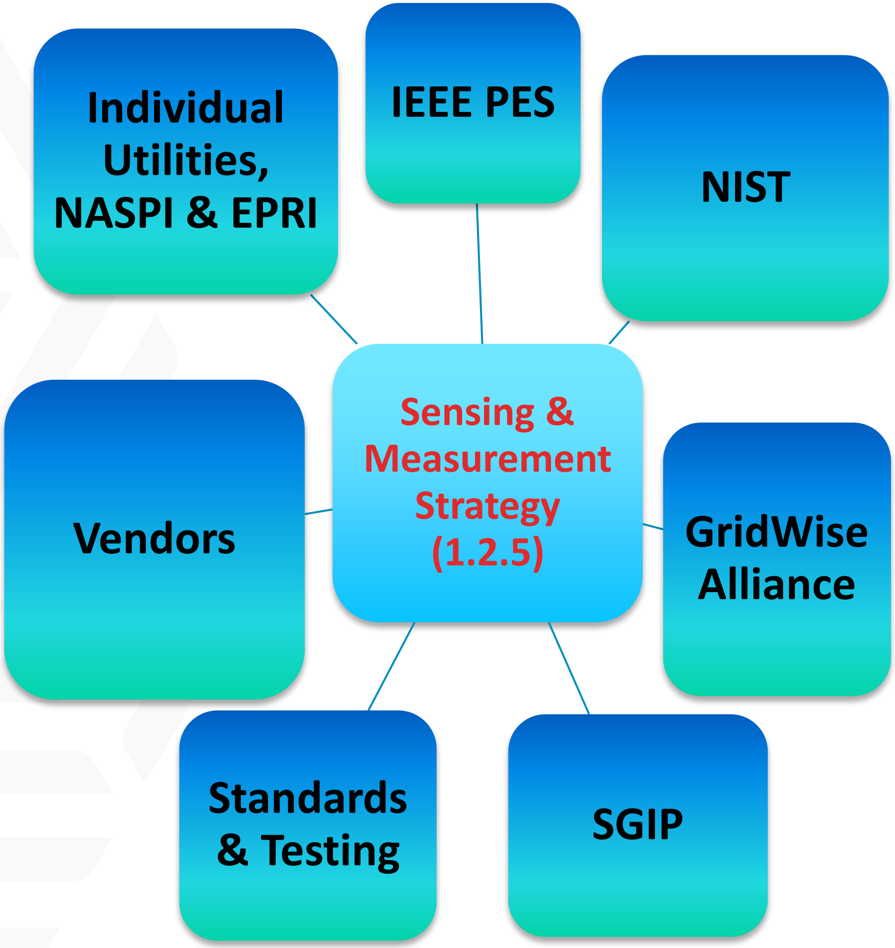
- ✓ Alstom, OSIsoft, Quanta, GE

IEEE PES

- ✓ IEEE Smart Distribution Working Group

Standards & Testing Organizations

- ✓ GridWise Alliance
- ✓ Smart Grid Interoperability Panel (SGIP)
- ✓ National Institute of Standards and Technology (NIST)



Sensing & Measurement Strategy

Next Steps and Future Plans

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- **Extended Grid State**
  - EGS reference model and definitions will continue to be enhanced
  - Plan to share the reference model and definitions with standard development organizations such as the IEEE, IEC
- **Technology Roadmap**
  - Continue to refine/share roadmap with industry partners/stakeholders for feedback
  - The R&D thrusts of the three areas (devices, communications, data management) will be prioritized
- **Optimization Tool**
  - SPOT Tool development is underway; 1st application is a distribution state estimator
  - Testing will start on three IEEE test systems (13-nodes, 37-nodes 123-nodes)
  - Survey of industry partners/stakeholders to determine priority for distribution system applications
- **Outreach**
  - Efforts will continue to expand the industry partners/stakeholders
  - Identify vendors that can support the SPOT tool beyond the project period
  - Follow-up meetings with utility partners to identify additional use cases and prioritization of roadmap areas

Sensing & Measurement Strategy

Technical Details – Roadmap of Sensor Device Area R&D Thrusts

1) **Harsh Environment Sensors For Flexible Generation**
   - Harsh Environment Sensing for Real-Time Monitoring
   - Advanced Electromagnetic Diagnostic Techniques
2) **Generator Controller Technology**
   - Electrical Parameter Measurements for More Flexible Centralized Generation Controls
   - Electrical Parameter Measurements for “Distributed Generation” Controls Including Conventional Generation, Renewables, and Energy Storage
3) **Grid Asset Health Performance Monitoring**
   - Large Power Transformer Health Performance Sensor Technology Development
   - Distribution Grid Asset Health Performance Sensor Technology Development
   - Transmission Line Monitoring
4) **Grid Asset Functional Performance (Operational Effectiveness) Monitoring**
   - Broadband Frequency-Selective Sensors
   - Derivative Sensors
   - Sensors for Next Generation Power Electronics and Transformers

Sensing & Measurement Strategy

Technical Details – Roadmap of Sensor Device Area R&D Thrusts

5) **Dynamic System Protection**
   - Rapid Abnormality Detection Sensors for Protections
   - Integration of Sensing and Control Systems
6) **Weather Monitoring and Forecasting**
   - Electrical Parameter Measurements for More Flexible Centralized Generation Controls
   - Electrical Parameter Measurements for "Distributed Generation" Controls Including Conventional Generation, Renewables, and Energy Storage
7) **Phasor Measurement Units for Grid State & Power Flow**
   - Improve the dynamic response of PMU technologies
   - Lower the cost of PMUs to enable greater wide area utilization
   - Incorporate alternative, high reliability timing methods into PMU architectures
   - Develop advanced phasor calculation algorithms
   - Develop micro-PMU that can capture really small phase angle differences in phase angles
   - Improve the estimate in frequency on transmission-side PMUs
8) **End-Use / Buildings Monitoring**
   - Development of High-resolution Distribution Sensors
   - Development of Multi-component Integrated Intelligent Sensors/Meters

Sensing & Measurement Strategy

Technical Details – Roadmap of Communications Requirements and R&D Thrusts

1) Distributed Communication Architecture Development

- Comparative Studies of Existing Architecture and Distributed Communication Architecture
- Architecture Design for Distributed Communications
- Impact Analysis to Power System Applications

2) Low Latency, Rapid, Robust, and Secure Communication Technologies Development for Sensing in Distributed System Environments

- Efficient Spectrum Utilization with Interference Management
- Leverage IoT Technologies in Power System Communications
- Cost-Effectiveness Analysis of Deploying New Communication Technologies

3) New Networking Technologies to Tackle the Challenges of Scalability, Diverse Quality of Service Requirements, Efficient Network Management, and Reliability

- Networking Technologies for Scalability Issue while Satisfying Diverse QoS Requirements
- Efficient Network Management to Support New and Dynamic Services
- Reliability and Resilience enabled by Networking Technologies

4) Input into Standardization Efforts for Interoperability among Diverse Equipment and Standards

- Identification of Requirements and Use Cases from Sensing & Measurement Perspective
- Large-scale Co-simulation of Cyber-Physical System Integrating Interoperability Solution

Sensing & Measurement Strategy

Technical Details – Roadmap of Data Management Requirements and R&D Thrusts

1) **Support for advanced applications for Visibility**
   - ☐ Data collection methods for ingesting data from many legacy applications as well as new sensors and systems
   - ☐ Visualization and human interface in order to have effective advanced applications that are be accessible, trusted, and easily understandable by the grid operators
2) **Big Data Management for Grid Applications**
   - ☐ Data access and interfaces for satisfying the constraints of a variety of existing data access requirements while maintaining the flexibility to support future applications.
   - ☐ Data organization methods since the wide range of data types and data rates originating in large power systems stretch the capabilities of traditional tools for organizing data
3) **Distributed Analytics support**
   - ☐ Data Distribution ("delivery") methods to deliver data to the appropriate processing locations to ensure that distributed analytic algorithms work properly
   - ☐ Monitoring and evaluation to ensure the distributed processing across the grid is performing effectively and not experiencing issues

GRID MODERNIZATION INITIATIVE PEER REVIEW
1.4.4 ADVANCED SENSOR DEVELOPMENT

YILU LIU, OLGA LAVROVA, TEJA KURUGANTI

April 18-20

Sheraton Pentagon City – Arlington, VA

Advanced Sensor Development
Project Summary

Sensing and Measurement

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 proposal is organized around three major segments: end-use, transmission and distribution (T&D), and grid components

Expected Impact:

Increased visibility throughout the future electric delivery system. Demonstrate approaches to data analysis

Objective

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 transducers.

