GRID MODERNIZATION INITIATIVE
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GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.2.5 – Sensing & Measurement Strategy

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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

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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

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- **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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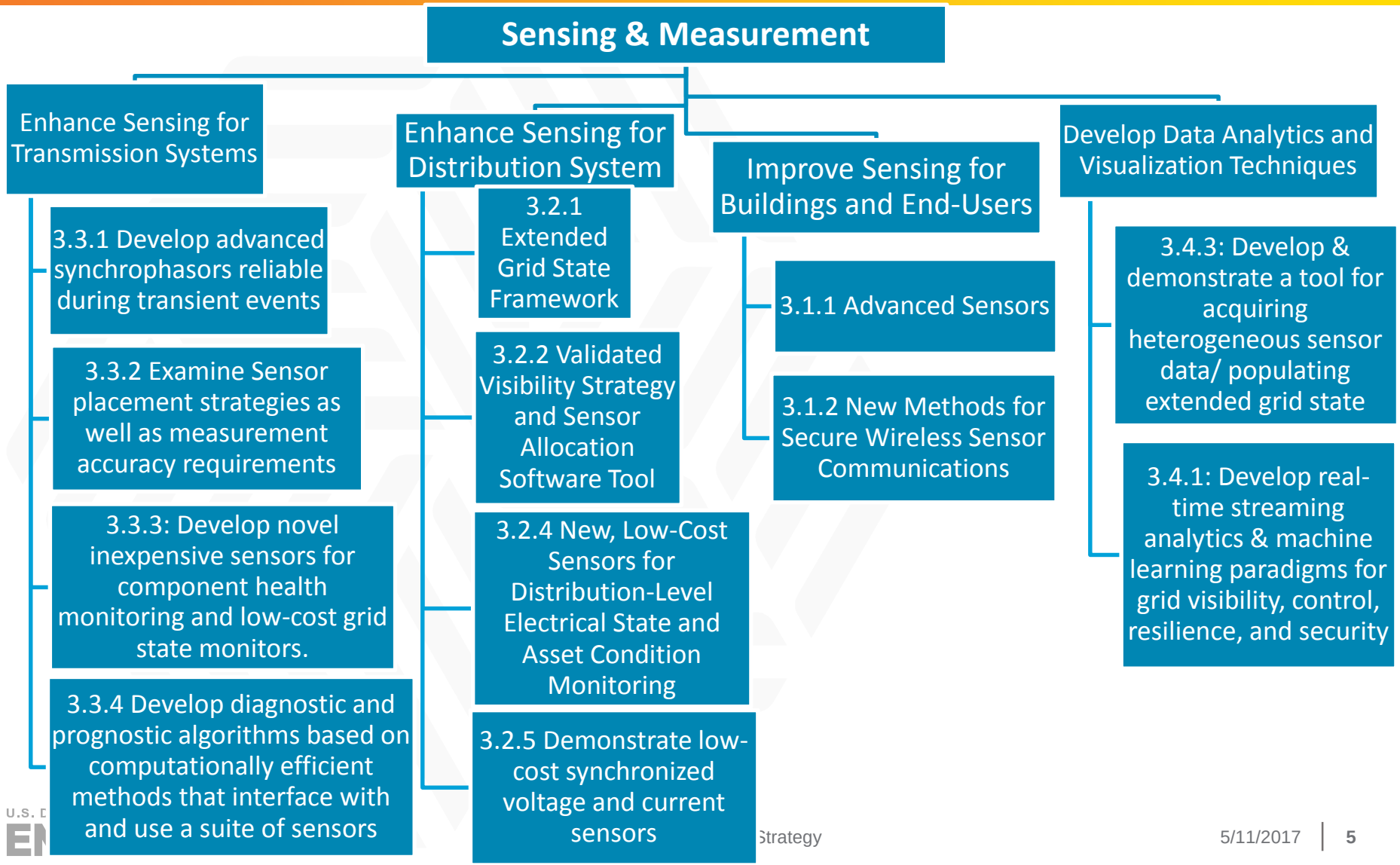

Sensing & Measurement Strategy
Approach

- **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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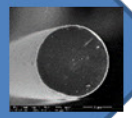
Sensor Roadmap & Tool

