2018 Grid Modernization Peer Review Report

Foundational Projects and Technical Area Portfolio Review

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Chairs' Letter

Dear Colleagues,

The Grid Modernization Initiative (GMI) coordinates activities with offices and programs across the United States Department of Energy (DOE), with the goal of developing the tools and technologies that measure, analyze, predict, protect, and control the grid of the future.

As part of the GMI, the Grid Modernization Laboratory Consortium (GMLC) strives to streamline and optimize collaborative efforts across DOE's National Laboratories to modernize the nation's grid by bringing together leading experts, capabilities, and resources. In January 2016, DOE announced funding of up to $220 million over three years for the GMLC and its more than 100 strategic partners. Funding supports critical research and development that works toward a reliable, resilient, and sustainable power system as outlined in the Grid Modernization Multi-Year Program Plan (Grid Modernization MYPP). This effort also recognizes the need to balance regional perspectives, while defining and developing a coherent national strategy.

From September 4–7, 2018, DOE held its second annual Grid Modernization Initiative Peer Review. In addition to hearing from utilities, vendors, and state and local representatives on their vison of grid modernization, DOE conducted a formal peer review 26 GMLC projects across six key technical areas defined in the Grid Modernization MYPP. The peer review process is an invaluable opportunity for external stakeholders to rigorously evaluate the technical approach, progress, relevance, and overall merit of all the projects in the GMI portfolio. To ensure accountability and stewardship, DOE actively manages projects for outcomes and impact.

On behalf of DOE, we are pleased to announce the release of the 2018 Grid Modernization Initiative Peer Review Report.

We would like to thank the 18 peer reviewers representing industry, academia, nonprofit organizations, and government for their guidance and feedback. These subject matter experts included some of the most experienced and knowledgeable professionals in the grid community. Results from this peer review will be instrumental in providing guidance for programmatic decision-making and will also impact future budget and funding opportunity decisions. An important recommendation shared by almost every reviewer emphasized the importance of transferring technology developed by the National Laboratories to the marketplace. In January 2019, DOE's Office of Technology Transitions and the National Laboratories held an InnovationXLab Initiative Summit focused on grid modernization. The Summit showcased the broad array of technical resources available from across DOE's National Laboratory complex that can be leveraged by industry to address grid modernization challenges. DOE and the National Laboratories will continue to ensure grid modernization is a priority moving forward.

As we look to the future, GMI will continue to focus on strengtheningthe foundational core capabilities for a modernized grid. We will expand our body of research to include a more fully integrated modernized grid—from fuels, to generation, to load. Finally, we will continue to emphasize the efforts of building a more resilient, reliable, and secure grid.

Thank you for your interest. See you next year!

Gil Bindewald
Chair, Grid Modernization Initiative

Kevin Lynn
Co-Chair, Grid Modernization Initiative

Acronym Guide

AC OPF	Alternating Current Optimal Power Flow
ADC	Aggregated Device Controllers
ADMS	Advanced Distribution Management System
API	Application Programming Interface
APPA	American Public Power Association
BA	Balancing Authority
BMS	Building Management System
CAIDI	Customer Average Interruption Duration Index
COTS	Commercial-Off-The-Shelf
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DMS	Distribution Management System
DO	Distribution Operator
DOE	Department of Energy
DSO	Distribution System Operator
DSPx	Next Generation Distribution System Platform
EIA	Energy Information Administration
EMS	Energy Management System
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESI	Energy Systems Interface
FLISR	Fault Location, Isolation, and Service Restoration
FEUR	Future Electric Utility Regulation
FVP	Field Validation Project
GAAP	Generally Accepted Accounting Principles
GMI	Grid Modernization Initiative
GMLC	Grid Modernization Laboratory Consortium
GRIP	Grid Resilience and Intelligence Platform
HELICS	Hierarchical Engine for Large-scale Infrastructure Co-Simulation
HEMS	Home Energy Management System
HIL	Hardware-in-the-Loop
HPC	High Performance Computing
HVAC	Heating, Ventilation, and Air Conditioning
ICE	Interruption Cost Estimate
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-Owned Utility
IRP	Integrated Resource Planning
ISO	Independent System Operator
LCOE	Levelized Cost of Electricity
LEN	Logical Energy Network

LVAT	Laboratory Value Analysis Team
MagSense	Magneto-elastic sensor
MAIFI	Momentary Average Interruption Frequency Index
MYPP	Multi-Year Program Plan
NARIS	North American Renewable Integration Study
NASEO	National Association of State Energy Officials
NASUCA	National Association of State Utility Consumer Advocates
NARUC	National Association of Regulatory Utility Commissioner
NERC	North American Electric Reliability Corporation
NRECA	National Rural Electric Cooperative Association
OpenFMB	Open Field Message Bus
PCM	Production-Cost Modeling
PFO	Power Flow Optimizers
PMU	Phasor Measurement Unit
PUC	Public Utility Commission
PV	Photo Voltaic
RADIANCE	Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Control, and Energy Storage
RDS	Resilient Distribution Systems
RTO	Regional System Operator
SAG	Stakeholder Advisory Group
SAW	Surface-Acoustic Wave
T & D	Transmission and Distribution
TA	Technical Assistance
TDC	Transmission, Distribution, and Communications

List of the GMLC National Laboratories

ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
INL	Idaho National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
LANL	Los Alamos National Laboratory
NETL	National Energy Technology Laboratory
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
SNL	Sandia National Laboratories
SRNL	Savannah River National Laboratory
SLAC	SLAC National Accelerator Laboratory

About the Grid Modernization Initiative

Why is Grid Modernization Important?

The National Academy of Engineering named "electrification" the greatest engineering achievement of the 20th century. However, today's grid must be modernized to include attributes to meet the demands of the 21st century and beyond, as access to electricity is critical to a robust economy and national security.

Five key trends that challenge the capacity of the grid are driving this transformation:

1. Changing mix of types and characteristics of electric generation;
2. Growing demands for a more resilient and reliable grid (especially due to weather impacts and cyber and physical attacks);
3. Opportunities for customers to provide grid services and participate in electricity markets;
4. Increasing use of digital and communication technology in the control of power systems; and
5. Aging electricity infrastructure.

The current trajectory for grid modernization within the electricity industry may result in missed opportunities for efficient energy utilization, economic growth, and—in some cases—the protection and well-being of citizens. Changes to regulatory, market, and business sectors may be required to allow advancements and innovation to the electric power sector. The federal government is in a unique position to help enable grid modernization by working with and across states, industry, and other key stakeholders to invest in critical research and development, analysis, and outreach and catalyze private-sector innovation.

Grid Modernization Initiative

The U.S. Department of Energy (DOE) established the Grid Modernization Initiative (GMI) in January 2016 to develop a holistic vision for grid modernization across the Department. GMI represents a comprehensive partnership between DOE, the National Laboratories, industry, and other stakeholders to accelerate the development of technologies, modeling, analysis, tools, and frameworks to help enable grid modernization adoption. To this point, GMI's efforts have focused on the following main technical areas:

- **Design and Planning Tools** – Create grid planning tools that integrate transmission and distribution, as well as system dynamics over a variety of time and spatial scales.;
- **Devices and Integrated Systems** – Develop new devices to increase grid services and utilization and validate high levels of distributed energy resources at multiple scales;
- **Institutional Support** – Provide tools and data that enable more informed decisions and reduce risks on key issues that influence the future of the electric grid/power sector;
- **Security and Resilience** – Develop resilient and advanced security (cyber and physical) solutions and real-time incident response capabilities for emerging technologies and systems;

- **Sensing and Measurements** – Incorporate information and communications technologies, and advance low-cost sensors, analytics, and visualizations that enable 100% observability; and
- **System Operations, Power Flow, and Control** – Design and implement a new grid architecture that coordinates and controls millions of devices and integrates with energy management systems.

DOE and the National Laboratories implement GMI projects, working closely with external public-private partnerships involving more than 100 companies, utilities, research organizations, state regulators, and regional grid operators. A significant indicator of success of the initiative is the adoption and implementation of the GMLC-developed technologies by industry partners and industry at large.

Through GMI, DOE and its partners have the opportunity to transform our grid into a platform for greater prosperity, growth, and innovation. Our portfolio of work will help better integrate all sources of electricity, improve the security and resiliency of our nation's grid, enable effective integration of energy storage and distributed energy resources, and provide a critical platform for U.S. competitiveness and innovation in a global energy economy.

Grid Modernization Multi-Year Program Plan

In partnership with the Grid Modernization Laboratory Consortium (GMLC), DOE released a detailed blueprint for modernizing the grid in 2016: The Grid Modernization Multi-Year Program Plan (Grid Modernization MYPP). Through the Grid Modernization MYPP, DOE has coordinated a portfolio of activities to help set the nation on a cost-effective path to a resilient, secure, sustainable, and reliable grid that is flexible enough to provide an array of emerging services while maintaining affordability.

The Grid Modernization MYPP defines a vision for the modern grid, identifying key challenges to the realization of this vision, as well as opportunities to overcome these challenges. The direction and priorities outlined in the Grid Modernization MYPP drew upon DOE's ongoing work, as well as numerous engagements with the private sector. It described an initial suite of research, development, and demonstration activities that DOE would focus on over the ensuing five years, including opportunities for public-private partnerships. The overview descriptions of GMI's six technical areas were formulated at the time the Grid Modernization MYPP was written, and they have guided GMI's activities and efforts since the document's release.

As of this past year, Grid Modernization MYPP is currently undergoing revisions. One major revision includes creating separate technical areas for Security and Resilience, and creating a new technical area called Generation. Details of the changes were shared and discussed during the GMI Peer Review's GMLC Overview session on September 4, 2018.

Grid Modernization Lab Consortium

Recognizing the skill sets across the National Laboratories, DOE formed the GMLC—a strategic partnership that brings together leading experts and resources across 13 National Laboratories to collaborate on grid modernization projects. This crosscutting approach ensures that DOE's research and development investments and capabilities are coordinated efficiently and in a synergistic manner. The GMLC also supports DOE by consolidating resources, identifying research gaps, providing regional breadth, and supporting the Grid Modernization MYPP.

Grid Modernization Research

In 2016, DOE announced the first Grid Modernization Lab Call—a comprehensive, $220-million, three-year plan to mobilize 88 projects across the country, bringing together more than 100 companies, utilities, research organizations, state regulators, and regional grid operators to pursue critical research and development in advanced storage systems, clean energy integration, standards and test procedures, and a number of other key grid modernization areas.

In 2017, DOE announced up to $32 million over three years for seven Resilient Distribution System (RDS) projects that will develop and validate innovative approaches to enhancing the resiliency of U.S. electricity distribution systems and focus on the integration of distributed energy resources, advanced controls, grid architecture, and emerging grid technologies.

Introduction to the GMI Peer Review

In September 2018, GMI conducted its second external peer review of projects awarded to the GMLC to execute a diverse portfolio of technologies to modernize the nation's grid. Currently, GMI's portfolio is organized into six technical pillars. The 2018 GMI Peer Review took place September 4–7, 2018, in Arlington, Virginia. Of the 94 publicly funded projects in GMI's portfolio, 26 were formally evaluated, while the entire portfolio was reviewed during a poster session on the second day.

Among the projects that were formally peer reviewed, 19 were Foundational projects (Category 1)—larger, multi-lab, holistic cross-cutting projects that receive support from multiple DOE offices and programs. The other seven projects were then in September 2017 under GMI's RDS Lab Call.

The peer review process enables external stakeholders to provide feedback on the responsible use of taxpayer funding and provide recommendations for ways to accelerate the development of grid modernization technology in the industry and community. This report summarizes and presents the results of the Peer Review.

The six technical areas reviewed during the 2018 Peer Review are as follows (in alphabetical order):

- Design and Planning Tools;
- Devices and Integrated Systems;
- Institutional Support;
- Security and Resilience;
- Sensing and Measurements; and
- System Operations, Power Flow, and Control.

Eighteen external experts from industry, academia, other government agencies, and the non-profit sector participated as reviewers. Each review panel developed overall recommendations regarding the focus, management, and impact of the projects. In addition, a team of lead reviewers recommended overall guidance for GMI based on the Peer Review as a whole. DOE is using results from the 2018 Peer Review to help inform programmatic decision-making, modify or discontinue existing projects, guide future funding opportunities, and support other budget and strategic planning objectives.

GMI Peer Review

The 2018 GMI Peer Review was implemented over the course of three and half days, with two simultaneous review sessions of the 26 Foundational and RDS projects. Over the course of the Peer Review, participants also heard overview presentations from DOE leadership and industry executives on a variety of topics, including security and resilience, the growing importance of the grid edge, and the grid of the future. This format brought together DOE, National Laboratories, industry, academia, regulators, and other important stakeholders to have an open discussion regarding the grid of the future.

Reviewers

The 18 reviewers were selected based on technical expertise and the high-level qualifications in their designated technical areas. Efforts were made to ensure balance within the review panel by including a mix of reviewers from the public, private, and university sectors, with a range of expertise within each technical area. Reviewers certified that they had no conflict of interest with the projects they reviewed. Reviewers were asked to evaluate projects based on specific criteria. All of the feedback from the reviewers will help to shape the focus, scope, and strategic direction of GMI's portfolio.

Lead Reviewers

The GMI Peer Review Planning Committee chose a lead reviewer in each of the six technical areas to represent the thoughts and recommendations of all reviewers assigned to each technical area. The lead reviewer for each technical area compiled all reviewers' input and presented the collective findings to GMI and DOE leadership on the last day of the review. In addition, lead reviewers provided additional insight on how DOE and the National Laboratories could overcome obstacles and improve project performance and impact.

Evaluation Criteria

Reviewers were asked to evaluate projects based on specific criteria. The evaluation criteria (see Table A) and descriptions served as the standard template for the evaluation of each project. Projects received scores and comments on the first five criteria described below, with the lowest score of 1 and the highest score of 10. The last criterion, Overall Impressions, consisted of open-ended written responses with no numerical score or weight. Project Relevance was not weighted in the overall score, as the projects' scope, objectives, and goals were determined prior to projects commencing and should not reflect the overall scores of project performance.

Table A. Evaluation Criteria: Score and Weighting by Project

Criteria	Score	Weight
Project Relevance	1–10	No Weight
Approach	1–10	25%
Progress, Accomplishments, and Impact	1–10	50%
Project Integration and Collaboration	1–10	15%
Future Work	1–10	10%
Overall Impressions	No Score	No Weight

Project Relevance

Projects were evaluated on the degree to which they:

- Contribute to meeting the goals and objectives of the Grid Modernization MYPP; and
- Align with the goals of GMI and Grid Modernization MYPP, and relevance for the overall grid industry.

Approach

Reviewers were asked to evaluate a project's approach based on how well the principal investigator could:

- Describe the history, context, and high-level objectives of the project;
- Describe the overall technical and management approaches;
- Explain the approach, including management approach, use of milestones for monitoring progress, and any unique aspects of the approach;
- Address critical success factors (technical, market, and business) that define technical and commercial viability; and
- Discuss the top 2–3 potential challenges (technical and non-technical) to overcome for successful project results.

Progress, Accomplishments, and Impact

Reviewers were asked to evaluate a project's progress, accomplishments, and impact based on how well the principal investigator could:

- Describe the progress made in meeting project objectives and following the project management plan;
- Describe the most important technical accomplishments achieved (from the last review to the present for sun setting and existing projects, or progress to date for new projects);
- Benchmark progress versus previously reported results from the 2017 GMI Peer Review; and
- Benchmark accomplishments against the technical targets (if applicable).

Project Integration and Collaboration

Reviewers were asked to evaluate a project's integration and collaboration based on how well the principal investigator could:

- Demonstrate how the project is working with other GMLC projects, noting any project work that has enhanced other projects; and
- Demonstrate how the project is working with other grid work outside of GMLC projects.

Future Work

Reviewers were asked to evaluate a project's future work based on how well the principal investigator could:

- Explain the project's plan through its end date, with emphasis on the next 18 months;
- Highlight upcoming key milestones; and
- Address any critical decision points results, and any remaining issues.

Overall Impressions (Not Scored)

Reviewers were asked to provide an overall written assessment of the project based on the above criteria. No score is given for this criterion.

DOE Feedback

Based on reviewer comments, DOE staff provides guidance and direction to the project team.

Technology Area Overviews and Peer Review Findings by Project

Within this section, portfolio information and Peer Review results have been compiled as follows:

Technical Area Overview: For each technical area, this section contains overview information, including background, goals, and context for the projects reviewed.

Overall Scores: A scoring chart depicting the range of overall scores assigned by reviewers to each project in the technical area is also included.

Peer Review Findings by Project: This section describes and summarizes the results of the peer review process for each project. Information provided for each reviewed project includes:

- DOE Project Number, Project Title, Principal Investigator, and Project Run Time.
- Project Descriptions compiled from the peer review abstracts submitted for each project. In most cases, abstracts were edited to fit within the space allotted.
- A summary of reviewers' overall comments, as provided in response to the Overall Impressions criterion. Content in quotations signifies exact written words from a reviewer.
- A description of DOE's initial reaction to the project presentation and final day discussions with the lead peer reviewers.

Technology Area Portfolio Overview Discussions: For each technical area, this section contains a summary of the discussion on overall portfolio performance between the panel of peer reviewers and the GMLC lead for each of the six technical areas. Discussions occurred after all project reviews were completed. Content in quotations are exact words expressed by a reviewer.

Design and Planning Tools Portfolio

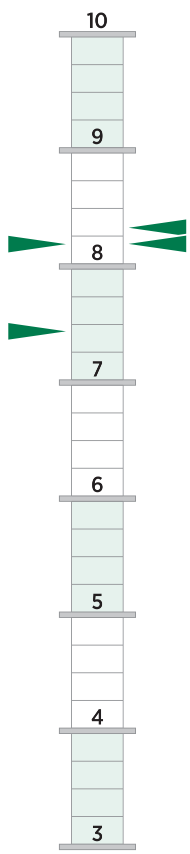
Design and Planning Tools Technical Area Overview

Today's design grid and planning tools which typically run on desktop personal computers or small servers, cannot handle uncertainty, even as they rely on simplifying the underlying physics of power systems. While more capabilities are added, these tools do not take advantage of modern and advanced computing techniques; they will ultimately be unable to keep pace with the increasing complexity of the grid.

The *Design and Planning Tools* technical area seeks to drive development of next-generation planning and design tools to more accurately perform cost-benefit trade-offs and improve grid reliability and resilience. Expected outcomes include the following:

- Develop a software framework to combine grid transmission, distribution, and communications models to understand cross-domain effects.
- Incorporate uncertainty and system dynamics into planning tools to accurately model renewables, extreme events, etc.
- Design and build computational tools, methods, and libraries that enable 1,000x improvements in performance for analysis and design.

Design and Planning Tools Overall Scores



Design and Planning Tools Peer Review Findings by Project

Development of Integrated Transmission, Distribution and Communication Models

Project Number:	1.4.15
Principal Investigator:	Henry Huang
Project Period:	April 2016–April 2019

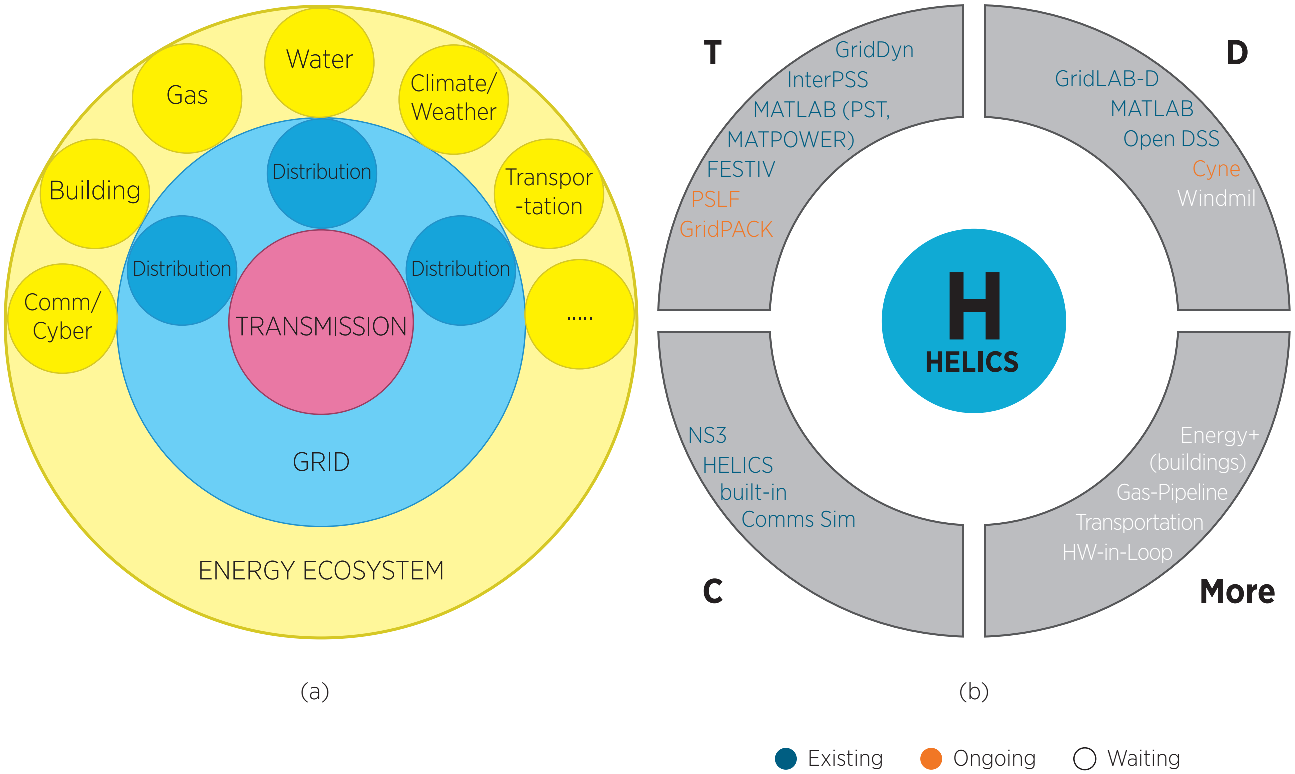


Figure 1. Co-simulation enables assessment, optimization, and control of the interdependencies of the power grid and other supporting systems.

Project Description

To meet increased demand and diversity, the U.S. power grid is evolving on a path different than traditional generation and transmission expansion. As significant amounts of variable and distributed generation, and other distributed resources are added to the U.S. electric infrastructure, the traditionally-abundant reserves in the system have eroded due to impaired system reliability. To operate the power system with a leaner reserve margin, distributed energy resources (DERs) need to participate in maintaining—or improving—system resiliency and reliability. This requires new control and protection systems, along with supporting communications networks. Historically, power systems have been designed with a centralized control systems concept. However, the power system is now relying more heavily on hierarchical and distributed control systems, with greater dependency on a variety of communications media. Further, communications system delays can introduce price spikes in distribution-level transactive energy markets, a phenomenon that requires simultaneously capturing full transmission, distribution, and communications (TDC) as well as market interactions. Industry currently lacks the modeling and simulation capabilities to understand such TDC interdependencies and is less confident in deploying systems that will meet, or improve upon, current reliability, efficiency, and cost-effective benchmarks.

This project team is developing a new, layered, high-performance, open-sourced co-simulation framework called Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS) to fill this gap. HELICS, built on the collective experience of multiple National Laboratories, offers increased scalability and advanced features for TDC modeling for grid modernization.

The approach is to integrate simulators designed for separate TDC domains to simulate regional and interconnection-scale power system behaviors at unprecedented levels of detail and speed. The target is to scale up to linking a 50,000-node transmission system with millions of distribution nodes, coupled with 100,000 communications points. This simulation should enable the turnaround time for planning studies of minutes to hours, instead of days—a speed up of up to several hundred times faster—compared to today's simulation technologies.