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

Advanced Sensor Development
Project Team

Project Participants and Roles

National Labs: ORNL, PNNL, LBNL, NREL, NETL, SNL
UTK: improve GridEye sensor algorithms
EPRI: demo advanced sensors for monitoring transformer bushings and arresters.
Genscape: develop dynamic line rating approach using wireless monitoring devices
Southern Co., TVA, ComEd: advisory role to ensure the research is aligned with utility needs
EPB: host site for demonstrating advanced sensor technologies
NI: provide hardware platform
SmartSenseCom Inc.: integrate the developed phasor estimation algorithms, GPS timing, and communication module

PROJECT FUNDING

Lab	**FY16 $K**	**FY17 $K**	**FY18 $K**
ORNL	1,460	1,445	1,165
LBNL	145	145	150
NREL	145	145	150
SNL	250	250	250
NETL	150	150	150
PNNL	75	75	
Non-lab Team	650	550	
Total	**2,875**	**2,760**	**1,865**

Advanced Sensor Development

Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- Sensing & Measurement is a fundamental technical activity with linkages throughout the entire MYPP
- Limited activity in the DOE portfolio prior to the GMI and GMLC

Devices and Integrated System Testing

- MYPP Activity 1
  - MYPP Task 2.1.4
- MYPP Activity 2
  - MYPP Task 2.2.4
  - MYPP Task 2.2.5

Design and Planning Tools

- MYPP Activity 2
  - MYPP Task 5.2.1
  - MYPP Task 5.2.2
  - MYPP Task 5.2.5
  - MYPP Task 5.2.6

Sensing and Measurements

- MYPP Activity 1
  - MYPP Task 3.1.1
  - MYPP Task 3.1.3
- MYPP Activity 2
  - MYPP Task 3.2.2
  - MYPP Task 3.2.5
- MYPP Activity 3
  - MYPP Task 3.3.1
  - MYPP Task 3.3.2
  - MYPP Task 3.3.3
  - MYPP Task 3.3.4
  - MYPP Task 3.3.5
- MYPP Activity 4
  - MYPP Task 3.4.1
  - MYPP Task 3.4.2
  - MYPP Task 3.4.3
  - MYPP Task 3.4.4
- MYPP Activity 6
  - MYPP Task 3.6.2
  - MYPP Task 3.6.3

System Operation, Power Flow and Control

- MYPP Activity 1
  - MYPP Task 4.1.1
  - MYPP Task 4.1.2
  - MYPP Task 4.1.3
- MYPP Activity 2
  - MYPP Task 4.2.1
  - MYPP Task 4.2.3
- MYPP Activity 3
  - MYPP Task 4.3.1
  - MYPP Task 4.3.2
  - MYPP Task 4.3.3

Advanced Sensor Development – End Use

Project status

Milestone (FY16-FY18)	Status	Due Date
Draft requirements specification document. The requirements will be harmonized with sensing and measurement strategy developed in 1.2.5 through industry-specific requirements from workshop	Completed	11/30/2016
Draft specification of sensor development to measure airflow at an accuracy > 90% and current at >95% accuracy.	Complete	2/28/2017
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.	Identification algorithm completed	5/31/2017
Draft design document for physical and data-driven sensors incorporating functional and deployment requirements. The document will describe the sensor designs and accuracy taergets.	System integration	8/30/2017
Demonstrate sensors to meet the design targets described in requirement specification document. Evaluate in real building sites and data collected from buildings	Collecting data from field test in building sites	2/28/2018

Advanced Sensor Development – End Use

Project status

Milestone (FY16-FY18)	Status	Due Date
Develop Ultra-PMU Algorithms for transient capture in noisy conditions, including adaptive zero-cross algorithm and phase-locked loop algorithm.	complete	11/30/2016
Develop Optical CT/PT Integrated PMU Monitoring System: Tailor ORNL high-accuracy phasor and frequency measurement algorithms for optical CT/PT.	complete	11/30/2016
Develop Ultra-PMU Algorithms for Transient Capture: Experiment with adaptive window size for optimal performance. Ensure the algorithms be able to detect the transients in one cycle or less.	The performance of the Ultra-PMU algorithms are being tested under the power system transients	5/31/2017
Develop Optical CT/PT Integrated PMU monitoring System: Algorithm should achieve accuracy of 0.001 degrees for phase angle and 0.2 mHz for frequency which is the state-of-the-art accuracy of the commercial PMUs. Develop data pre-processing and signal conditioning functions. Design GPS synchronization scheme and interface. Design high precision timing functions and data flow functions	Conduct a test at SmartSenseCom and the results show good PMU accuracy from optical sensor data	5/31/2017

Advanced Sensor – Asset Monitoring

Project status (cont)

Milestone (FY16-FY18)	Status	Due Date
Demonstrate chemically treated 3D nanostructured sensing scaffold with characterized gas interactions. Gas concentration levels of 50 ppm (for CH_4) and 500 ppm (for H_2) will be used for the characterization for the proof of concept. (Abnormal concentration of CH_4 is typically ~80ppm, H_2 is ~1000ppm.)	Completed	5/31/2017
Develop CoFe electrodeposition process for integrated biasing magnets.	Completed	11/30/2016
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).	Building testing platform for 1A - 1000A current detection	5/31/2017
Completed investigation of several different potential H_2 sensing materials with some exploration of CO and CH_4 sensitivity (to be reported in the annual report)	Investigating the potential of H_2 sensing materials	11/30/2017

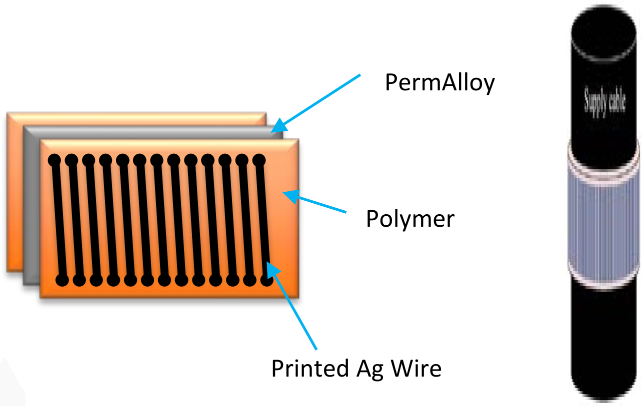
End-use Sensors
Physical Sensors

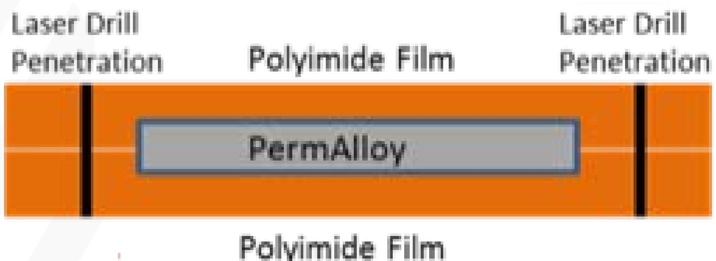
Background

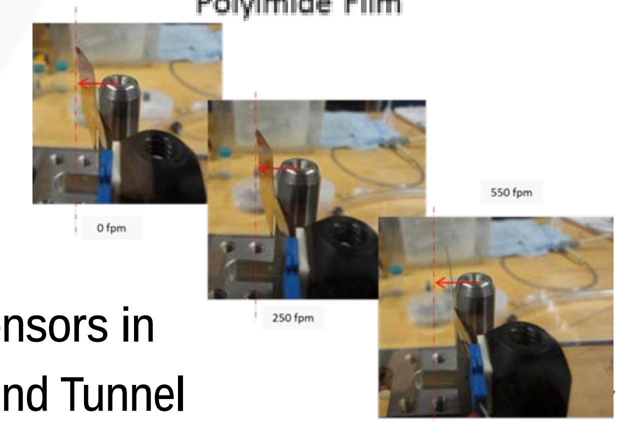
- Buildings consume 74% of electricity. Low-cost sensing that can observe end use state and improve energy efficiency are needed.
- Economical electric current measurements are necessary to enable building loads as grid resources facilitating high-resolution end-use state observability

Accomplishments

- During FY17, a current transformer approach was determined that is compatible with low cost manufacturing techniques.
- During FY16, a Piezo electric/resistive material-based thin- film sensor is developed with additive manufacturing to measure flow. Device enables fault detection and improve efficiency (20-30%)
- Platform technology for signal conditioning and communication aspects are currently underway for ubiquitous deployment
- Outcome:
    - A retrofit compatible thin film low-cost sensors for improving energy efficiency in forced air cooled/heated buildings and enabling sub-metered end-use observability
    - Three Invention Disclosures filed and one underway on flexible current clamp sensor





