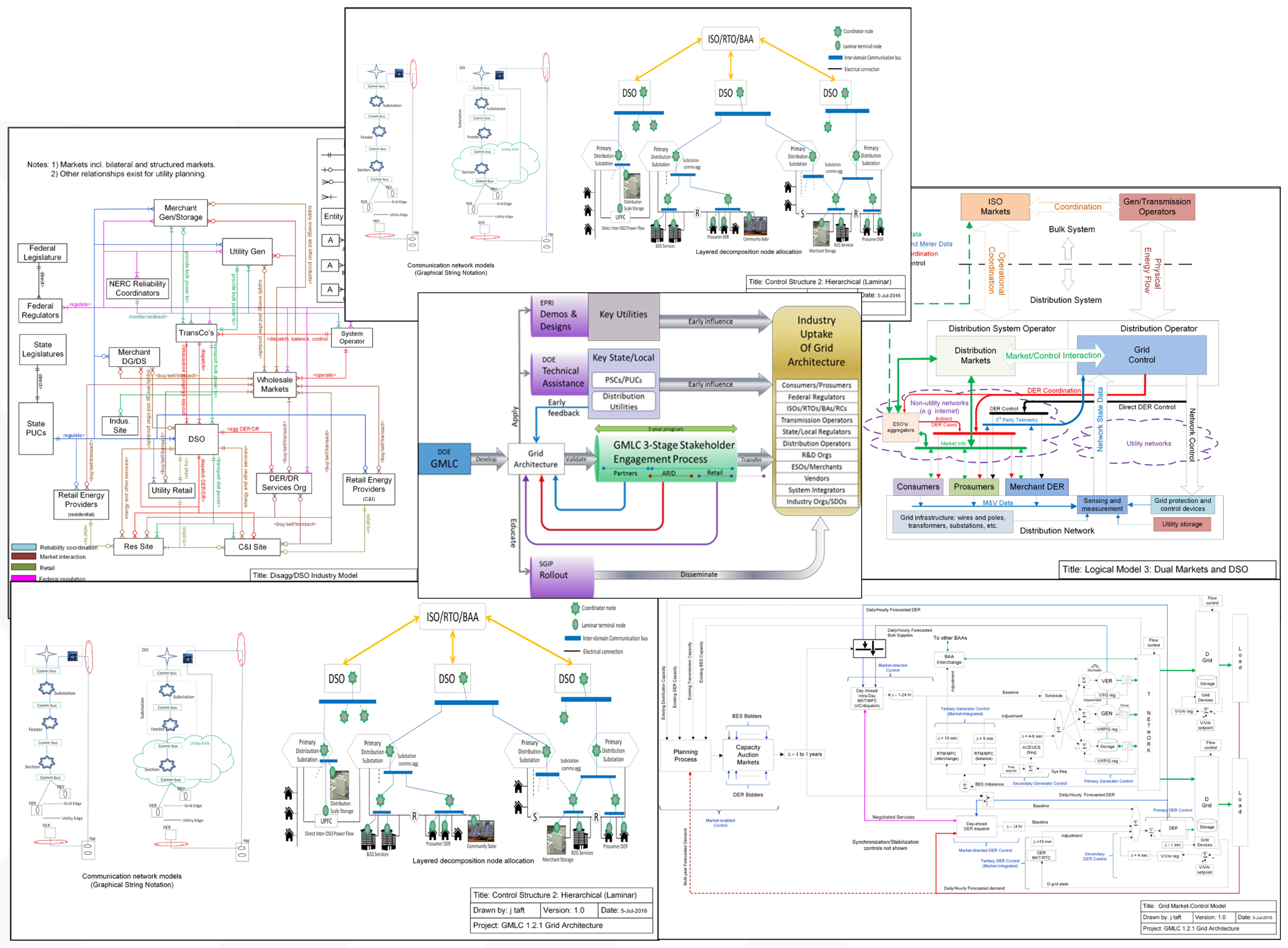
Grid Architecture

Project Description

Grid Architecture is the application of system architecture, network theory, and related disciplines to the whole grid, seen as a network of structures. This project is building a new stakeholder-driven grid architecture reference set, providing it to industry along with the tools and methods to adapt it to their needs, and coordinating with other GMLC projects.



The Grid Architecture project is providing methods and tools to the electric industry, such as architectural views containing structure drawings, specifications, and component models, that describe the future design of the power grid.

Expected Outcomes

- Build stakeholder consensus around a DOE-convened vision of grid modernization, expressed as a new set of grid reference architectures.
- Enable superior stakeholder decision-making to reduce risk of poor functionality and stranded investments.
- Provide a used and useful framework for GMLC projects,
- Establish and win industry acceptance for the use of Grid Architecture work products and methodologies for grid modernization.
- Develop tools, architectural depictions, and skills to help the electric industry and extended stakeholders achieve a national consensus for grid modernization.
- Supply a common basis for roadmaps, investments, technology and platform developments, and new services and products for the modernized grid.

Significant Milestones	Date
Architecture Initialization	10/2016
Reference Model Development	10/2016
Component/Interface Model Development	4/2017
Architecture Development	10/2017
Architecture Validation	4/2018
Architecture Completion	10/2018

Progress to Date

- Completed lists of emerging trends and systemic issues, and created architectural views list containing structure drawings, specifications, and component models that describe forward-looking design of grid.
- Set priorities for architectural scenarios with external partners.
- Established initial collaboration with 11 other GMLC programs to ensure consistency across programs.
- Developed reference models, structure diagrams for market control mechanisms, and industry structure models for high distributed energy resource grids.
- Created six component/interface models needed to support development of complete architectures.
- Conducted training for SGIP, carried extensive outreach via webinars, presentations, and direct meetings; applied Grid Architecture in the DSPx project and elsewhere; and delivered architecture package to GMLC control theory team.

Southeast Regional Consortium

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Create a consortium of utilities, universities, national laboratories, regulators, and industry in the southeast to address grid related technical challenges specific to this region.

Expected Outcomes

- Southeast Regional Workshop
- Technical Demonstrations
  - Dual secure wireless communications demo at Duke Energy
  - Optical sensors for step-distance protection and bidirectional power flow for distribution.
  - Time sensitive networking test at EPB
  - Test of CSEISMIC app based distributed controller.

Significant Milestones

Significant Milestones	Date
Complete Design of Design of Wireless Sensor Network	9/30/2016
Hold Southeast Region Workshop	3/30/2017
Documentation of optimization for restoration of at least one distribution feeder	12/31/2016
Report detailing the development of the Geographic Information System with Duke Energy's Distribution Feeders	5/31/2017
Complete Demonstration of Wireless Sensor Network at Duke Facility	6/30/2017
Report detailing test results of time sensitive network hardware and protocols	3/30/2016
Document functional verification of CSEISMIC distributed controls	3/30/2016
Document design and testing of optical step-distance protection	3/30/2016
Finish integration of distributed controls on EPB site-specific infrastructure	12/31/2016

Progress to Date

- Held southeast regional workshop at the Clemson Zucker Center with attendees
  - DOE OE ISER, DOE SR, Duke Energy, Santee Cooper, SCE&G, Southern Company, Electric Power Board, EPRI, General Electric, Resilient Power Systems, Clemson University, UNC Charlotte, NC State, ORNL, SRNL, PNNL
- Technical demonstrations are nearly complete.

U.S. DEPARTMENT OF ENERGY

OAK RIDGE National Laboratory · SRNL SAVANNAH RIVER NATIONAL LABORATORY · epb · UNC CHARLOTTE

Systems Operations and Control

April 18, 2017

Smart Reconfiguration of Idaho Falls Power Distribution Network for Enhanced Quality of Service

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

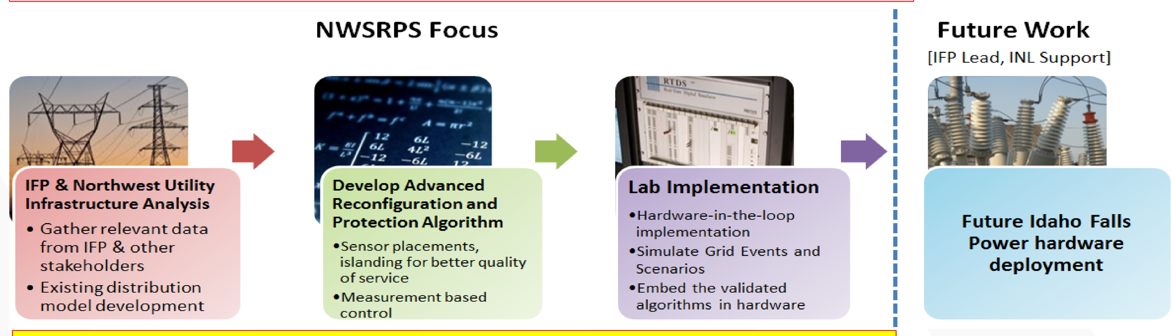
- Develop methods for keeping as much of the system operating as possible during **system events** at **transmission or distribution level**
- **Provide a generalized roadmap**, including **best practices based on the regional case for IFP**, which the utilities and power system operators across the United States can use
- Show **effectiveness** of the implemented **smart reconfiguration schemes** in **comparison to state-of-the-art**

Expected Outcomes

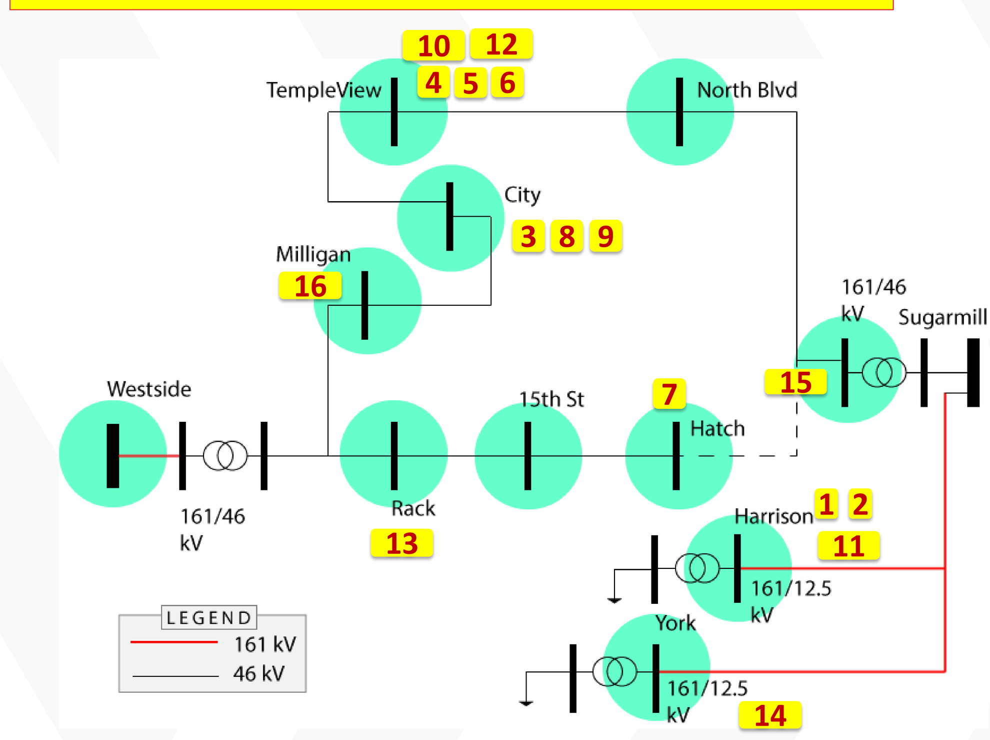
- Baseline for the IFP grid via a digital blueprint
- Improved reliability and resiliency of IFP grid by serving critical loads during outages
- Smart reconfiguration and protection schemes for islanding and resynchronization using advanced measurements for a regional distribution grid
- A generalized roadmap for using a digital blueprint approach for developing and implementing advanced reconfiguration and protection methodologies in distribution grids

Significant Milestones	Date
Digital Blueprint	Sep. 2017
HIL with one relay (700G)	Dec. 2017
Evaluation of PMU data from dynamic simulations	Dec. 2017
Transmission fault scenarios / events	Dec. 2017, Ongoing
Black start demo with one hydro-generator and HIL	Mar. 2017
Reconfiguration algorithm	Dec 2017
Include dynamics in reconfiguration algorithm	Ongoing
Tech Transfer / Regional Collaboration	
- SunValley Institute, Blaine County, ID	Feb. 2017
- Richland Energy Services, Richland, WA	Mar. 2017