Past research has shown that accurately capturing communications system delays reveals multifold increases in simulated-transmission-system voltage recovery time. TDC simulation will also help with the design of power systems with wide-area and distributed controls. Finally, the simulation will enable informed decisions on the investments necessary to support data and communications needs. This capability aligns with DOE goals for power grid architecture and system analysis. It will allow for the exploration of future scenarios for a wide variety of applications such as DER integration and distributed control. A high-fidelity TDC integrated simulation capability will help with the design, of the future grid to minimize outages and outage costs; operation of the grid with a leaner reserve margin while still maintaining reliability through holistic analysis; and increased penetration of DERs by informing decision-makers with quantified impacts on system reliability and economics.

Reviewers' Overall Comments

This project aligns with the platform goals and objectives of the Grid Modernization MYPP, which calls for the Design and Planning Tools technical area to "develop the next generation of modeling and simulation tools . . . [to] handle emerging needs . . . [and] reflect future integration of transmission and distribution and communications." This project is specifically focused on this area. In addition, this project is a platform that uses existing tools—meeting the goal of allowing for "more rapid development and widespread adoption of these tools and technologies." By allowing users to use their existing tools as part of the platform, this project hastens adoption of new approaches. The tool is being utilized by thirteen other projects in the GMLC portfolio which clearly demonstrates the tool's value. Some recommendations for this project include the following:

- Develop more use cases: The use cases presented illustrated the use of HELICS. More use cases that clearly indicate the benefits of co-simulation, along with specific education of stakeholders, including regional transmission organizations (RTOs)/independent system Operators (ISOs), state regulators, state energy officials, on the benefits of a tool such as HELICS, is very necessary.
- Develop a community of users: A detailed plan on building the community of users for HELICS in the planning and operating arena would be a great next step.

DOE Feedback

DOE sees potential to expand beyond the TDC infrastructures, and plans to work with industry to ensure the lessons learned in this project are not lost moving forward.

Extreme Event Modeling

Project Number:	1.4.17
Principal Investigator:	Russell Bent
Project Period:	April 2016–April 2019

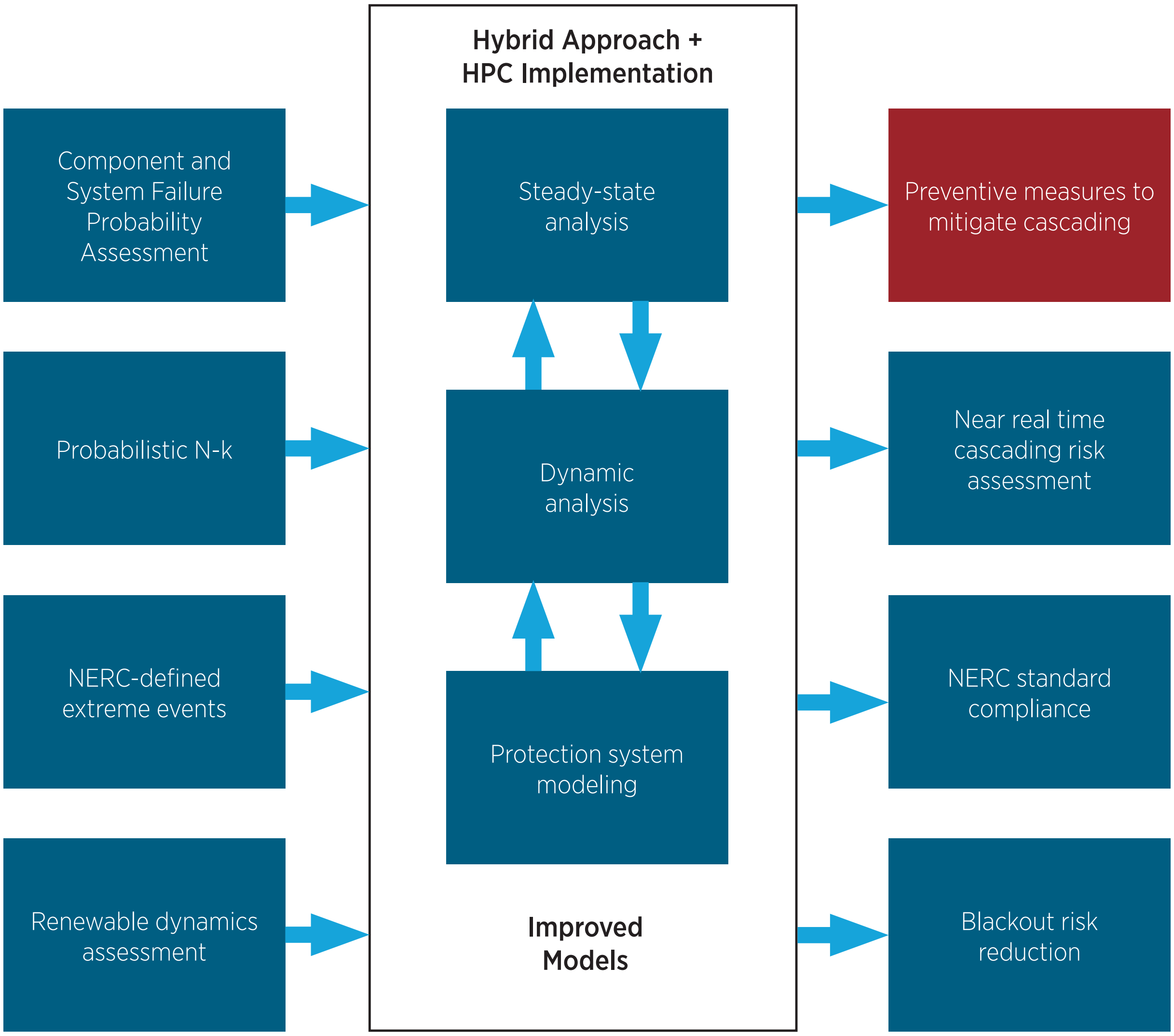


Figure 2. Extreme Event Modeling Process Flow

Project Description

Catastrophic situations (e.g., Hurricanes Katrina and Sandy and the 2003 Northeast Blackout) pose an enormous threat to the nation's electric grid, and the socioeconomic systems that depend on reliable and resilient delivery of power. Although the economic costs and social hardships are significant utilities are struggle to adequately plan and prepare for such events.

One primary bottleneck that impedes progress for such planning and preparation is the ability to model what happens to power systems during extreme events. In this project, the project team addresses two key aspects of extreme events in energy: (1) sequential component failure (cascading) and (2) near-simultaneous component failures (N-k contingencies). The team is using a novel combination of existing capabilities, high-performance computing, and new capabilities to improve the computational efficiency of models and simulations to address modeling inadequacies and incorporate probabilistic approaches to deliver significant advances in extreme event modeling.

Current tools are 10 to 100 times slower than real-time, leaving planners with insufficient time to analyze and prepare for high-consequence events. The Extreme Event Modeling project team will deliver a prototype tool that simulates multiple component failures up to 500 times faster than existing approaches. This tool includes capabilities for probabilistic N-k, and works with existing trusted commercial power software.

Reviewers' Overall Comments

This project demonstrates a good link to the goals of the Grid Modernization MYPP, as resiliency and reliability are key factors in any grid modernization effort. Modeling cascading outages and the developing new approaches for contingency analysis are critical to ensuring the resilience of the electric grid. The project assists in filling gaps around modeling cascading and N-k vulnerabilities and addresses the objectives for speed to computation and vulnerability identification. Examples of clear successes included scaling N-k from 100's to 1000's of nodes and decreasing the computation time for simulations. In addition, the team developed an impressive list of peer-reviewed articles. Recommendations include:

- **Standard practice:** Extreme event modeling should become a standard practice for any GMLC project involving resource or planning/system operations.
- **Connections with other projects in the portfolio:** There may be more potential for other GMLC projects to leverage the findings of this project.
- **Coordination:** The team should coordinate closely with the North American Electric Reliability Corporation (NERC) and the independent system operators.
- **Use cases:** The project should focus on developing use cases, business cases, and transition plans for wide use of the capability in protecting the bulk power grid.
- **Interdependencies:** The project team should consider interdependencies of infrastructure and expansion to other infrastructures.
- **Arresting cascading outages:** Investigating how to stop or mitigate cascading outages is very important.

DOE Feedback

DOE understands the importance of this project and agrees with the recommendations of the reviewers, including the need for continued coordination with NERC, the development of use cases, and stronger consideration of the importance of interdependencies across infrastructures.

Computational Science for Grid Management

Project Number:	1.4.18
Principal Investigator:	Mihai Anitescu
Project Period:	April 2016–March 2019

Project Description

The power grid continues to increase in complexity, in good part by the growing use of DERs, such as storage and solar power. Compounding this complexity are the vastly-increased dynamics that these DERs introduce, along with greater uncertainty surrounding supply and demand results when computationally modeling the integration of wind, storage, and solar power.

The Computational Science for Grid Management project addresses these challenges by developing and deploying new algorithms and solutions for grid optimization, uncertainty, and dynamics. Key to this effort is an advanced framework that allows for prototyping of computationally-intense analyses 10 times faster, and open-source solutions that compute 100 times faster by harnessing parallelism. The project team is also identifying use cases where they can demonstrate the framework and solutions at scale.

The project's algorithms and solutions will be key to supporting efforts by utilities to assess renewable variability effects in operations and planning. They will also be important in helping DOE understand the effects of renewable energy variability on grid reliability.

Reviewers' Overall Comments

Reviewers agreed that this is a foundational activity supporting modeling and analysis, which make this project relevant to the Grid Modernization MYPP goals and to the efficient and effective operation of the grid planning and operation industry. Reviewers also agreed that the high-level objectives of improving the mathematical approach behind optimization under uncertainty came across clearly. The challenge of improving the execution speed of multi-period optimization as the new focus was clearly explained and demonstrated by successfully speeding up the Security-Constrained AC OPF by a factor of 63. Reviewers were concerned whether outreach to other areas of potential application have been fully developed to date. Reviewers pointed out that some of the immediate results were not communicated effectively, and that there was no reference to the last year's results. The reviewers recommended the following:

- Identify a metric that includes both the risk of a cascading event and the impact of the event at the same time (Risk x Impact).
- Demonstrate how this project can be incorporated into other GMLC projects.
- Develop multiple applications for methods developed under this project.

DOE Feedback

DOE understands the importance of this project and its applicability to other projects. DOE continues to support this project, and encourages the project team to establish ways to work with other existing and future projects.

Development and Deployment of Multi-Scale Production Cost Models

Project Number:	1.4.26
Principal Investigator:	Jessica Lau
Project Period:	March 2016–November 2018

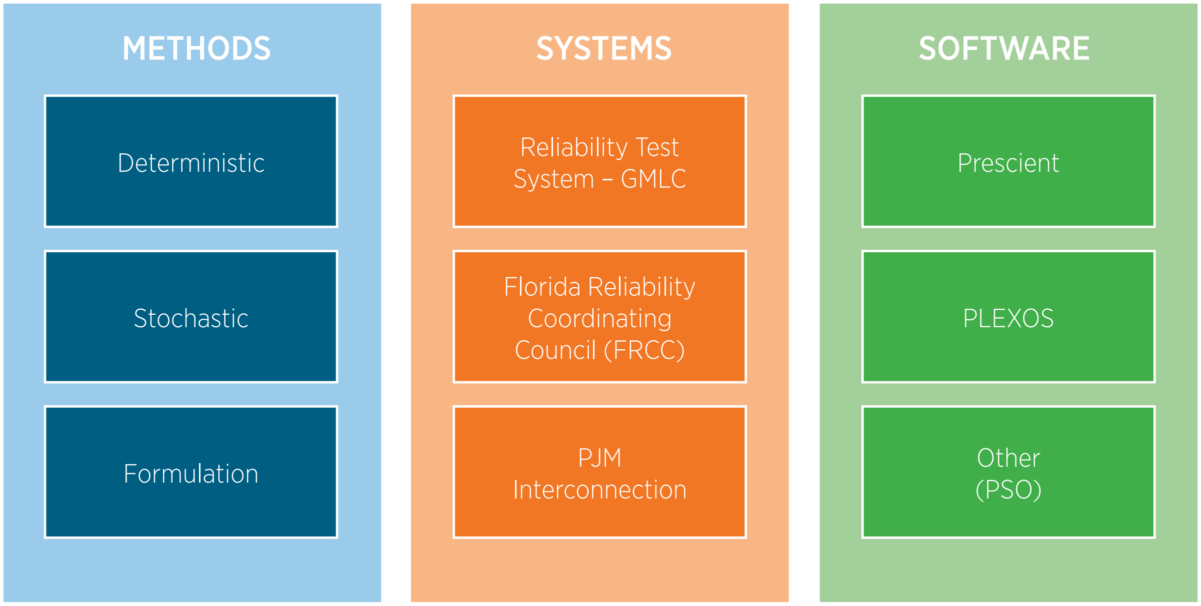


Figure 3. Advancing state-of-the-art methods, systems, and software for production cost models.

Project Description

The complexity and resolution required to model the modern power system are rapidly increasing. DER, demand response, new bulk power generation, variable energy resources, inter-sectoral dependencies, and evolving consumer preferences further contribute to the need to develop new production cost modeling (PCM) capabilities to address growing uncertainty and system complexity.

The larger magnitude of data, granularity, and scenarios force power system planners and reliability coordinators to choose between conflicting choices: model execution time or model fidelity. Model fidelity is the ability to model a system as accurately as possible. Reducing model fidelity detrimentally impacts the relevance of the simulations, but improves (reduces) execution time. On the other hand, increased execution times result in improved model fidelity but limit the number of scenarios that planners and reliability coordinators can analyze.

The Development and Deployment of Multi-Scale Production Cost Models project team has developed methods to reduce execution time required by industry to analyze future power system scenarios, while simultaneously considering higher-fidelity system representations and integrating common software platforms. The project team has significantly accelerated existing PCM simulations, which otherwise would be infeasible or impractical to study, by developing advanced computational methods and deploying tools through industry outreach. This project has resulted in numerous published peer-reviewed journal articles and release of open-source code to enable further development and deployment.

Reviewers' Overall Comments

This is an excellent project and represents how DOE should coordinate and integrate with industry. Working with ISOs and utilities—to speed up the analysis time of existing PCM models—is critical to enabling more efficient and robust analysis of economic projects. The presenter did an excellent job providing context of existing PCM tools and describing the high-level objectives: to dramatically reduce the time required to analyze high-fidelity power system scenarios through production cost modeling. The technical approach was clearly of: accelerating deterministic PCM, accelerating and evaluating stochastic PCM, and accelerating and improving optimization formulation. Specific technical approaches such as geographic and temporal decomposition, and warm-starting, were also discussed. The project areas of emphasis were described as keys to success:

- Reduced simulation time;
- Successful validation against existing tools;
- Customizable tools to analyze operation of specific markets;
- Visualization of results; and
- Collaboration with bulk grid operations.

The results of the project have already been used to implement other projects, including the Interconnection Seams Study, the North American Renewable Integration Study (NARIS), and the Wind Vision Study.

Recommendations included:

- Technology transfer: DOE should consider additional funding specifically targeted at sharing and offering training on the results of the project to encourage adoption.
- Use cases: Future work should include evaluation of specific regions and use cases using these methods.
- Stochastic modeling: More stochastic modeling should be incorporated.

DOE Feedback

DOE understands the important results of this project and how they apply to other projects, including the Interconnection Seams Study, NARIS, and others. DOE will continue incorporating the results of this work into future modeling simulations. In addition, DOE will encourage the National Laboratories to work with industry to incoporate these results into their own tools.

Design and Planning Tools Portfolio Overview Discussion

The Design and Planning Tools lead reviewer identified three main challenges in this technical area:

- **Interdependencies:** Modeling frameworks like HELICS are very important because the transmission and distribution systems can no longer be viewed in isolation.
- **Uncertainty calculations:** With greater amounts of variable renewable energy being added to the system, calculating uncertainty and using stochastic processes continue to be extremely important challenges to include in models.
- **Developing faster models:** As more technologies and infrastructure are added to the power system, the challenge of how to incorporate all of these variables in models while still have reasonable run times must be addressed.

Several projects, like *Development of Integrated Transmission, Distribution, and Communications Models* and *Extreme Modelling*, were favorably identified as extremely important projects. Cascading outages is a real concern, and how to identify and predict those events is important. All of the reviewers identified understanding interdependencies as extremely important, especially between electricity and gas. Ensuring the tools in this technical area were capable of incorporating cybersecurity challenges was also identified as being critically important. The reviewers felt that DOE needed to take a leadership role on the issue of cybersecurity.

While recognizing the potential and value of the work underway, reviewers recognized these projects were soon coming to an end. Reviewers emphasized that more attention needs to be focused on technology transfer to industry. In addition, more focus is also needed in creating use cases. DOE needs to work with the labs on developing new use cases because there is minimal value without them. There is also potential for more interaction between projects, specifically the foundational projects, in computations science.

The Design and Planning Tools Technical Lead appreciated the feedback, especially on the topic of transitioning the work to industry after the conclusion of the project. In many cases, even at the near-end of the projects, much more work is needed to communicate capabilities and to implement developed tools in the community. The Technical Lead requested help with applying and transitioning tools and technologies developed under GMI to end users. Finally, in areas of modeling the gas and electric infrastructure, there will be a lot of development efforts in the resiliency space. However, a significant amount basic research still needs to be pursued.

Devices and Integrated Systems Testing Portfolio

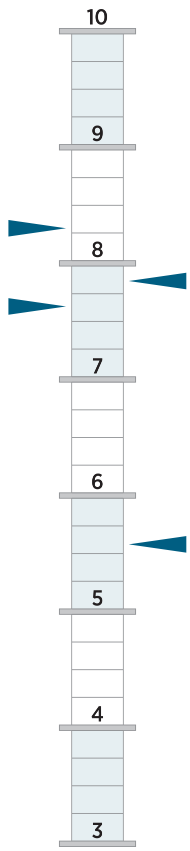
Devices and Integrated Systems Testing Technical Area Overview

Devices and systems on both sides of the electric meter can help the grid function more efficiently, manage variable generation, and be more resilient under adverse conditions.

The *Devices and Integrated System Testing* technical area advances the characterization and testing of energy technologies that could provide grid services to improve system affordability, reliability, and sustainability. Expected outcomes include:

- Develop new grid interface devices to increase the ability to provide grid services and utilization.
- Coordinate and support the development of interconnection and interoperability test procedures for the provision of grid services.
- Validate secure and reliable grid operation with high levels of variable generation at multiple scales.

Devices and Integration Systems Overall Scores



Devices and Integration Systems Peer Review Findings by Project

Interoperability

Project Number:	1.2.2
Principal Investigator:	Steve Widergren
Project Period:	March 2016–September 2019

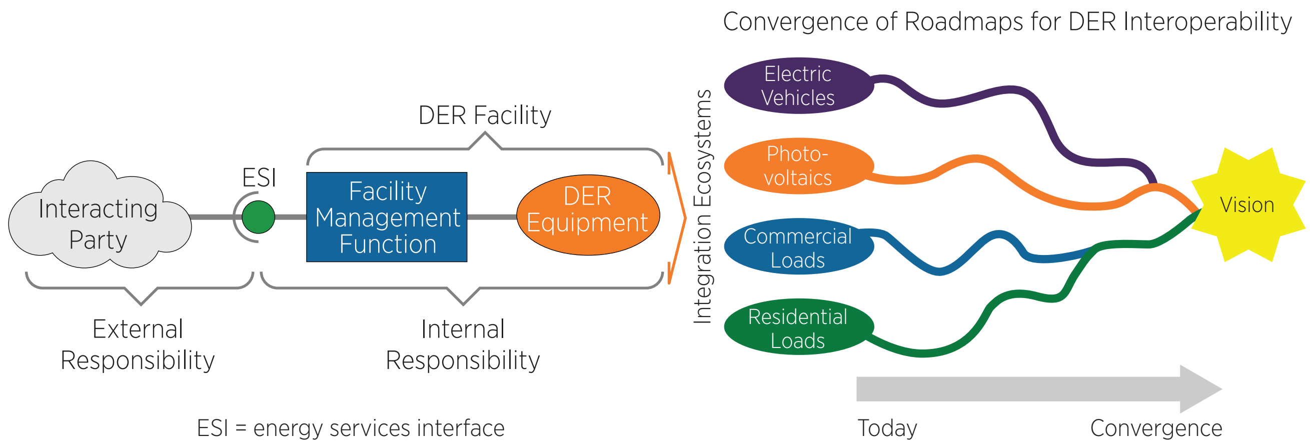


Figure 4. Performance-oriented interface agreements drive convergence of standards across technologies.

Project Description

The key to delivering greater flexibility and reliability in the face of rising smart devices and systems deployment is interoperability—the ability of different devices and systems to connect and operate easily. For efficient grid operation, the broader electricity industry must have access to general interoperability requirements, methodologies, and tools that simplify the integration and secure interaction among the many devices and systems that make up the grid.

The work coming out of the Interoperability project promotes the alignment and commitment of stakeholders within the broad electricity industry relative to the future of interoperability, including developing a strategic vision for integrating devices and systems into the nation's power grid. The project team will also develop and provide methods and tools the electricity industry needs to identify gaps in interoperability, as well as develop roadmaps to address the gaps. Participating in the development and execution of the resulting roadmaps will provide significant benefits to the electricity industry, including easier integration of renewables and associated long-term costs, reduced complexity when new devices and systems are incorporated, and clarity of the responsibilities of interacting parties—all combining to ensure the continued evolution of a reliable, secure, efficient, and flexible electric grid into the future.

The mission of this project is to establish a strategic vision of interoperability for grid modernization with implementation illustrations. The objectives are:

- Establish a strategic vision for interoperability.
- Measure the state of interoperability in technical domains.
- Identify gaps and roadmaps.
- Ensure industry engagement.

Reviewers' Overall Comments

This project is foundational to the Grid Modernization MYPP. Achieving interoperability is key to a grid operating in an inclusive, cost-effective, and reliable manner. However, how the "roadmap" and vision in this particular project will contribute to providing tangible solutions is unclear. While the principal investigators are facilitating meetings with stakeholders and presenting in conferences, the value of "roadmap ecosystem engagements," as well as the exact scope of work under these engagements, is not clear.

One potential area of successful engagement includes the interoperability procurement language, which may be valuable if well thought out with adequate stakeholders buy-in—especially the potential actual users. The "Plug-and-Play" challenge may also be a great showcase of how important interoperability is to the future. The project team has engaged with technology buyers to influence the vendor's products. Many documents, articles, and presentations have been published to gain awareness and feedback on the work taking place.

DOE Feedback

DOE is aware of the difficulty in executing some of these core, foundational projects. This is not the first Federal effort to develop a roadmap for interoperability. Receiving buy-in and convergence on a national scale around interoperability is a enormous effort, so it is not surprising that reviewers identified limitations in the project. DOE supports reviewers' views that some of the efforts, particularly around the Plug-and-Play challenge and the procurement language, were seen as successful.

Grid Modernization Laboratory Consortium (GMLC) Testing Network

Project Number:	1.2.3
Principal Investigator:	Matt Lave
Project Period:	April 2016–April 2019

Figure 5. Screenshots of www.gridmodtools.org, the online platform of gridPULSE.

Project Description

The *GMLC Testing Network and Open Library* project work helps accelerate grid modernization by (a) providing comprehensive information about testing infrastructure available at the National Laboratories and (b) creating a repository of models and testing resources, including testing protocols. These goals are critical to accelerate the development, validation, standardization, adoption, and deployment of new grid technologies. The National Laboratories have developed significant testing and modeling resources; however, these capabilities were not previously documented in a consistent manner, making it difficult for external partners—and even National Laboratory members—to leverage available resources and avoid duplication of efforts.

The project has two main components: (1) the Testing Network and (2) the Open Library, which together form gridPULSE (Public User Library for Systems Evaluation of grid-related devices). The Testing Network is a collection of test facilities from 12 different National Laboratories, including a catalog detailing the capabilities and technology areas of each laboratory facility, and an interactive capability browser on the gridPULSE website. The Open Library is a public repository for component and system models, data sets, and testing procedures focused on National Laboratory products to which anyone can contribute and browse; the library is also hosted on the gridPULSE website.