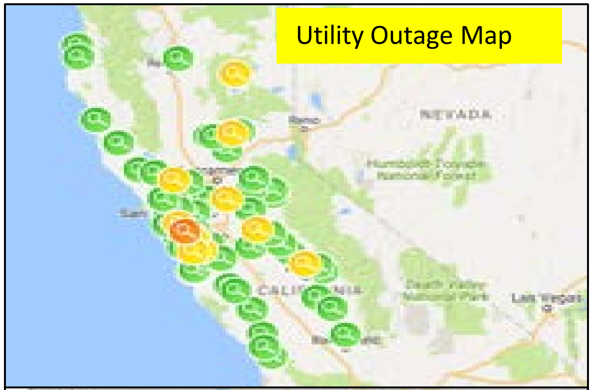


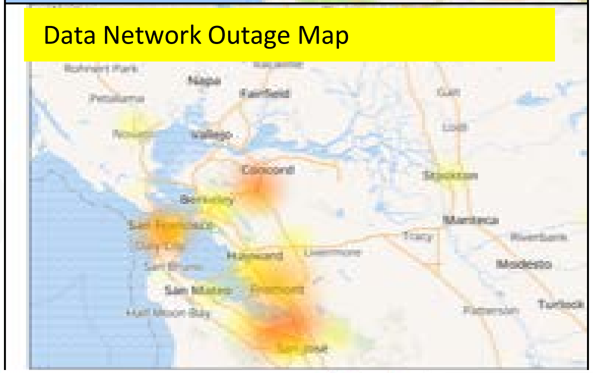
Sensors in Wind Tunnel

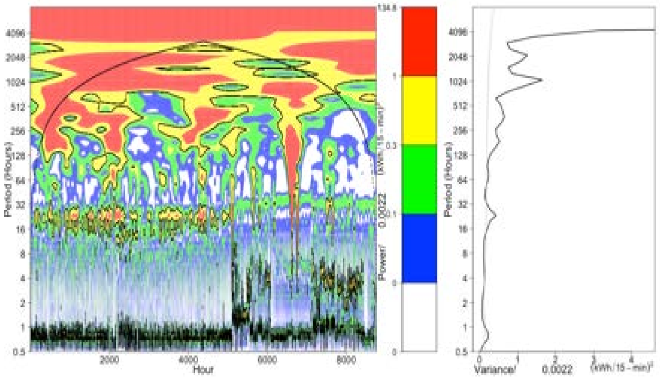
End-use Sensors
Virtual Sensors

Data-driven sensor development

- Develop utility-scale power outage maps using data from internet-connected device data to enable utilities with regions affected by power outage in a timely fashion
- Technology – Collect status data from internet-connected devices to act as sensors for power outages.
- Partnership with Comcast NBC Universal to utilize Comcast internet-connected device information and obtain data sets
- Data analysis and processing algorithms were developed and are currently being tested.
- Utilize weather-correlated building load activity to facilitate utility-scale load shape estimation and demand forecasting
- Developed R-code for extracting and post processing 15-minute interval kWh data over 28-months for 101 homes in NEEA RBSA* data set, including whole building electric and ~25 submetered loads per house.
- Outcome
    - Developed data-driven outage map creation in partnership with a major network connectivity company. Established NDA and data agreement with Comcast NBC
    - Open-source package in R for residential-level load shape estimation and forecasting
    - One conference publication accepted and one journal publication in review for method to generate data-driven load shape
    - Partnership with University of Colorado and Elevate Energy, Chicago Illinois



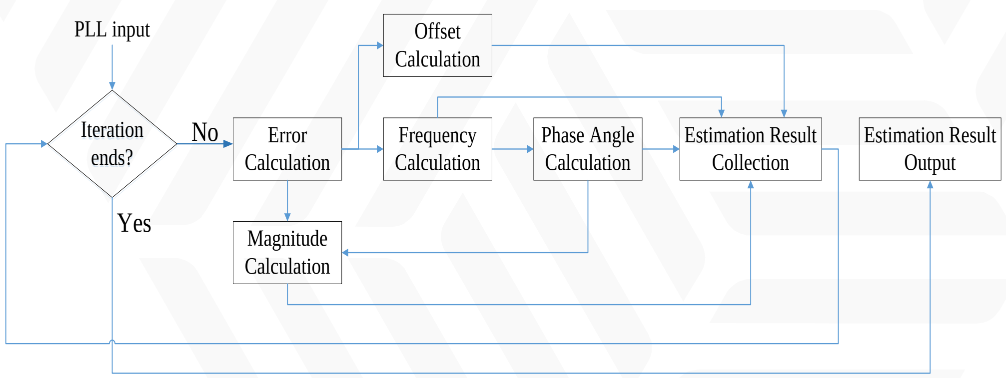




Objective: Improve dynamic responses to capture fast transients in the grids.

Methodology: Modified Phase-Lock Loop (MPLL) Algorithm

- No data window or filter
- Fast gradient descent method and variable step
- Recursive structure



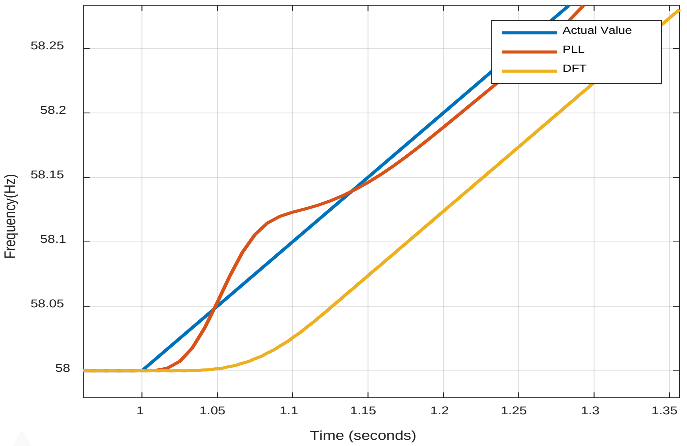


Fig. 1 Frequency ramp test

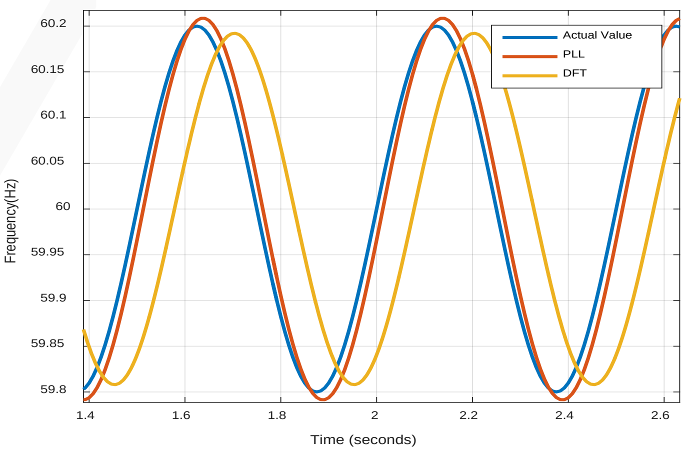
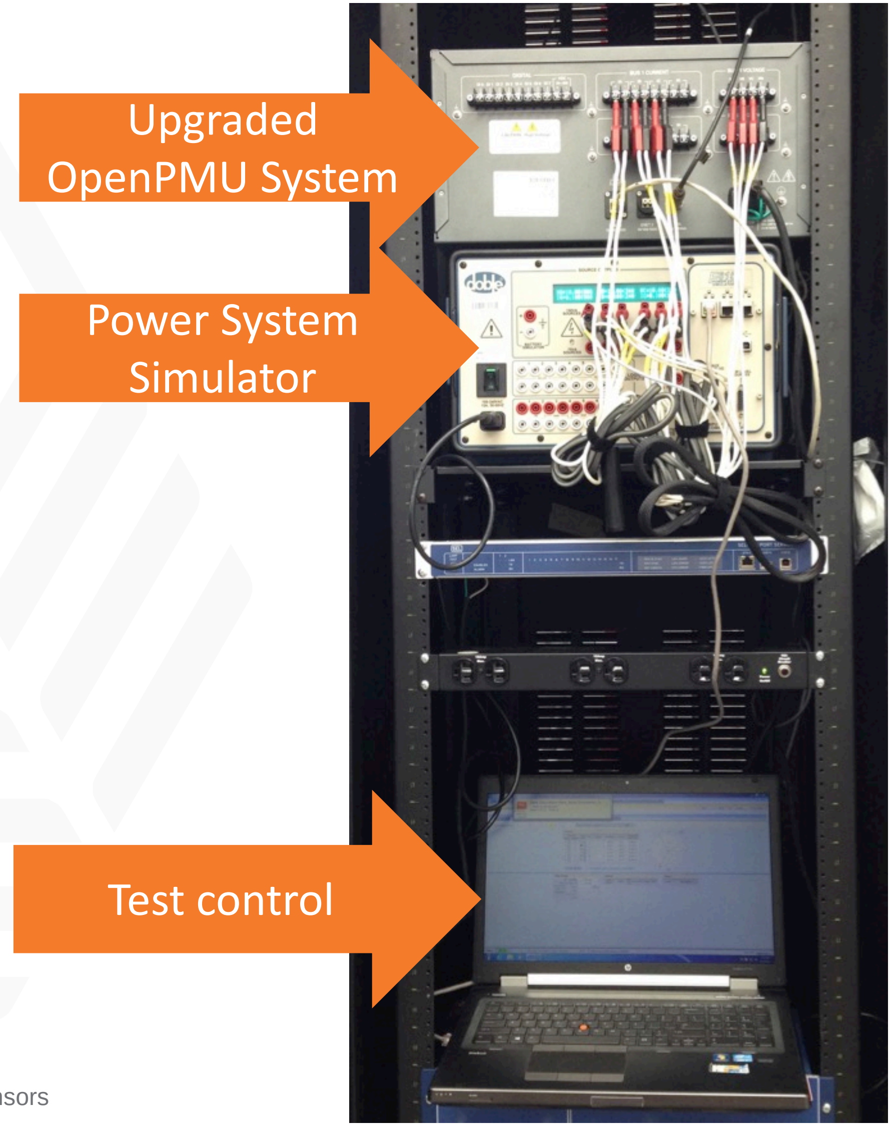


Fig. 2 Phase modulation test

T&D Sensors

Test setup and work completed

- PMU testing system has been built.
- Multiple ultra fast PMU algorithms for phasor estimations have been developed.
- Dynamic response tests including frequency step change and frequency ramp tests demonstrated the fast response capability of **one cycle** (compared to 6 cycles DFT based algorithms).
- Steady-state tests verified feasible steady state measurement accuracy.
- Response time of a commercial PMU has been tested to provide a benchmark for the proposed algorithms