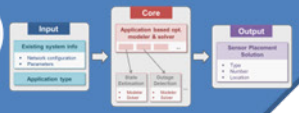
Extended Grid States

- 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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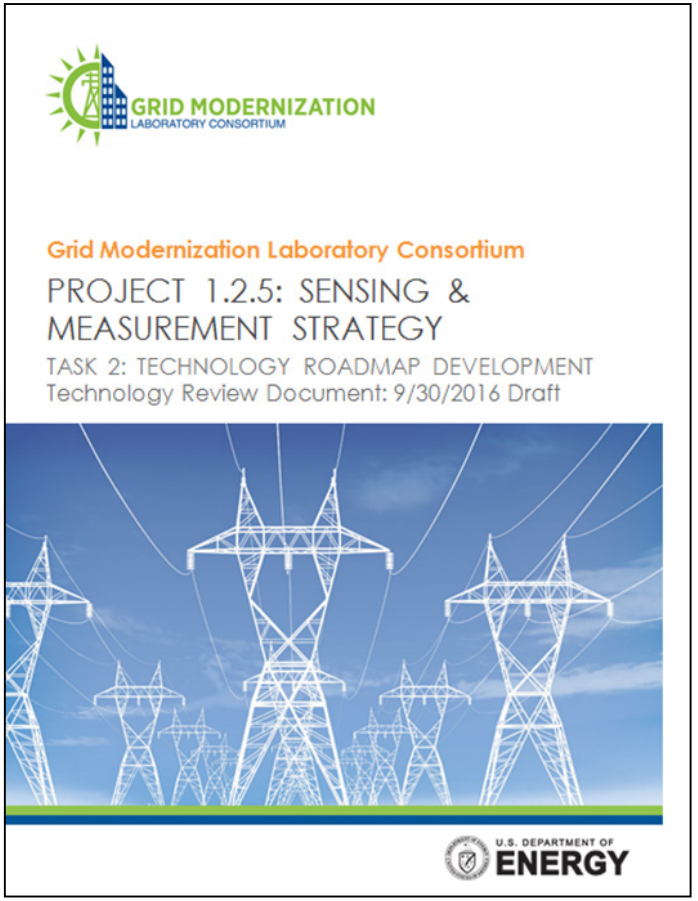
2016

- ✓ 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



Sensing & Measurement Strategy
Accomplishments to Date (Roadmap is a Key One)

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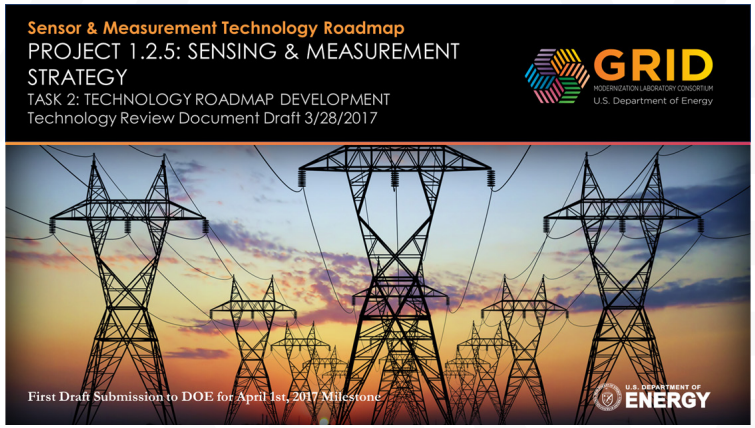
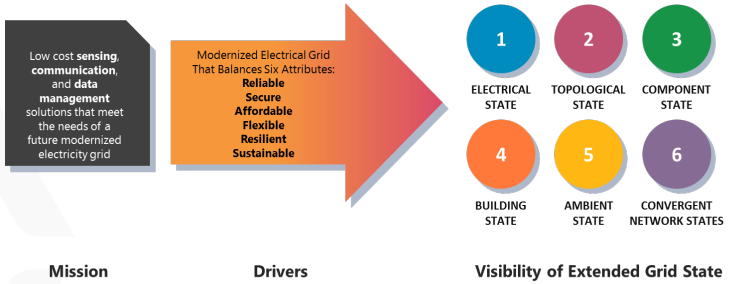
Sensor & Measurement Roadmap*

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)

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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.