Reviewers' Overall Comments

This is a very good project with immediate internal value to the labs and DOE, with potential longer-term value to the industry. The principal investigators provided a very good description of the Testing Network and information from the gridPULSE program. This project is essentially a true foundational project for performing work in an effective, efficient, and non-duplicative fashion between the labs for various GMLC projects. The web access could be very important to entities that are looking for possible testing facilities. This is an important way for small utilities to do testing without making huge investments. Even large utilities will benefit from the time savings that can be achieved by leveraging what the labs have developed. The GMLC testing network extends well beyond the technical areas of devices and integrated systems and is a great way to bridge gaps between all GMLC initiatives. Without this work, the potential exposure of DOE labs contributions is substantially diminished.

However, it is critically important to find a sustainable path forward for this project after the GMLC funding ends for both the testing network and the open library. A lot more due diligence and industry feedback are required to accomplish this goal. The open library seems to be at a high risk of going unutilized outside the National Laboratories unless there is buy-in and commitment from the industry on the models that will reside in the open library. The open library is analogous to a pantry of ingredients (the device models) and the cooking tools (the device tools) to cook up a new grid, and that pantry has so much value to so choose from. It is an open repository of modeling tools, and it is the operating system that the applications sit upon. However, currently, the open library is just a "collection of stuff."

DOE Feedback

The gridPULSE platform has done an excellent job characterizing the facilities that exist in the National Laboratory complex in a clear and concise way. DOE concurs that more work is necessary to develop a seamless Testing Network across the National Laboratories. DOE continues to work to find ways to leverage the capabilities of the National Laboratories to work with industry. The work products from this project is an important step in that process. DOE also agrees with the reviewers that the Open Library could be extremely important in developing a coherent national strategy around modeling, but much more work is required within the laboratories and with industry to make this endeavor successful.

Standards and Test Procedures for Interconnection and Interoperability

Project Number:	1.4.01
Principal Investigator:	David Narang
Project Period:	March 2016– March 2019

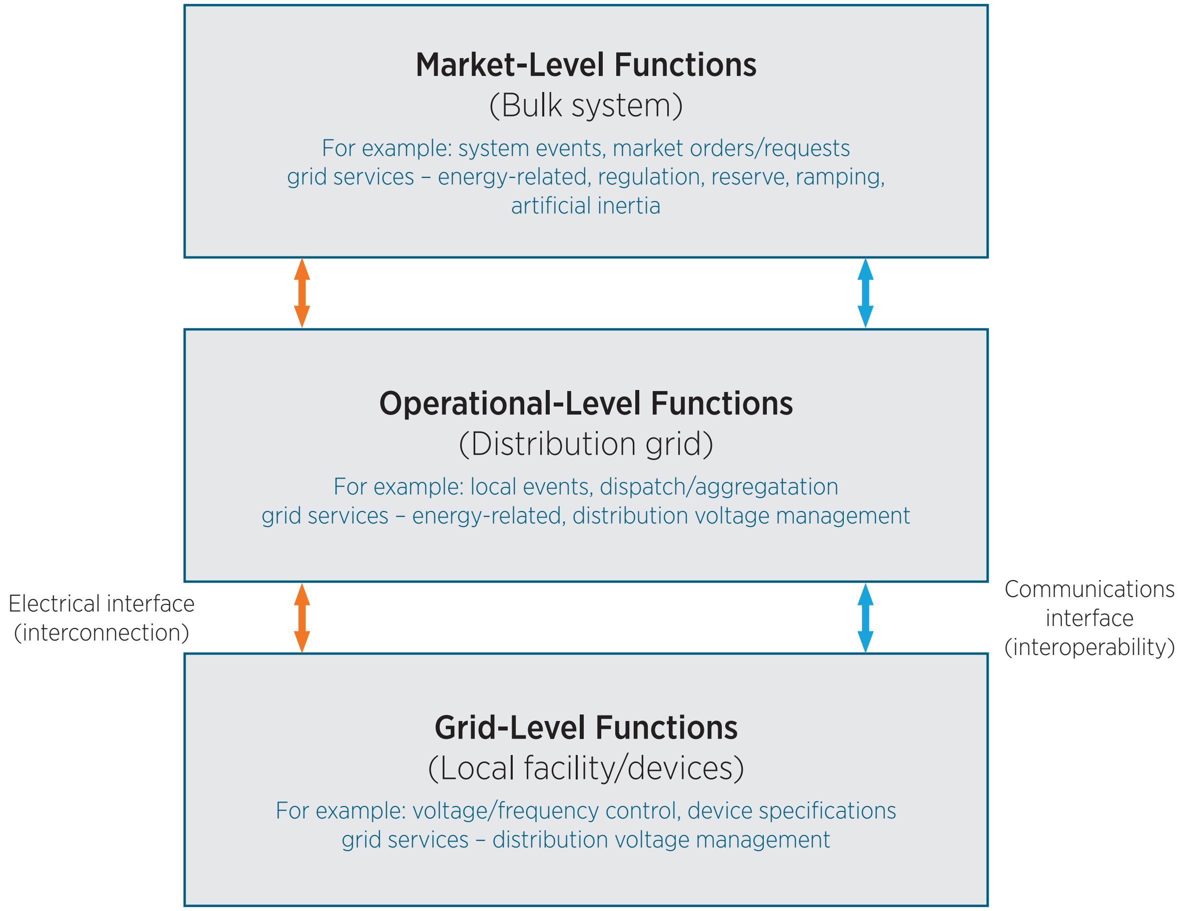


Figure 6. High-level view of coordinated grid functions.

Project Description

Next-generation smart grid technologies include distributed generation, battery storage, electric vehicles, and dispatchable loads, among others. To achieve widespread deployment of these technologies on the electric grid without compromising grid reliability, safety, or security, the devices must be able to connect and exchange data on the grid. Standards for interconnection and interoperability enable such coordination, allowing these devices to smoothly connect and communicate with the electric grid during normal operation and unexpected events. Standards however, are typically developed within a technology domain. Often, this means the standard doesn't consider end-to-end interoperability with other important devices and systems. Unless this type of harmonization is considered from the beginning, those interoperability elements may not be included in revised standards. This is even more important as we look to new grid services from DER devices that will be used by many different stakeholders in different markets to solve their own challenges.

The *Standards and Test Procedures for Interconnection and Interoperability* project team has a wide breadth of lab capabilities and team member expertise under the same project. To advocate and support the harmonization discussed above, this project's team members provide leadership and direct technical contribution to key standards development activities at multiple standards organizations. In addition, the team leverages significant laboratory capabilities to help develop testing regimes that may be used to accelerate standards development.

Outputs from this project include near-term actions to improve and validate standards for smart grid technologies, a gap analysis and method for prioritizing different technologies, and a new conformance test procedure for key grid technologies and services.

Reviewers' Overall Comments

This project is a key enabler in unlocking the various capabilities of new technologies and is necessary for safe and reliable operation of the grid with high penetration rates for new technologies. Support from the National Laboratories on studying the impacts of the new requirements on the smart grid can be very helpful by providing the independent assessments needed to ensure that standards are generally applicable and not influenced by individual vendors or other stakeholders. Dave Narang and the many other National Laboratory researchers who participated in the Institute of Electrical and Electronics Engineers (IEEE) 1547 standard efforts were very effective in the meetings and behind the scenes to study and assess the impacts of particular DER functions. The presentation lacked many of these types of details, but it was clear that many additional efforts in the development of standards and testing were also undertaken by different groups. Additional IEEE standards are needed, so hopefully the National Laboratories will continue to support these efforts. IEEE SCC21 is working on standards for storage (including controllable loads) and is planning to revise IEEE 1547.3 on data models, protocols, and cyber security. IEEE 2030.x is expected to address microgrids in more detail.

In addition to working with IEEE, involvement with the International Electrotechnical Commission (IEC) standards would lead to more comprehensive and coordinated functionality and interoperability. Increasingly, the DER and utility system vendors are providing products globally, so remaining solely focused on the IEEE is short-sighted. Currently, IEEE 1547 is leading the standards efforts for DER grid codes, so the U.S. could take the lead in supporting other similar efforts in the IEC. Since cybersecurity is definitely a global challenge, collaboration across IEEE and IEC with support from the National Laboratories could be beneficial. In the area of interoperability, the IEC has taken the lead with IEC 61850, which already addresses the data modeling of IEEE 1547 functions, and is starting to address microgrids, including intentional and unintentional islanding.

There is great value in utilizing National Laboratories resources in a crosscutting fashion, bringing expertise from one standards-making process to another. This is a very critical project that needs to focus on addressing the gaps in existing standards and continue beyond current project funding.

DOE Feedback

Interconnection and interoperability are important areas for GMI to be successful, and DOE agrees that further investment is necessary using this approach when the project is completed. DOE must ensure that the actions of our representatives in the areas of interconnection and interoperability are driving toward convergence, and this approach has supported that push.

Definitions, Standards, and Test Procedures for Grid Services from Devices

Project Number:	1.4.02
Principal Investigator:	Robert Pratt
Project Period:	April 2016–April 2019

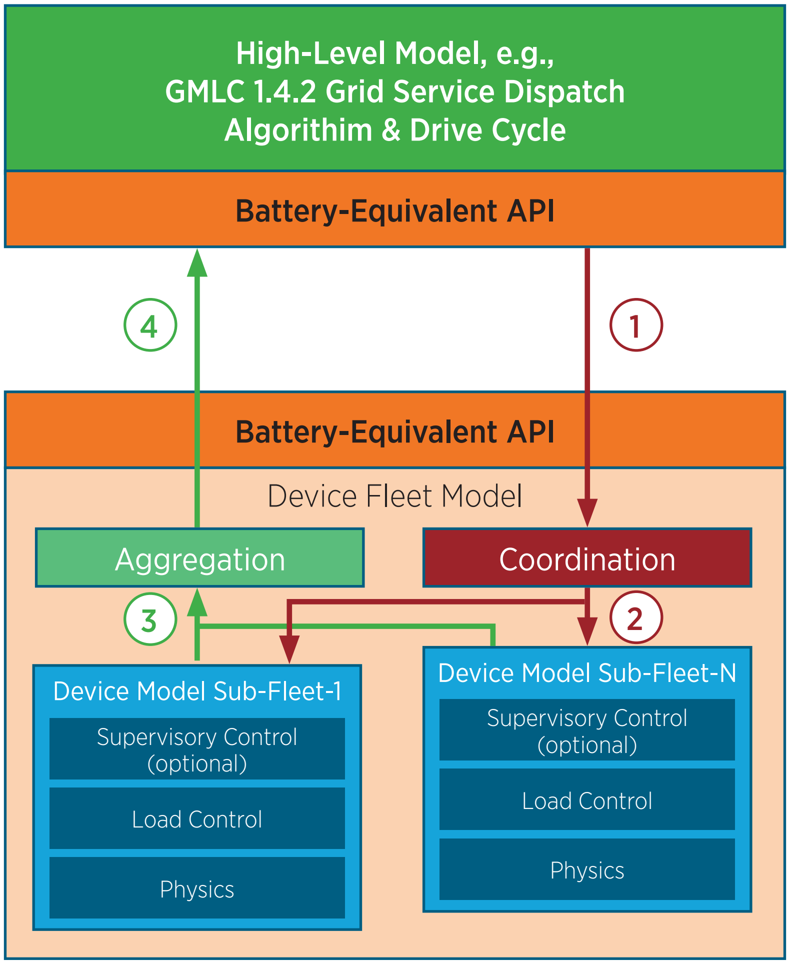


Figure 7. Software architecture of services and device models. Device fleets are composed of individual devices that are representative of diversity in population and usage.

Project Description

The goal of this project is to enable a broad range of devices—primarily DERs—to provide much of the operational flexibility required by the power grid in the form of a growing number of increasingly valuable services at the bulk system and local distribution levels. DER devices include responsive load-serving equipment and appliances in buildings, battery storage, electric vehicle chargers and their batteries, smart inverters for photovoltaic (PV) solar and batteries, and fuel cells and electrolyzers. To achieve this goal, the project focuses on developing standard methods for modeling the ability of individual devices of various classes to respond to provide services.

As its primary technical goal, the project will provide a general, standard device model, with a battery equivalent interface applicable to each device class. This will be in the form of an equivalent battery model, useful for comparing and aggregating the capabilities of devices from different classes and extrapolating their ability to perform grid services. This model is designed to be readily incorporated into grid planning and operational tools. It will be simple and generic to use, representing all device types together, with only a single, simple dispatch algorithm for each grid service, rather than a custom algorithm for each device class. Such a model of DER devices is required for the tools used to plan and design new and modernized grid infrastructure, as well as to operate transmission- and distribution-level grid management/control systems and markets, so they can properly represent the roles and functions of DERs in the future grid. The project will:

1. Define prototypical “drive cycles,” representing the time-series injection or withdrawal of real and reactive power that each of a wide variety of grid services require from device fleets, including a method for summarizing the performance of devices against those drive cycles in engineering and economic terms.
2. Develop and publish a standard set of device models describing the operational and engineering constraints (including human factors) for each of a wide variety of device classes so that fleet performance in providing grid services can be readily estimated with high fidelity.
3. Develop and publish a battery equivalent model interface for each of the device classes to provide a simple, standard, and common (across device classes) “virtual battery” interface so that high-level grid planning and operation tools can readily evaluate grid services from device fleets.

Reviewers’ Overall Comments

Modeling devices and their responses to energy services are very useful in general. At this time, utilities and aggregators are struggling to understand the impacts of high penetrations of different types of DER units, individually and in aggregate. For instance, how can DERs, which can provide grid services, affect hosting capacity of feeders? How can mandatory grid services affect reliability and sustainability of grids? How reliable can market-based grid services—which are provided by customers with different types and capabilities of DER, different levels of interest in different types of incentives (money is not always the only incentive), and different regulatory environments—be?

This project is relevant to the goals of the GMLC program and has the potential to reduce technology integration costs and risks. The direction of the project—to show the equivalent per device class—is the first step in bringing a baseline battery equivalent in integrated system and planning tools. The logical next step would be developing around the layered grid services to see what is achievable by that class, while implementing multiple services at once. During this next step, the team should also combine different mixes of the device classes together to compare new battery equivalent compositions.

However, more validation needs to be performed on the battery model for devices. A clear definition of the set of capabilities should be tested for the battery model and the original device model. In addition, guidance on usage of the battery models versus the actual device models would be helpful. Future work includes looking at how to model the interaction between multiple devices using the developed battery models. The National Laboratories should also reach out more often to standards organizations and other groups to investigate what other device models have been developed.

DOE Feedback

This project is a starting point for understanding how different kinds of devices with different operating characteristics can potentially work together (through the battery equivalent model) to provide grid services. This effort is a critical, and DOE needs to continue working diligently with industry and standards organizations in this area.

Devices and Integrated Systems Portfolio Overview Discussion

The Devices and Integrated Systems lead reviewer, called devices at the edge of the grid—such as solar, storage, electric vehicles, and load—the building blocks of the modern grid. With the right conductor, these devices could work together like instruments in an orchestra. Reviewers believed the projects in this technical area were foundational to making this vision a reality, and a lot of progress had been made since the 2017 Peer Review. However, more work is necessary to make this vision a reality.

Reviewers focused on convergence, specifically, regarding interoperability standards, interconnections standards, test procedures, and device modeling. Several projects support this effort. Progress on developing procurement language—to ask vendors to ensure devices meet interoperability standards—was outstanding. There was great progress in looking across device interconnection standards, although more effort may be necessary in reconciling IEEE and IEC standards. In addition, the effort to model devices' abilities to provide grid services when compared to a battery was also very helpful. Grid operators need to understand how devices, and groups of devices, can work together to provide flexibility on both the distribution and transmission systems, and developing models for different devices that can work together will help them understand where that flexibility can be obtained.

However, the reviewers were unclear on how a path to convergence would occur. With the multiplicity of standards, DOE needs to constantly assess how its actions ensure a drive towards convergence. There also needs to be a closer alignment between this portfolio of activities and the work in grid architecture. It is not clear how the outcomes of that project are affecting the direction of this portfolio. In addition, the work in this area needs to be closely aligned with the work in systems operations, and it was not clear to the reviewers where those connections were being made. The Open Library project could help develop the "pantry of ingredients" to develop a new grid; however, it needs more focus and organization for it to be successful.

Reviewers also thought that while the documentation outlining all the capabilities at the National Laboratories was very helpful, they questioned how the proposed GMLC testing network might be used. It was not clear from what was presented.

Again, the lead reviewer stressed the importance of going beyond the 3rd year on these projects or to build upon them through follow on projects to ensure results are useful to industry.

Institutional Support Portfolio

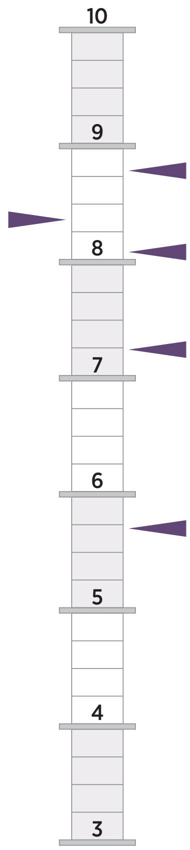
Institutional Support Technical Area Overview

State policymakers, regulatory agencies, and regional planning organizations play a critical role in shaping both the direction and pace of grid modernization, but many state regulatory agencies find it challenging to address the complex issues related to grid modernization and the deployment of distributed energy and renewable resources. Thus, the demand for objective technical assistance and information on grid modernization is high and likely to increase.

The Institutional Support technical area seeks to enable regulators and grid operators to make more informed decisions on key issues that influence the future of the electric grid and the power sector. Expected outcomes include the following:

- As states continue to adapt their regulatory models, utility interests are better aligned with grid modernization and/or enacted policies.
- Methods for valuation of DER technologies and services are defined and clearly understood by stakeholders to enable informed decisions on grid investments and operations.

Institutional Support Overall Scores



Institutional Support Peer Review Findings by Project

Foundational Metrics Analysis for GMLC Establishment

Project Number:	1.1
Principal Investigator:	Michael Kintner-Meyer
Project Period:	April 2016–March 2019

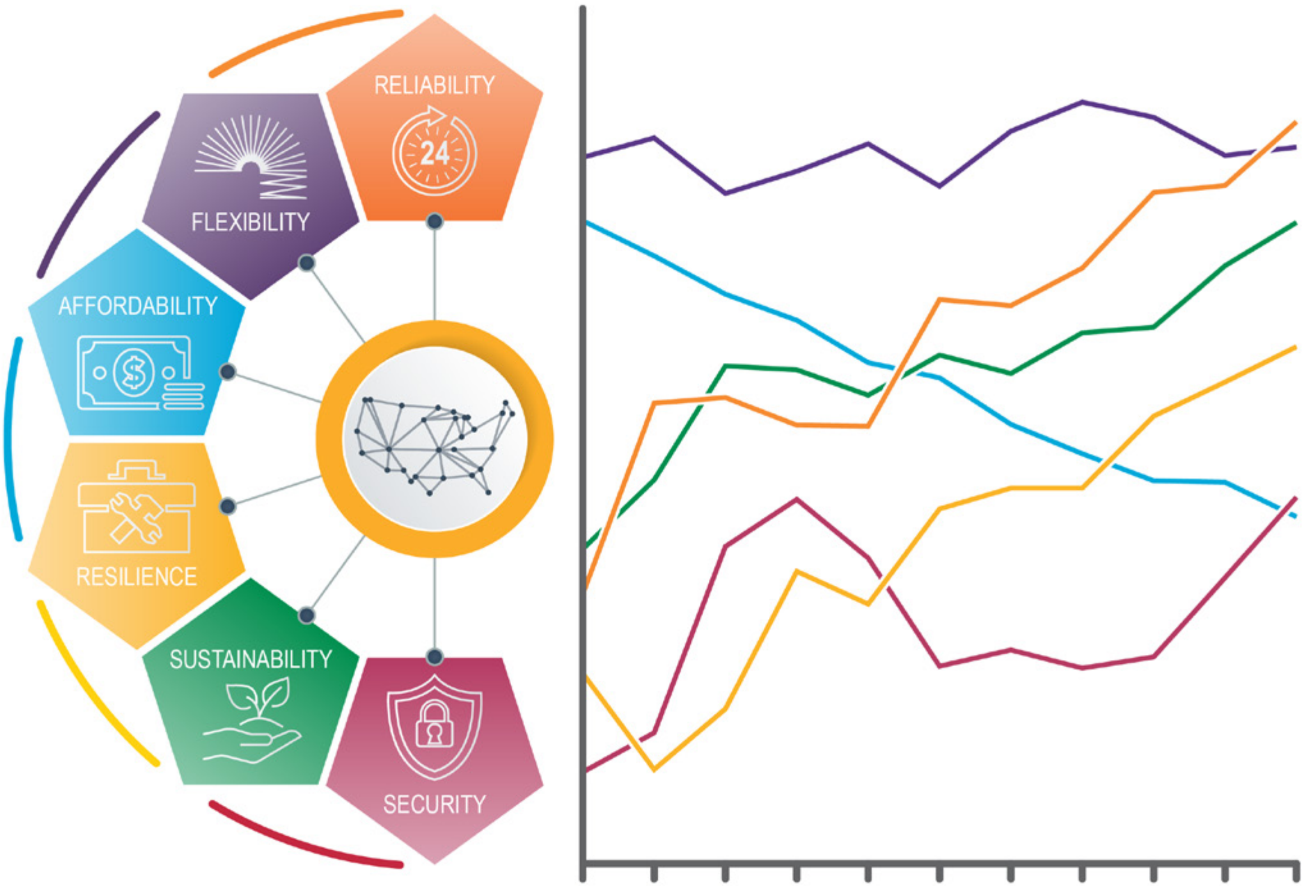


Figure 8. Six metrics are being developed in this project. This graph is illustrative only of trends and does not represent actual values.

Project Description

Growing digitalization of the grid-enabling customers' interactions with their devices—as well as the rising penetration of energy resources such as solar and wind power—are adding more challenges to the nation's power grid. As part of the GMLC, researchers across the national laboratory system and industry are partnering to modernize the grid with the goal to deliver reliable electricity to the millions of consumers across the U.S. . However, the electricity industry and its stakeholders do not have consistent means to capture the current state of the grid or measure progress of modernization efforts.

Several DOE National Laboratories and industry organizations—including NERC, Electric Power Research Institute (EPRI), and American Public Power Association (APPA)—are partnering to identify and define six major attributes of the grid, including reliability, resilience, flexibility, sustainability, affordability, and security. The following outcomes were achieved over the last several years of the project:

- Reliability: Improvements to reliability metric designs are needed to better link metrics to reliability *value* (e.g., costs to the consumer and utilities when power is interrupted). The team is assessing the types of customers that have experienced a power interruption, the duration of power interruption, and the economic costs that power interruptions impose on them. This will result in new metrics that will enable direct consideration of costs to customers that support distribution system planning and operation.
- Resilience: The project developed a set of metrics to help utilities better plan for and respond to low-probability, high-consequence disruptive events—such as a major storm—as well as provide effective means for utilities and regulators to communicate about resilience issues.
- Flexibility: Twenty-three potential flexibility metrics were identified that can be used in planning models to estimate flexibility requirements; these include loss of load, price spikes, volatility of wind and solar generation, and available energy storage. The team also developed a process to identify the top two or three key metrics from this list.
- Sustainability: The team compared differences among eight federal electric sector greenhouse gas data products and evaluated how greenhouse gas metrics and reporting procedures may need to be modified to assess changes in environmental sustainability as the grid evolves. They noted that none of these data products can fully allocate the electric sector portion of carbon dioxide emissions from several growing energy sources, such as biopower energy, energy storage, and combined heat and power. The team is developing recommendations with the data product owners to improve the ability to capture carbon dioxide emissions from the electric sector in the future.
- Affordability: The team focused on cost burden to the residential customer and the proportion of electricity costs to a household's income, and they defined six metrics that can be applied to the residential sector: (1) household electricity burden, (2) household electricity affordability gap, (3) household electricity affordability gap index, (4) household electricity affordability headcount index, (5) annual average customer cost, and (6) average customer cost index.
- Security: During this first year, the project focused on physical security. The team's proposed metrics process involves a survey instrument designed for utilities interested in understanding their physical posture. The utilities may then use the outcomes of the surveys to assess and identify insufficiencies and how investments can improve their security posture.