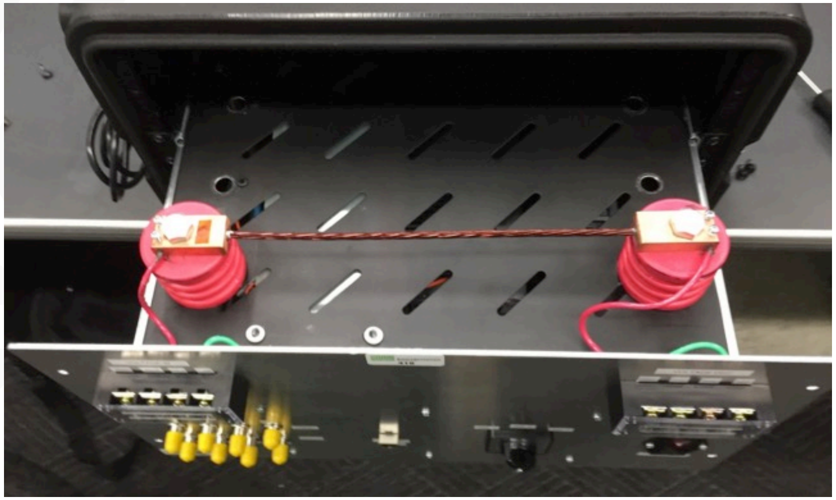


T&D Sensors

Optical PMU

Objective:
To achieve better dynamic range, high linearity, and cost competitive measurement technology.

- Optical sensor test system designed and built for 110V-480V voltage and 0A-20A current measurements
- GPS-Synchronized measurement system set up for acquisition of analog output from optical sensor system
- Additional system designed and built for 24V operation
- Safety analysis of test unit performed
- Plan created for modification of test unit to meet ORNL safety standards



Asset Health Monitoring

Magneto-elastic Sensor (MagSense)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- A -first-of-its-kind electrochemically deposited (ECD) cobalt ion (CoFe) alloy with a high degree of magnetostriction was developed.

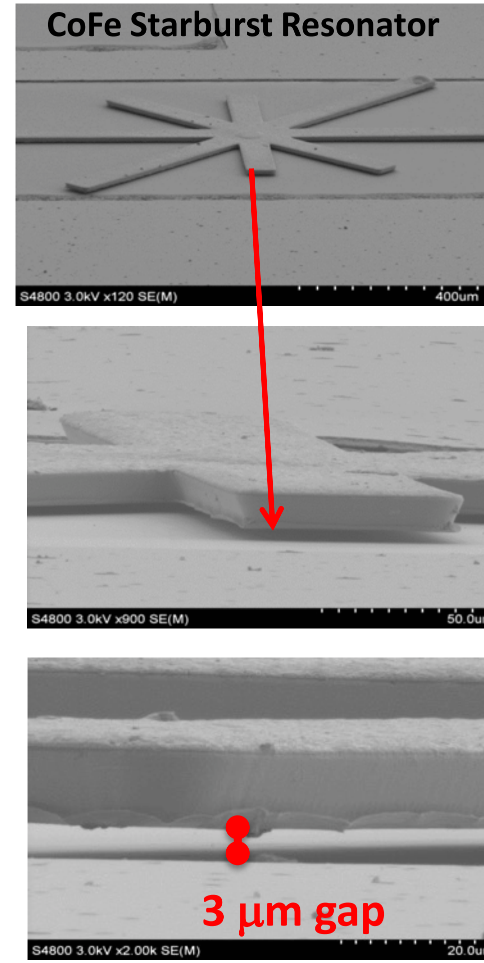
- Fine-tuning process parameters to result in higher magnetic sensitivity parameters (increase resistivity, lower coercivity, and increased magnetic softness).

Two patent applications:

- US Appl. 14/876,652 “Electrodeposition processes for magnetostrictive resonators”.
- Passive Magnetoelastic Smart Sensors For A Resilient Energy Infrastructure

- When commercialized, this sensor will drastically reduce the costs associated with sensors manufacturing and deployment

2.4 mm long freestanding resonator



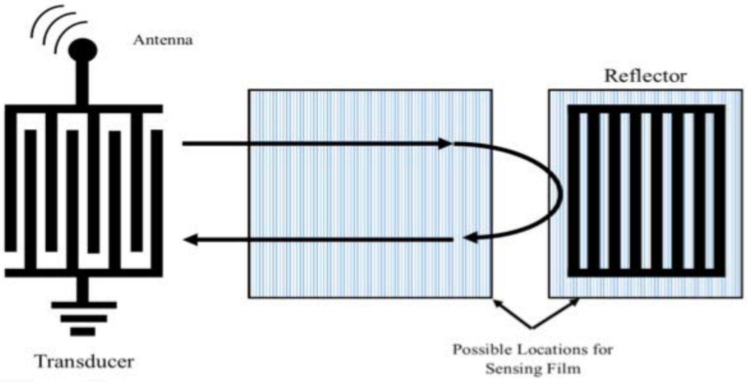
Asset Health Monitoring

SAW sensor

Sensing and Measurement

- Have developed high-surface area porous nanostructured silica and phase-separated metal-oxide films, coated with cryptophane-A, on QCM substrates for methane detection. Selectivity and sensitivity are promising.
- Hydrogen-sensitive chemical coating is used on nanostructured QCM surfaces for hydrogen detection.
- Successfully transferred the nanostructured coating technology on $LiNbO_3$ SAW devices for further characterization. Will pursue to achieve selectivity and sensitivity at the target levels.

- Patent disclosure is filed (DOE S-Number: S-138,412): *"Innovative three dimensional nanostructured thin film scaffolds for gas sensors"*
- When commercialized, our sensor platform will ***reduce the cost of online gas analysis of power transformer (incipient) failures by an order of magnitude***



Surface –Acoustic Wave (SAW) sensor

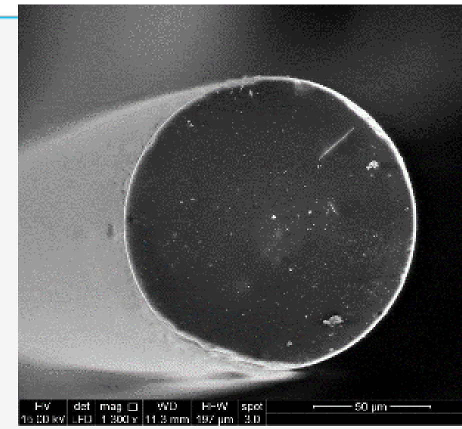
Asset Health Monitoring

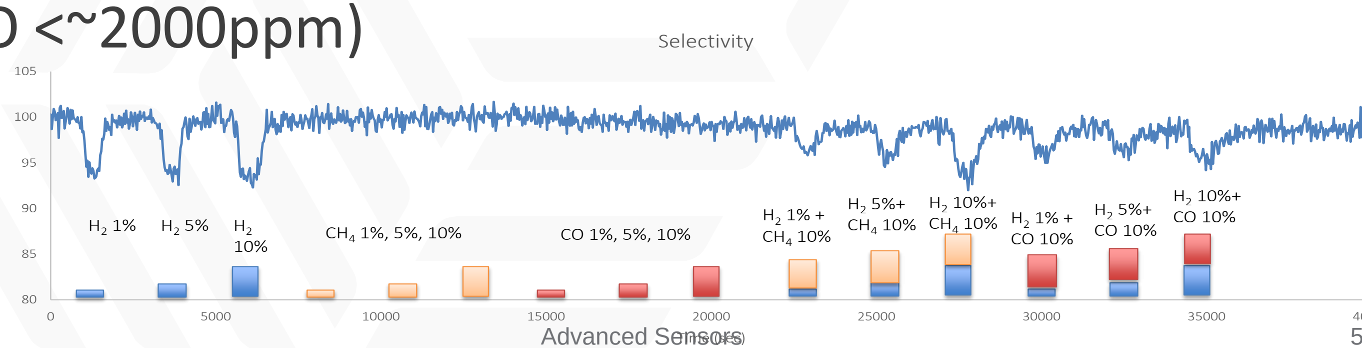
Nano-Enabled Optical Fiber Sensor

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Sensing and Measurement

- Integrated nanomaterial with optical fiber platform for selective H_2 chemical sensing;
- Demonstrated real-time temperature monitoring for operational transformer core;
- Will pursue sensing materials to achieve improved selectivity and sensitivity at relevant levels (H_2, CH_4, CO <~2000ppm)





Advanced Sensor Development

Response to December 2016 Program Review

Recommendation	Response
Please make a strong case for why airflow sensors are important for grid modernization	**Detection of equipment malfunction, quick demonstration, 3D printing technology developed here has a broader applications.**
Please work with DOE program manager Charlton Clark and INL on any work in dynamic line rating to ensure there is no duplication of effort	**Followed up with DOE Wind Program Manager. No duplication since our focus is low-cost, wireless, current measurement technology**
Please be prepared to provide more detailed information on the "buildings as sensors" effort at the Peer Review in April	**Our approach is to use information at building level to project the sum at grid level**