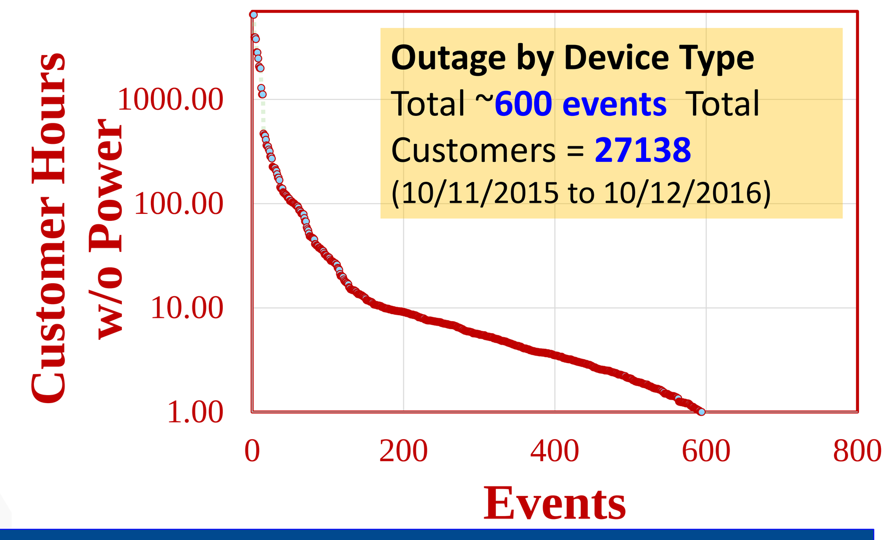
Project Scope and Timeline



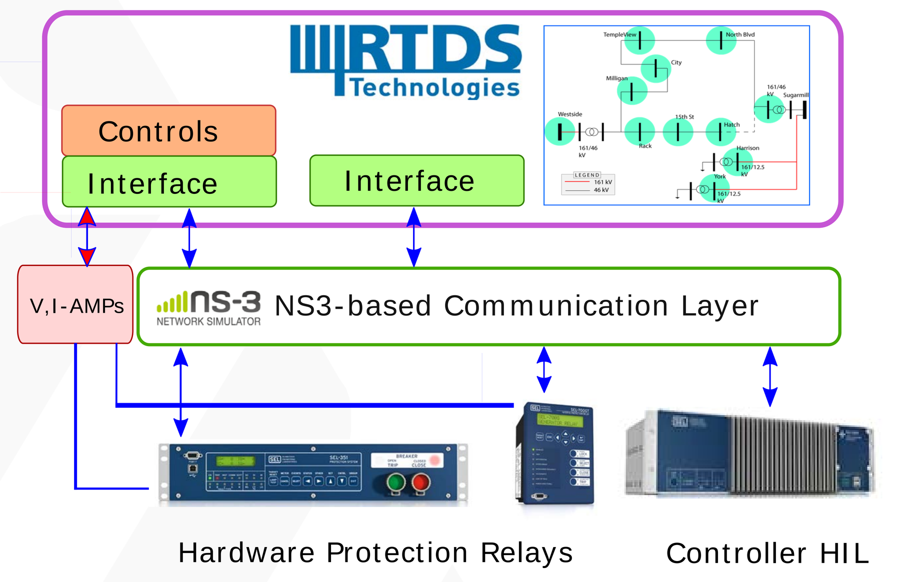
Critical Loads in IFP Digital Blueprint



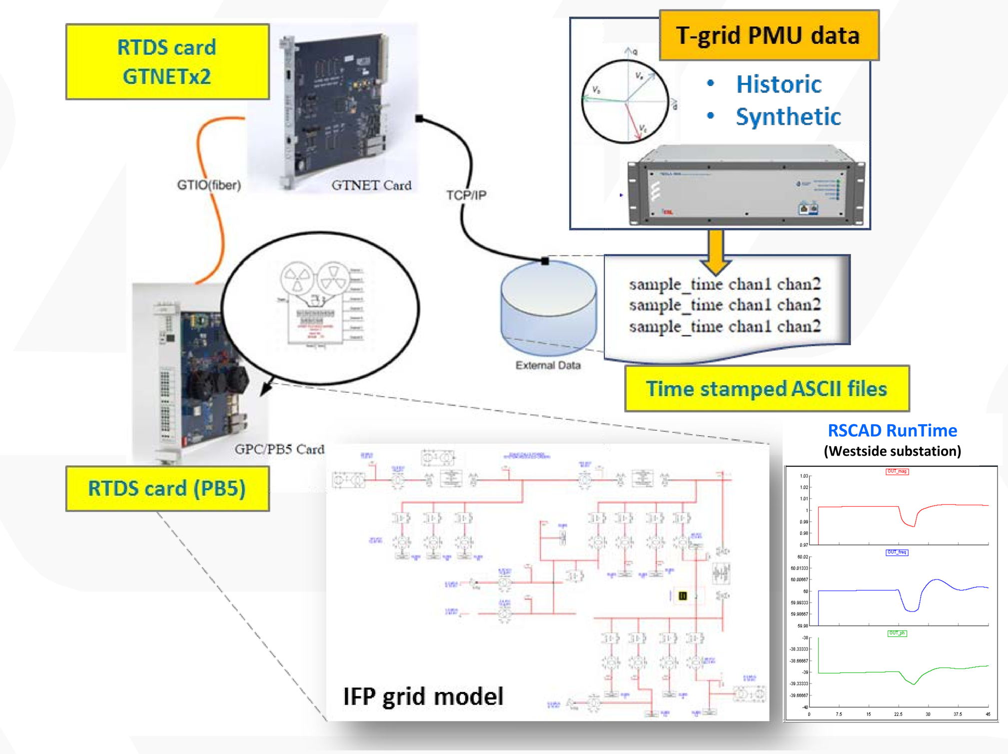
Establishing a Baseline



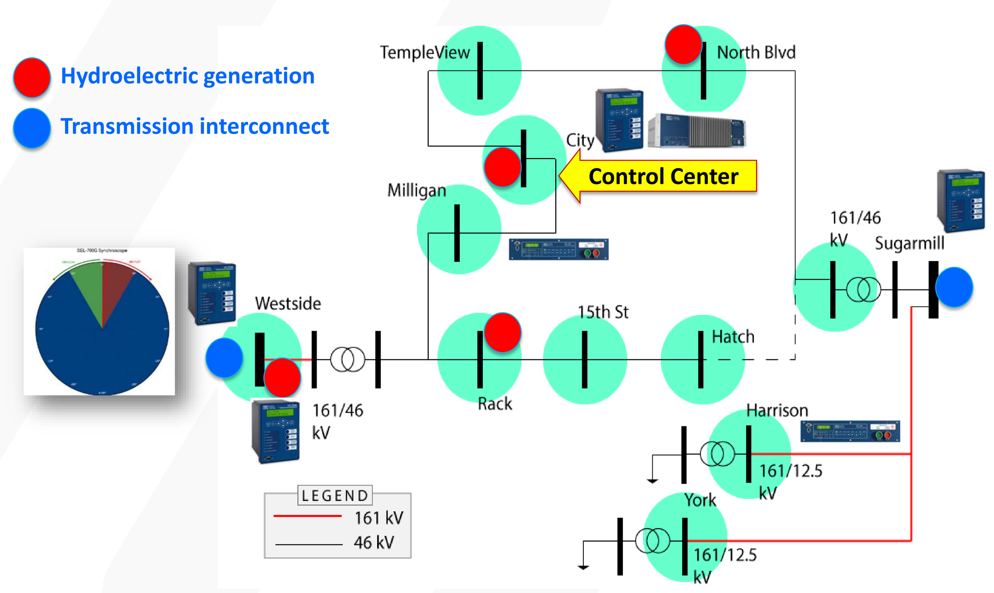
NS3-based Communication Layer Emulation



PMU Event Data Replay in RTDS



Hardware-in-the-Loop Testing for Black Start



Progress to Date

- Real-time **digital blueprint** of Idaho Falls Power distribution grid network for **baseline**
- **Critical load** priorities and locations identified in IFP digital blueprint
- **PMU event data** synthesized using realistic scenarios
- **Black start** of one City Bulb hydro-generator with **HIL**
- **NS3-based** communication layer for **co-simulations**
- Established **cross-project contributions** and interest from **regional** utilities for future projects

Vermont Regional Partnership: Facilitating the Effective Expansion of Distributed Energy Resources

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

GMLC 1.3.10 PI: Robert Broderick (SANDIA); Plus 1: Mark Ruth (NREL)

Utility Partners

Green Mountain Power; Vermont Electric Co-op Inc; Vermont Electric Power Company VELCO

University Partners

The University of Vermont; Georgia Tech

Project Description & Objective

Develop an optimal and replicable approach to distributed energy resource (DER) integration at the distribution level to meet the state's goal of 90% renewable energy penetration by 2050. Key insights from what we learn in Vermont can be applied to the rest of the nation.

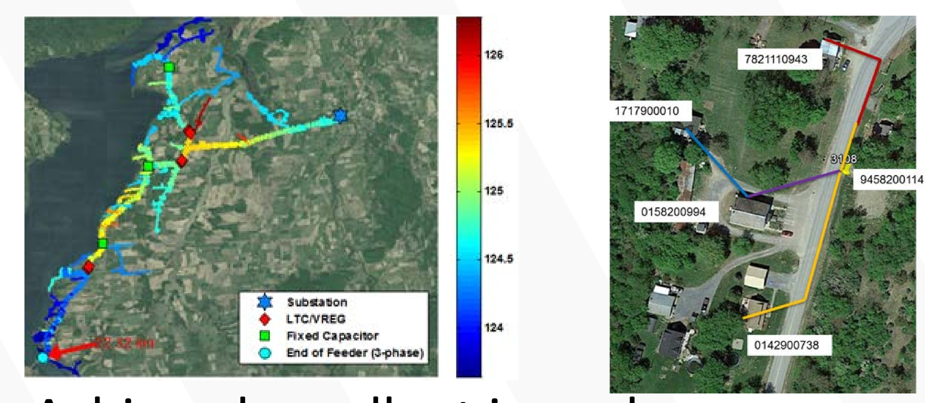
Expected Outcomes

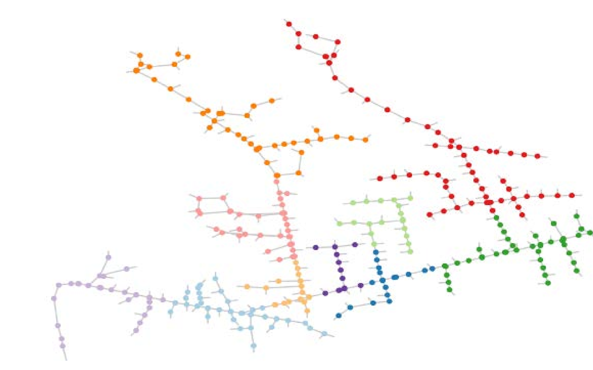
1. Achieve high levels of DER integration without causing negative impacts to the distribution system
2. Develop a replicable approach for DER integration at the distribution level in each of the three task areas
3. Disseminate the results and replicate methodology for other stakeholders

Significant Milestones Completed	Date
Task 1 – DER integration Received Seven models, AMI data and controller data. Begin conversion and data cleaning. Data integrated into models for running analysis and visualization	3/30/2017
Task 2– DER control Formulate network model and develop preliminary optimization algorithms. Grid LAB-D models, populated with residential ES system models, running in IESM. Update algorithms after analysis and simulation. Ability to control residential ES systems from aggregator module within IESM demonstrated.	3/30/2017

Task #1: DER Integration and Modeling

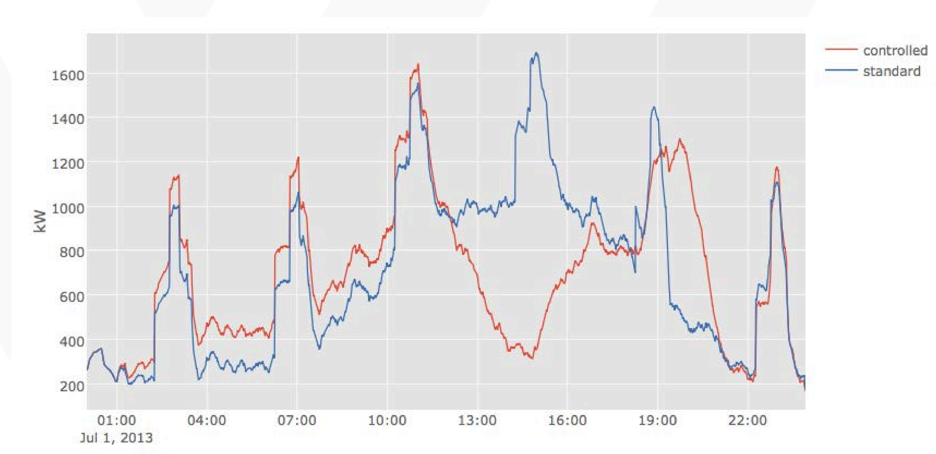
Goal: Improve distribution system models through innovative parameter estimation methods and use them to determine optimal amount and placement of photovoltaic (PV) solar and battery storage


Achieved excellent impedance estimates on Panton – 9G2 Feeder

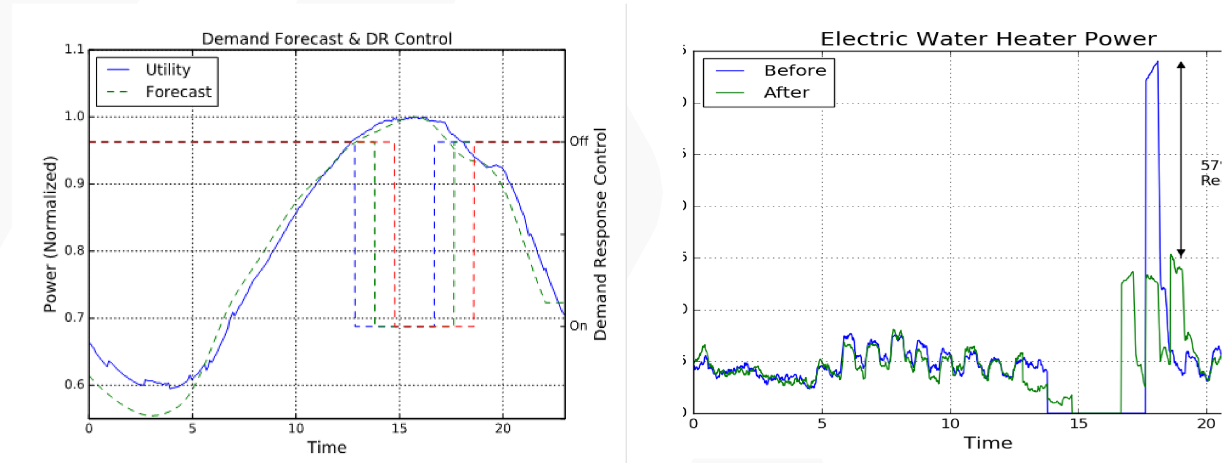

Developed circuit reduction methods for energy storage optimization

Task #2: DER Control & Optimization

Develop and validate new control strategies for managing demand response rebound effects