Reviewers' Overall Comments

This project is foundational to the GMI effort. Formulating widely-accepted metrics is a difficult process but must be done. Providing stakeholders with a common mechanism to evaluate costs and benefits of investments helps form an integrated and advanced grid of the future. Some states are trying to evaluate their own grid modernization needs, but the challenge is that individual states develop different approaches and methodologies. This type of comprehensive and nationally applicable work— spearheaded by DOE and the National Laboratories— is appropriate and useful.

This project is relevant and foundational to GMI. It contributes to platform goals by establishing clear and consistent metrics that, when adopted, can provide a uniform methodology for evaluating investments in grid modernization. Adopting these metrics can also provide key progress benchmarks while the process of investing and deploying new modern grid technologies occurs.

The other key objective of this project is to provide a methodology for establishing a baseline for the current electric grid. While the task seems simple, establishing metrics across the objective areas is difficult, and stakeholders can end up spending a great deal of time litigating issues—such as how to measure resilience or sustainability. This effort, at a high level, should be a key part of DOE's work. Key progress accomplishments include the project team working with APPA to incorporate the Interruption Cost Estimate (ICE) Calculator into eReliability Tracker, collaborating with the NERC Performance Analysis Subcommittee (responsible for preparing Annual State of Reliability report), and working on demonstrating probabilistic transmission planning metrics with Electric Reliability Council of Texas (ERCOT). These are positive indications of progress and indicators of the development of partnerships to assist with adoption and implementation when the project reaches that phase. The progress in integrating the sustainability metric into Energy Information Administration (EIA) data tracking systems to incorporate more robust tracking of electric sector emissions of carbon dioxide and beginning work on assessing water scarcity as part of the sustainability metric are also all positive benchmarks. However, there is clearly more success in certain metrics areas (e.g., reliability) than others. Recommendations from reviewers include the following:

Stakeholder Involvement:

- The project team needs to consider stakeholder input from consumer advocates.
- The stakeholders participating in the development of the project could play a critical role in the implementation and adoption of these metrics as the project moves from the development to implementation stages.
- While industry was clearly involved in the development of metrics, more emphasis in the future should be placed working with state officials and other regulators to get their perspectives.

Use Cases:

The applied test case working with New Orleans, Louisiana, is a key opportunity to demonstrate how the use of the resiliency metric would be applicable in other jurisdictions. Identifying additional test cases would be very useful and helpful in overcoming challenges around stakeholders adopting and implementing these metrics.

Reliability:

Determine if the existing reliability metrics themselves [i.e., System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Index (MAIFI), Customer Average Interruption Duration Index (CAIDI), etc.] are adequate for the grid of the future. Consider looking at how other sectors, like the defense sector, evaluate reliability.

Broad Adoption:

- It will be a challenge to identify and produce metrics that are replicable across the industry without significant technical assistance.
- More effort and activity need to take place to communicate the results of this work in this project beyond the existing partners.
- Defining metrics in ways that will result in buy-in from both industry and regulators will continue to be a challenge. The project could use state agency engagement to support meeting this challenge.

DOE Feedback

DOE understands the importance of measuring the six attributes of the power system. The ability to measure the performance of power systems as they exist today and determine the value of investments (whether through research and development or regulatory processes) is vital to the industry as a whole. However, creating this evaluation is a difficult process. Developing a comprehensive set of metrics for each of the grid attributes is complicated; however, gaining national adoption, as well as agreement across the industry stakeholders (regulators, industry, utilities, and consumer advocates), is an equally onerous challenge. DOE will continue to work with all stakeholders to ensure these efforts continue to be understood and adopted across the country.

Grid Services and Technologies Valuation Framework Development

Project Number:	1.2.4
Principal Investigator:	Amy Wolfe
Project Period:	April 2016– March 2019

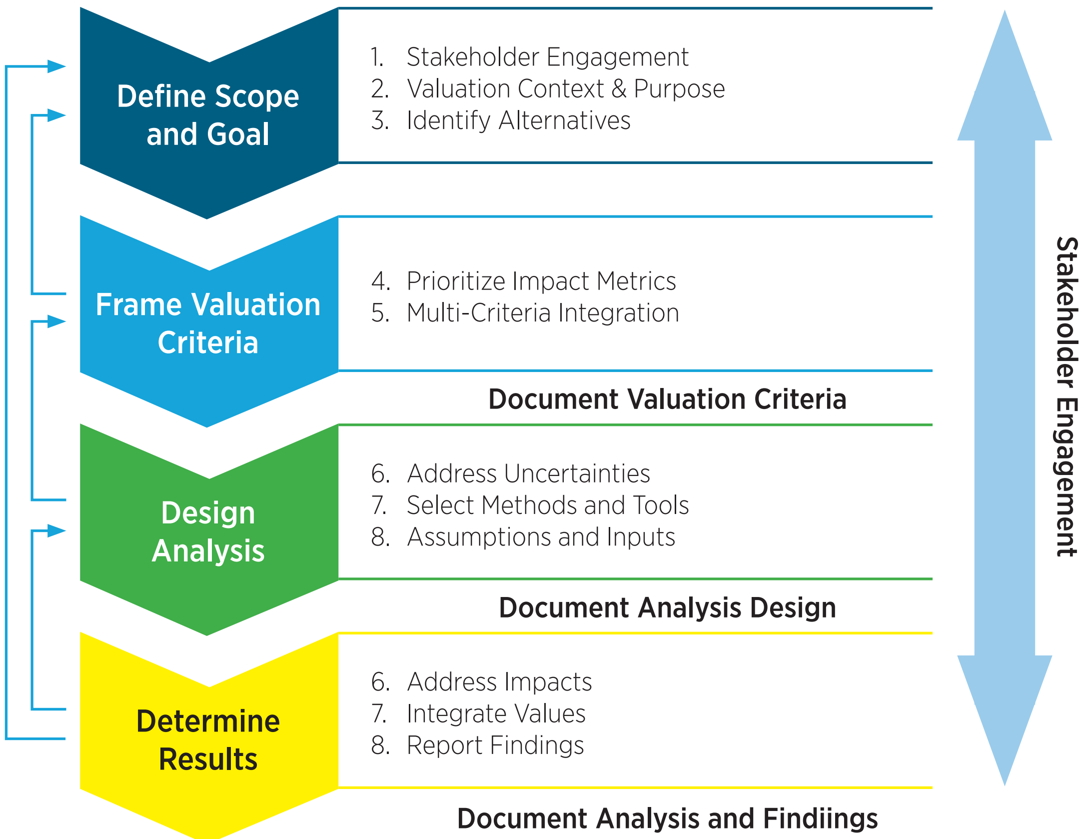


Figure 9. *Grid Services and Technologies Valuation Framework Development* process.

Project Description

The diverse community of electricity stakeholders applies a variety of methodologies to assess the values for decision making. Decisions range from investments in generation, transmission, or distribution assets, to compensation mechanisms for distributed technologies, to a multitude of other policies. The assessment results often vary widely for the same or similar types of projects. The differences in assessment results can be attributed to different assumptions with respect to economic and engineering inputs, time, geographic, and power system scales; the closed-source inner workings of models and analysis methodologies; and stakeholder choices of the key metrics or grid attributes included in the valuation results. Therefore, there is a need for creating clear, transparent, and repeatable methodologies and practices to generate easier-to-interpret and easier-to-compare studies.

The Grid Services and Technologies Valuation project aims to take the first steps toward improving the transparency, consistency, and repeatability of these valuation studies. A long-term vision of this project is to establish "Generally Accepted Valuation Principles" akin in spirit to those more rigorously developed for the field of accounting. At the end of three years, the project will have produced a set of guidelines for valuation vetted through interactions with the project's stakeholder advisory group and external reviewers. The guidelines will consist of a step-by-step process—from determining the study scope, to assembling information, to supporting decision making with associated deliverables, checklists, and other aids.

Reviewers' Overall Comments

This project is foundational to the GMI effort. Similar to the metrics project, creating a consistent, transparent, and repeatable valuation process is essential for evaluating investments. This project advances a consistent, recognized valuation approach, similar to Generally Accepted Accounting Principles (GAAP). The challenge through this project and process will be to advance valuation as a discipline. The overarching objective of this project is to develop a consistent methodology that would allow all stakeholders to develop valuation studies, as well as provide a consistent framework for evaluating other valuation studies. The key deliverable from this project will be a guide to the decision-making process, including the definition and the consistent application of key terms and a standardized procedure for conducting valuation studies, which will enhance transparency for all stakeholders. The objectives are clear and align with GMI's objectives. The project links directly with GMI's goal to integrate new technologies, including DER, into grid modernization planning, operations, and optimization. It utilizes the National Association of Regulatory Utility Commissioners (NARUC) to assist in its regulator outreach and act as a conduit to its stakeholder advisory group (SAG), which includes two consumer advocate organizations. The project team wants to remove DOE involvement and give practitioners and participants a document they can own, and it is looking for champions outside DOE, ideally regulators.

The presentation provided a great deal of information on progress, steps taken, and benchmarks. Unfortunately, the draft paper, which was distributed to reviewers, was disappointing. It lacked process or substantive support for a state agency engaging in valuation. It was repetitive, hard to follow, and far too focused on stakeholder engagement. It was thin on advice about how to proceed through thorny valuation issues. The paper focused on technology-based solutions rather than the harder services-based or portfolio approaches. In addition, the audience for the paper is unclear: the intended audience sometimes appeared to be utilities and sometimes appeared to be state agencies. In addition, the analogy to GAAP standards seems challenging. The GAAP standards have a huge number of accountants to keep them up and rely upon them from an institutional perspective. The project leaders have not yet identified a similar group of professionals who could keep a complex set of valuation processes standards up to date. Further, process standards are much more fluid than accounting standards.

There is a huge need for this work—clear, easy-to-follow methodologies and explanations of the types of studies, anticipated pitfalls and how to avoid them, and recommendations on how to move through a process—which would be incredibly useful to the industry and to regulators. Unfortunately, this effort has a great deal of work left to do before that work product is ready for prime time. The reviewers want the team to focus more on adoption and targeting audiences.

After two years, the project has yet to find a "champion;" i.e., a regulatory utility commission, utility, or other interested stakeholder to utilize the framework. It is unclear how regulators and other stakeholders might utilize the lengthy process as set forth in the draft report. It will be necessary to provide succinct, clear, executive summaries of process elements to potential "champions" going forward.

Finally, it is unclear who the audience is and how utilizing the framework might benefit that audience.

DOE Feedback

DOE believes developing a valuation framework is an important endeavor; however, results of this effort must be more accessible to stakeholders and should clearly identify the audience for this work. The challenges presented by the reviewers are well taken and will be addressed in this project and in future work on this complicated topic.

Distribution System Decision Support Tools

Project Number:	1.4.25
Principal Investigator:	Michael Ingram
Project Period:	April 2016–March 2019

Project Description

The D*istribution System Decision Support Tools* project work identifies strategies and provides technical assistance to states and utilities on enhanced electric distribution system planning methods and tools, with a focus on incorporating grid modernization technologies and systems, as well as DERs.

The project team provides educational materials and technical assistance for state public utility commissions (PUCs) and utilities, as well as training for PUCs and state energy offices. The team also identifies and applies new tools and methods to address significant gaps in existing and emerging electric distribution planning approaches.

Figure 10. Barry Mather presents at training to Mid-Atlantic States region commissioners and regulatory staff | Photo source: Aminta Daves on behalf of DC Public Service Commission

Accomplishments to date include:

- Publishing a report on distribution system planning tools and analysis, including maturity and gaps, for addressing high levels of DERs;
- Publishing a report on state engagement in distribution system planning, documenting approaches in 16 states;
- Providing training for 33 states on distribution systems and planning, as well as emerging issues; and
- Supporting several states to incorporate new national interconnection standards and deployment of grid modernization.

Reviewers' Overall Comments

This is a great project for initiating the Grid Modernization MYPP roadmap activities to the states, as well as for encouraging relationships between individual states and the National Laboratories by engaging in regional trainings. In doing so, the project permits the National Laboratories to better understand the needs of the states—assisting the National Laboratories in better developing methods and resources around grid modernization. From a technology and regulatory/business point of view, it is relevant and needed to equip state regulators and utilities with tools to plan for distribution systems and technologies of the future that are substantially more complex than today's distribution systems. The project team hosted regional workshops in the Northeast, Midwest, and West to discuss distribution planning and tools, reaching 33 states through a variety of stakeholder groups, including the APPA, a trade association representing the interests of 2,000 Municipal-Owned Utilities (MOUs); the National Rural Electric Cooperative Association (NRECA), a trade association representing 900 cooperatives; NARUC; and the National Association of State Energy Officials (NASEO). The satisfaction survey sent to participants received a highly favorable response: 100% would recommend the training to their colleagues. Also, the National Laboratories provided a thoughtful approach in including the cooperative and MOU trade associations, rather than the Investor-Owned Utility (IOU) community, to give regulators greater comfort in discussing distribution issues and decisions outside removed from those entities they regulate. And, at least seven states received technical assistance from this project. Some more specific points of the comments include the following:

- The workshops are a huge accomplishment, as they take an enormous amount of work and effort to pull off coherently and successfully.
- The report that includes the summary of state activities can be very valuable in helping states and stakeholders figure out where to look for additional information regarding various issues.
- The impact that the combination of reports, technical assistance, and outreach is enormous. There are commissions that had no idea about the work the National Laboratories were doing and are now deeply engaged because of this project.
- The technical support for states applying new standards is vital because it provides models for how to address issues like the IEEE 1547 standard. Those models are then reviewed, adjusted as appropriate, and applied in other states.

DOE Feedback

DOE hopes to integrate this work and similar DOE efforts [e.g. Next Generation Distribution System Platform (DSPx)] to develop a more holistic technical assistance program.

Future Electric Utility Regulation

Project Number:	1.4.29
Principal Investigator:	Peter Cappers
Project Period:	April 2016–December 2018

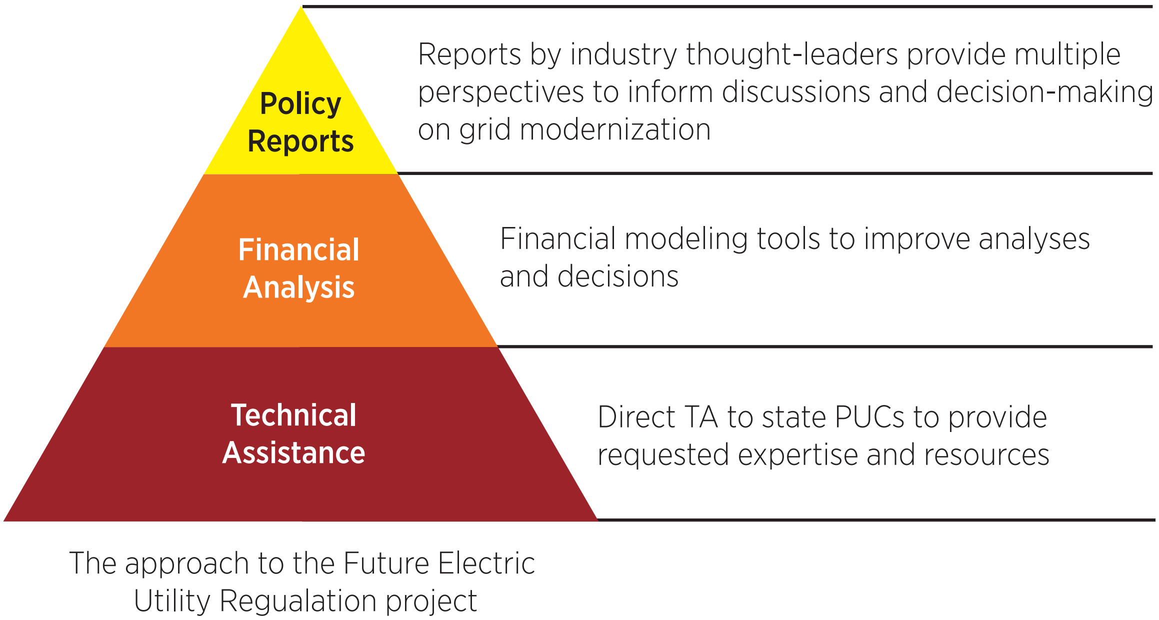


Figure 11. The approach to the *Future Electric Utility Regulation* project.

Project Description

The *Future Electric Utility Regulation* (FEUR) project work assists states in addressing regulatory, ratemaking, financial, business model, and market issues related to grid modernization in the power sector. These issues include adapting electric utility regulation and ratemaking to new technologies and services, assessing potential financial impacts on utility shareholders and customers, and investing in infrastructure that enables customer engagement and provides incentives to utilities to achieve their own grid modernization goals.

The goal of this project is to improve states' abilities to consider alternative regulatory and ratemaking approaches to invest in grid modernization. In addition, the project's work will better tie utility earnings to consumer value, economic efficiency, and other public policy goals. Anticipated outcomes include improved financial analysis tools, direct technical assistance in the forms of tools and reports, and webinars by industry thought-leaders who will provide diverse views on issues facing the power sector.

Reviewers Overall Comments

The project team established several avenues for meeting goals, including producing policy reports that have been widely applied by many industry creating financial models to improve decisions and providing direct technical assistance to specific states. The FEUR papers are some of the most well-respected work products in the industry. They are smart and useful to regulators. The technical assistance is vital to help determine what sorts of research needs to be undertaken at the National Laboratories, but also to ensure that the research works in real life. Reports out of the technical assistance projects—even reports that are anonymized or cleared with the state before publication—can be extremely helpful. The approach of providing a wide variety of resources—from direct technical assistance, to papers—is vital to the success of the laboratory research programs because it ensures that the work gets out into the real world. Key areas the reviewers want to address include:

- *Awareness*: It is unclear if there is national awareness that DOE is providing technical assistance. It would seem beneficial to let other parties know of this federal government assistance on complex electric regulatory proceedings and issues.
- *National applicability of technical assistance*: Reports on the types, findings, and potential transferability of the technical assistance given in these states has not been shared in a report or by any other means. It would be helpful to understand more about the nature of the assistance.
- *Coordination*: Improved integration and collaboration with other GMI projects in the Institutional Support sector of GMI, as well as with other DOE projects, such as DSPx, would be beneficial.

DOE Feedback

The combination of widely available reports combined with targeted technical assistance serves a critical need for variety of stakeholders in the power system industry. It is critical that the team captures the lessons learned from the technical assistance they provided.

Laboratory Value Analysis Team

Project Number:	1.5.07
Principal Investigator:	Michael Kintner-Meyer
Project Period:	October 2017–September 2020

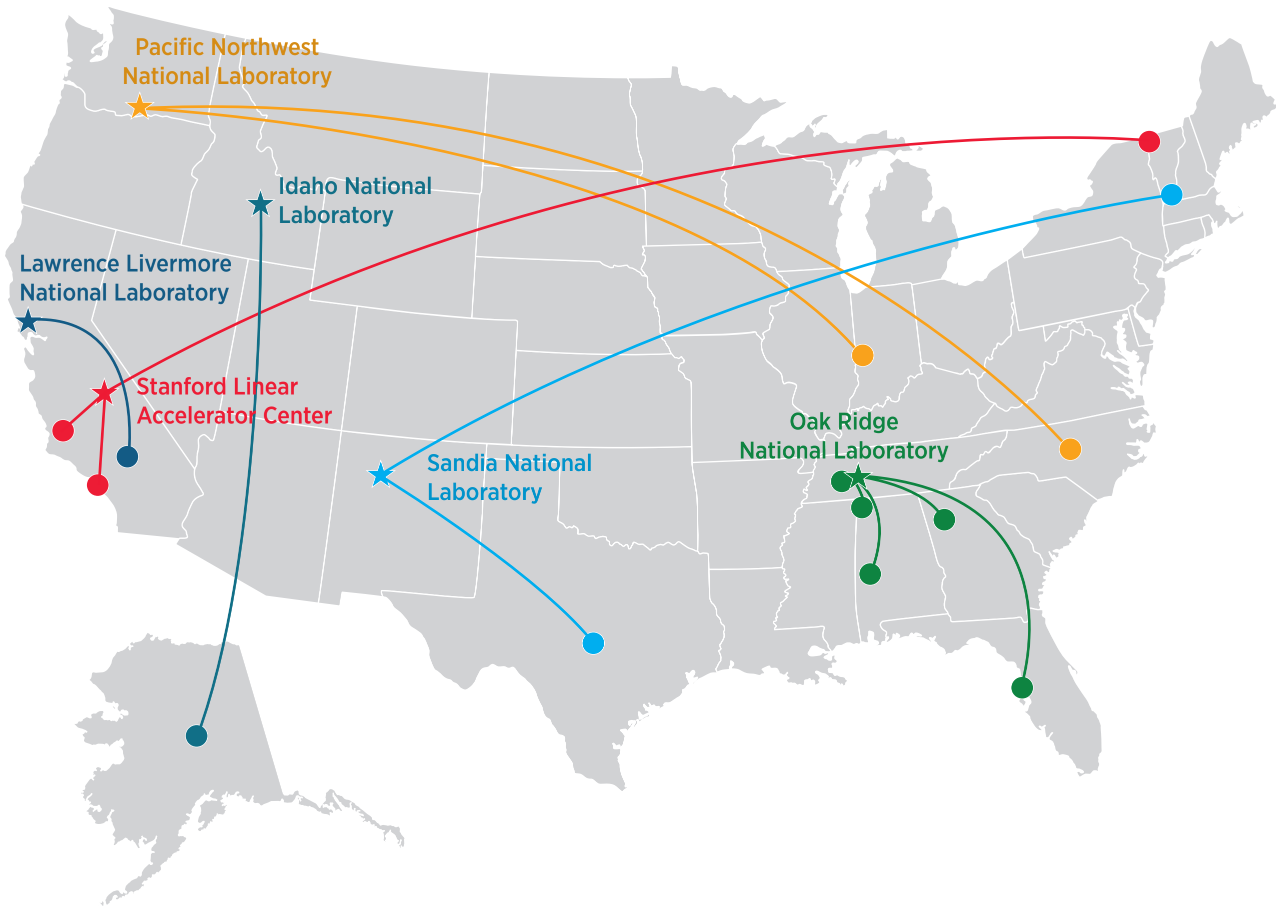


Figure 12. The *Laboratory Value Analysis Team* project will utilize data points from several sites across the U.S.

Project Description

The Laboratory Value Analysis Team (LVAT) consists of five National Laboratories and is tasked with working with DOE program managers and the six field-validation project (FVP) teams that have been selected by DOE in response to the GMLC Resilient Distribution Systems Lab Call. A key objective of the project is to ensure maximum consistency in the assessment and valuation of the impacts of the six FVP projects using GMI's comprehensive set of metrics and valuation framework. In conducting the valuation effort, the LVAT will consider and account for the region-specific context of projects (e.g., organized ISO markets, vertically integrated utilities, relative role of public power and rural cooperatives), including electricity market structure and design, as well as the threats (e.g., hurricanes, earthquakes, cyber events) that utilities must consider in their resilience and reliability planning.