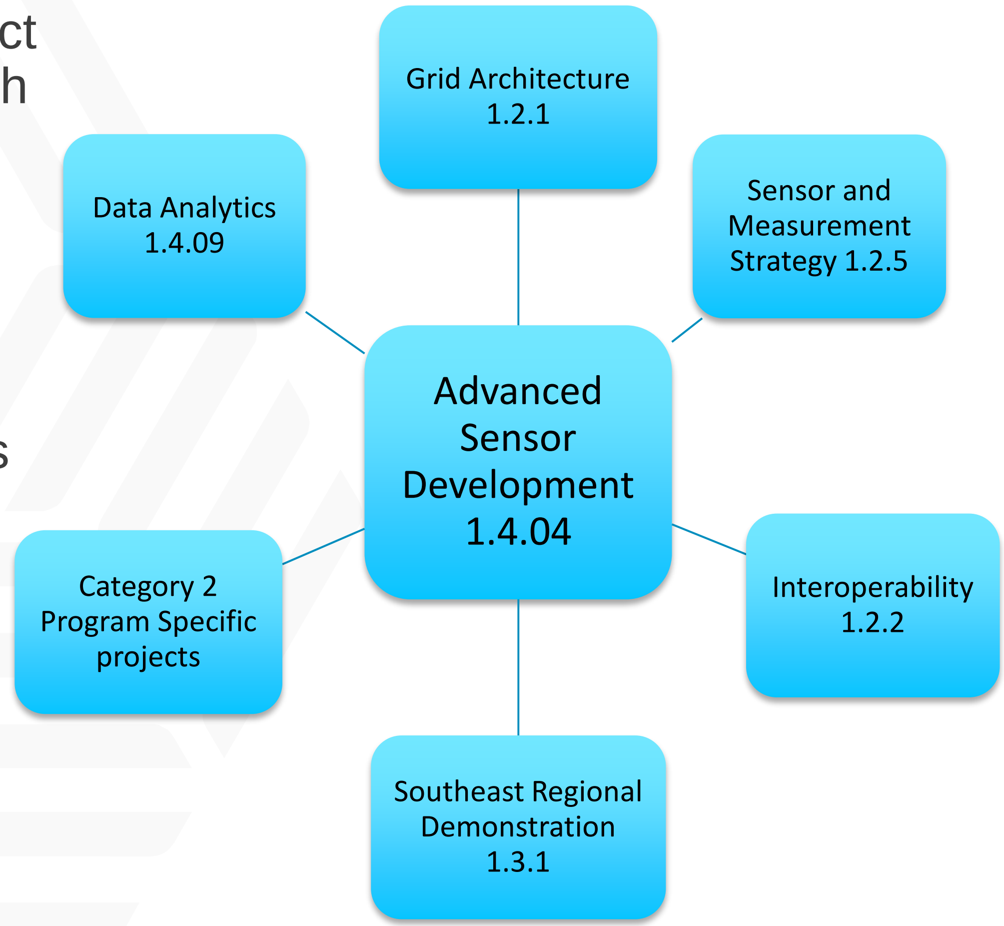
Advanced Sensor Development

Relationship to other projects

Advanced Sensor Development project relates to other GMLC projects, in both Foundational and Program-Specific.

Program Specific Areas include:

- GM0072 Suite of Open-Source Applications and Models for Advanced Synchrophasor Analysis
- GM0073 HVDC and Load Modulation for Improved
- Dynamic Response Using Phasor Measurements
- GM0077 Advanced Machine Learning for Synchrophasor Technology



GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.4.9 Integrated Multi Scale Data Analytics and Machine Learning

EMMA M STEWART – LAWRENCE LIVERMORE NATIONAL LABORATORY

MICHAEL CHERTKOV (+1) – LOS ALAMOS NATIONAL LABORATORY

April 18-20, 2017

Sheraton Pentagon City – Arlington, VA

Integrated Multi Scale Data Analytics and Machine Learning

High Level Summary

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Develop and demonstrate distributed analytics solutions to building to 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

Project Objectives

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

Value Proposition

Cohesive view of the future distribution grid and its building interface, an interactive environment where there are consumer benefits and motivations to leverage customer behind-the-meter assets. Large spatial footprint of the distribution grid and diverse locations of its assets make **observability, monitoring and diagnosis of abnormal (faults) and even planned (demand response or DER dispatch) events** challenging tasks for the existing descriptive analytics field, but great for Machine Learning.

Integrated Multi Scale Data Analytics and Machine Learning

Project Team

LLNL: Lead Lab, LANL: +1

LLNL *– Data collection and application definition, ML for incipient failure and DR verification, distributed communications*

LBNL *– Platform development, incipient failure detection*

LANL – *Anomaly detection and platform integration*

ANL *– Distributed analytics for resiliency apps,*

NREL *– Application definition, ML for DER verification*

ORNL *– OpenFMB integration, platform review and selection, new sensor streams*

SNL *– Application development, topology detection*

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
LBNL*	267	150	125
LANL	220	220	220
LLNL*	83	200	225
ANL	83	83	83
NREL	41.5	41.5	41.5
SNL	41.5	41.5	41.5
ORNL	104	104	104

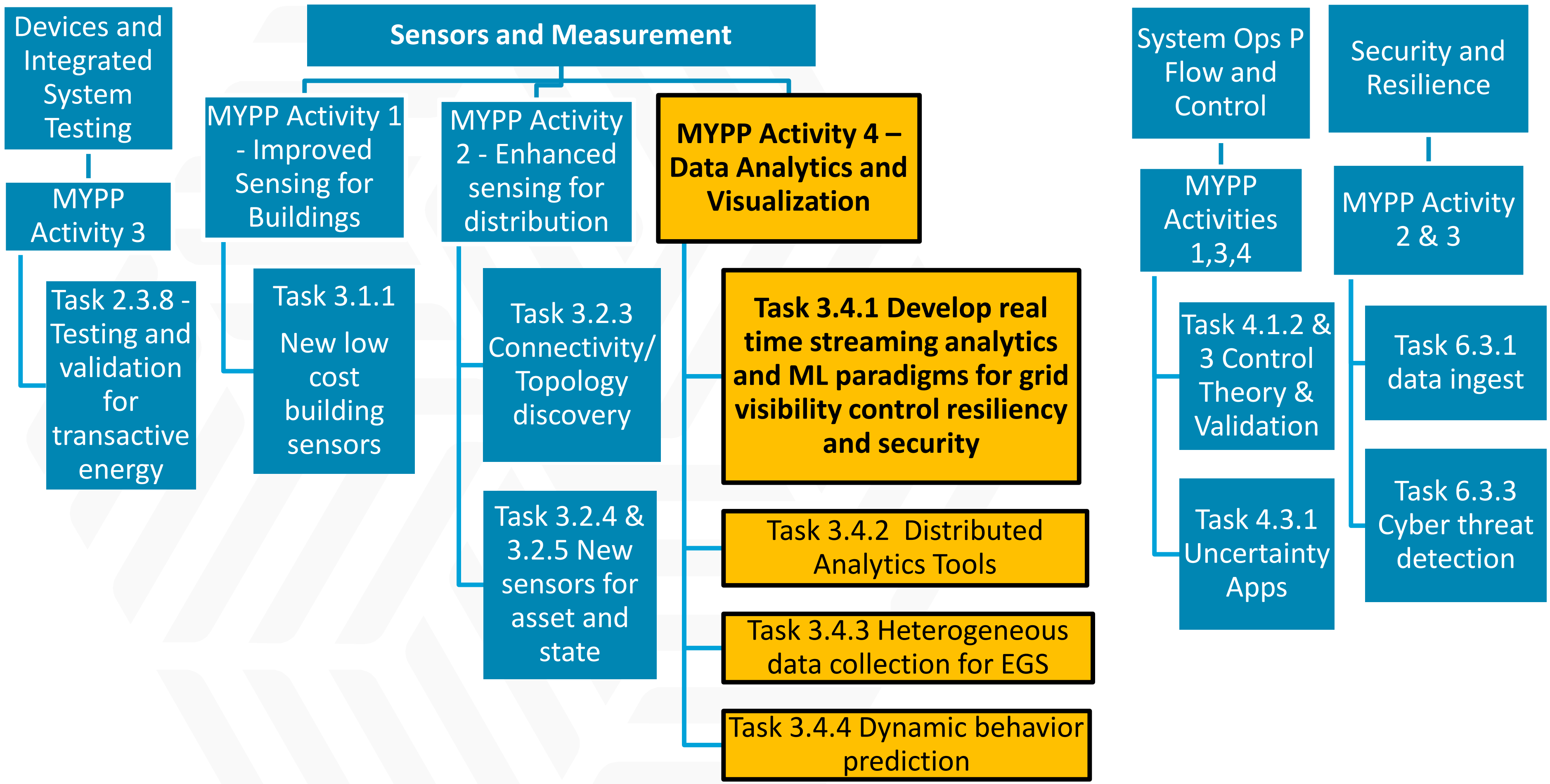
*budgets being reorganized due to change in personnel

Industrial Partners*: PSL, National Instruments, OSISoft, SGS, Sentient, SGIP*

Utility Partners*: Riverside Public Utility, Pecan Street/Austin Energy, PG&E, Duke Energy*