Developed & populated model of Green Mountain Power ER-G51 feeder with aggregator control and showed peak shaving

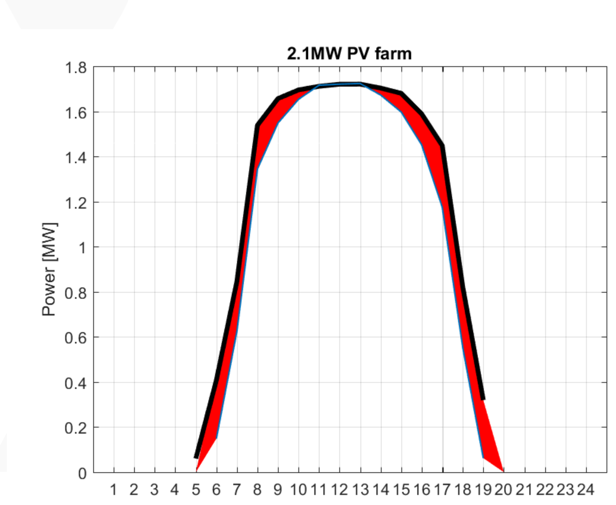


Developed multiple bin control approach that shaves water heater peak load and reduces rebound. Initial estimate of 57% reduction in rebound peak

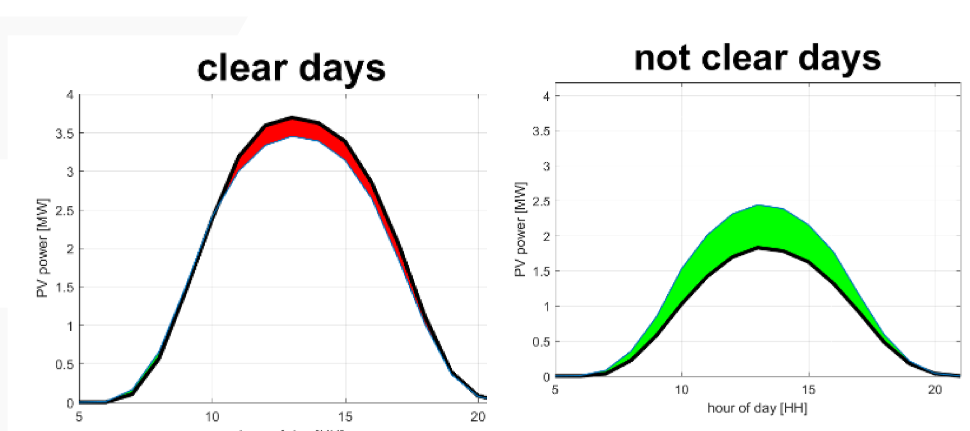
Task #3: DER Forecasting

Improvements to the solar forecasting to improve generation predictions and system management. Identified three:

- Account for azimuth of PV modules
- Faster adjustments to changes in distributed PV capacity
- Separate forecast training on clear vs. cloudy days



Capture dual axis tracking and module azimuth



Separate forecast training on clear and cloudy days

Clean Energy and Transactive Campus Project (CETC)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

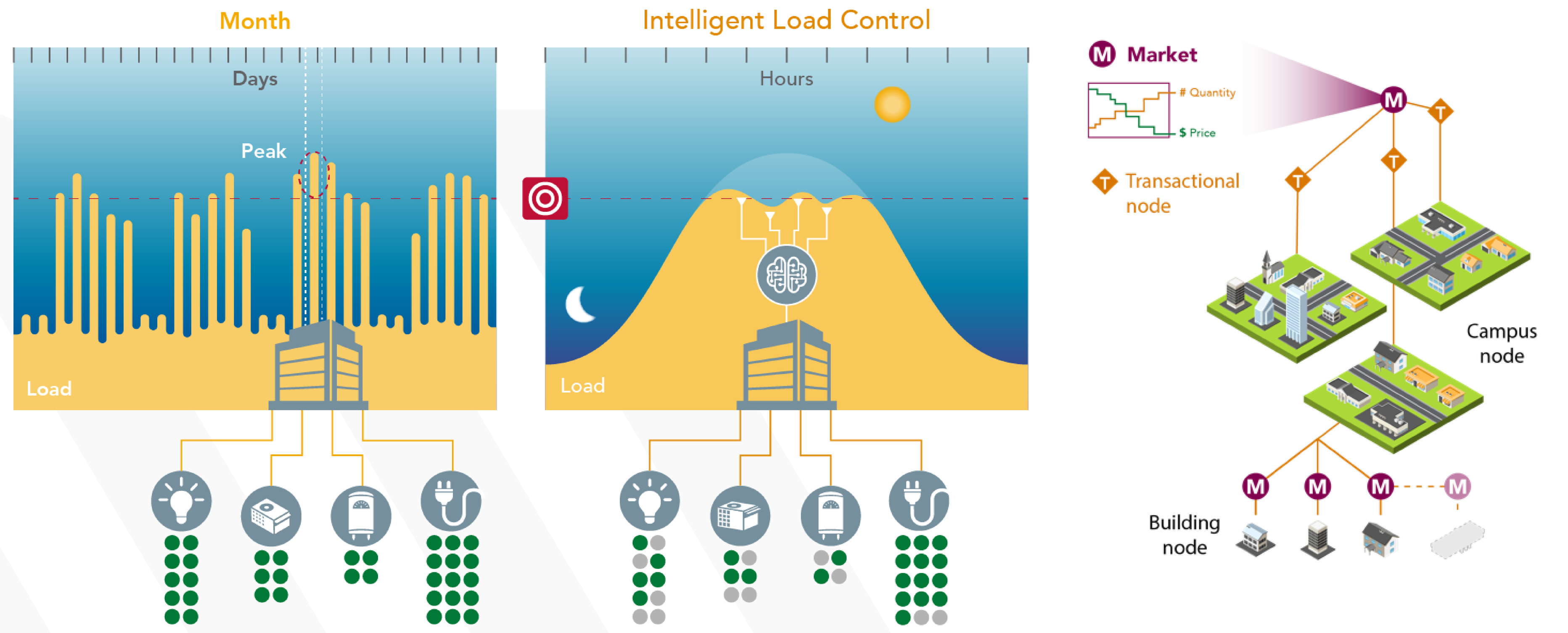
Project Description

CETC will create a “recipe” to replicate and scale transactive control technologies for application in buildings, campuses, and communities across the nation. CETC will also establish a clean energy and responsive building load research and development infrastructure in Washington and Ohio

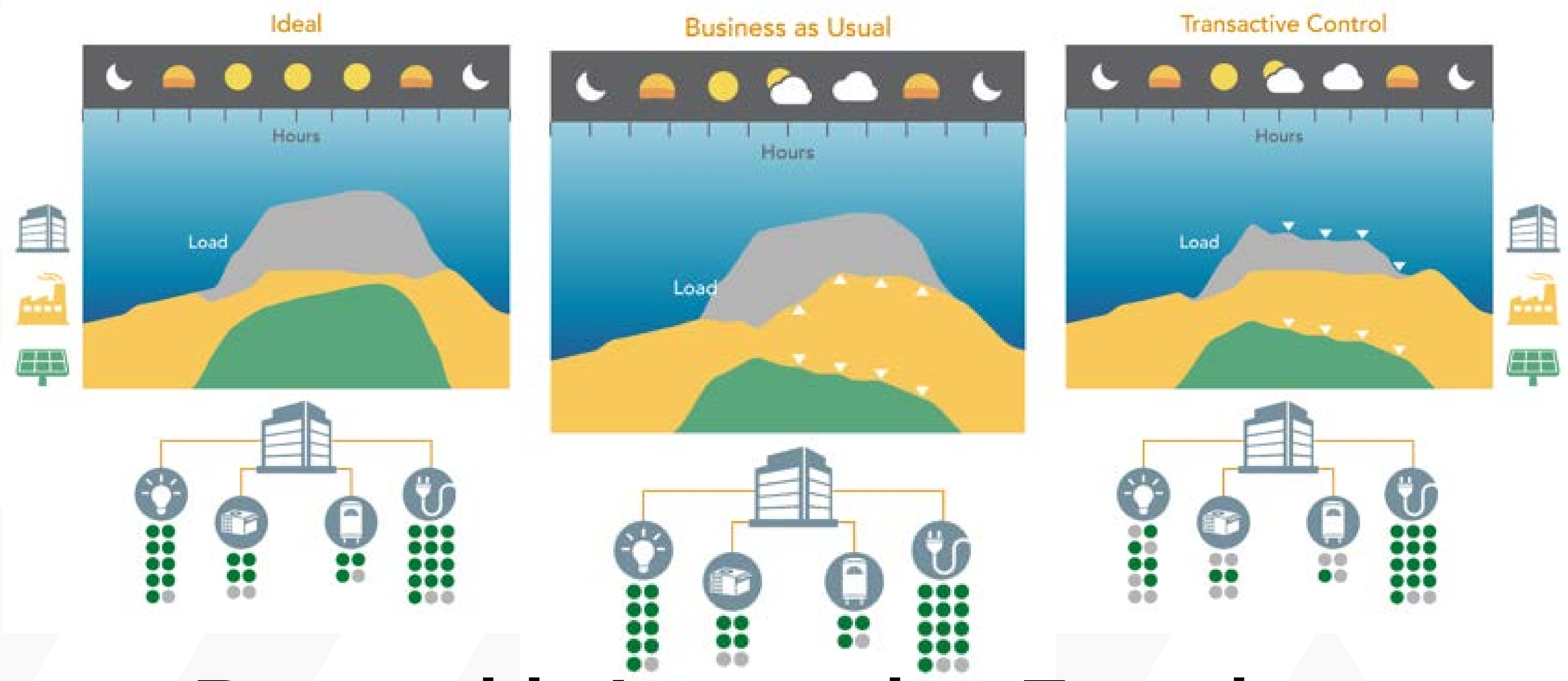
Expected Outcomes

- CETC will provide tools that enable the buildings sector to replicate the project’s technology implementations and methods, leading to **improved energy efficiency**, **increased integration of renewable energy, and enhanced power grid reliability**
- **Outcomes of the project include**:
  - **Short-term (immediate)**: Development, validation, and release of open source energy efficiency and transactive control software tools compatible with VOLTTRON™; associated technical documentation and user guides that will comprise the “recipe” and enable replication
  - **Medium-term (<3 years)**: Two or more energy service providers to deploy the software tools to benefit buildings and the grid
  - **Long-term (>3 years):** One or more utilities to deploy transactive energy concepts at a distribution scale

Significant Milestones	Date
Preliminary report of transactive controls on PNNL campus project	9/30/16
Development and testing of “max-tech” controls complete	9/30/17
Testing and validation of multiple-campus experiment complete	12/31/18



Transactive Control Experiments



Renewable Integration Experiment

Progress to Date

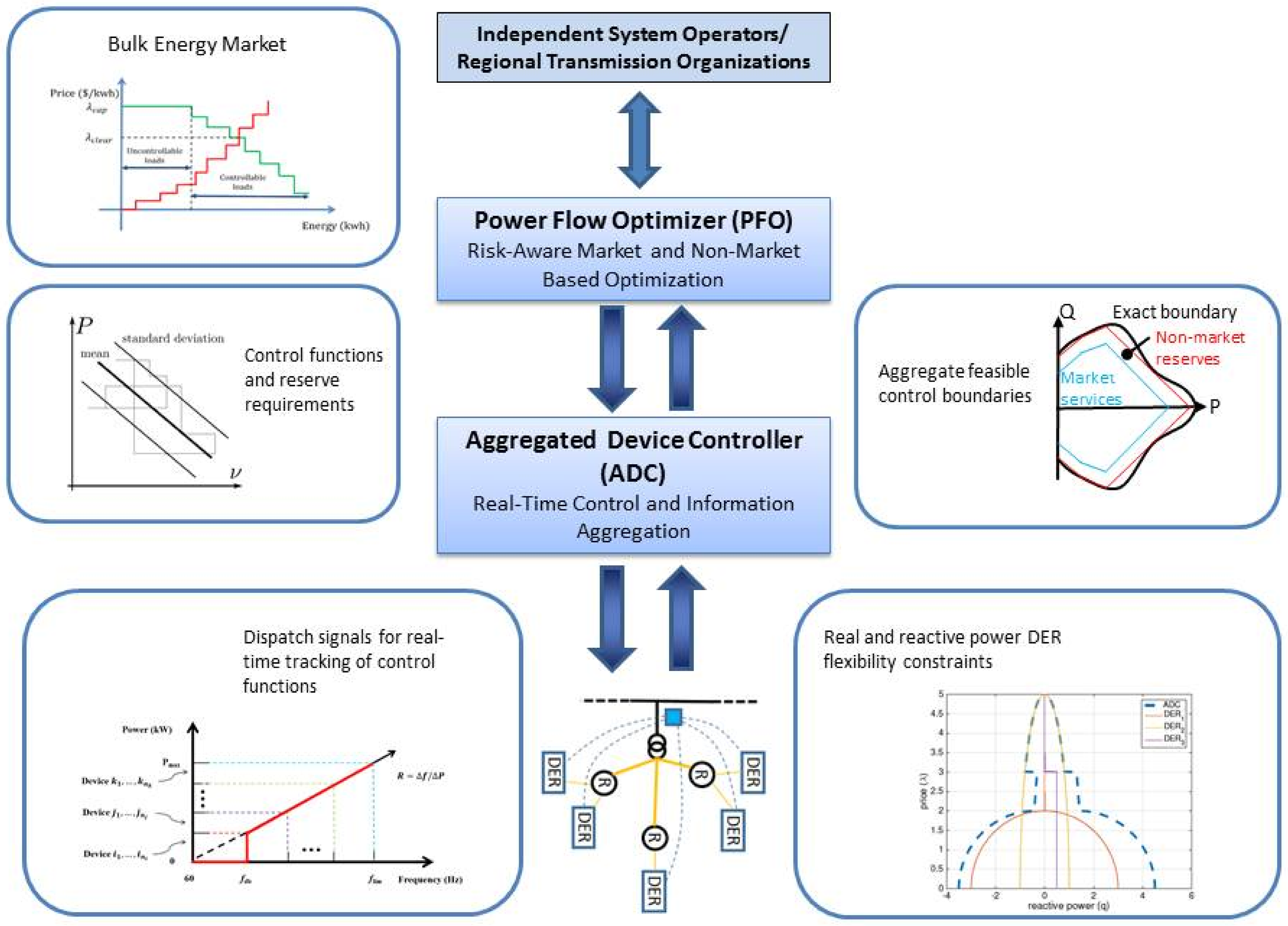
- Three transactive control and one energy efficiency experiment designed, developed, and validated on PNNL campus buildings
  - 5 peer-reviewed journal papers and one magazine article published
  - 4 technical reports and 4 user guides completed
- Solar panels, totaling 100 kW, and micro-inverters installed and commissioned at University of Washington
- 72 kW PV system and inverters procured, installed, and operational and VOLTTRON nodes integrated into PVs at Washington State University