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

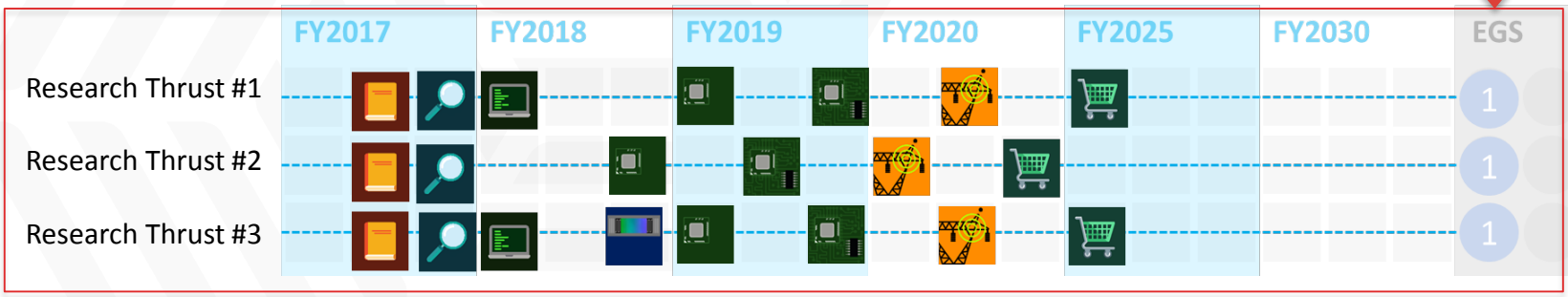
Key Parameters

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

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

Direct Links to GMI MYPP and EGS

Graphical Timelines with Icons



Sensing & Measurement Strategy
Accomplishments to Date

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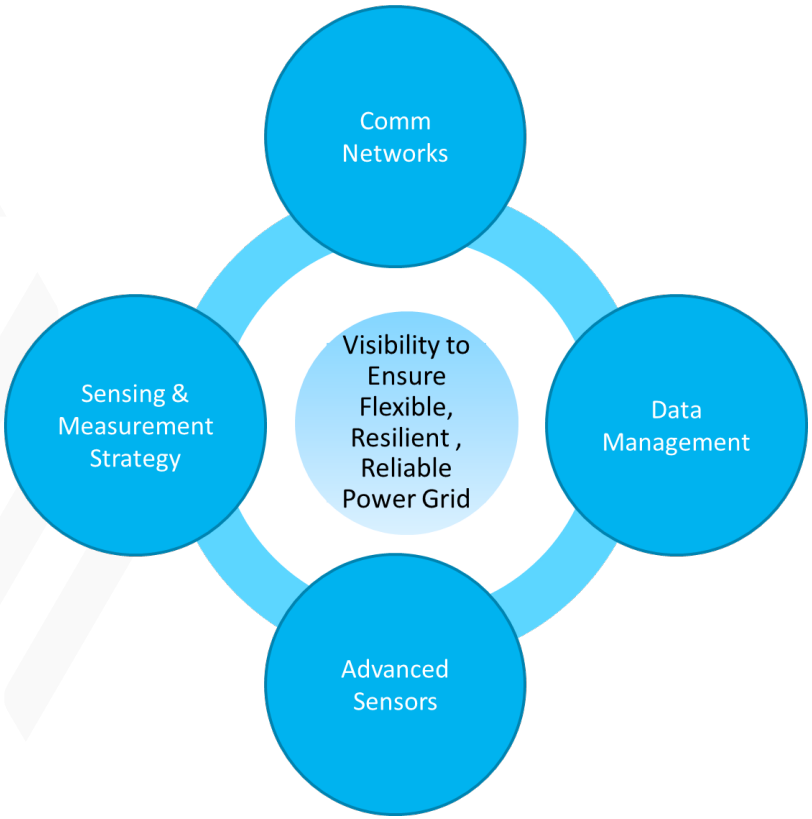
Lessons Learned