Integrated Multi Scale Data Analytics and Machine Learning

Relationship to Grid Modernization MYPP



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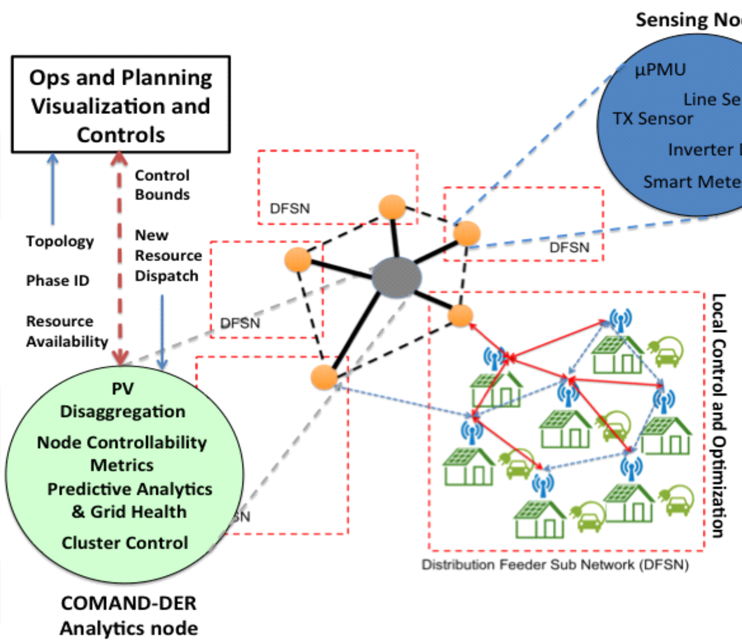
Approach Overall

- 1) Setting the stage
- 2) Evaluation and testing demo of state of art in Distributed ML
- 3) Stakeholder demonstration at metrics evaluation
- 4) New ML technique development and application
- 5) Coordinated project integration



- In year 1 we are illustrating R & D analytics white space with application of both existing and new techniques
  - Benefits to consumers and utilities at the building to grid interface

Unique Aspects of approach:

- **Streaming data demonstrated in field,**
- **Distributed and in data in motion, as opposed to centralized**
- **Novel algorithms to be applied at building to grid interface**

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Approach 1: White Paper & Use Case Development

- White Paper Goals
  - What is machine learning and why do we need it from two perspectives building/grid and data science
  - Illustrate the potential for application development
    - Where we can improve and innovate?
    - Where can we improve existing techniques with new data?
  - This will enable value streams to be derived from new sensing and grid architecture for many years to come
    - Outline a framework to define clear benefits to consumers and utilities

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Approach 2 – Case Study Identification and Review

Use Case	DR & DER Local Availability & Verification	Incipient Failure Detection in Distribution	Topology & Parameter Estimation
Present State of Art	Estimated forecast and manual communication	Local sensing, smoke signals, outage management	Successful applications in highly sensed environments,
Present Granularity	Sub or Individual Customer, Day+	Limited prior to outaged component	Sub or Individual Customer, Day+
Future Requirement	Cust & Dist XFRMR Real time and Hrs Ahead	Dist XFRMR/ component level Real time, Months and Hrs Ahead	Switch, Distribution Component Planning and Event Driven
Useful Data	AMI, Irradiance, Green/Orange Button, PMU, model	AMI, Model, PMU, GIS	AMI, Model PMU, GIS, Model
Stakeholders	Consumers, DERMS and PV Vendors, Operators	Consumers, Asset Managers, Operators	Planners, vendors, PV integrators, Operators

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Approach 3 – Application Development

Phase 1: Application benchmarking and testing for existing state of art, benefits assessment

Data Layer – Streaming AMI, PMU, Distribution Models, OMS

Platform & Initial Distributed Comms

Simple Anomaly Detection – Learning Baseline Behavior

App 1: DR & DER Verification & Prediction	App 2: Distribution Incipient Failure	App 3: Topology & Parameter Estimation
PV Disaggregation Load response Dependency (FIDVR)	LTC failure analytics XFRMR Impedance detection	Load Identification Inverter Estimation Topology ID

Upper Supervisory Layer – OSISoft, OpenFMB integration

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Approach 4 – Data and Industrial Support

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Approach 5 – Metrics, testing and benefits

- Algorithms will be tested on reference (but real time) streaming data then evaluated against benefits framework for distributed multi-variate analysis
- Benefits framework will identify areas for development
  - Platform and distributed communications (latency, data quality)
  - Information prioritization (emergency vs normal ops)
  - New algorithm development (granularity of information, timeliness, ease of use)
  - Sensor fusion and flexibility of algorithms to data sources (can we use new data?)
- Metrics for success are tied directly to the use case and stakeholders and feed into phase 2

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Key Milestones

Milestone (FY16-FY18)	Status	Due Date
Task 1: White paper delivery and review	Draft Delivered & reviewed, publication in process	9/1/16 (complete)
Task 2: Workshop on white paper and use cases development, data gathering and use case specification complete	Workshop was delivered on Feb 9 216	2/1/17 (complete)
Task 3: Data collection, mapping of data to use case and platform access for team established	Data mapping presented at stakeholder review	2/1/17 (complete)
Task 4: Demonstration of selected use case with streaming data, with stakeholders, bench-top demonstration with real time streaming data validated	Use case selection in progress per 12/1/16 Benchtop data streaming platform demonstration in progress (uPMU and pqube data)	7/1/17
Task 5: Use cases developed within same framework, new algorithm development reviewed		9/30/17
Task 6: Framework proposed to integrate new data streams from sensors development tasks, benefits assessment		6/1/18

Integrated Multi Scale Data Analytics and Machine Learning Accomplishments to Date

- Identified and reviewed with stakeholders, 3 high value use cases where new distributed ML techniques would have high impact on the building to grid interface
- Two white papers (in process of publishing)
- Structure for testing and benefits assessment of the existing state of the art is identified and initial application will be demonstrated in early July
- Coordinated with synergistic activities across programmatic boundaries

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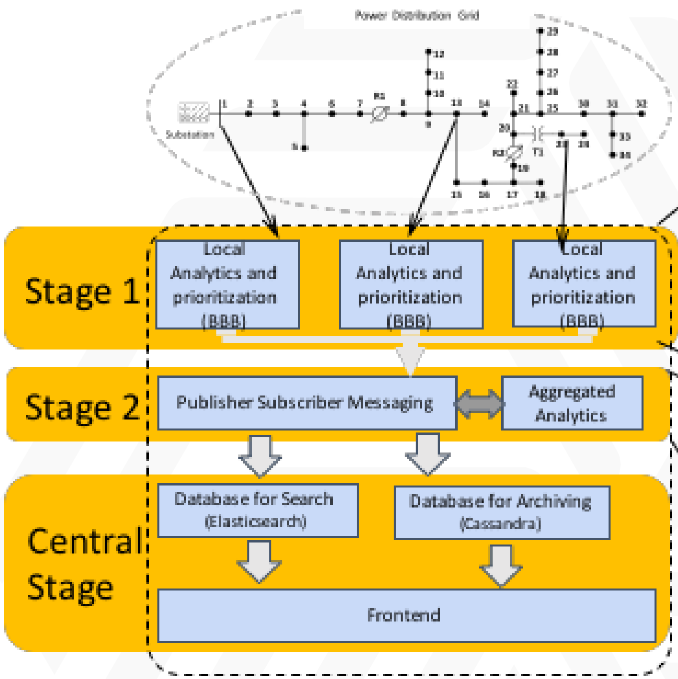
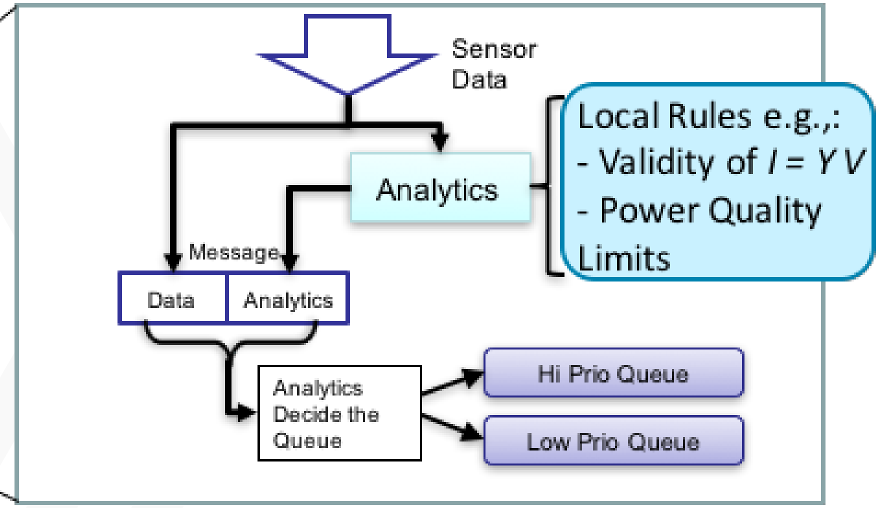
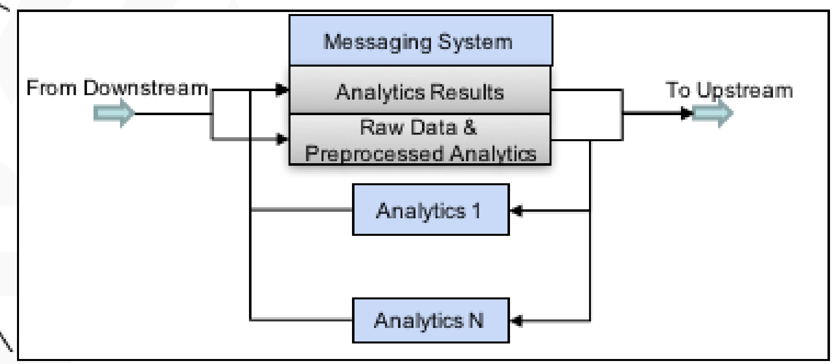
Accomplishments to Date: Platform Selection







- Archive the data & analytics results
- Frontend to the user

Platform Dev: Reinhard Gentz and Sean Peisert (LBNL)

Recommendation	Response
Lab team should use the workshop planned in February to work with the stakeholder committee and identify the highest priority ML applications. Consult with the DOE program managers to select the best use cases moving forward	3 sets of use cases were presented at the stakeholder review meeting in February Questionnaire responses highlighted all 3 as being of importance, with incipient failure rating highest. These use cases were also highlighted as being of high importance to the S & M activities overall and have been integrated into the roadmapping work The team have presented this to the PM's and a strategy to review existing state of the art, and develop all applications concurrently within the multi-lab team.