GMLC 1.4.10: Control Theory

Project Description

The focus of this project is to develop new integrated optimization and control solutions, including architectures, algorithms, and deployment strategies for the U.S. power grid. This effort will support the GMLC multi-year program plan vision for transitioning the power grid to a state where a huge number of distributed energy resources (DERs) are participating in grid control. The specific objectives of the project are to:

- Ensure architectural compatibility of control theory and solutions.
- Coordinate and control diverse DERs (>10,000) with widely different responses.
- Incorporate power flow physics and network constraints into control solutions.
- Systematically manage uncertainty from intermittent generation and large number of controlled DERs.
- Integrate with legacy and bulk power system markets.



Interfaces for PFO and ADC systems

Expected Outcomes

- Integrated optimization and control systems that are more effective at maintaining operating margins.
- A 33% decrease in cost of reserve margins while maintaining reliability by 2025.
- Interconnection of intermittent power generation with less need for electrical storage and lower integration costs.

Significant Milestones	Date
Documented architectural reference models for control	11/1/2016
Completed integrated optimization and control theory roadmap	11/1/2016
Documented real-time control strategies for providing ancillary services from aggregated DERs	10/1/2017
Completed risk-aware control of ~10,000 DERs	10/1/2018

Progress to Date

- Completed integrated optimization and control theory roadmap consisting of:
  - Reference control system architectures
  - Cataloged existing and alternative power flow approximations and relaxations
  - Method for determining aggregate DER real and reactive power controllable domains
  - Design of real-time control strategies for aggregated DERs with uncertainty quantification.
- Validated architecture and development roadmap with Industry Advisory Board (Go/No-Go milestone).
- Submitted 5 conference papers and 2 journal articles.

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

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

This project aims to create an integrated grid management framework for the end-to-end power delivery system – from central and distributed energy resources at bulk power systems and distribution systems, to local control systems for energy networks, including building management systems.

Expected Outcomes

- Develop an open framework to coordinate EMS, DMS and BMS operations.
- Demonstrate the new framework on a use case at GMLC national lab facilities.
- Deploy and demonstrate new operations applications on that framework.

Significant Milestones	Date
FY16 Mid-year Milestones: Completed the use case report and data exchange requirements/protocols report.	12/2/2016
FY16 Annual Milestones: Complete integration of LANL ED with SNL UC engine; Complete integration of renewable forecasting into UC and ED.	3/30/2017
FY17 Annual Milestones: Demonstrate integration of DMS and BMS information on the use case proposed under task 1; Complete the formulation of new DMS/BMS applications for EMS operations and implementation into UC/ED.	3/30/2018
FY18 Annual Milestones: Successfully demonstrate integrated EMS/DMS/BMS platform; Demonstrate new DMS/BMS applications in UC/ED EMS; Demonstrate the uncertainty modeling and forecasting method in the integrated EMS/DMS/BMS system.	3/30/2019

National Lab Team: Liang Min and Philip Top/LLNL, Mark Rice and Emily Barrett/PNNL, Yingchen Zhang and Rui Yang/NREL, Cesar Silva-Monroy/SNL, Sidhant Misra/LANL, and Zhi Zhou/ANL

Partner: Anjan Bose/WSU

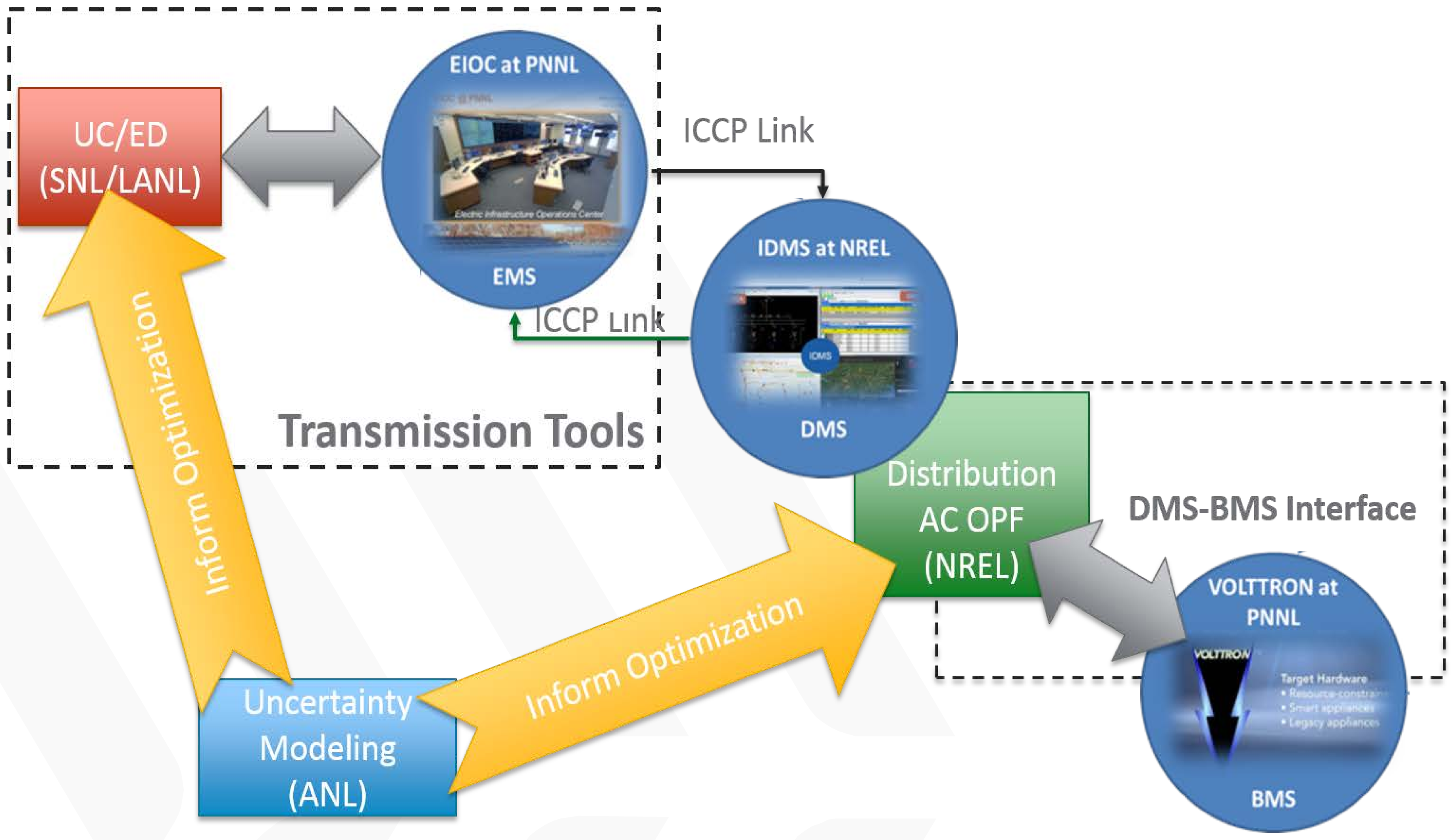


Figure 1 EMS/DMS/BMS System Architecture

Progress to Date

- Completed Version 1 of use case document and communication/control requirements document.
- Implemented the BMS in VOLTTRON™, which allows for control actions based on communication from the DMS.
- Collected Duke Energy's distribution data and PJM's transmission data for the Y2 and Y3 demo.
- Completed the benchmarking of stochastic unit commitment and economic dispatch.
- Completed integration of stochastic Unit Commitment (UC) and stochastic Economic Dispatch (ED); Completed integration of renewable forecasting into UC and ED.

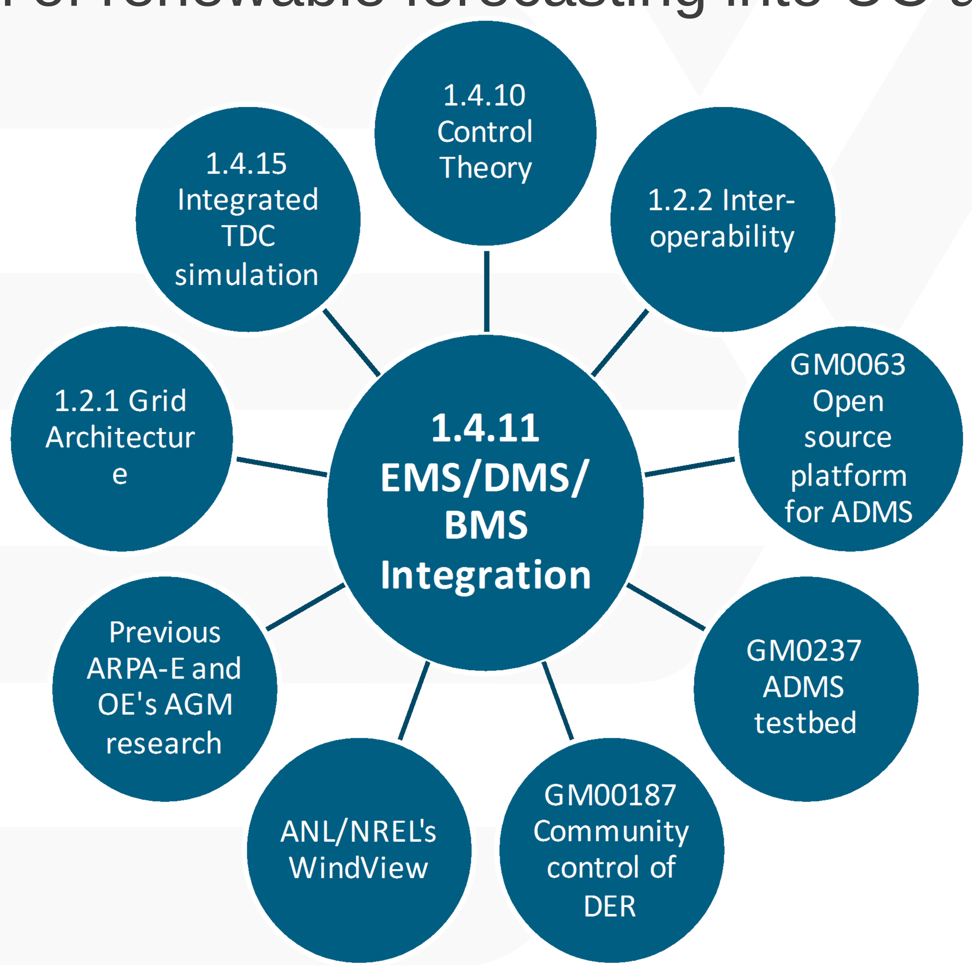


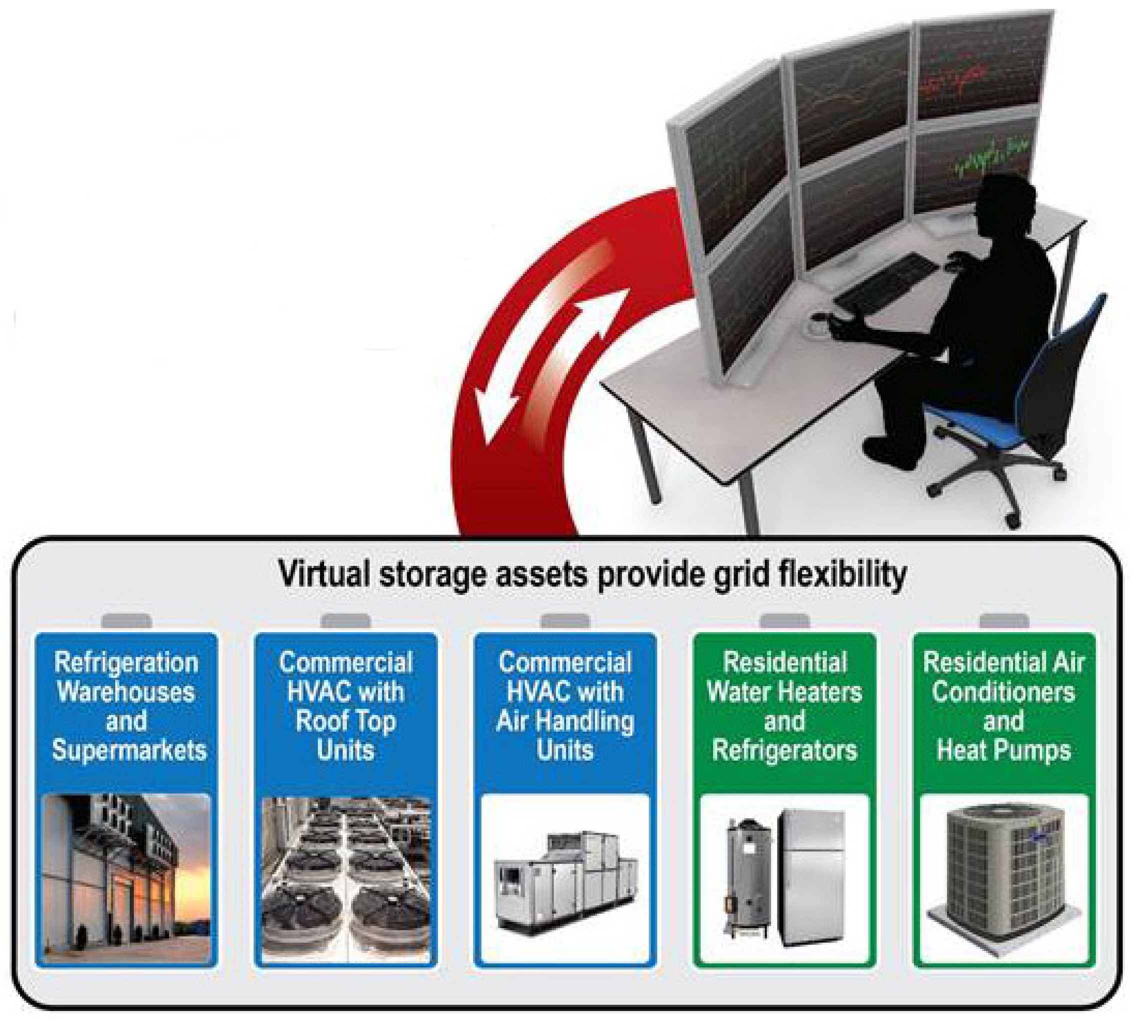
Figure 2 Project Integration and Collaboration