The LVAT project consists of three major interrelated work elements:

1. Provide technical support to the six FVPs: The LVAT team will engage with each FVP team and their respective DOE program managers during the negotiation of each project's final Statement of Work, as well as in the initial execution phases of each project.
2. Perform value analysis for all FVPs: The LVAT will interface with the FVP teams to obtain system performance data for a set of specific use cases as input for the value analysis. The team will analyze the costs and benefits of the technologies deployed and field tested for specified use cases performed. A goal of this project is to attempt to estimate as many value streams as possible, which may include values other than the improvement of resilience against certain threats. The team will address values from the utilities' and the customers' perspectives.
3. Report valuation results of each of the six FVPs and communicate lessons learned to stakeholders: This project will summarize the results and lessons learned of each FVP based on the field validation activities that were performed. As part of outreach and education efforts, the team will also facilitate information sharing of the lessons learned to laboratory technology researchers, industry partners, and utility or industry policymakers. The synthesis will also assist DOE in communicating results of this GMLC investment to Congress, policymakers, and DOE offices.

Reviewers' Overall Comments

This seems to be a good investment of resources to determine actual results based on field-tested technologies. The project is line with the objectives of the Grid Modernization MYPP. It is an approach to help determine valuation of untested and unique resilience measures prior to their introduction by a utility in a rate case before a regulatory commission.

This is an important and relevant effort. Figuring out how to assign a value to the resilience benefit from each of the RDS projects is very important. There is a good start on a plan to achieve that, but it is probably lacking the level of clarity it needs at this stage of the project.

It will be very interesting to see as the project develops, to what extent the results could it be used in an Integrated Resource Planning (IRP) process. As mentioned with other projects in the Institutional Support sector, continued and increased engagement and communications to raise awareness about the overall project would be helpful to many of the stakeholders within the government sector. DOE should increase the level of engagement and communication with organizations, such as NARUC, NASUCA, and NASEO, as well as regional organizations, to get feedback and to encourage more widespread implementation and uptake of available resources.

Having state and/or municipal decision makers involved in understanding the costs and benefits of a project is very important to making judgment calls. In this case, if time permitted, the approach should have more engagement by additional, non-technical parties that can help provide advice regarding what the inputs of the cost-benefit analysis should be and what the work product needs to include.

One significant challenge is that it seems as though the goal of having replicable and applicable metrics for resilience is still far off, especially considering the challenges of defining the societal benefits associated with outage avoidance. A further challenge is sorting out the likelihood of a high-impact, low-probability event, which could lead to the need for some of these sorts of technologies. The reviewers did not hear anything about how the project is considering that element (e.g., how to prioritize between various sorts of low probability events like flooding versus cyber versus physical attack, etc.).

Further explanation regarding outward-facing work product and how they intend to address the threat scenario and long-term outage challenges raised in the presentation would have been beneficial. Under the umbrella of resilience projects, this one is vital going forward. It will be interesting to see how the output is explained to the greater world, which will be a significant challenge given the diversity of sites and technologies included. All in all, this is a really exciting project, and we look forward to the output in a couple of years.

DOE Feedback

It is clear that this effort is important, yet will be difficult to execute. It will be important to make the results consistent across diverse projects and to be able to articulate the results outside of the laboratory community. It may also be valuable to include regulatory engagement.

Institutional Support Portfolio Overview Discussion

The lead reviewer for Institutional Support, thought the projects were foundational to what states are doing and consistent with the pace of grid modernization at the national level. The projects are filling a void that is needed. The reviewers viewed the three main areas of Institutional Support to be the following:

- General technical support;
- Specific technical support for next-generation utility regulation; and
- Development of tools that are useful for evaluating emerging technologies, as well as valuing attributes and metrics related to grid.

It was noted that most of the projects reviewed are in their final year, so ensuring the project work is implementable and transferable is critical. The test use-cases for metrics provided very useful feedback for jurisdictions.

The technical manuals for utility commission are extremely useful, and they are being used for deeper dives into areas where utility commissions don't necessarily have that level of expertise. Tools to support distribution planning are also filling important gaps.

Moving forward, the engagement of stakeholders is very important, including consumer advocates, utilities, vendors, etc. Many organizations are ready to partner to implement the GMLC work. Reviewers recommended that DOE and partners continue to identify how to operationalize the work in these projects. DOE and the National Laboratories need to clearly identify the next steps to disseminate this work to practitioners who really need this work. Communications that leverage regional organizations on those projects are also critically important.

The lead reviewer also noted that the GMLC project teams are finding answers to tough questions that decision makers and regulators are facing. She emphasized the need to think about how to share those findings with stakeholders.

The Institutional Support Technical Lead, acknowledged that this area is different from the other technical areas. Unlike projects in the other five technical areas, all of the work Institutional Support is addresses near-term challenges. As a result, there must be a balance between supporting activities that meet near-term needs of practitioners, regulators, and utilities (near term meaning a few months) while still supporting more foundational solutions (tools, grid metrics) for them to consider as options to help with future decision making.Finally, there is always a challenge of scaling up regional solutions to a national scale.

Security and Resilience

Security and Resilience Technical Area Overview

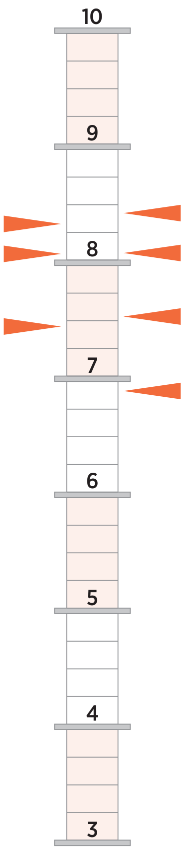
Extreme weather events, physical attacks, and cyber-attacks on the nation's electrical grid have necessitated actions to secure the grid.

The Security and Resilience technical area seeks to provide a pathway to comprehensive multi-scale security and resilience for the nation's power grid. Expected outcomes include:

- Develop a holistic approach to grid security and resilience—from devices, to micro-grids, to energy systems.
- Design inherent security into components and systems, not security as an afterthought.
- Address security and resilience throughout system life cycle and cover the spectrum of legacy and emerging technologies.

The *Resilient Distribution System* projects will develop and validate innovative next–generation tools, technologies, and approaches to enhance the resilience of the nation's electric grid with high levels of clean, DERs and emerging grid technologies at a regional scale. The project results are expected to deliver credible information on the technical and economic viability of a range of technologies, as well as demonstrate new solutions to key stakeholders who are ultimately responsible for investing in grid modernization activities.

Security and Resilience Overall Scores



Security and Resilience Peer Review Findings by Project

Grid Resilience and Intelligence Platform (GRIP)

Project Number:	1.5.01
Principal Investigator:	Ashley Pilipiszyn
Project Period:	September 2017–September 2020

Figure 13. *GRIP* V1 UI/UX design for anticipation analytics for pole vulnerability in Southern California.

Project Description

Increasing extreme weather events poses an enormous threat to the nation's electric power systems; consequently, extreme weather events can cause major ruin to socioeconomic systems that depend on the reliable delivery of electric power. While utilities have software tools available to help plan their daily and future operations, these tools do not include capabilities to help them plan for, and efficiently recover from, extreme events. For the *Grid Resilience and Intelligence Platform* (GRIP) project, the team is developing and deploying a suite of software tools to anticipate, absorb, and recover from extreme events. The project team will use applications of artificial intelligence, machine learning, predictive analytics, and image recognition to increase "learning" and "problem solving" capabilities for anticipating grid events, which will increase resilience on a distribution grid.

Major efforts of this project include the following:

- Anticipation analytics will be tested and validated with Southern California Edison (e.g., pole vulnerability).
- Absorption algorithms will be tested in Vermont with 150+ controllable loads that demonstrate virtual islanding capability (e.g., power balancing water heaters).
- Extremum seeking controls that support recovery by following an objective function, such as voltage stabilization, broadcasted at the feeder will be tested with one of NRECA's members' utility.

Reviewers' Overall Comments

The *GRIP* project provides field validation that directly supports the GMLC objectives of delivery of resilient grid, seamlessly integrated resources, and U.S. prosperity, competitiveness, and innovation in a global energy economy. This project is building off of other National Laboratory projects and work products (e.g., VADER, GridLab-D). Moreover, technologies developed by partners (e.g., X, Packetized Energy) shows breadth that goes beyond GMLC projects.

To build resiliency, leading metrics may be needed to describe how well virtual islanding is able to improve infrastructure conditions. For example, at least three different DER types and at least 150 water heaters or other controllable devices will be used to operate a dynamically formed microgrid after an extreme event. The description of how the project was going to be successful—demonstrating virtual islanding—was a bit vague. Success metrics need to be described.

The project team needs to document how they plan to achieve interoperability. Even though utilities are more accepting of using the cloud, utilities are still concerned about security and have many legacy systems that require interfaces. Although the project's work is on an open-sourced platform, interfaces to related systems need to be anticipated.

Commercialization of the technologies being developed beyond the handful of utilities involved does not seem to be getting much focus (or if it is, it is not well articulated). In the end, the potential for this project to have long-lasting impact comes down to commercialization that will enable other utilities that are not involved in this project to easily adopt and deploy the technologies that are being developed. Two challenges that need to be resolved include: (1) determine what capabilities can be run locally behind firewalls versus remain in the cloud and (2) get data agreements in place that address ownership, access, and use.

DOE Feedback

GRIP is a timely and comprehensive effort to address a variety of resilience issues across a range of utilities. This is an ambitious project still in its early stages, and the DOE team is looking forward to more substantive success in year two. Industry partnerships were a critical requirement of all the RDS projects, and the National Laboratory team has done an excellent job of assembling strong partners in both the information technology and utility worlds. Developing plans that lead to the successful adoption of laboratory products by industry continues to be a high priority and increases the value of the research.

Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Control, and Energy Storage (RADIANCE)

Project Number:	1.5.02
Principal Investigator:	Rob Hovsapian
Project Period:	December 2017– December 2020

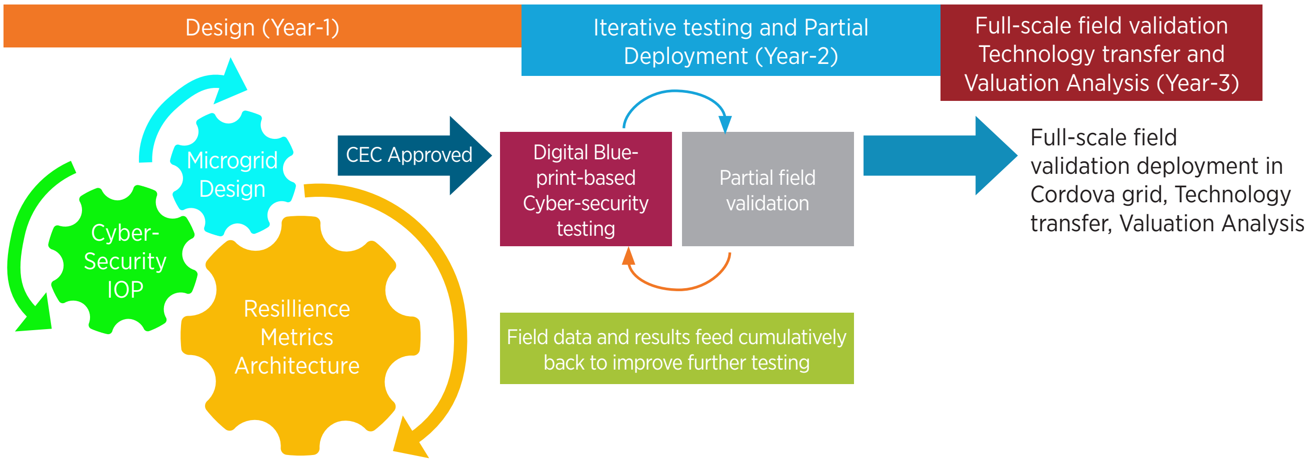


Figure 14. The major components of the *RADIANCE* project.

Project Description

The *Resilient Alaskan Distribution System Improvements using Automation, Network Analysis, Control, and Energy Storage* (RADIANCE) project consists of regional field validation and full-scale deployment of advanced technologies and methods enhancing resilient operations of a distribution grid under harsh weather, cyber threats, and dynamic grid conditions. The project team will utilize advanced concepts such as loosely and tightly networked microgrids, run-of-the-river hydropower, existing diesel generation, battery energy storage, early-stage technologies [such as distribution-level phasor measurement units (micro-PMUs)], smart meters, metrics-based approaches for resiliency quantification and enhancement, zonal configuration approaches, and cyber-vulnerability analyses. Iterative real-time hardware-in-the-loop testing and field validation will be used to de-risk the full-scale deployment.

In order to ensure success and greater impact of the project, the RADIANCE team evaluates quarterly progress through on-site, face-to-face technical interchange meetings.

Reviewers' Overall Comments

The history and context of issues in the Cordova utility system are well explained. The project appears to have a sound technical and management approach to address the grid resilience issues that Cordova faces. The project is implemented in a way to hopefully address collaboration effectively across the various partner institutions and teams, which is done using three integrated project teams. Field demonstrations are being done in harsh environments using early-stage technologies to cultivate a better understanding of resiliency by design using a multi-dimensional framework that reduces outages, uses less diesel, increases use of hydro and storage for inertia/reserve, and de-risks deployments. The development of coherent resilience metrics is an added bonus.

Some technical details were not well explained (or are perhaps not fully fleshed out as of yet). For instance, probabilistic analysis of extreme events is exceedingly challenging. Getting tail probabilities wrong can have huge implications for planning and operations. The project team may want to consider other approaches to representing uncertainty. It is also not clear how the project team plans to validate their transient system models. Will they have access to data from actual faults? If the team does not have access to data, how will they do this without such data?

It is also not clear if the project team has fully thought through commercialization and broader applicability of the technologies and tools that are being developed and will be developed. For instance, the Cordova utility partner has a low baseline with admittedly limited information about its system, assets, and physical infrastructure. Moreover, the system is quite unique in terms of topology and design. How much of the "science" learned in this project applies to other utility systems in the United States? The project lead said that they would address this issue through publications and presentations. However, publications and presentations only take care of dissemination of knowledge. They do not address generalization of findings to other settings and contexts.

DOE Feedback

The RADIANCE project is an important case demonstrating the importance of resiliency in extreme environments like those in Alaska. DOE program managers will work with the team to ensure the project baseline is as well defined as possible and the resiliency metrics are shared across the other projects. The concerns about national replicability are well-taken, and DOE will work with the team to identify how lessons learned derived from this project can be used nationally.

Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB (Decentralized FLISR)

Project Number:	1.5.03
Principal Investigator:	Kevin Schneider
Project Period:	October 2017–September 2020

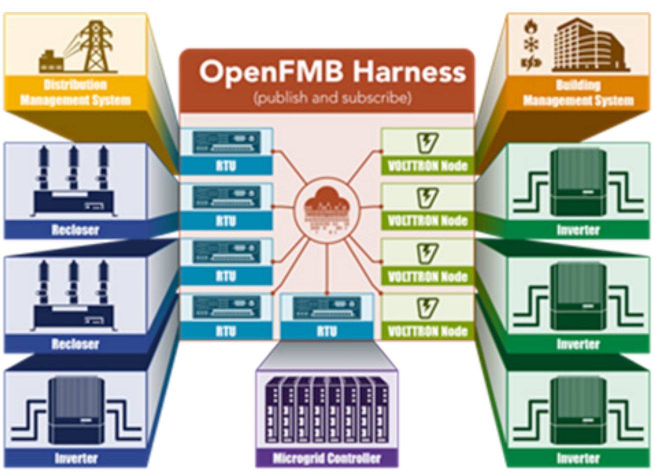


Figure 15. A segmented, self-healing distribution system uses decentralized assets and forms microgrids to isolate disruptions and minimize outages.

Project Description

The goal of this *Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by Open Field Message Bus (OpenFMB) (Decentralized FLISR)* project is to increase the resiliency of distribution systems at utilities around the nation by deploying flexible operating strategies, which enable a greater range of functionality for deployed assets. Deploying flexible operating strategies will be accomplished by coordinating the operations of centrally operated utility assets, with distributed utility and non-utility assets using Open FMB. For this project, a field validation will be conducted with the goal of demonstrating the ability to integrate the operations of a centralized self-healing system with distributed protection relays, which ensures that proper protection coordination is maintained during a wide range of potential system reconfigurations. Using OpenFMB, the system will be able to operate in the presence of moderate-to-high penetration of non-utility photovoltaics (PV) as the system reconfigures to maintain resiliency. Additionally, laboratory-level testing will be conducted to explore how non-utility assets such as PV inverters can be engaged through a transactive energy scheme to actively participate. The participation of the non-utility assets will change their role from a boundary condition to an active asset.

The operational framework developed for this project is broadly applicable to any utility with centralized and decentralized assets. To increase the portability of the developed capabilities, the project is using open standards and protocols. The lessons learned from the laboratory work and field validation will be transitioned to industry through presentations, peer-reviewed publications, and an active industry advisory board.

Reviewers' Overall Comments

The primary goal of this project is to increase distribution resiliency through flexible operating strategies. This will be accomplished by actively engaging utility and non-utility assets as flexible resources. Duke Energy has halted some self-healing systems deployments due to moderate/high penetration PV concerns, pointing to a need for a coordinated operation of distributed PV to make it a resource. This project will develop and deploy a layered control architecture using commercial-off-the-shelf (COTS) equipment and open-source code to engage assets to increase the resiliency of critical end-use loads. The project work contributes to the Grid Modernization MYPP because it provides a layered control structure with elements of a laminar control architecture developed to coordinate self-healing, microgrids, and DERs. This open functionality is needed for devices to autonomously operate and provide protection coordination as part of the Grid Modernization MYPP. The project team has made good progress in developing flexibility, as well as asset-level and system-level performance metrics. These will be important to assess the benefits of the technology. The team is also building on previous work, including HELICS, GridLAB-D, NS-3, Typhoon-HIL (hardware-in-the-loop), and the Advance Distribution Management Systems (ADMS) Testbed.

Planned work to simulate the effects of communications losses on the performance and behavior of the system is a good idea. This work should be expanded to determine whether the control system is robust to cyber-attacks. Can nefarious actors disrupt the system by sending erroneous control/price/incentive signals to individual DERs or sets of DERs? How can they be designed to protect against such attacks?

However, a number of technical issues need further investigation. One is the design of the control/price/incentive signals to incentivize the behavior of non-utility DERs. The project team proposes using an in-home control system with a "sliding scale" that indicates how the controller trades off between providing DER response and the resulting probability of service/outage. A number of pilot demand response programs that were deployed in the past ten years showed that if customers find that their automated control systems behave in an unanticipated way, they may forever opt out of using those systems in the future. The project team should be careful in thinking about this issue.

Also, it is not fully clear is what design criteria the team has in mind to develop incentive/price signals. Are they aiming for allocative efficiency, incentive compatibility, individual rationality, equity, payment minimization, or something else? Without clear design criteria in mind, the incentive design may go astray from achieving a socially desirable outcome.

DOE Feedback

This is a comprehensive project addressing a number of important challenges, including dynamic protection schemes and transactive energy. DOE staff are excited that this project is building off of successful, previously funded projects, such as *Development of Integrated Transmission, Distribution, and Communication Models* and the *Advanced Distribution Management System Testbed Development*. DOE will work with the principal investigators to address concerns about transactive energy and cybersecurity.

Integration of Responsive Residential Loads into Distribution Management Systems

Project Number:	1.5.04
Principal Investigator:	Teja Kuruganti
Project Period:	October 2017–September 2020

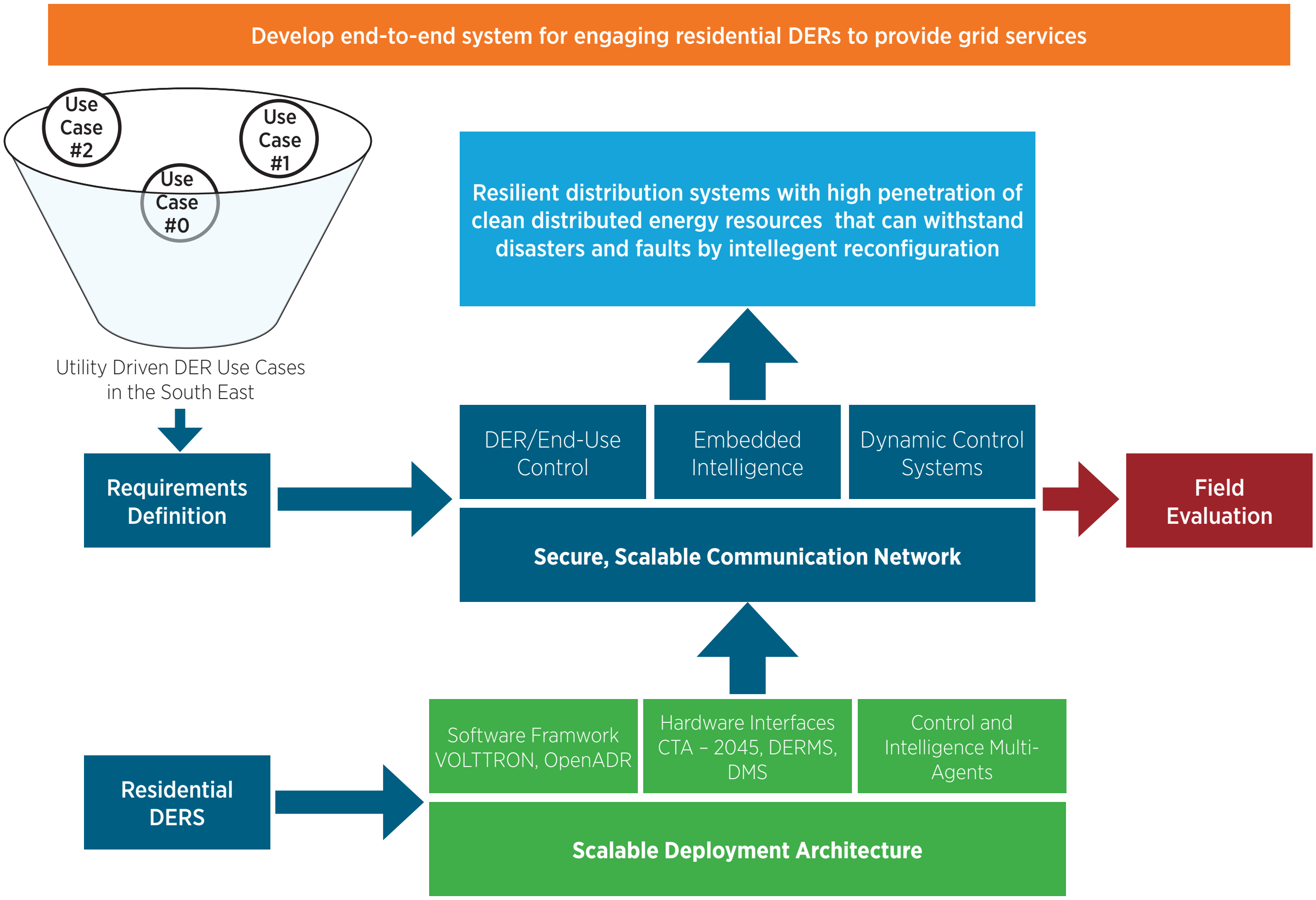


Figure 16. The major components and process of the *Integration of Responsive Residential Loads into Distribution Management Systems* project.

Project Description

The goal of this project is to provide electric utilities with the necessary software and hardware, all based on open standards, to leverage demand-side management of residential DERs. The team will develop and validate a home energy management system (HEMS) as a grid interface with a utility. The HEMS will serve as a platform for deploying intelligent algorithms to execute grid-responsive functionality of a collection of residential multi-vendor devices. The team will develop hierarchical, decentralized control and optimization systems capable of providing the response needed to deliver guaranteed grid services to utilities.

The team will work with selected Southeast utilities to identify existing or future grid service programs of interest, such as demand response or renewables integration, for five appliance types: (1) water heaters; (2) heating, ventilation, and air conditioning systems; (3) electric vehicle chargers; (4) pool pumps; and (5) residential photovoltaic inverters.

This project improves the economics and resilience of grid operations by taking advantage of a rapidly increasing trend in homes and small businesses—internet-connected smart appliances. With access to the project's open-source specification and reference implementation, utilities and co-ops can cost effectively use aggregated residential loads to offer resilience-based grid services to their customers. This gives utilities an important new tool to balance supply and demand, even in times of unexpected fluctuations, thereby improving grid resiliency.