- ✓ 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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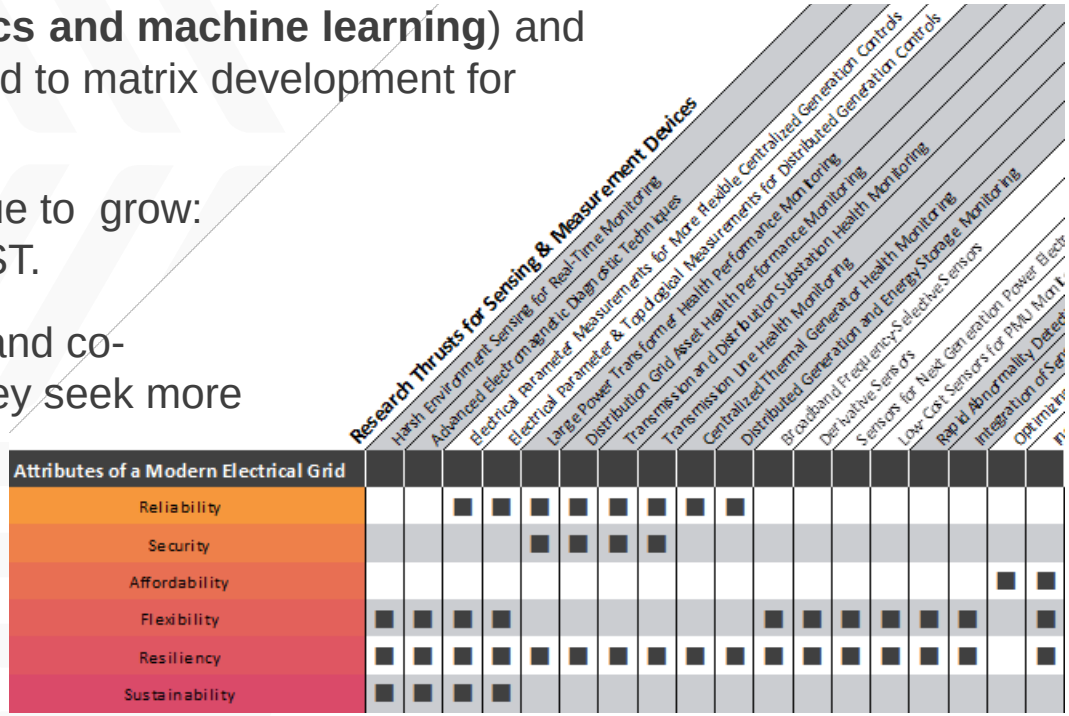
Market Impact

- ✓ 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



Sensing & Measurement Strategy
Response to December 2016 Program Review

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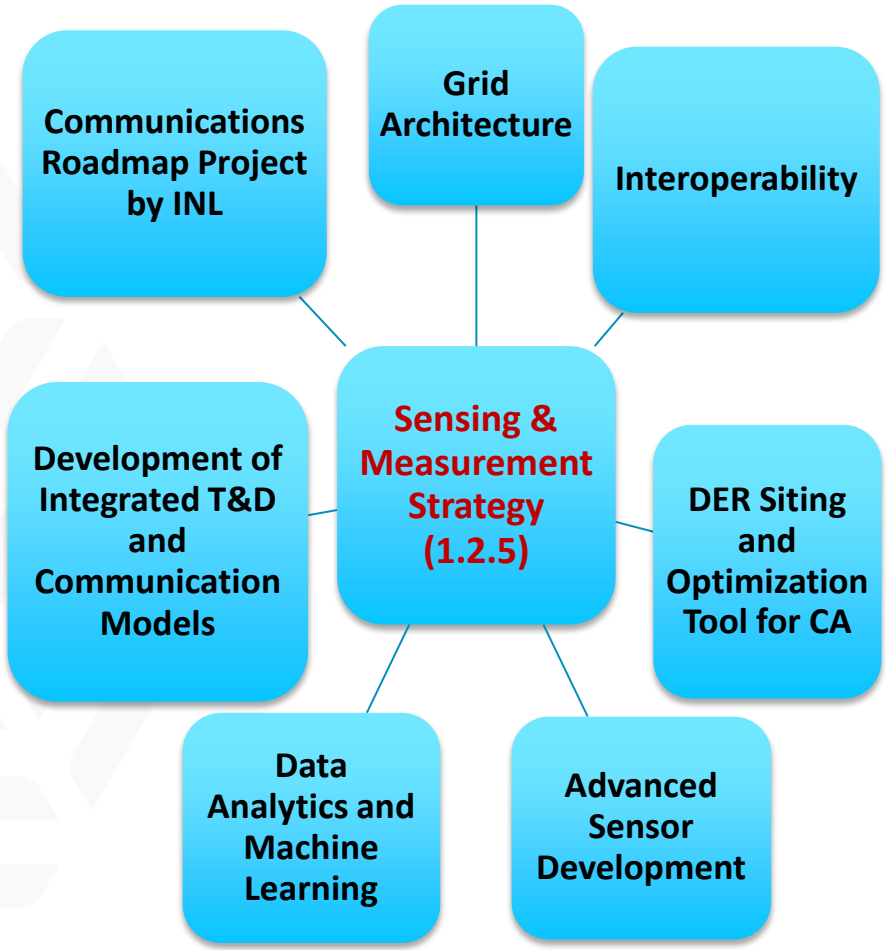
Recommendations	Responses
Please share the draft technology roadmap with program managers to get their feedback on the document	**Shared with them both at the Feb Meeting and prior to this meeting which includes industry feedback**
Please invite DOE program managers to the February 2017 workshop in Chicago	**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