Virtual Battery-Based Characterization and Control of Flexible Building Loads Using VOLTTRON

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

The need for grid flexibility is growing, and energy storage could be a key part of delivering that flexibility. While grid-scale energy storage technologies are rapidly improving, they still require considerable capital investment, while existing residential and commercial building infrastructure, such as water heaters and air conditioning systems, might be able to provide distributed "virtual storage" at a much lower first cost. This project is working to identify, quantify, and assess the difficulty of controlling these virtual storage assets to complement grid-scale physical energy storage systems.



Decision support tools developed by this project allow building owners and utilities/grid operators to quantify the amount of virtual storage potential.

Expected Outcomes

The major outcome is to provide the lowest-cost delivery of grid services using behind-the-meter virtual storage assets enabled by:

- Flexibility screening tools that provide building owners and utilities a means of quantifying the potential of virtual storage resources to provide grid services.
- Decision-support tools for grid operators and building owners to evaluate investments for using virtual storage resources.
- Widely available control applications implemented in VOLTTRON that enable virtual storage assets to provide grid services.
- Testing in realistic environments to prove that virtual storage resources can complement physical storage systems.

Significant Milestones	Date
Flexibility characterization methods developed for residential and commercial buildings	2/2017
Control apps developed in VOLTTRON and deployed in at least one test site	12/2017
Completed techno-economic assessment of virtual building and dedicated grid storage systems	2/2018

Progress to Date

- Performed a national opportunity assessment to quantify the potential (GW/GWh) virtual storage resource. If all assets could be engaged, the maximum virtual storage resource would be a power capacity of 81 GW (approximately 10 percent of national generation capacity).
- Developed first version of flexibility screening tool that enables users to assess regional (state and county) power and energy limits from virtual storage assets.
- Completed preliminary benefit assessment study for California, including revenue assessment and physical storage requirements.
- Simulated tracking of BPA balancing reserves with 100,000 electric water heaters.

Pacific Northwest NATIONAL LABORATORY
OAK RIDGE National Laboratory
UF UNIVERSITY of FLORIDA
United Technologies Research Center
TVA
BONNEVILLE POWER ADMINISTRATION

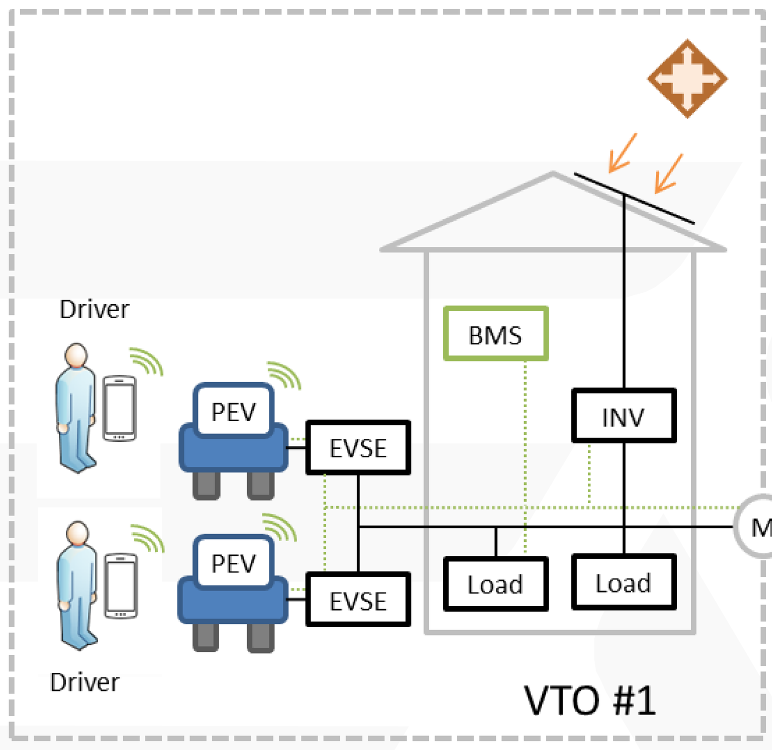
GM0062: Vehicle to Building Integration Pathway

**Multi-Lab Team: ANL *(Keith Hardy & Jason Harper)*, INL *(Don Scoffield)*,
LBNL *(Samveg Saxena & Dai Wang)*, NREL *(Andrew Meintz & Myungsoo Jun)*,
and PNNL *(Rick Pratt(rmpratt@pnnl.gov) and Carl Miller)***

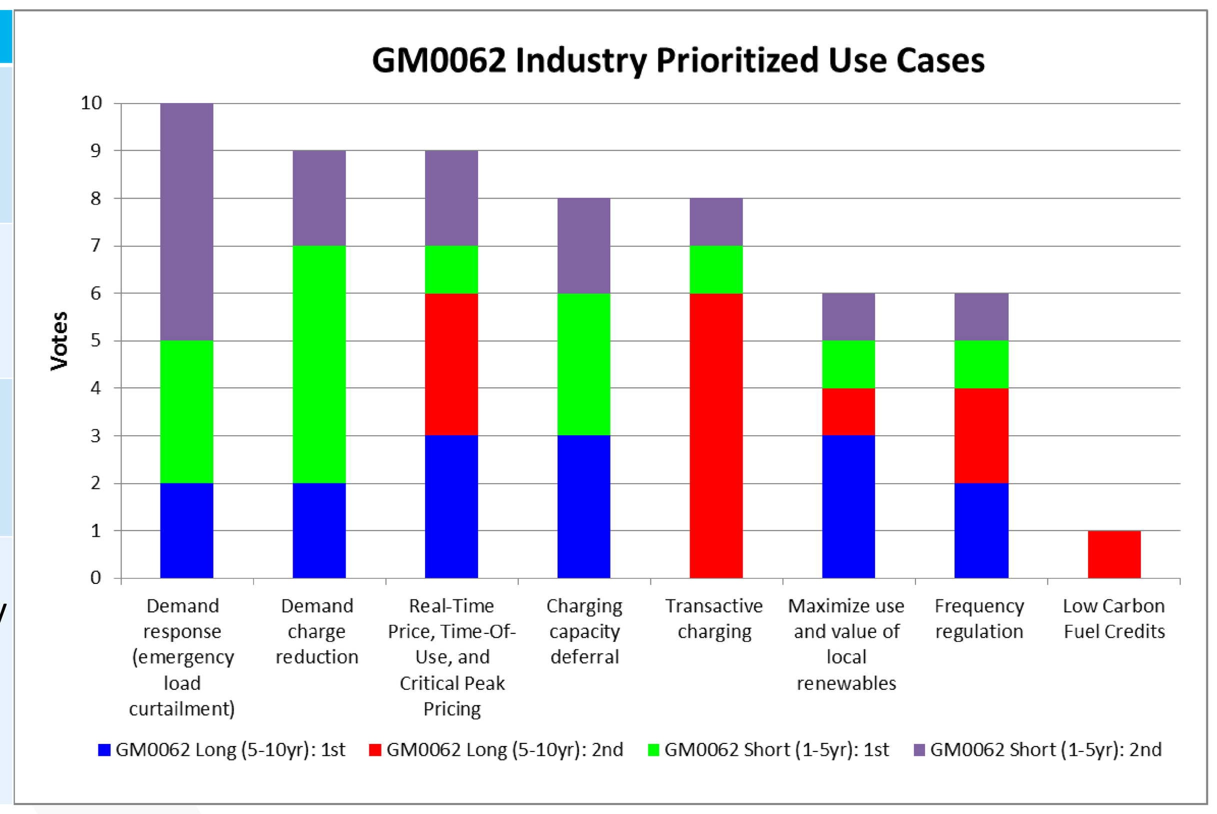
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Demonstrate a scalable communications and control system that enables managed energy use between dissimilar grid-connected devices (i.e., PEV/EVSEs, building systems, and rooftop photovoltaic (PV) arrays) in the workplace and mitigate building owner's demand charges

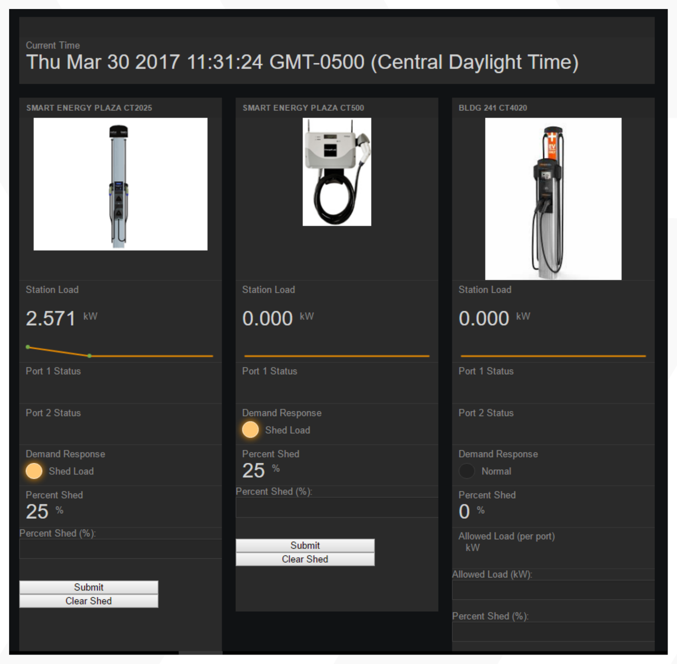


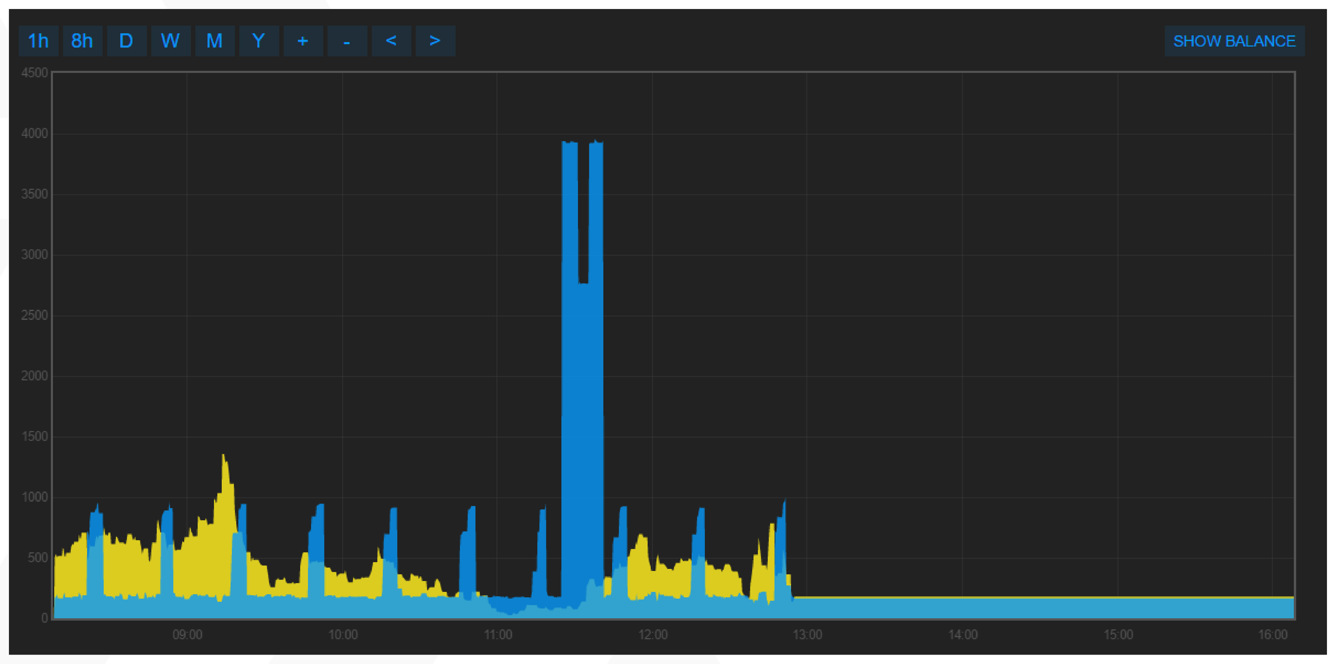
Time Horizon	GM0062 Use Cases		
Short (10's of seconds)	Demand Charge Mitigation	Frequency Regulation	Maximize Local Renewables
Medium (10's of minutes)	RTP (Real-Time Price)	CPP (Critical Peak Price)	
Long (10's of hours)	Demand Response (DR)	TOU (Time-Of-Use)	Charging Capacity Deferral
Transactive	Example: 5-minute market with an energy and electricity price relationship. Loads negotiate energy demands with market coordinator based on the load's price sensitivity. An initial implementation is closed-loop RTP.		