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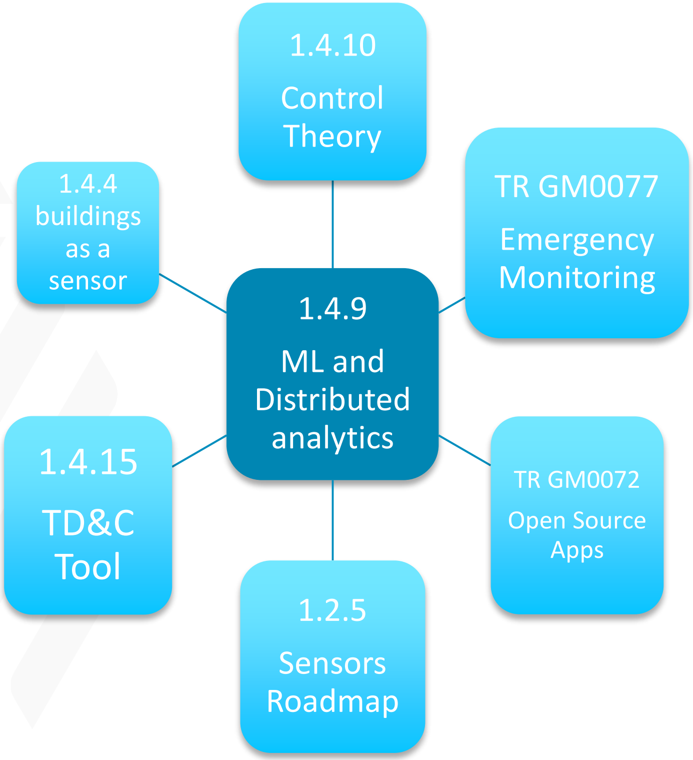
Project Integration and Collaboration

- GM0077: Anbient and Emergency Response – Scott Backhaus LANL
- GM0072: Load Model validation – Pavel Etingov LLNL
- 1.4.15: TDC test-bed development - Philip Top
- 1.4.10: Anomaly detection are precursors to control theory – Scott Backhaus
- 1.4.23: Threat Detection

- External project collaborations include ARPA-E uPMU for distribution, Sunshot ENERGISE and CEDS uPMU projects



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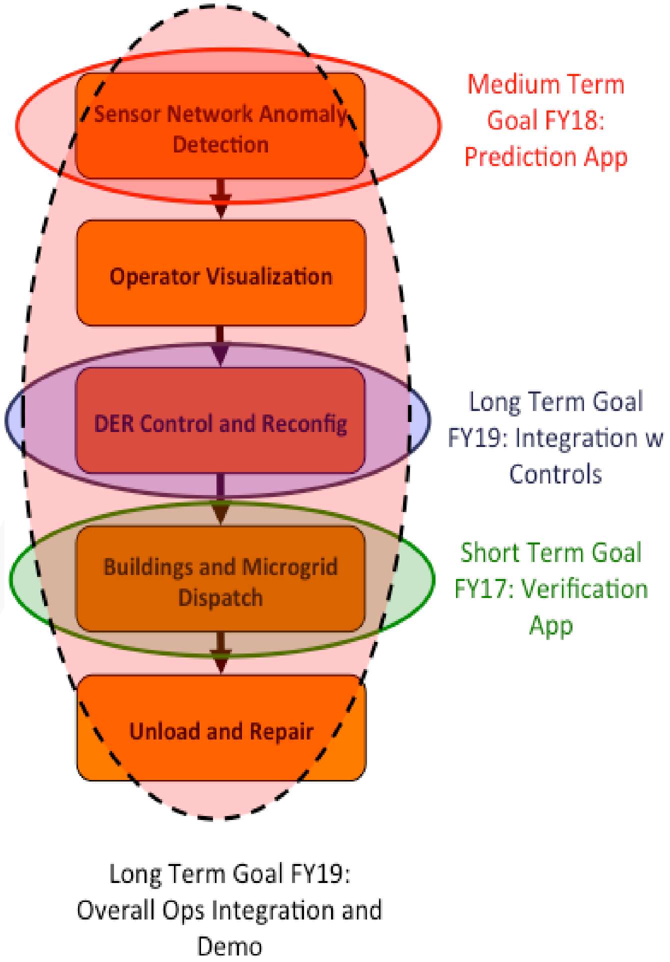
Next Steps and Future Plans

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- **Primary goal of project is to develop architecture and analytics to transform data into actionable information – delivered to the right place, at the right time.**
- Next Steps: Complete first testing phase and report out benefits and requirements for development - July
- Outcome of phase 1 will include a map of activities required to meet final application development development
  - **Review demonstration with stakeholders at a workshop at LLNL**
  - **Conference papers for FY17**
- Phase 2 – new analytics techniques in each case study will be developed and implemented. Reference platform will be deployed at select locations and tested with enhanced features developed in phase 2
- Phase 3 – Selected analytics from the project will integrate with controls and upper layer hierarchy at BMS and DMS levels



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Building to grid interface focus

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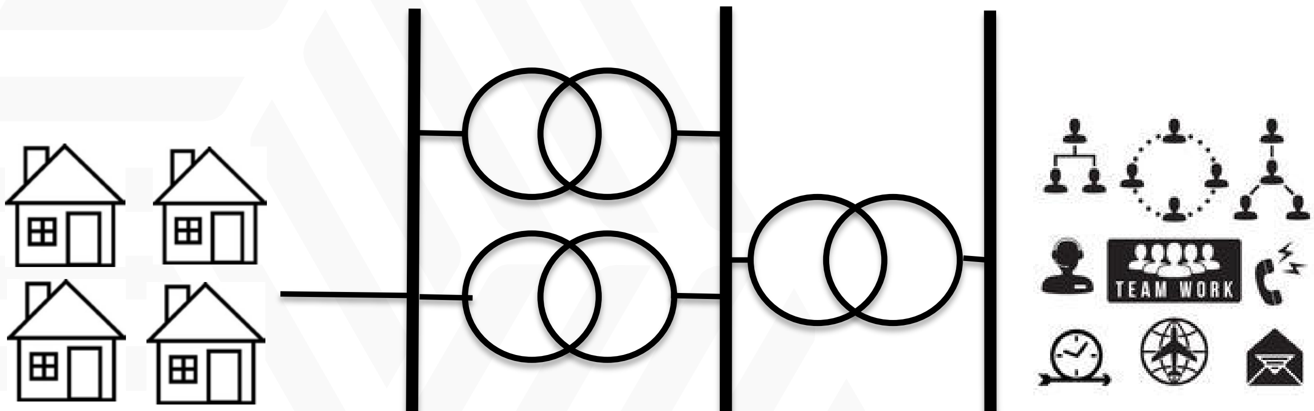
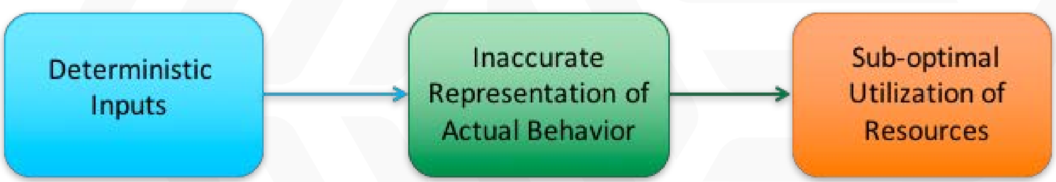


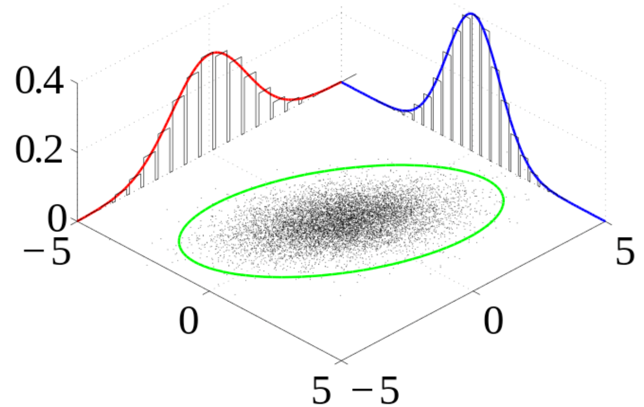
	LV – Customer Side	Distribution	Transmission	Ops and Planning
Timeframes	Hours, days, mins	us, s, mins	us, s, mins	Real time to 6 months+
Data	Green button, AMI, local, HVAC inverter	uPMU, Line sensor	SCADA, PMU	OMS, GIS, Models
Analytics Priorities	lighting, comfort, $$$	V, P, I management	Constraint management	CAIDI, SAIFI, MAIFI, safety
App 1 Impact	new markets, better economy	New services for granular automated management		Operational intelligence
App 2 Impact	less outages, reduced cost of service	Preventative rather than reactive maintenance		
App 3 Impact	less outages, more efficient management	More accurate modeling, increased efficiency		