Sensing & Measurement Strategy

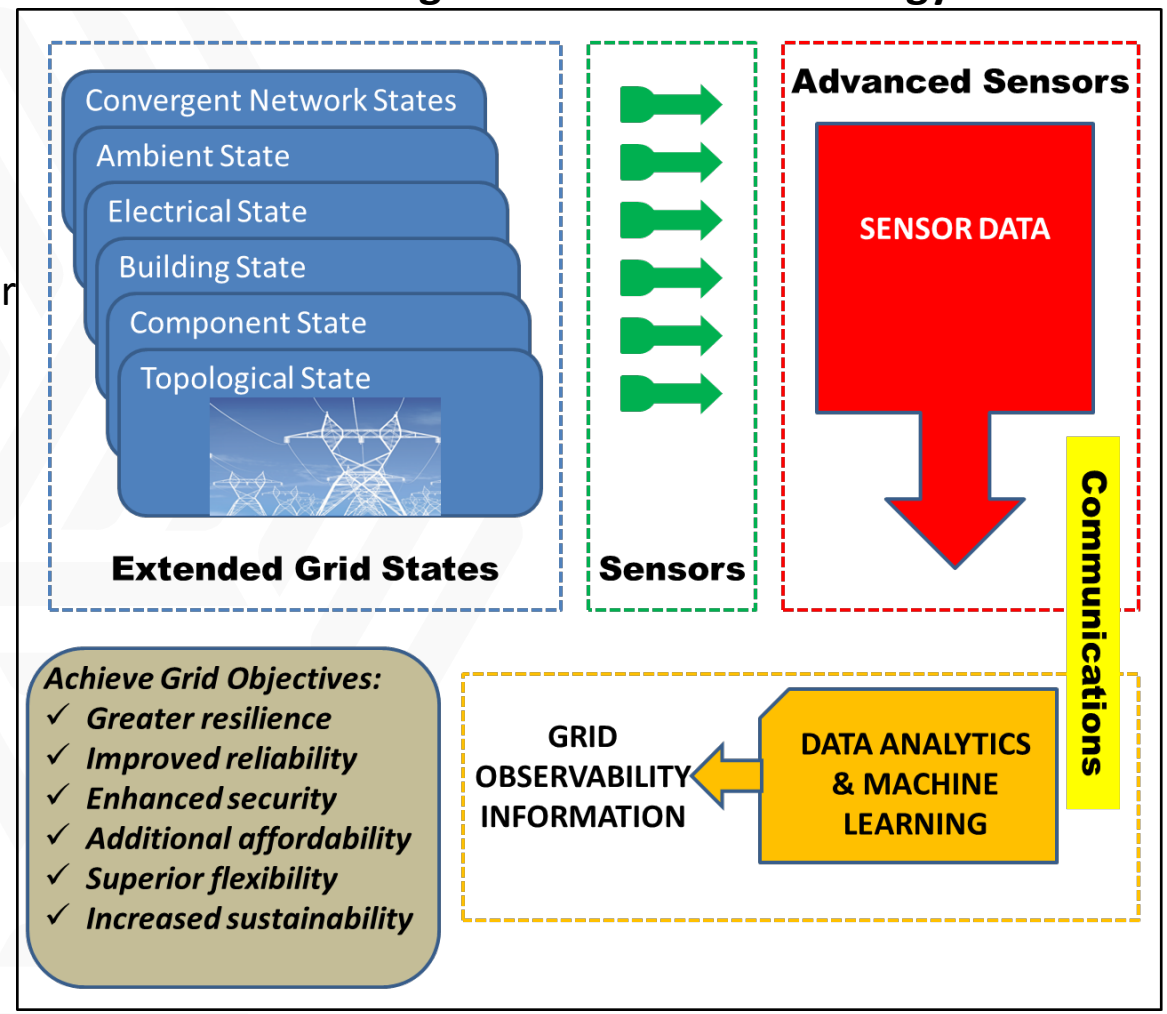
- ✓ Overall strategy for sensing & measurement including grid states, sensors, communication requirements and data management and analytics needs.
- ✓ Identify gaps and priorities in sensor R&D and optimizes sensor placement.