Expected Outcomes

- Publically available modular software design to implement and test algorithms and control methods
- A physical platform to develop and test control system performance
- Demonstrations promoting commercialization of hardware and software methods and provide standards committee's technical requirements basis.
- Economic value will be determined using tools developed in GM0086, Simulations Supporting Vehicle Grid Integration

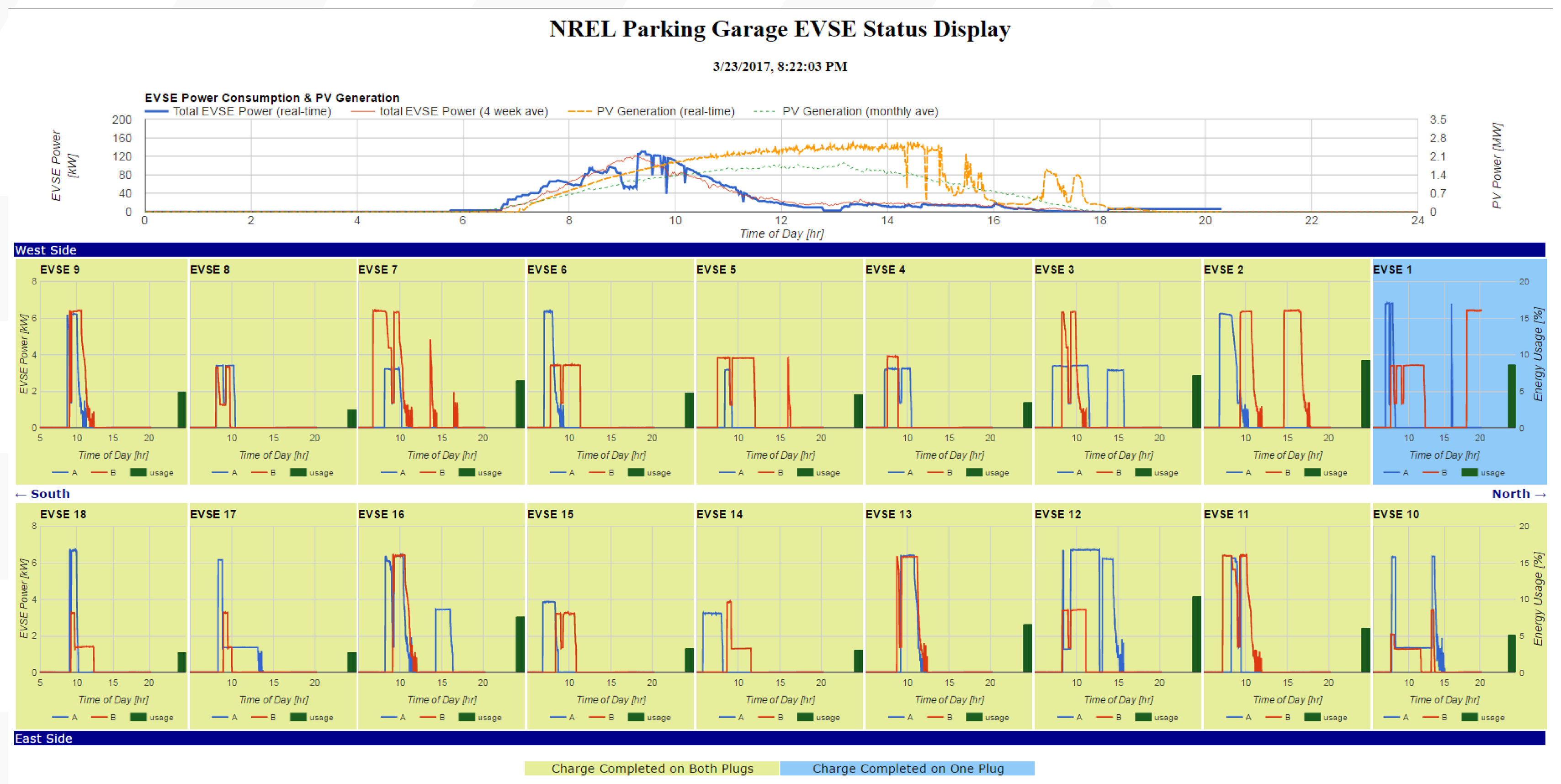




ANL Control Display and DR response

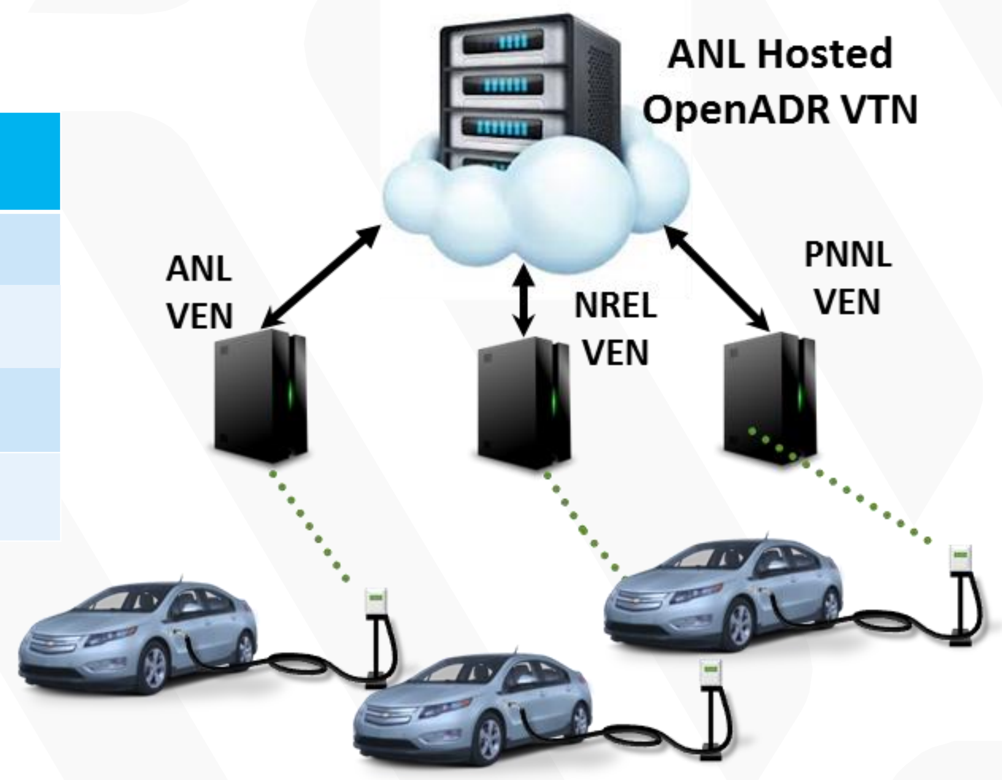
Progress to Date

- Use Cases selected and peer reviewed by industry advisory board
- Communications requirements developed
- DR demonstrations at ANL, NREL and PNNL responded to ANL hosted OpenADR Demand Response signal

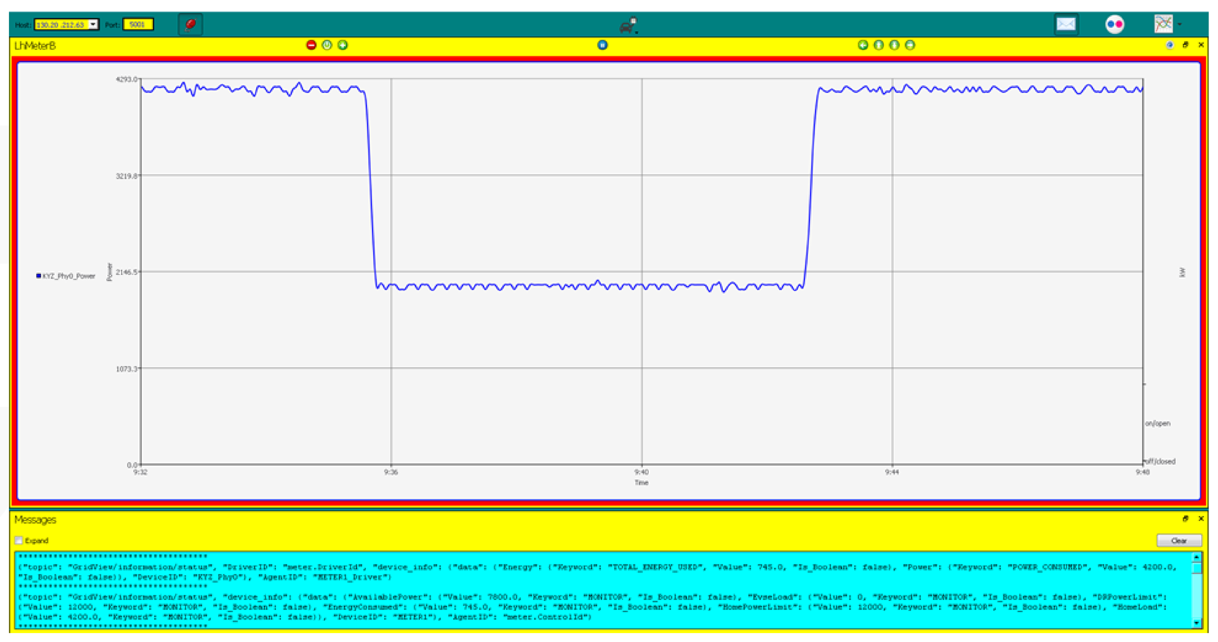


NREL System and DR response

Significant Milestones	Date
Demand Response Demonstration	4/2017
Renewables Integration Demonstration	10/2017
Demand Charge Reduction Demonstration	4/2018
Transactive Charging Demonstration	10/2018



System Operations
Rick Pratt, PNNL, PI
Andrew Meintz, NREL, One Over



PNNL System and DR response

U.S. DEPARTMENT OF ENERGY

April 18, 2017

Development of an Open-Source Platform for Advanced Distribution Management Systems

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

A partnership from Department of Energy national laboratories, academia, and industry is developing and deploying GridAPPS-D, a platform for developing advanced applications needed to reliably operate modernized electric power distribution systems. The goals:

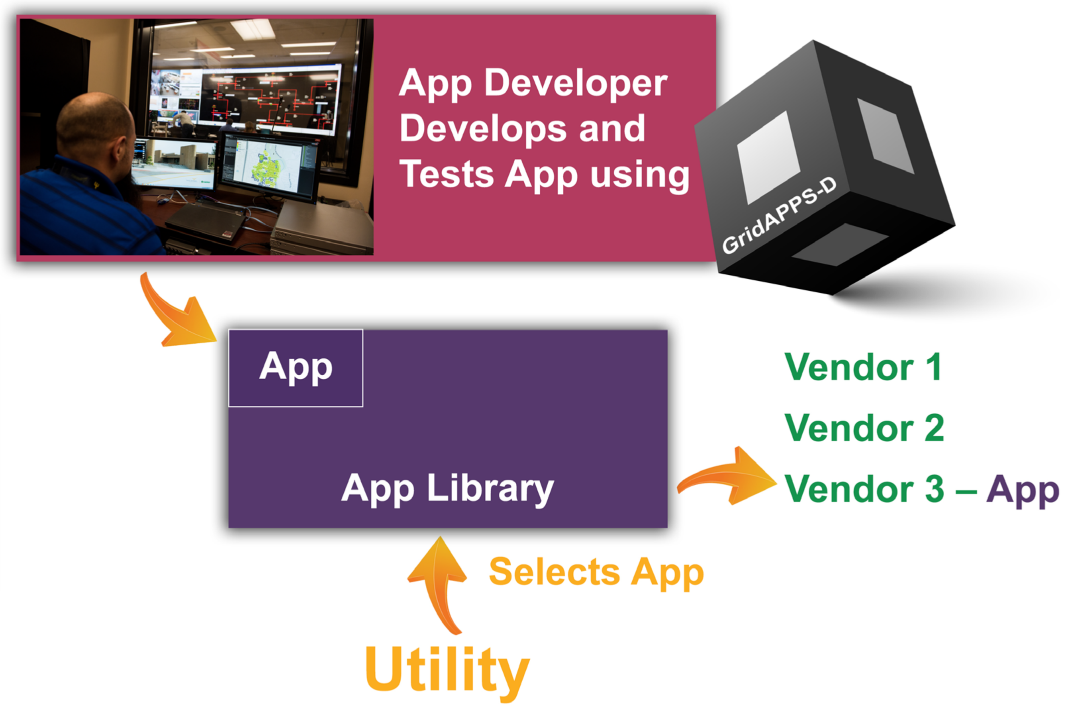
- Building applications in future data- and control-rich environment.
- Building community of developers who use capabilities provided in the platform.
- Impacts and interactions with industry.
- A documented reference implementation of the platform useful to industry and the research community for related endeavors

Expected Outcomes

- Enables standards-based development of advanced applications that can be deployed on any vendor's compliant system, reducing cost to develop, integrate and maintain future systems while increasing utility options.
- Data-rich, data-driven applications will improve distribution system reliability with increasing penetration of distributed energy resources.
- Provides a common platform for distribution system planning and operations research and development within the DOE labs and industry.