Predicting Ancillary Service Availability
Current Practice & Role of Machine Leaning

- Building Operator/Aggregator forecasts availability using deterministic techniques
  - Electric vehicles are scheduled and available capacity predicted and bid into markets
  - Solar PV production is forecasted
  - Load is forecasted as a function of temperature and time of day

- Following the formulation of forecasts the operator predicts the loads flexibility and its ability to provide ancillary services to the various markets and bids in this corresponding amount





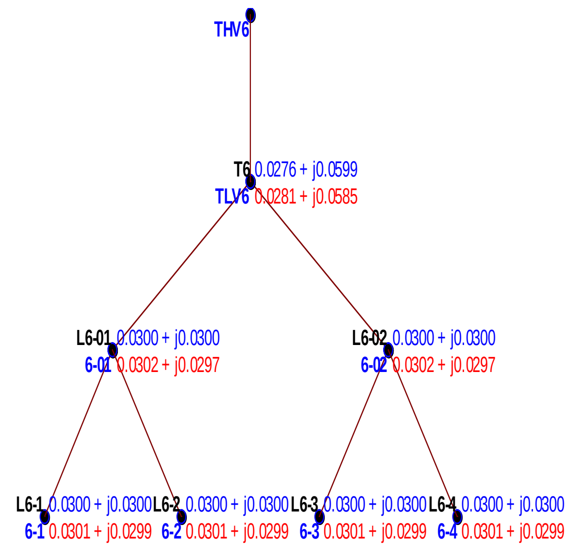
Machine learning can help automate and improve this process

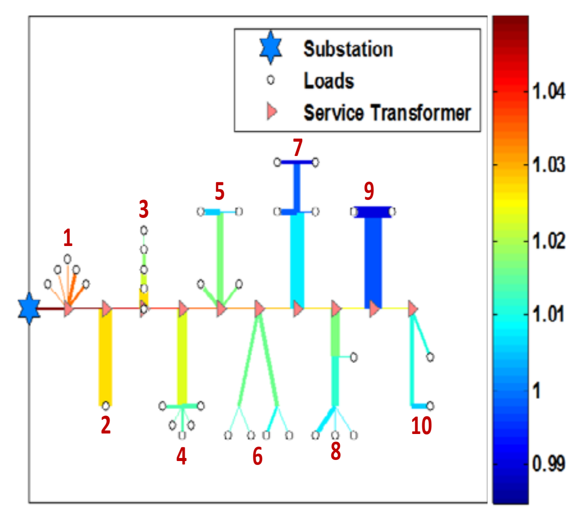
Algorithms can understand complex intra-dependencies of processes, e.g., how does the scheduled electric vehicular fleet availability affect load

ML can better understand and account for stochastic behavior arising form occupant interaction and forecasts error and how these stochastic behaviors propagate through the system

Grid Topology and Parameter Estimation New Approaches

- New Machine Learning Approaches
  - Self-organizing maps for outlier and bad data detection
  - Random forest for topology identification
  - Robust regression for grid parameter estimation
- Sensing requirements
  - Historical power and voltage measurements from all buildings. Do not need high-resolution data. AMI data at 15-minute resolution, but for machine learning, several months of AMI data is required.
  - Meter accuracy is extremely important

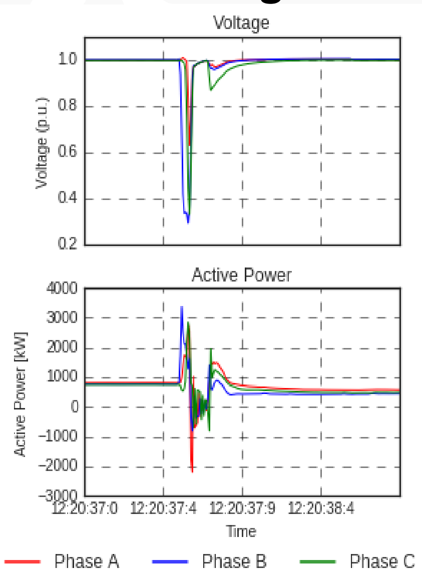




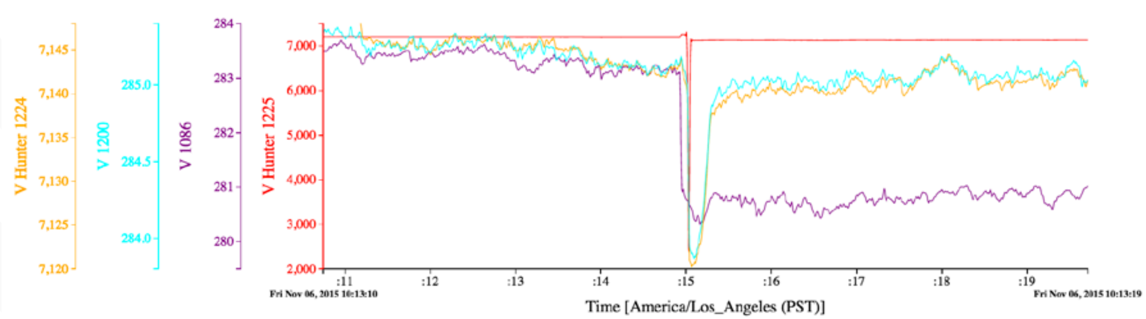
Case 2: Fault Analysis & Incipient Failure Problem and Background

- There are millions of distribution transformers and unmonitored equipment in the US
- Measurement of each individual device is economically and technically challenging
- Direct measurement approaches include Dissolved Gas Analysis, and
- Difficult to attribute anomalous behavior to a specific device or type of device

Bird Blowing a Fuse

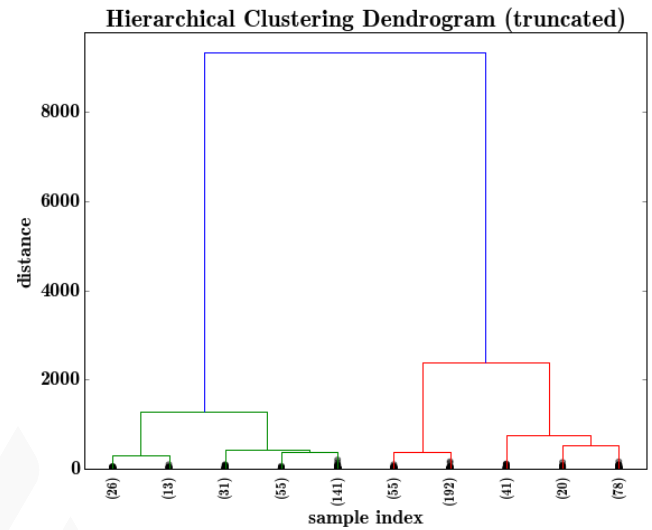


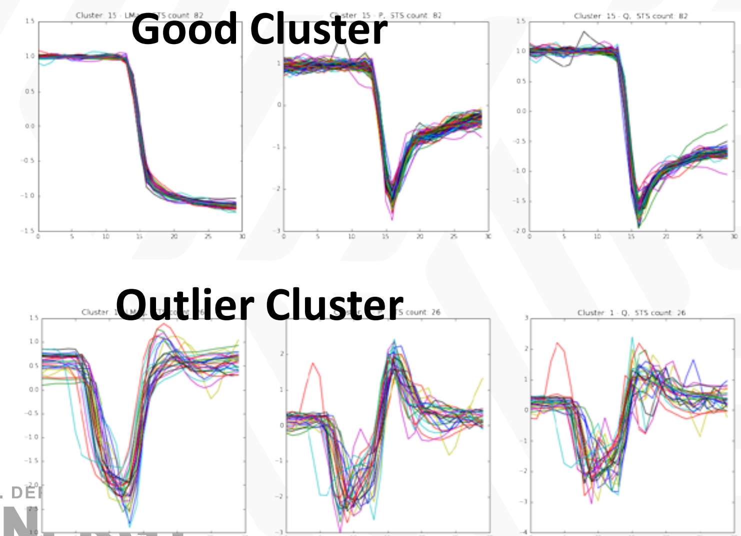
Tap Changer Oil Leak



Equipment Incipient Failure New Approaches

- Hierarchical clustering allows for classification of power system phenomena via multi-dimensional clustering, both across phases and quantities
  - utilize derivative of phase angle as informative stream in clustering behavior
  - Can be applied to any time series behavior, utilize power flow modeling in relational analysis of potentially failing component





- Sensor needs
  - Phase angle and time series measurements
  - Relational and synchronized
  - Fused with power flow physics for locational analysis
  - Impact analysis and reconfiguration can utilize building data
  - Low accuracy as normal behavior is learned