Oak Ridge National Laboratory (ORNL), in collaboration with Pacific Northwest National Laboratory (PNNL), and Electric Power Research Institute (EPRI), will perform field evaluation for a utility-integrated, demand-side management solution using open standards and open-source reference platforms with utilities in the Southeast. The goal of this project is to provide grid resiliency services and to improve grid resiliency prior to any event.

Reviewers' Overall Comments

There are an increasing number of smart residential-level assets, including controllable loads, rooftop solar, and storage technologies. While imposing new challenges in distribution operations, these assets can be leveraged to make distribution circuits more resilient by managing demand, voltage, and power flows. However, an end-to-end solution—where interoperability occurs across the meter that has coordinated control technology—needs to be established and field validated. This kind of end-to-end solution will enable the control of residential loads to be used for grid services. This is an adequate description of the opportunity for making distribution benefits a reality from dynamic capability occurring behind the meter.

The team used feedback from stakeholder questionnaires and created use cases to define information exchange requirements to build the system architecture. The team created an end-to-end system architecture design to support hierarchical control of demand-side assets. This architecture design provides a unified response by having the demand management system coordinate the communication with HEMS for transactive control using incentives to drive optimization. The local HEMS coordinates responses to grid service requests, while maintaining customer constraints and ensuring that the interoperability requirements are cyber-secure. Hardware, software, testing, measurement, and verification plans are included. Several publications, meetings, metrics, and guides have been developed. Implementation cybersecurity technology is addressed through Beholder (malware detection for appliances) and a review of multi-speak protocol for ADMS and Distributed Energy Resource Management System (DERMS) communication. Also, an interoperability crosswalk is being performed across protocols of interest to support use cases: OpenADR (Complete), OpenFMB (partial), Multispeak (partial), SEP (complete), CTA2045 (complete). This project is on solid ground and is well represented.

However, some aspects of the approach can use some further deliberation. It is not clear the extent to which the performance and convergence behavior of the distribution optimization scheme will be examined. This is an important issue to ensure that load oscillations or synchronization of loads (for instance, due to time-of-use pricing) does not occur. The project team aims to pool loads to ensure load heterogeneity. Nevertheless, these aspects of the optimization should be fully explored.

Creating a reference guide for end-to-end use with input from EPRI and NRECA is great! In the fourteen use cases, there is a lot of interaction between Distribution Management Systems (DMS), HEMS, etc. In thinking through the end-to-end architecture, the events triggering control and sequence of events needs to be identified. What has precedence in different scenarios? How is cybersecurity being addressed?

There is an opportunity to integrate more consumer behavior studies, regulatory barriers, standards, and associated challenges into this project. They should be identified and addressed. Because the research is conducted behind-the-meter, standards domains between consumer and delivery apparatus requirements need to intersect; this is an opportunity to add clarity for expectations and gaps.

DOE Feedback

This project is addressing fundamental challenges in using residential loads to provide grid resilience, including end-to-end interoperability, optimization, controlling heterogeneous loads, and cybersecurity. The principal investigator has done a great job in working with utility partners. The questions regarding optimization algorithms and behavior studies are very important. DOE staff will work with the team to be sure they are investigated and addressed.

CleanStart-DERMS

Project Number:	1.5.05
Principal Investigator:	Emma Stewart
Project Period:	October 2017–October 2020

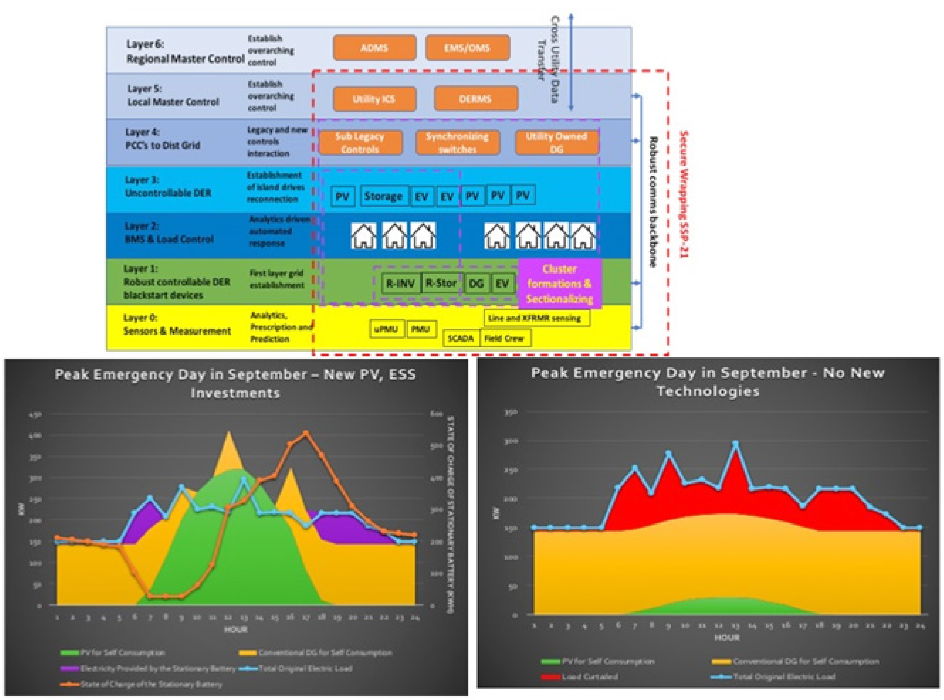


Figure 17. The *CleanStart-DERMS* project will achieve the black start and restoration objective through a layered approach addressing critical grid forming needs, then overall steady-state and time-series dispatch for peak days in summer at the City of Riverside's facilities.

Project Description

The *CleanStart-DERMS* project team will develop a black start and restoration solution to leverage 100% of DERs, with distributed energy resource management system (DERMS) integration at the utility partner, the City of Riverside Public Utilities.

The project team will design, implement, and demonstrate a novel method for fast customer restoration during a system outage. In addition, the team will provide the capability to black start utility services from a high penetration of DER distribution feeders. This demonstration—which will show the efficacy of a new DER-driven resilience concept—is multifaceted. It will include validation and implementation real-time analytics to evaluate the stability of each line segment, reconnected generation clusters during the segmented restoration, and device and DER cluster control layers optimized for the black start application. The CleanStart-DERMS project will implement a repeatable design process using a TDC simulation that is agnostic to the generation source. In addition, the project will use high-fidelity sensing and predictive analytics, modular DER control, and a dynamic microgrid configuration that can be optimized in real time. The real-time optimization will provide support to the bulk power system during restoration primarily from small distributed generators, including Solar PV, while simultaneously considering critical load constraints.

The control and real-time analytics framework integrates real-time analytics from high-fidelity sensor data, including information from distribution synchrophasors and point-on-wave line current measurements. These capabilities enable users to evaluate the ongoing risk of an outage to the feeder, while allowing proactive segmentation and the stability of each node during the CleanStart-DERMS restoration process. The control strategy is leaves-to-root, or customer to bulk system—a fundamentally opposite approach to the normal condition in restoration, where bulk system is the first consideration.

The analytics, enabled by application of reinforcement learning to advanced sensors, will determine the best available controllable device configuration before the outage. The resources from that configuration—in conjunction with inverter-based black start devices—will be used to create a robust islanded network. In turn, the islanded network can then be optimized to black start the remaining feeder and non-controllable DER devices.

The self-healing microgrid and distribution grid configuration will be robust to both cyber and physical events, with application of a secure Supervisory Control and Data Acquisition (SCADA) protocol wrapper to the DERMS platform. It will also provide critical restoration support to the primary substation from renewable energy, other small distributed resources, loads, and buildings. The CleanStart-DERMS methodology can enable parallel restoration, accounting for uncertainty in topology and resource availability.

The outcome of this project is a strategy for a resilience-based microgrids, DER-driven black start, and segmented restoration that can be adapted anywhere in the country. This approach integrates technologies, system control theories, and advanced analytics, and it demonstrates their application through field validation. CleanStart-DERMS will demonstrate the capability to start a feeder from a complete outage from the leaves (e.g., the DER and customers) to the root (e.g., feeder head) and will resynchronize with the wider-area-network—all with a minimal amount of conventional electricity generation. It will achieve this through integrating and validating distributed analytics, controls, and DERMS/ADMS concepts with enhanced communication and control for agile islanding.

Reviewers' Overall Comments

Currently, black start and restoration is a centralized, bulk-system-driven solution; DER, in contrast, is decentralized. This project aims to enable DERs and their controls as a mechanism for black start and restoration. The project team is developing and implementing a DERMS integrated application, which provides a separate communications, analytics, and control layer, purely for a black start and restoration application. The project's objectives are to minimize the outage time for as many customers as possible using the greatest contribution from distributed and clean energy resources, to implement methods for predictive analytics and advanced controls, to provide support services from DER back to the transmission system during critical outages, and to integrate an Cybersecurity for Energy Delivery Systems (CEDS)-funded cybersecurity technology with the resilient DER architecture. The product will be transformational to utilities experiencing a rapid DER influx, considering both controlled and (now) uncontrolled resources as part of the resilient resources utilized in wide-scale events. This work contributes to meeting the platform goals and objectives mapping to the System Operations pillar of the Grid Modernization MYPP by increasing security, resiliency, and improved architecture that assist the grid operator in black start conditions.

This project effectively makes use of other grid work, including using HELICS (of the *Development of Integrated Transmission, Distribution, and Communication Models* project), Los Alamos National Laboratory's optimization toolbox, and PNNL's GridLAB-D. Further integration and linkages with other GMLC projects could be considered. It is very impressive that the project team will be able to test the solution on a real utility grid.

The team needs to address how to scale the results of this project nationally. The application in this project scenario is unique. The team needs to capture the lessons learned that can be generally applied across utilities and then develop the training, tools, and other efforts required motivate the existing workforce to think positively about operations that incorporate distributed supply.

The team needs to address, test, and describe the time synchronization for model integration carefully. HELICS should be used to examine the synchronized behavior. Lessons about data collection/classification, data requirements, diesel requirements, and specifications about locations are all important information for others to learn, advance, and build upon the work done in this project.

DOE Feedback

This project leverages important work done in OE, EERE, and the Advanced Research Projects Agency-Energy (ARPA-e) to address a difficult, yet important challenge of how DER can provide black start capabilities to the grid, increasing resilience. DOE is encouraged that work in controls, sensing, microgrids, and devices will test and prove out black start capability in the field on a utility feeder. This project is pushing boundaries and has the potential to have widespread application.

Designing Resilient Communities

Project Number:	1.5.06
Principal Investigator:	Robert Jeffers
Project Period:	December 2017–September 2020

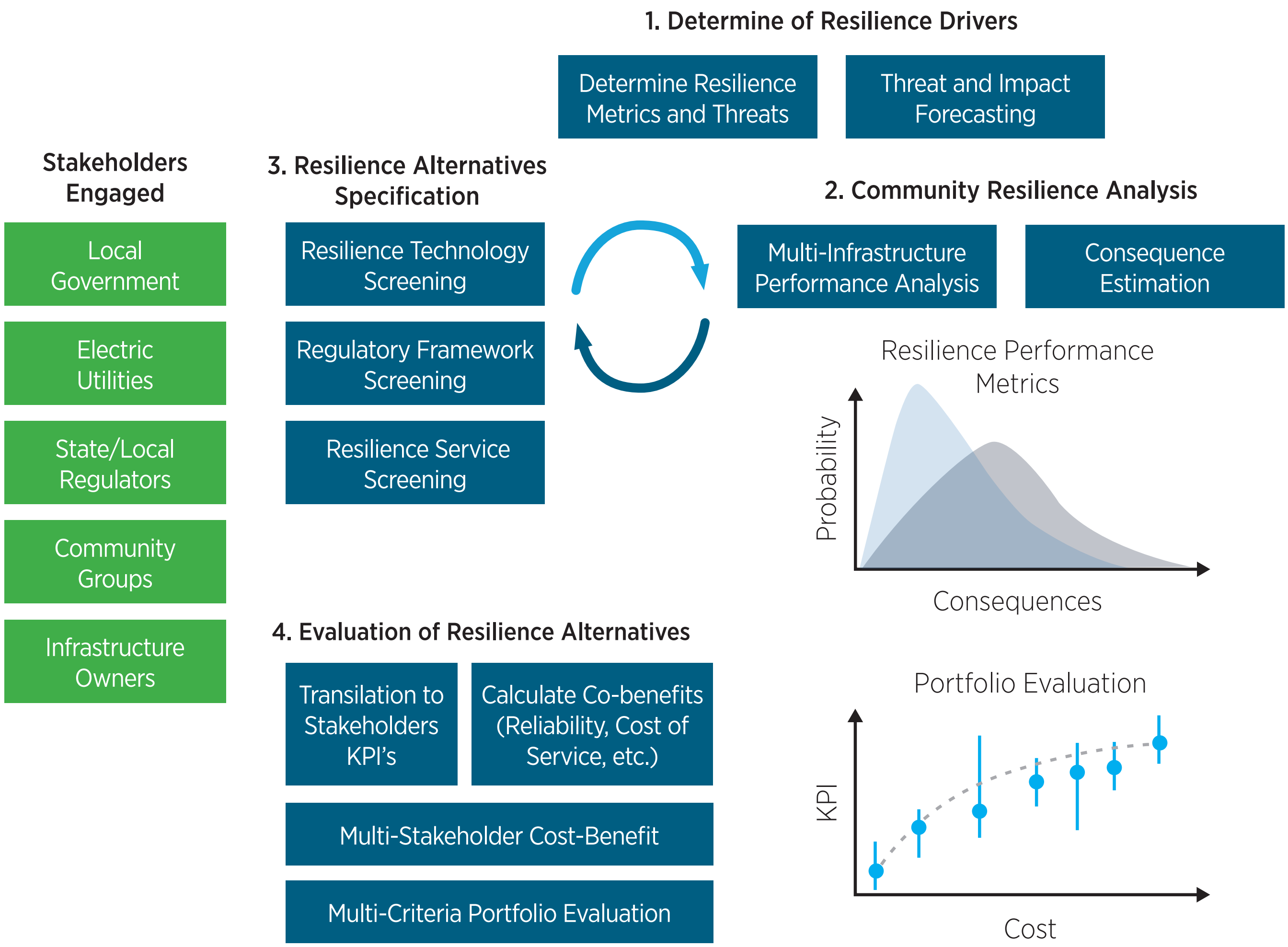


Figure 18. *Designing Resilient Communities* project's resilient community design framework.

Project Description

The high-level goal of the *Designing Resilient Communities* project is to demonstrate an actionable path toward designing resilient communities through consequence-based approaches to grid planning and investment, as well as through field validation of technologies with utility partners, using distributed and clean resources. Based on previous GMLC projects such as *Grid Analysis and Design for Resiliency in New Orleans* and feedback from Chief Resilience Officers of member cities in the 100 Resilient Cities organization, the National Laboratory team has identified a critical disconnect between resilience planning for the electric grid and resilience planning for communities. Utility resilience planning has not been standardized across the industry and still largely focuses on standard reliability goals, metrics, and cost recovery strategies. This gap between true resiliency planning at utilities today and standard reliability practices are largely due to a lack of resilience-oriented regulations and the difficulty in assessing the multitude of resilience benefits that grid investment can provide to multiple stakeholders. Emerging grid modernization technologies such as ADMS, advanced microgrids, novel protection schemes, and others offer the opportunity to greatly improve grid resilience. In the meantime, DERs—such as solar PV, energy storage, electric vehicles, home and building energy management systems, fuel cells, and combined heat and power (CHP), among others—can potentially play a much bigger role in improving grid resilience. However, without making the connection between grid resilience and consequence to communities, these technologies will fail to reach their potential impact to society.

To address the gap between community and utility resilience planning, this project will investigate how a community can be designed to be resilient through coordinated grid investment and how electric utilities of various configurations (e.g., municipal, investor-owned, or cooperative; vertically vs. horizontally integrated; etc.) can plan for resilience and benefit from these investments. While this project primarily focuses on developing general design methodologies and metrics for resilient grid system, the specific designs may be adopted by project partners for future field demonstrations and full implementation. The project will develop detailed case studies for San Antonio, Texas, and Buffalo, New York. In addition, by working with a broad set of stakeholders across many areas of the United States, this project will tackle regional differences in costs, benefit stacks, and resilience challenges, and it will identify a national path forward to internalizing resilience planning via partnerships between utilities, communities, and regulators.

Reviewers' Overall Comments

The *Designing Resilient Communities* project work is relevant to the goals and objectives of the Grid Modernization MYPP because it maps to infrastructure support in its pillar framework—looking at infrastructure investment and development in a way that increases resiliency to better serve society. The planning process, regulatory model, and infrastructure design are all activities within the project. This is an extremely important project, because rather than just thinking about electrical systems, the project team contemplates on a broader scale, addressing social and economic resiliency and the role that electricity (and potentially other energy resources) can play. This sort of systems thinking is valuable, and a very good role for DOE.

The project would be strengthened if the goals and measures of success were more quantifiable and would describe the contribution of this outcome to the overall GMI outcome.

DOE Feedback

This work leverages the resilience improvement process developed and demonstrated via the *Grid Analysis and Design for Resiliency in New Orleans* project. The project will determine a path toward adoption of Resilient Community Design Framework by multi-regional, resilient community design discussion in the form of national outreach meetings with a SAG. DOE will consider the reviewer feedback as it explores opportunities to strengthen this important project.

Threat Detection and Response with Data Analytics System Operations and Control

Project Number:	1.4.23
Principal Investigator:	Jovana Helms
Project Period:	June 2016–March 2019

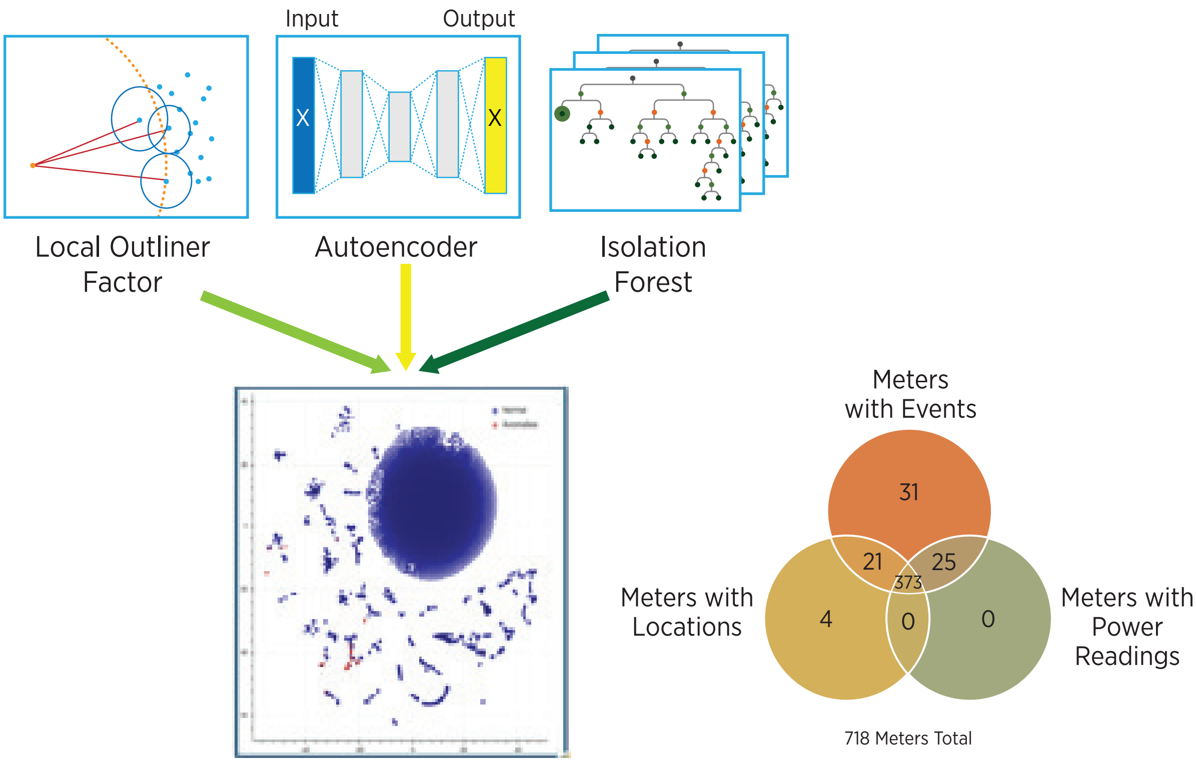


Figure 19. Combining multiple anomaly detection algorithms allows for detection of "true" anomalies in smart meter data.

Project Description

The *Threat Detection and Response with Data Analytics System Operations and Control* project focuses on identifying "cyber-physical" signatures that will allow one to quickly differentiate between cyber events and non-cyber events on the grid. By differentiating between cyber-related and non-cyber-related or operational events, determinations can be made about the type of incident and its root cause, which can allow for timely detection and response to cyber-attacks. Research results will lead to development of commercial tools that will improve a utility's ability to differentiate between cyber and non-cyber incidents so that they can make the most appropriate response during an event. Analytics for smart meter, inverter, network security gateway, and building-to-grid data have been developed to identify viable data sources that can inform cyber-attack detection.

Reviewers' Overall Comments

This project aims to develop advanced analytics on operational technology cyber-data in order to detect complex cyber threats. It is looking at sensor data, developing analytics, and attempting to differentiate cyber incidents from other hazards on the grid. The immense variety of cyber-attacks yield an immense variety of profiles and footprints. Finding cyber threats and keeping up with the changing face of cybersecurity challenges is important and relevant work. Overall, the approach is sound. While many accomplishments have been made in this project, there is still a significant amount of work to accomplish in the next six months.

There are some issues that the project team may wish to consider. First, what (at least empirically) are the sensitivities and specificities of the detection models (e.g., false-positive and false-negative rates)? Moreover, the project team should consider the cost or consequences of false-positives and false-negatives. False-negatives seem to be of lower consequence, in the sense that the system would behave as it does today with no threat detection in place. However, a false-positive could have major consequences depending on what the non-threat is and what (incorrect) corrective action is taken against the non-threat. It would be beneficial to at least model or, even better, empirically determine what these incorrect impacts would be.

DOE Feedback

Executing cutting-edge research on cyber and physical security continues to be one of the highest priorities at DOE, and the Department will continue to support work in this important area.

Security and Resilience Portfolio Overview Discussion

After the RDS and Security and Resilience project reviews, project principal investigators, DOE project staff, and interested stakeholders holistically discussed the Security and Resilience portfolio. The Security and Resilience lead reviewer repeatedly focused on the challenges faced when bringing these technologies to market and recommended that industry adoption and market uptake be considered as early as possible. He encouraged GMLC members and principal investigators to incorporate utility partners and to leverage utility assets and skills wherever possible to hasten commercialization.

Looking specifically at the projects and the GMLC organization, the success metrics used to evaluate projects should be more closely tied to the GMLC goals, and, more specifically, projects should require project statements that clearly point to these goals. To best address issues of scalability and replicability, DOE should improve partnerships and collaborations across the GMLC and outside of DOE to consider the broadest swath of problems possible.

The usefulness of regional-specific case studies was questioned, as the specific characteristics may not be applicable across the country.

Sensing and Measurements Portfolio

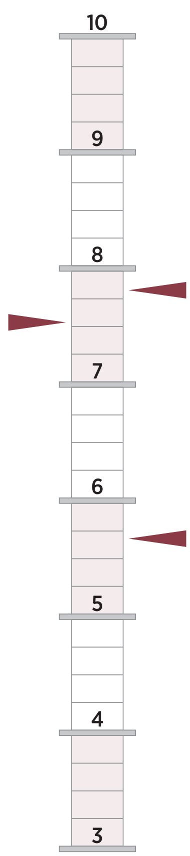
Sensing and Measurements Technical Area Overview

To assess the grid's health in real time, predict behavior and potential disruptions, and quickly respond to events, it is necessary to have visibility throughout the electric infrastructure—from generation to the end user. Supporting advances in system operation and control requires improved sensing and measurements across multiple spatial and time scales—from microseconds, to hours, to days.