Progress to Date

- Completed conceptual design and functional requirements specification
- Performed advanced distribution management systems gap analysis
- Gave presentations at Innovative Smart Grid Technologies Conference 2016 and the SGIP Grid Management Working Group
- Formed Industrial Advisory Board jointly with GM-0237
- Convened an Advanced Applications Workshop
- Implemented core functionality of GridAPPS-D in release cycle 1 (V0.3)
- Established project team made up of PNNL, NREL, Washington State University, Incremental Systems, and Modern Grid Solutions, as well as ongoing collaboration with Electric Power Research Institute and others



Develop Once - Deploy on Multiple Vendor Systems

- Utility choice of apps
- Vendor expanded functionalities, via variety of apps
- App developed - access to customer

Innovation - Enabled!

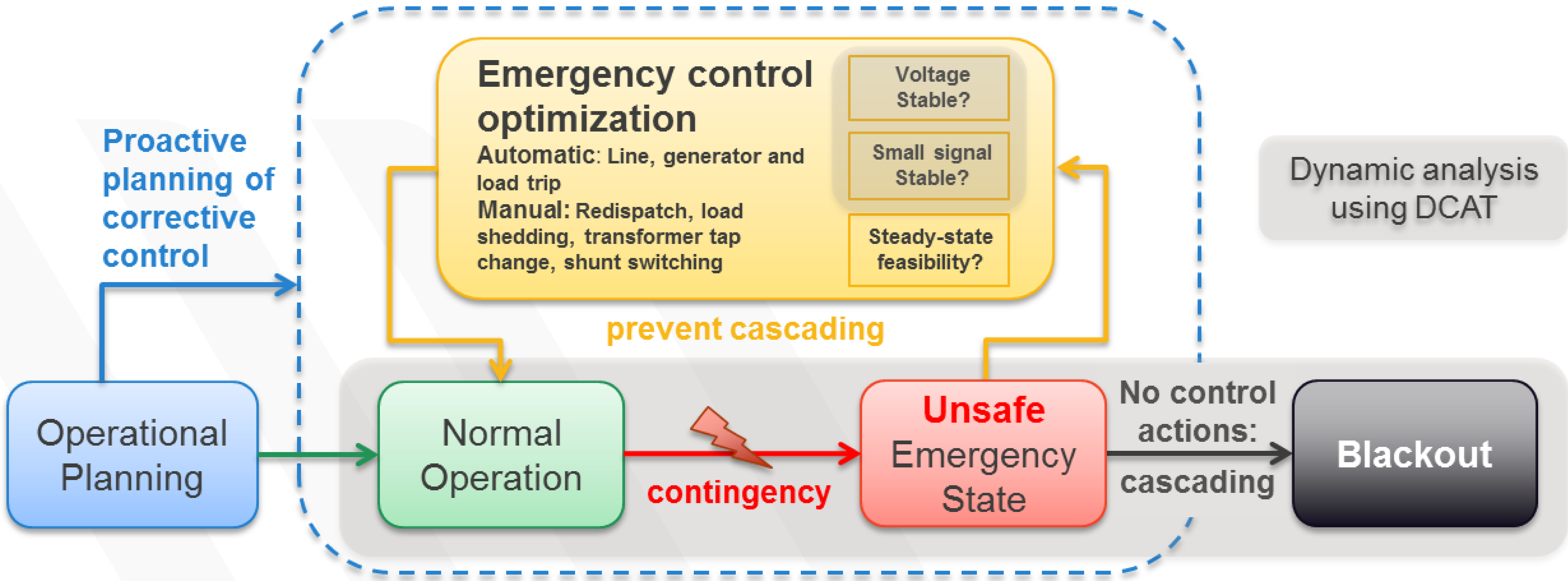
Significant Milestones	Date
Complete specification for open-source platform	8/16
Complete mapping of current industry state-of-the-art for advanced distribution management systems, including gap analysis	3/17
Complete next release of GridLAB-D	4/17
Complete first implementation release cycle	4/17
Release V1.0 of GridAPPS-D	4/18

Emergency Monitoring and Control Through New Technologies and Analytics (GM0076)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- Severe contingencies and unplanned events place transmission systems in emergency states where the system is vulnerable to cascading outages and blackouts
- Operators need timing-aware decision support to prevent further system degradation
  - Real-time computation of emergency actions on multiple time scales
  - Selection of preplanned corrective controls
- Consideration of corrective actions in operational planning to ease constraints and improve economic efficiency



Challenges

Fast emergency control to prevent cascading after severe disturbances

- Existing methods for power flow optimization and voltage stability analysis are too computational complex for real-time corrective control
- Alternative formulations are needed that are:
  - Amenable to real-time implementation
  - Accurately represent power system physics, including AC power flow and voltage stability
  - Are robust to uncertainties in system state

Economic leveraging of corrective control through proactive operational planning

- Require methods for proactive planning in high dimensional decision space

Expected Outcomes

Real-time Emergency Control:

- *Theoretical formulation* of real-time emergency control as an AC-OPF which minimizes impact on the system and guarantees system recovery
- *Computationally light representation of AC power flow feasibility domains* to substitute AC power flow constraints
  - Identification of feasibility region through machine learning methods with provable statistical guarantees
  - Derivation of conservative, convex domains (e.g., polytopes) through sufficient conditions on power flow solvability
- *Linear current-voltage optimal power flow formulation* with accurate AC power flow physics, approximate representation of objective
- *Software implementation* of feasibility domains and emergency AC-OPF
- *Numerical testing and validation* using Dynamic Contingency Analysis Tool (DCAT)
  - Robust testing tool for cascading outage analysis
  - Incorporates both automatic and manual emergency actions

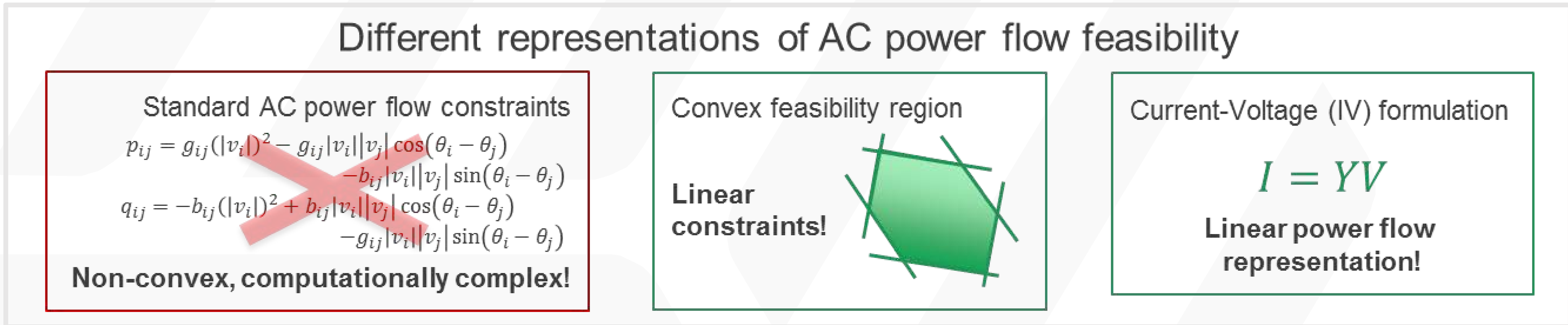
Proactive Planning for Emergency Control:

- Formulation and implementation of corrective controls in an uncertainty-aware, economically-based OPF that lower overall generation cost

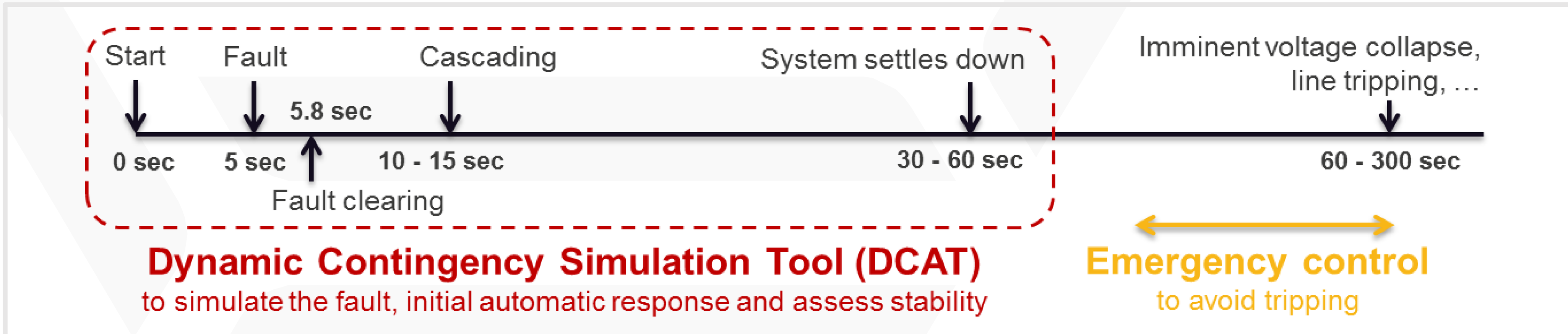
Progress to Date

Real-time emergency Control:

- Theoretical method development for computationally light AC OPF:
  - Formulation and implementation of sample-based feasibility domain approximation using kernel support vector machines and convex optimization [1]
  - Formulation and implementation of inner approximation of the power flow solvability region, using sufficient conditions for power flow solvability. Provides a set of linear constraints and improves state-of-the-art [2], [3].
  - Preliminary formulation of current-voltage power flow representation [4]



- Test-bed development with DCAT
  - Power system model development (IEEE 118 bus and 300 bus test cases, to include dynamic components and protections relays
  - DCAT integrated with manual and automated emergency controls to demonstrate prevention of voltage collapse and improving system security.



Proactive Planning for Emergency Control:

- Formulation and implementation of real-time corrective OPF that accounts for uncertainty and produces optimized control policies, which reduces operational cost. [5]

Publications

[1] A. Dymarsky, O. Horodnytskyi, Y. Maximov, K. Turitsyn, *Statistical Learning of Power Flow Feasibility* (in preparation)
[2] K. Dvijotham, H. Nguyen, K. Turitsyn, *Solvability regions of affinely parameterized quadratic equations*, submitted to the IEEE Control Systems Letters 2016, arXiv:1703.08881
[3] Y. Suhyoun, H. Nguyen, and K. Turitsyn. *Simple certificate of solvability of power flow equations for distribution systems*, IEEE Power & Energy Society General Meeting, 2015
[4] L. Roald, S. Misra, T. Krause and G. Andersson, "*Corrective Control to Handle Forecast Uncertainty: A Chance Constrained Optimal Power Flow,*" *IEEE Trans on Power Systems*, March 2017
[5] M. Chertkov, M. Vuffray, S. Misra, L. Roald, " *Fast and Robust Determination of Power System Emergency Control Actions,*" *accepted for IREP, 2017*

System Research Supporting Standards and Interoperability

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

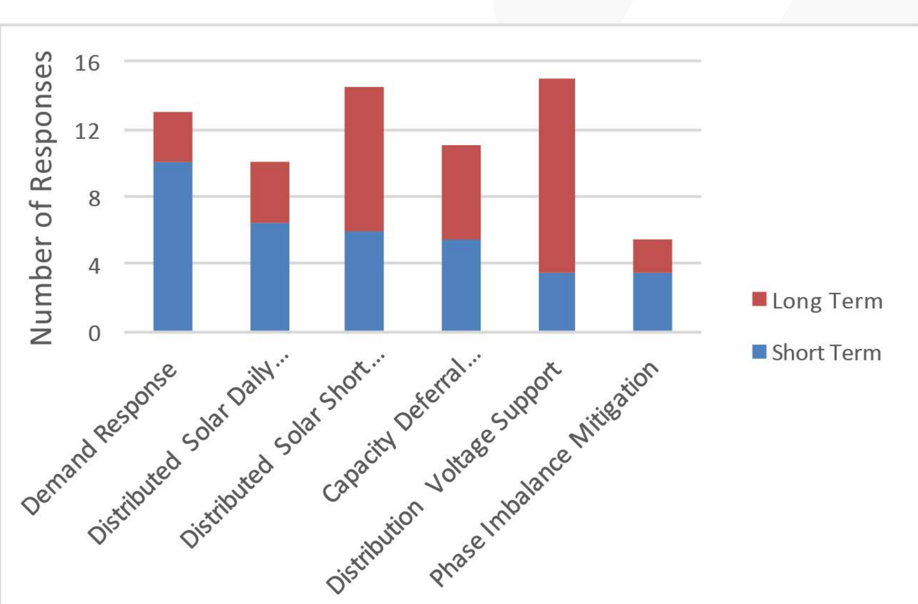
Determine the feasibility of Plug-in Electric Vehicles (PEVs) providing grid services at the electric distribution level without negatively impacting grid stability or the PEV customer experience. Use a hardware in the loop platform to develop PEV charging control strategies and to investigate PEV grid interactions that will aid standards development.