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
Project Integration and Collaboration (Industry Outreach)

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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

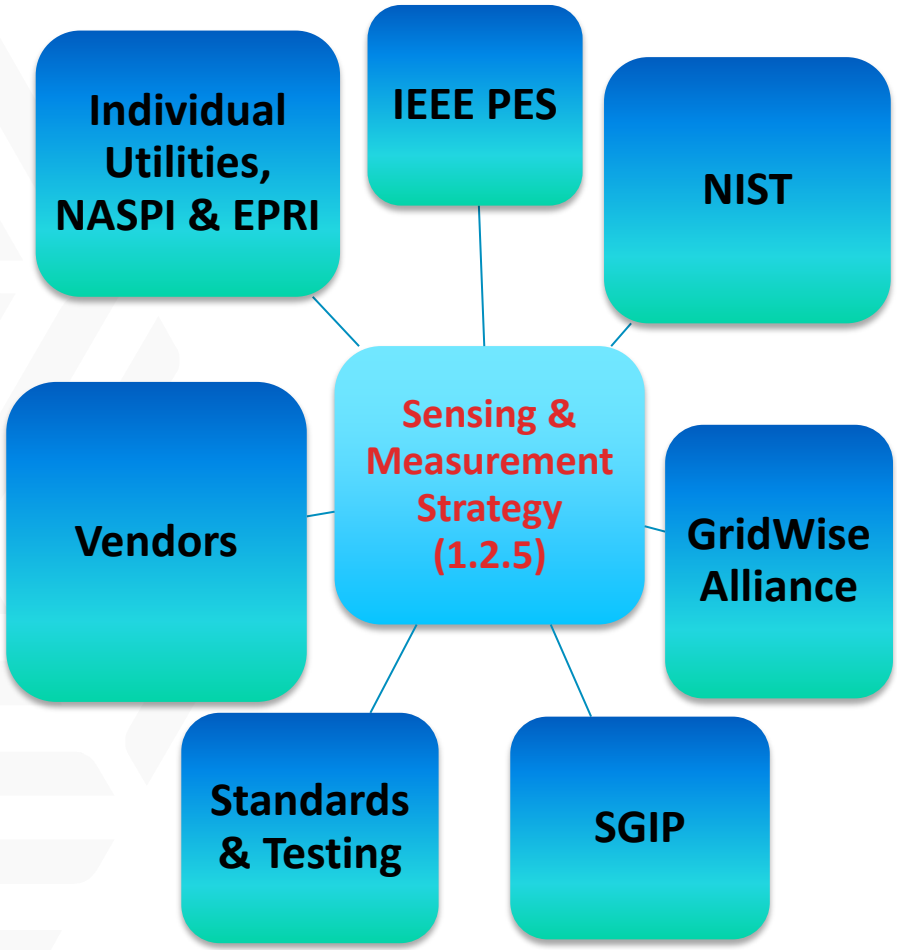
- ✓ Alstom, OSIsoft, Quanta, GE

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

- **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

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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

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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

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

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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

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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