The *Sensing and Measurements* focus area seeks to advance sensor development and strategies to provide complete grid system visibility for resilience and prediction. Expected outcomes include:

- Advance and integrate novel, low-cost sensors to provide system visibility.
- Incorporate new data streams (e.g., weather).
- Develop real-time data management capability 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.

Sensing and Measurements Overall Scores



Sensing and Measurements Peer Review Findings by Project

Grid Sensing and Measurement Strategy Methodology

Project Number:	1.2.5
Principal Investigator:	Tom Rizy
Project Period:	April 2016–April 2019

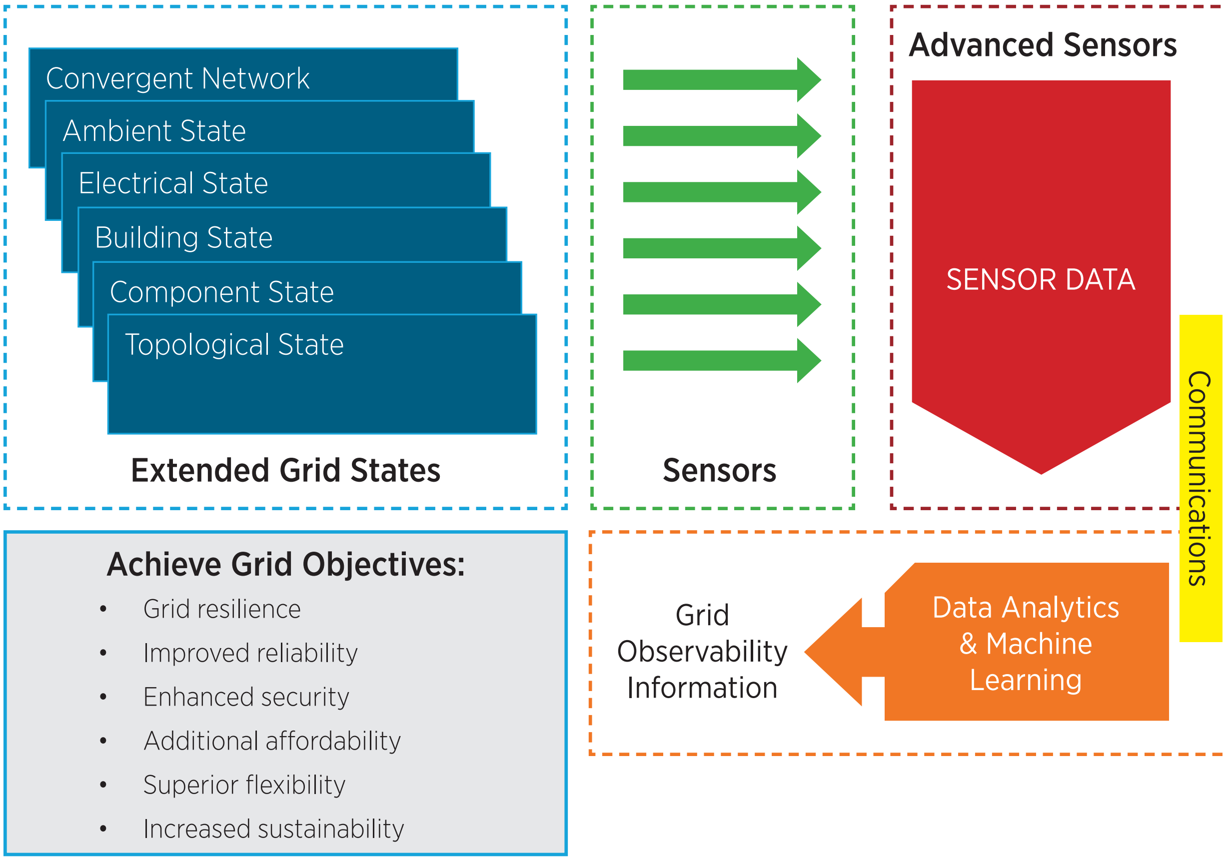


Figure 20. The grid and grid services relationship with advanced sensors and data analytics.

Project Description

The power system that once provided electric power—from central power plants to distributed loads using high-voltage transmission and lower-voltage distribution networks—now consists of distributed generation and energy storage, as well as conventional and renewable generation sources throughout the system. The distributive and additive sources of energy require an ability to measure and characterize the state of the system at a much higher fidelity and resolution than before, from generation through end use.

The *Grid Sensing and Measurement Strategy Methodology* project team is building a cohesive strategy to develop and deploy low-cost, multi-modal sensing and monitoring devices with improved accuracy. Equally important is minimizing measurement uncertainty and ensuring adequate deployment coverage for complete observability of the power system. Finally, the project team is working on ensuring the measurements will migrate to the control systems via a robust, secure, and resilient communications system. Therefore, the project work is focused on an approach to define the requisite parameters to measure, the devices needed to measure these parameters, the communication requirements to transfer data, and the ability to manage convert the data into actionable information.

Reviewers' Overall Comments

Overall, this project is an excellent effort at determining a coherent and defensible strategy for identifying gaps in measurements and needs in sensor development. This template for strategy development should be adopted a best practice across all GMI programs. The National Laboratories developed a good framework of the extended grid state that can show the value of developing sensors in terms of utility planning and operations. Extended grid state frameworks are foundational elements of a grid modernization strategy. The inclusion of asset health, physical/environmental states, and the status of grid-connected assets in addition to traditional power states are important.

Moving forward, DOE and the National Laboratories need to incorporate existing product development plans from sensor manufacturers to ensure that there are no duplicative development efforts. In addition, DOE needs to more explicitly consider how we can utilize all the data from existing sensors before deciding new sensing requirements. Advances in the sensor development project *Advance Sensor Development* and the data analytics project *Integrated Multi-Scale Data Analytics and Machine Learning for the Grid* could impact the overall strategy; however, it is not clear if that coordination was incorporated.

Industry partners are among industry leaders, but not necessarily representative of broader industry perspective. Outreach should include other forms of interaction with a broader range of utilities and utility forums.

DOE and the National Laboratories should consider developing the sensing placement tool on an open-source platform to ease integration with commercial tools. It has minimal usefulness on a single vendor platform.

DOE Feedback

When DOE announced this lab call, *Sensing and Measurement* was identified as an area where more focus was necessary. DOE expects this document to fundamentally support its efforts in sensing and measurement moving forward across the Department. As we further refine this strategy, DOE will more closely consider the impact of artificial intelligence and data analytics on the overall strategy, as well as consider a broader range of stakeholders.

Advanced Sensor Development

Project Number:	1.4.04
Principal Investigator:	Yilu Liu
Project Period:	April 2016–September 2019

Given the broad range of sensor development, this project has been divided into three different areas of research: End Use, Transmission and Distribution, and Asset Monitoring.

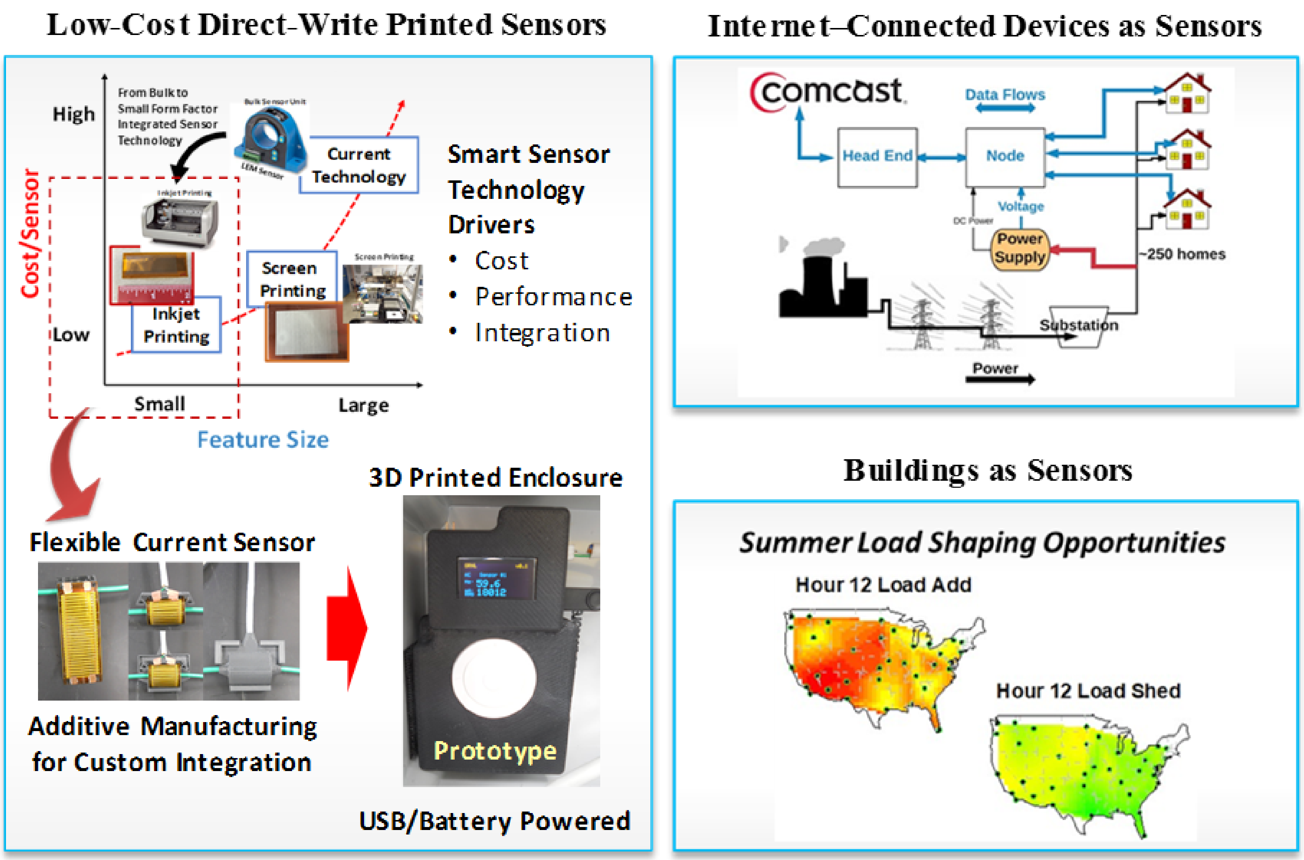


Figure 21. Low-cost sensors and algorithms using building-level, end-use data to provide utility-scale visibility of grid reliability.

Project Description

End Use

Fundamentally, low-cost, revolutionary technologies are required to increase visibility in end-use systems, such as buildings. Sensing, measurement, and data processing are needed to make utilities aware of consumption needs and enable them to effectively manage demand, while operating within safety and occupant constraints.

Heating, ventilation, and air-conditioning (HVAC) systems account for approximately 50% of the building load and have untapped dispatch potential. The proposed approach on the *Advanced Sensor Development* project for end-use applications has two key objectives: (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.

Transmission and Distribution

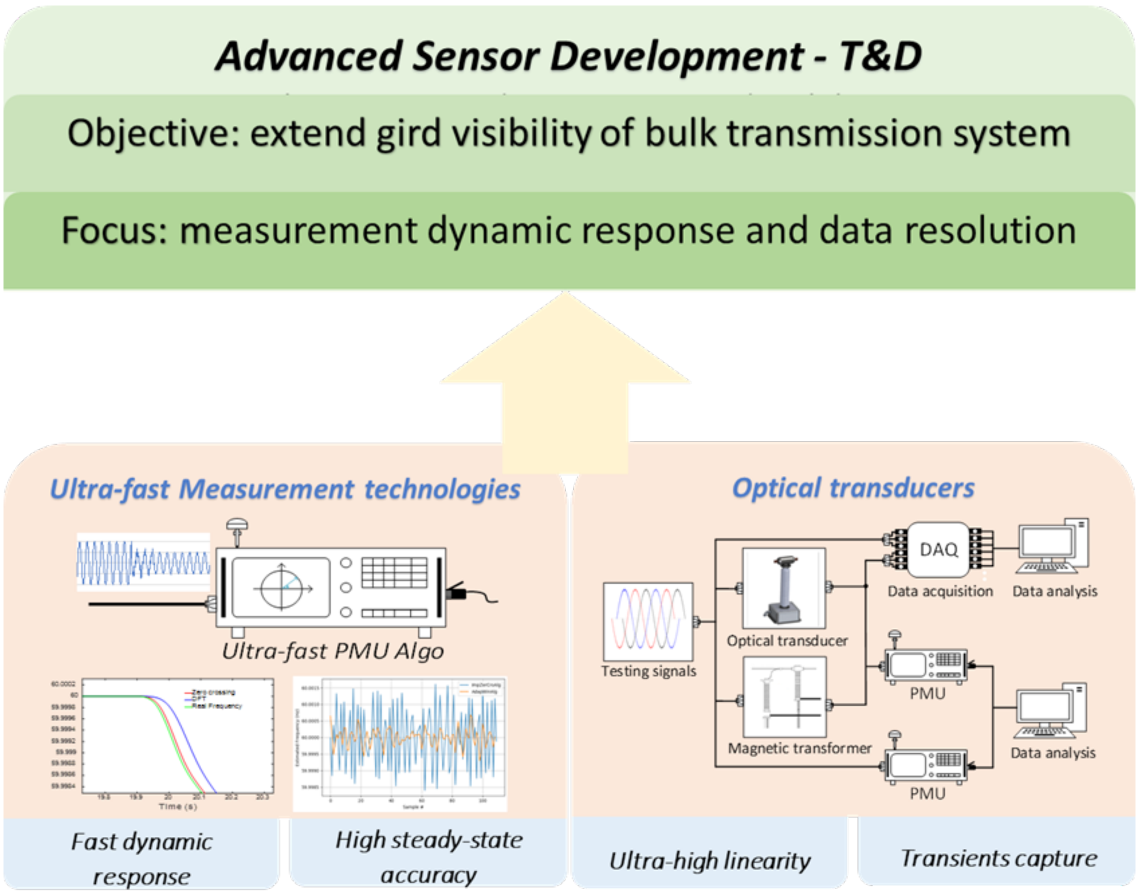


Figure 22. Transmission and distribution sensor characteristics and development.

The Grid Modernization MYPP identifies the need to increase visibility throughout the entire energy system to address challenges facing the nation's electricity infrastructure. For the bulk transmission grid system, ever-increasing fast transient swings in the future grids with predominant power converter-based generation and load introduce significant measurement challenges. The inability of existing devices to accurately measure rapidly changing values during transient conditions has been identified as a key challenge for grid stability. In addition, grid visibility at transmission grid system relies on the performance of instrument transformers. Existing instrument transformers are mainly dominated by magnetic transformers. However, magnetic transformers have inherent weaknesses and are subject to magnetic saturation, poor linearity, etc. Optical current and voltage transducers hold great promise for future measurement technology for many reasons, including the advantages of high linearity, immunity to magnetic saturation, no electromagnetic interference, no temperature sensitivity, little-to-no maintenance, etc. Unfortunately, although optical current and voltage tranducers have advantages, the progress of their application in the bulk transmission system are slow due to lack of successful demonstration and less user familiarity. The focus of this project is to extend the resolution of transmission grid visibility in orders of magnitude higher than current technologies and focus on measurement dynamic response and data resolution. The project team will develop ultra-fast system transient measurement technologies to capture system transients fast and accurately, improve grid visibility with optical transducers, and demonstrate the advantages of optical transducers over magnetic transducers with high-precision PMUs. The success of this project could provide system operators new capability to enhance grid stability by providing high-resolution grid measurements.

Asset Monitoring

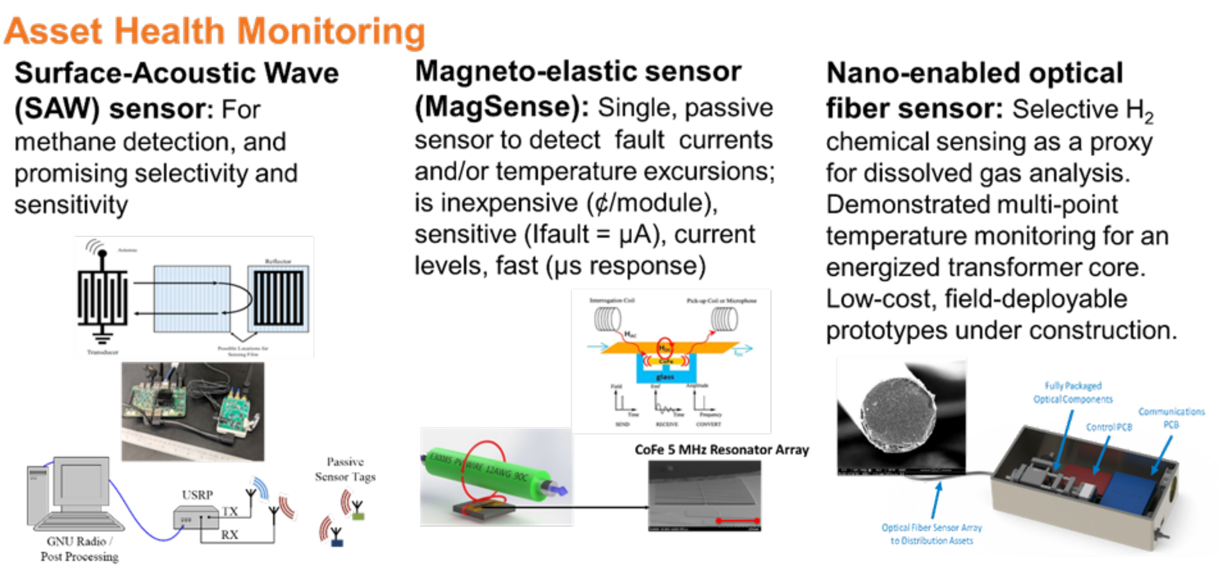


Figure 23. Examples of asset monitoring sensors.

The objective of this project is to develop extremely sensitive, low-cost sensors that can monitor grid assets' health, provide prognostic and diagnostic information in near-real-time, and detect asset failures before they occur to reduce time and maintenance. This project focuses on very low-cost gas and current sensors. There are three sensors being developed: (1) Surface-Acoustic Wave—sensors that can detect various gasses that are indicative of aging or incipient failure in power transformers; (2) Magneto-elastic sensors—frequency-selective current sensors that can detect faults and abnormal operating conditions with greater accuracy; and (3) Nano-enabled optical fiber sensors—selective chemical sensing proxies for detection of degradation of transformers, as well as temperature sensing for transformer cores.

Reviewers' Overall Comments

The National Laboratories have made progress on sensor development and identifying potential applications; however, this project needs more validation from utilities and the sensor industry. While the technical approach for each sensor makes sense, there was no explanation as to how these sensors were prioritized out of the sensing and measurement roadmap. Why were these applications selected? Why are these the highest priorities for development? What sensor applications and use cases offer the best value proposition for the industry? New, low-cost sensors will likely be very important to grid modernization, but it is critical to determine what applications to pursue.

Continue working with utilities on deployment. The principal investigators need to more clearly articulate the value of data gathered from PMUs through sensing—in addition to direct measurement from PMUs—rather than using the data for after-event analysis. Also, DOE needs to better understand the trade-offs between direct measurement and measurement through data analytics and incorporate those insights into this program.

It would be helpful to have a better explanation of the overall critical success factors and challenges for each sensor, as well as a project timeline with go-no-go decision points for each sensor. It would also be useful to understand how and when the team will pursue commercialization.

DOE Feedback

DOE is pleased that the National Laboratories are continuing to make progress in this important area. In the interest of coordination, many disparate projects were pulled together into one "megaproject," which created challenges. How and why these particular sensors were identified as priorities came up in last year's review, so it is unfortunate that wasn't clarified during this review. Understanding how and when direct measurement should be used versus data analytics has been a common theme through the sensing and measurement technical area and will be closely considered in the future.

Integrated Multi-Scale Data Analytics and Machine Learning for the Grid

Project Number:	1.4.09
Principal Investigator:	Emma Stewart
Project Period:	April 2016–April 2019

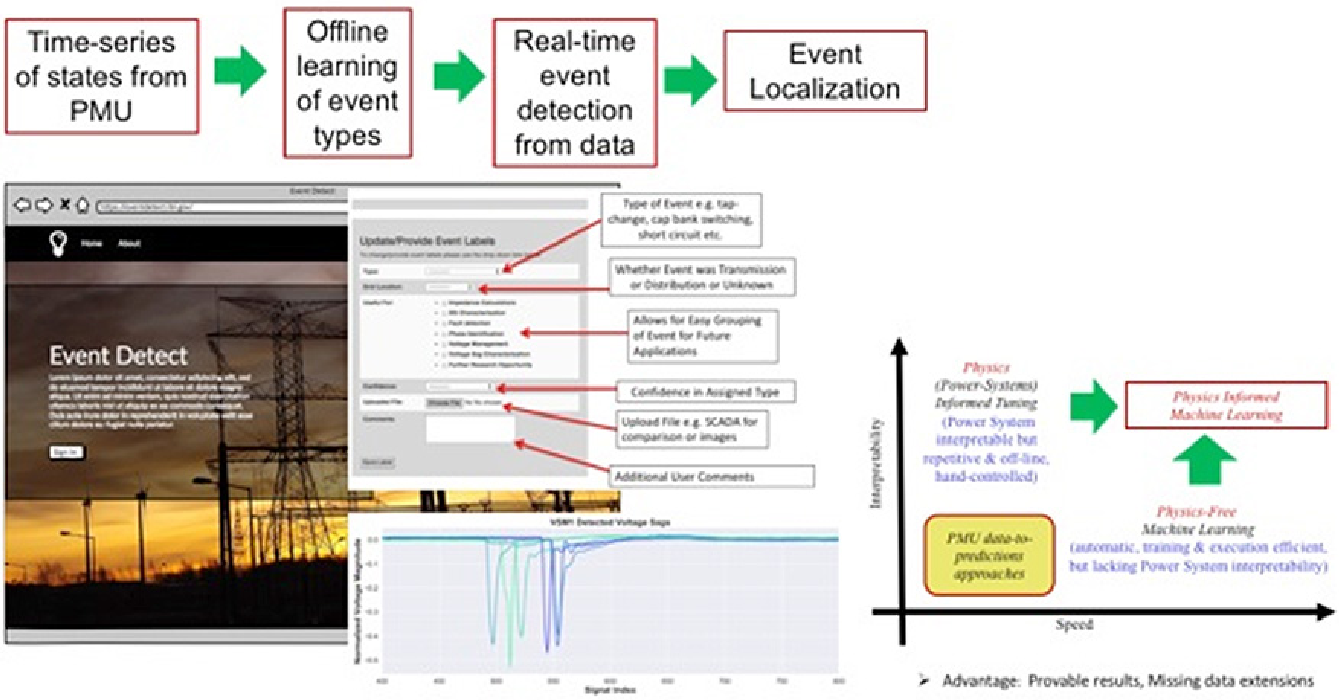


Figure 24. Data analytics and machine learning will help evaluate and utilize the growing number of data points for the distribution grid ato buildings interface.

Project Description

As the number of sensors and communication networks grow, analytics must adapt and enable consumers and providers to visualize and utilize the provided data effectively. Machine learning is one of the techniques proposed to manage this data deluge.

The *Integrated Multi Scale Data Analytics and Machine Learning for the Grid* project team is evaluating, developing, and demonstrating machine-learning and data-analytics capabilities for the distribution grid to buildings interface. This project's overarching goal is to create a foundation for the development of advanced data analytics—leveraging existing activities in machine learning in the energy industry, as well as alternate applications in other industries (e.g., the medical sector), academia, and other funding agencies. While there has been significant development of analytics methods with streaming data at the transmission level, distribution and buildings-level analytics are in the elementary stages. Machine learning is the basis for the analysis development and, with appropriate application, will enable new levels of visibility and resource integration using open and utility datasets at both the building and distribution level. This project will evaluate the current state-of-the-art distributed analytics and machine-learning technologies and applications and will develop the necessary framework to promote and integrate a larger distributed analytics activity utilizing existing and new data sources developed through both private and DOE partnerships.

The project team will validate the full capability of synchronized disparate data sources for distribution and building grid analysis and control and—with application of machine learning—will produce future distributed applications such as transactional energy validation, fault analytics and failure prediction, resilience applications, and a building management systems (BMS)/DMS integration strategy.

Reviewers' Overall Comments

Overall, this project has an outstanding plan that clearly aligned with the Grid Modernization MYPP and has the potential to provide great value to utility grid modernization efforts. Starting with a review and benchmarking of advanced machine learning algorithms in the grid and asking the question of what is actually needed in this space (algorithms, better applications, or supporting infrastructure)—along with the use cases and data targets—serve as a mini-roadmap and action plan for this area.

Advanced machine learning algorithms is clearly a space for the National Laboratories to be researching because there is less direct industry activity. The focus on data quality is central to the success of this project. There should be follow-on projects to exploit the progress made in this project for industry benefit. Moving forward, it would be useful to look beyond PMU-data analysis to analyzing data from Supervisory Control and Data Acquisition (SCADA) and other current utility systems to be of value to utility decision makers.

DOE Feedback

This has been an excellent project, and DOE will continue exploring the role of data analytics and machine learning moving forward.

Sensing and Measurements Portfolio Overview Discussion

The lead reviewer for Sensing and Measurement, felt the sensors research and development roadmap was significant and should drive future investments in that area at the National Laboratories and DOE at large. Specifically, the National Laboratories need to hone in on the elements of the extended grid state that are most important and relevant now.

DOE and the National Laboratories have made great progress across a wide range of sensors, including innovations with printable sensors. However, the reviewers advised simplifying the Sensors and Measurement research portfolio. Regarding machine learning, reviewers recommended that DOE should develop and maintain open-source Linux research for users who do not want to be locked into a particular vendor who has a turnkey solution. It was also suggested to apply machine learning to areas—DER, failure detections at the transformer level, and typology and parameter estimation (and the RDS projects)—that would achieve the highest level of impact.

Finally, it was stated that the GMLC research was "…a rich treasure trove of work, ready to be mined." More focus should be around amplifying, transferring, and commercializing this work. Now that the projects are nearly complete, the topic of technology transfer is very important, and there are different avenues to ensure the future success of the technology developed. Creating a summit (e.g., like the ARPA-E Summit) as a way to disseminate information would be helpful.

System Operations, Power Flow, and Control Portfolio

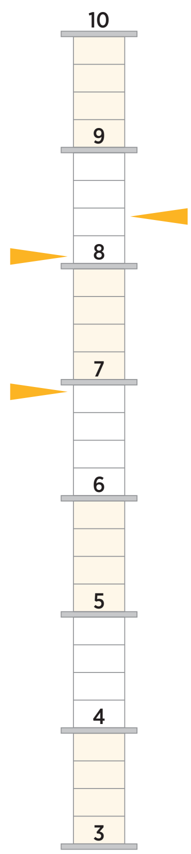
System Operations, Power Flow, and Control Technical Area Overview

The nation's electric grid is transitioning from one that is centrally controlled, with one-way delivery of power from central-station power plants, into one that features both distributed generation and distributed control systems based on advanced communications. There is opportunity to harvest advanced technologies to optimize the operation of the system and react to off-normal conditions in a way that preserves system reliability and improves resilience.

The *System Operations, Power Flow, and Control* technical area seeks to develop advanced, real-time control technologies to enhance the reliability and asset utilization of transmission and distribution systems. Expected outcomes include the delivery of:

- An architecture, algorithms, and control frameworks for a clean, resilient and secure grid;
- Advanced operations software platform for predictive operations and real-time adaptive control;
- New power flow control device hardware and concepts; and
- Advanced fundamental knowledge for new control paradigms.

System Operations, Power Flow, and Control Overall Scores



System Operations, Power Flow, and Control Peer Review Findings by Project

Grid Architecture

Project Number:	1.2.1
Principal Investigator:	Jeffrey Taft
Project Period:	April 2017–April 2019

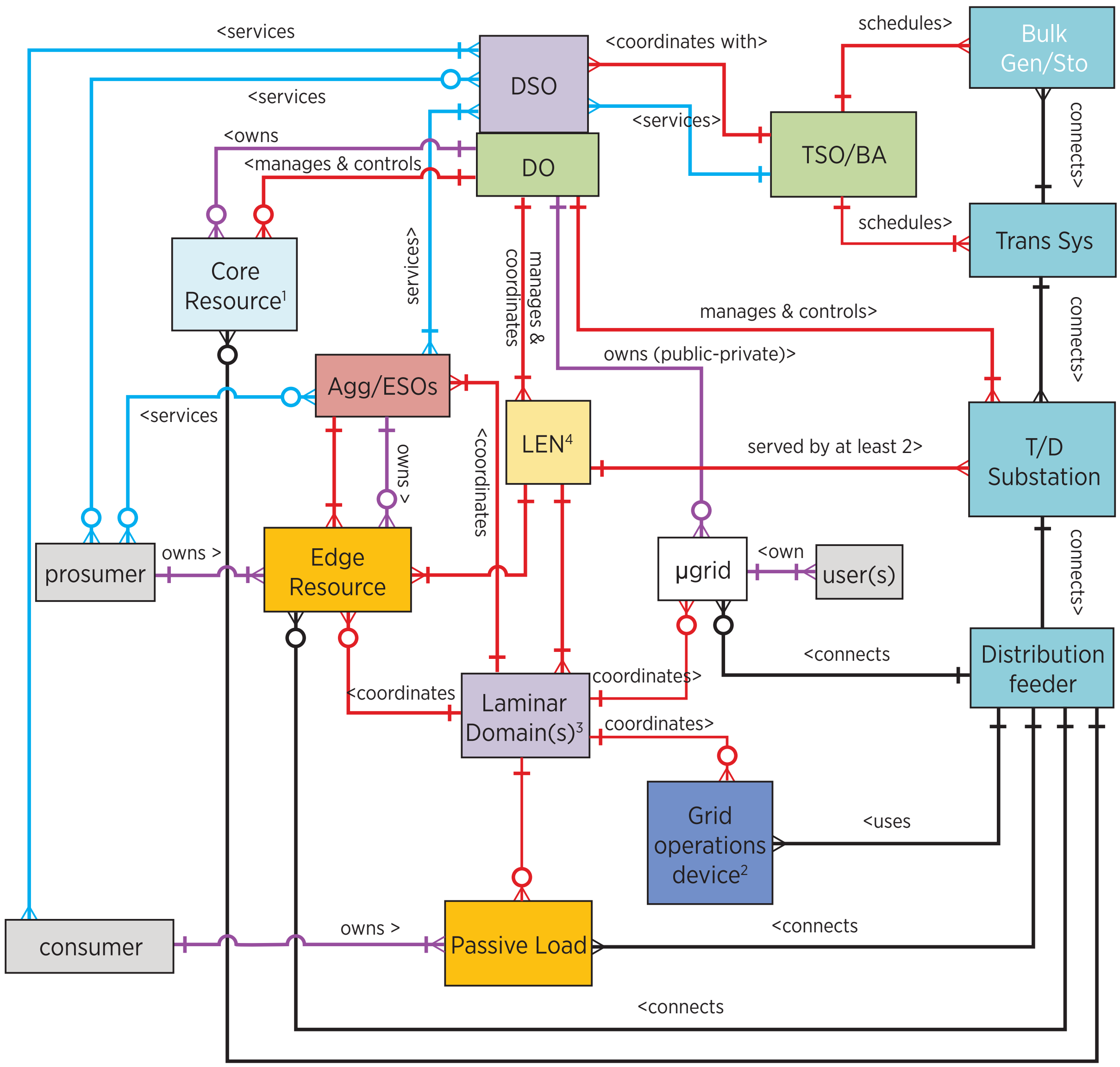


Figure 25. Distribution grid virtualization.

Project Description

The concept of grid architecture is the application of system architecture, network theory, and related disciplines to the whole electric grid. The purpose of this project is to re-shape the grid, remove essential barriers to modernization, redefine key grid structures, and identify securable interfaces and platforms. The project objectives are to (1) build stakeholder consensus around a DOE-convened vision of grid modernization expressed as a new set of five grid reference architectures; (2) establish and win industry acceptance on the use of *Grid Architecture* work products and methodologies; and (3) supply a common basis for roadmaps, investments, technology and platform developments, and new services and products for the modernized grid.

Reviewers' Overall Comments

Grid Architecture addresses a key issue: how to restructure the grid to better integrate modernization investments, while still meeting resilience, security, and functionality. The project addresses the needs outlined in the Grid Modernization MYPP and has a sound technical approach. This work is essential and is being done very well, but it is not yet accessible to practitioners. Developing a more effective strategy for impacting the way actual utilities build and document their architectures would be helpful. The focus in the next 18 months should be on more utility engagement, as well as on building consensus among ISOs/RTOs, reliability coordinators, and regulators. In addition, efforts in engagement that yield good results should be a roadmap that can be leveraged by related GMLC projects. Coordination and communication to external stakeholders needs some clarification and possible expansion.

DOE Feedback

DOE agrees that investigating the future architecture of the grid and engaging with utilities, ISOs, and regulators is critical; however, the deliverables from this effort do need to be more accessible to stakeholders.

Control Theory

Project Number:	1.4.10
Principal Investigator:	Sidhant Misra
Project Period:	May 2016–April 2019

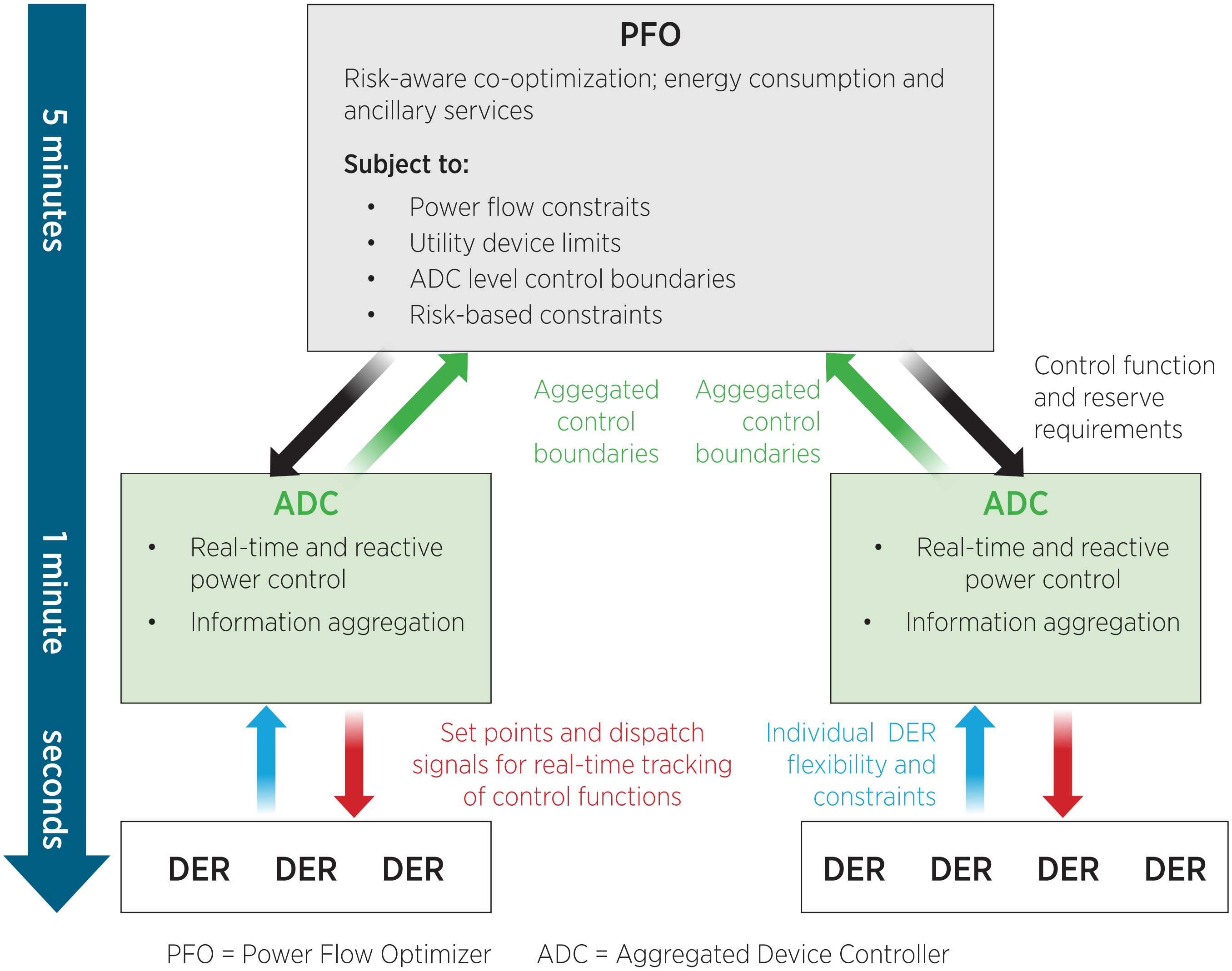


Figure 26. Integrated risk-aware optimization and real-time control strategy for distribution grid control with a large number of DERs.

Project Description

The *Control Theory* project team is developing new control theory solutions, including architecture and algorithms for distribution grids with the goal of enabling large-scale participation and integration of DERs in grid control and operation. Efficiency is achieved by ensuring synergy between the control architecture that dictates the information and decision flow and the corresponding control algorithms in a way that exploits separation of complexities and time scales.

The solution strategy consists of two primary building blocks: (1) aggregated device controllers (ADC) and (2) power flow optimizers (PFO). The ADC uses aggregated, controllable regions and bid curves to deploy a unified, real-time control strategy of otherwise highly inhomogeneous DERs. The PFO, which operates at a longer time scale, addresses risk-aware optimization, ensures incorporation and satisfaction of power-flow physics, and maintains safe operating margins in the presence of intermittent generation and load.

Reviewers' Overall Comments

Historically, the grid was a strictly hierarchical construction relying on the immense angular momentum of the central power stations for stability. The future grid will require the coordination of a much larger number of small and distributed resources on the supply and demand side. Thus, the grid of the future should have a fundamentally different design paradigm. The project provided a solution for resolving the power flow issues associated with a high degree of DER penetration, which is a very important problem, and evidence of these power flow issues exists at some utilities. The optimization formulation is well defined, and the solution approach is clear. The control platform must be supported by a communication platform and controllable DER, which is possibly a challenge for practical implementation of this system. Results must be disseminated to solution providers to ensure that the technology is put into practice. Knowledge dissemination could also include a mapping of the ADC and PFO platforms/functions with existing commercial platforms. Overall, the project is timely and valuable, as it provides solutions to system issues associated with a high degree of DER penetration.

While the results from this project are very valuable, the project team is not thinking far enough ahead. The current approach is hierarchical, and other approaches should be considered. The project should explicitly address mesh control models. Further, the project team should consider how the grid can adapt if components fail. New control-theoretic distributed models offer the potential for new approaches for resiliency. The project does not go far enough in this area. Optimization of distribution and sub-transmission level systems is crucial to the success of any modernization of the grid. As such, the project should also address sub-transmission-connected distributed resources.

In addition, the project may be creating some confusion with its terminology. While the project uses the term ADC, current IEEE terminology uses DERMS. Similarly, PFO may translate better as Distribution System Operator (DSO) or Transmission System Operator (TSO).

Moving forward, the team needs to work more with

1. The *Grid Architecture* project;
2. Interoperability standards organizations; and
3. Vendors that will implement the control paradigm.

DOE Feedback

Developing control paradigms for DERs is crucial to enable a future grid to use the millions of intelligent DERs—that continue to be installed across the country every day—in a way that can maintain the reliability and resiliency of the grid. This is an extremely difficult challenge that needs to build upon work from a variety of different fields, including advanced mathematics and grid architecture to name a few. This project will develop new paradigms for grid control based on theoretical constructs. Creating a stronger link between industry, standards organizations, and grid architecture will be next steps moving forward.

Multi-Scale Integration of Control Systems (EMS/DMS/BMS)

Project Number:	1.4.11
Principal Investigator:	Liang Min
Project Period:	May 2016 – December 2018

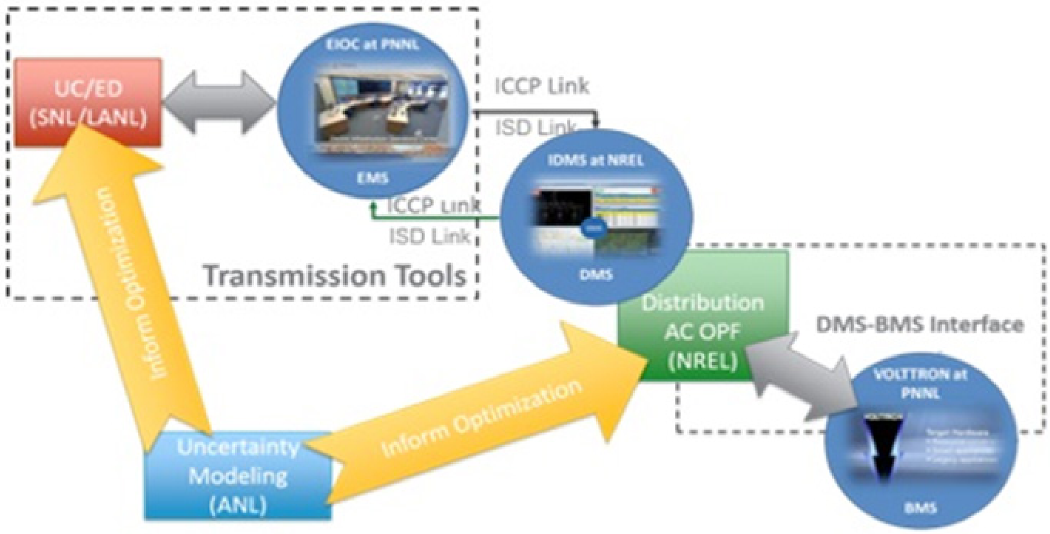


Figure 27. System architecture for EMS, DMS, and BMS.

Project Description

The current grid operating systems were developed over the last three to four decades within narrow functional silos. The control systems support a power system that is largely composed of central generation stations connected by high-voltage networks or grid-to-local distributions networks, which serve residential, commercial, and industrial loads. Electricity flows are primarily in one direction. With the increased use of DERs and the growing need to integrate customer devices, more advanced and integrated controls configurations are needed to increase the flexibility in future power systems. Better operating systems are required that can integrate among multiple components of this interconnected system for optimizing efficiencies and providing robust control.

The outcomes of the *Multi-Scale Integration of Control Systems* project create an integrated grid management framework akin to having an autopilot system for the grid's interconnected components—from central and distributed energy resources at bulk power systems and distribution systems, to local control systems for energy networks, including BMS. The team is developing an open framework to coordinate energy management system (EMS), DMS, and BMS operations. In addition, the project work is demonstrating the open framework and new operations applications.

Reviewers Overall Comments

The project team addresses a relevant industry requirement toward integration of DMS and EMS, especially with increasing DER penetration at the distribution level. The project team worked within the existing communication standards, setting the stage for greater industry acceptance. By the end of the project, the project team should ensure a comprehensive handover of this solution to stakeholders, especially to solution providers and utilities. The results of the DMS-BMS integration must be handed over to standards making bodies, such as IEEE and IEC, to help in setting the communication standards. Overall, these project technical results are commendable, and the proof of concept validation with an online demonstration of the integration signifies excellent project management and well-defined scope.

The three projects reviewed in the System Operations and Control technical area should have a summit to discuss how the projects are similar, different, how they overlap, and how they can be stretched. At root, they all ask how the future grid will be controlled, given that it will have many more components operated with control decisions being made at more points and closer to the load. This could be a very exciting and productive meeting.

DOE Feedback

As the reviewers have identified, the three projects identified in the System Operations and Controls area need close coordination. The *Grid Architecture* project serves as the foundation, and the *Control Theory* and *Multi-Scale Integration and Control* projects are operating at earlier and later technology readiness levels respectively. DOE is excited by the progress made and will strongly consider how these projects, and others, should be coordinated in the future.

Systems Operations, Power Flow, and Control Portfolio Overview Discussion

Systems Operations, Power Flow, and Control lead reviewer, outlined the challenges of developing grid architecture documents that will continue to be applicable in the future. He encouraged the GMLC to think about what the future grid will need and how to create tools that will be adopted to change industry. In order to best develop the modernized grid, GMLC will need to clearly articulate the problem each project addresses with a clear technology to market plan. The HELICS tool has been very successful and is being adopted by other projects, and DOE and the GMLC were encouraged to continue to use it in order to mature the product. However, he emphasized that the success of the tool will rely on its use across the whole stakeholder community.

The reviewers highlighted the important work done across the GMLC's large portfolio and recommended a holistic vision for the whole portfolio to make the pieces greater than the sum of its parts. More specifically, the challenges of developing different data models for every project was identified, and recommendations include a common dictionary as the starting point for commonality.

Finally, DOE should leverage its regional studies to develop regional- and state-focused projects that cater to the specific stakeholders, organizations, and issues in each region.

Looking Towards the Future

As the first Grid Modernization Lab Call (2016) comes to an end, the GMI will expand on the work started in 2016 with several major changes:

- Fully Integrated Vision: This effort will focus on a more fully integrated vision of the energy system, from fuel to generation to load, including interdependent infrastructures.
- Reliability and Resilience: This effort will strengthen, transform, and improve the resilience of energy infrastructure to ensure access to reliable and secure sources of energy. The complexity of the electricity grid and its interconnection with other critical systems can accentuate the risk of cascading failures. As a result, it is paramount that the grid is reliable and resilient against all malicious threats, natural disasters, and other systemic risks, such as human error or its dependence on other critical systems.
- GMI will rreflect a collaborative partnership among five DOE offices (the Applied Research Offices), including the Office of Fossil Energy (FE), the Office of Nuclear Energy (NE), the Office of Electricity (OE), the Office of Energy Efficiency and Renewable Energy (EERE), and the Office of Cybersecurity, Energy Security, and Emergency Response (CESER).

Thank You

Peer reviewers are vital to the success of projects and programs at DOE. Their input provides GMI with a powerful and effective avenue for enhancing the management, relevance, effectiveness, and productivity of the grid modernization project portfolio. The GMI peer reviewers committed to reviewing hundreds of pages prior to the review, as well as many hours after the actual review for follow-up actions. For their subject matter expertise and selfless actions, DOE—especially the GMI leadership team—would like to express its profound thanks to the following GMI peer reviewers:

Reviewer	Affiliation
John Adams	Electric Reliability Council of Texas
Tracy Babbidge*	Connecticut Department of Energy and Environmental Protection
Dave Bakken	Washington State University
Venkat Banunarayanan*	National Rural Electric Cooperative Association
Frances Cleveland	Xanthus Consulting International
Bob Cummings	North American Electric Reliability Corporation
Flora Flygt	Retired (American Transmission Company)
Kevin Fox	Duke Energy
Sheri Givens	Givens Energy
Rachel Goldwasser	New England Conference of Public Utilities Commissioners
Bryan Hannegan*	Holy Cross Energy
Paul Hudson	General Infrastructure, LLC
Rick Meeker	Nhu Energy
Craig Miller*	National Rural Electric Cooperative Association
Reynaldo Nuqui	ABB Inc.
Wanda Reder	Grid-X Partners
Bruce Rogers	Electric Power Research Institute
Ramteen Sioshansi*	The Ohio State University

**Lead Reviewer*

Finally, we would like to thank BCS; Energetics; and AtherQuest Solutions for providing support for all aspects of this review and ensuring that the peer review ran smoothly.

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