Expected Outcomes

- Guidance for standards development
- Quantified impact of widespread uncontrolled charging
- An open source control strategy to manage PEV charging that can provide grid services
- Understanding of cybersecurity risks

Progress to Date

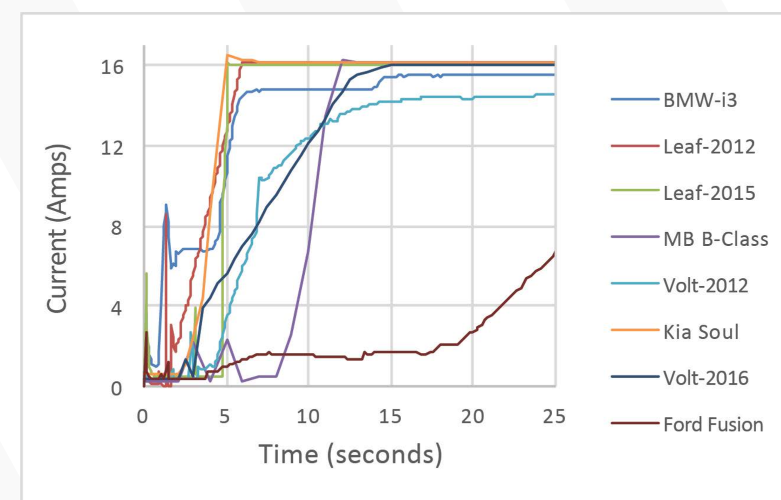
- Use cases developed by national laboratories and reviewed by Industry Advisory Board
- Completed dynamic characterization for several PEVs
  - These characterized results are being used to develop PEV dynamic charge models and PEV front end controllers
- Completed high level design for control system Aggregator and Front End Controller
- RTDS to RTDS connection set up between NREL and INL



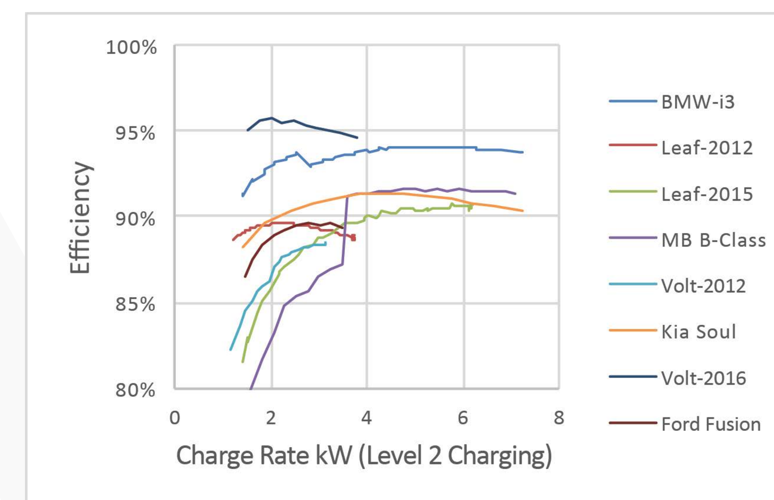
Use Case Survey Results from Industry Advisory Board

Partners

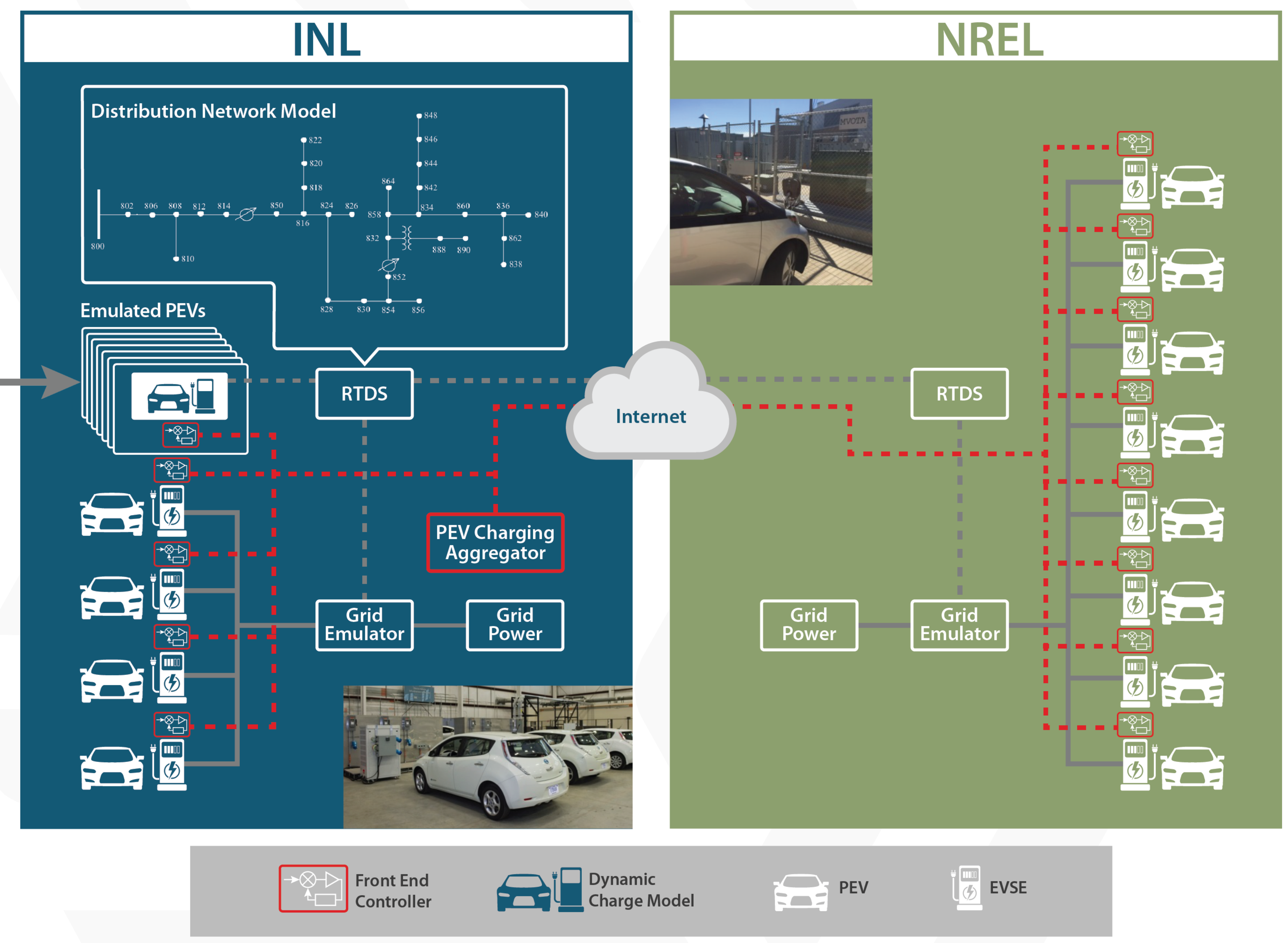
Idaho National Laboratory
Pacific Northwest National Laboratory
National Renewable Energy Laboratory
Argonne National Laboratory
Lawrence Berkeley National Laboratory
Siemens



PEV Charging Step Response



PEV Charging Efficiency



ANL is collecting data on communication latencies and coordinating with communications standards
PNNL is implementing VOLTTRON control agents and coordinating with the Vehicle to Building Integration Pathway Project

Hardware in the Loop Platform

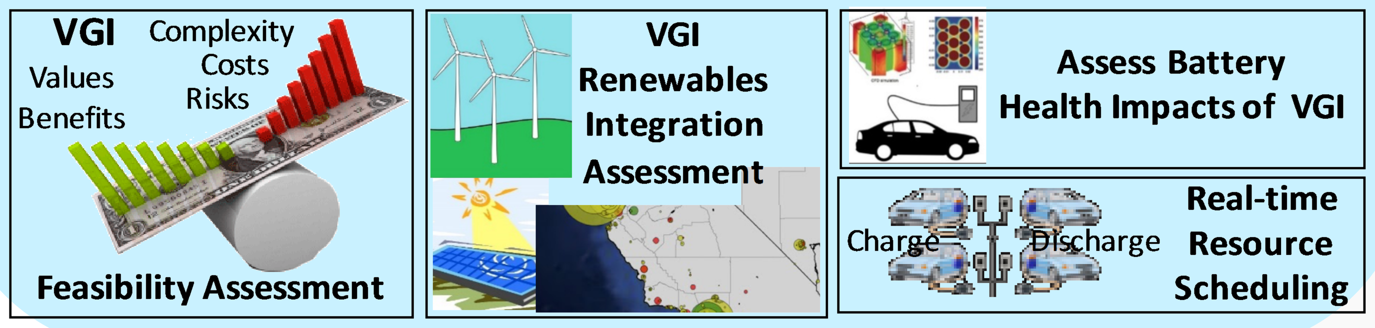
Significant Milestones	Date
Successful control of vehicle charging	Apr 2017
Demonstration of uncontrolled charging	Oct 2017
Control system developed and verified	Oct 2017
Complete study of three use cases	Apr 2018
Complete impact assessment of controlled PEV charging in use cases	Oct 2018

Modeling and Control Software Tools to Support Vehicle to Grid Integration

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- Grid services by EVs can be valuable for drivers, OEMs, and grid stakeholders. However, the feasibility of vehicle-grid integration (VGI) remain unclear.
- This project aims to:
  - o Quantify the feasibility of VGI by quantifying the potential value, cost, complexity, and risks in different implementations of VGI.
  - o Explore how to allocate value among stakeholders.
  - o Determine pathways for EVs provide grid services such as mitigating renewables intermittency.



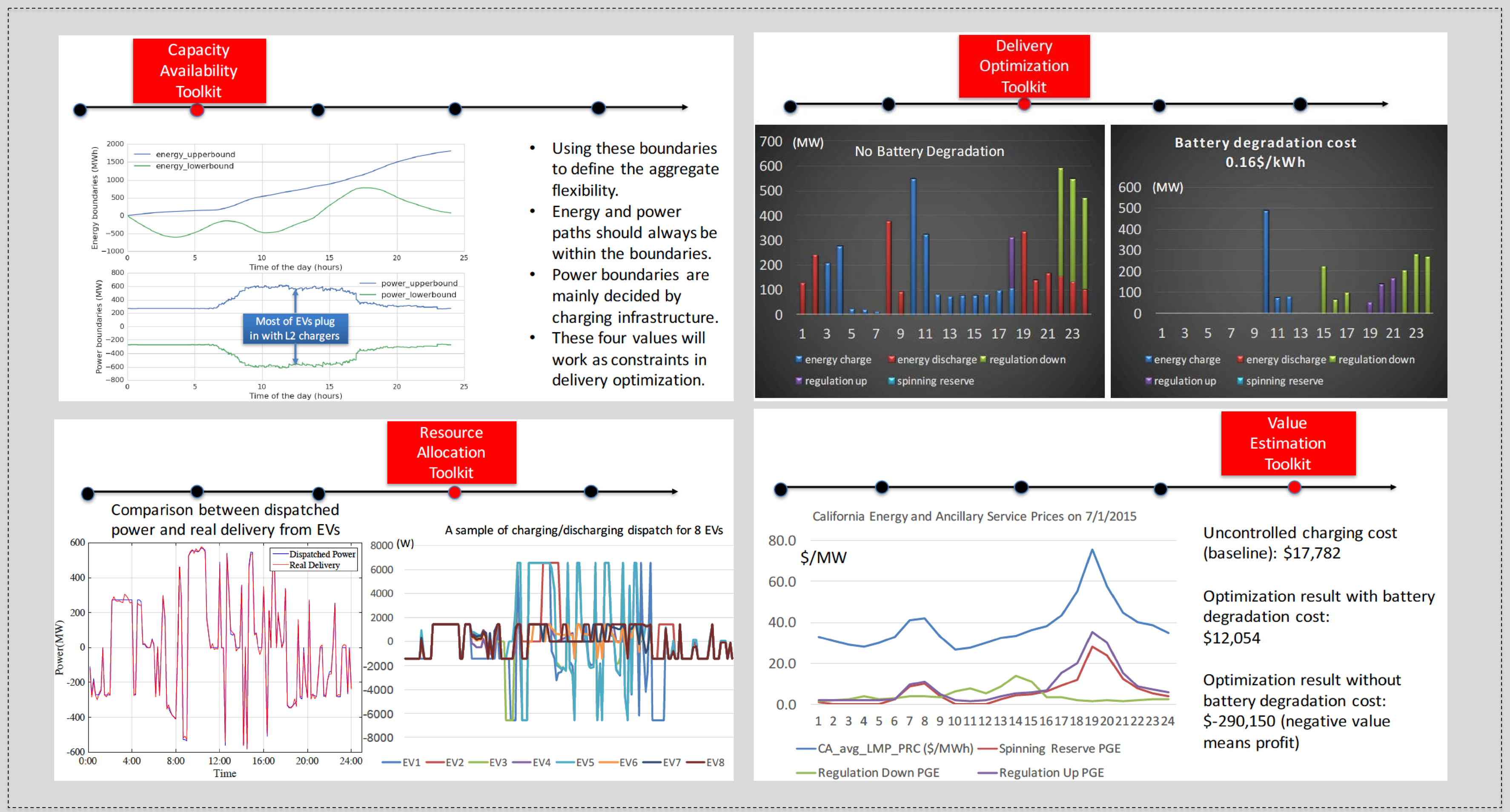
Research Approach

- Develop a simulation tool, VGISoft, comprised of several toolkits (illustrated below).
- Apply VGISoft across several case studies to quantify feasibility and implementation approaches of VGI.

PEV Estimation Toolkit	Capacity Availability toolkit	Delivery Optimization Toolkit	Resource Allocation Toolkit	Value Estimation Toolkit
➢ Initialize vehicle profiles; ➢ Model individual PEV state information (e.g.SOC, battery health, etc.); ➢ Determine individual PEV constrains.	➢ Estimate temporally & spatially resolved resource size; ➢ Generate aggregate battery constrains.	➢ Determine grid and local service portfolio; ➢ Wholesale market services; ➢ Retail market services.	➢ Disaggregate total dispatched power into individual PEVs; ➢ Guarantee PEVs have enough energy.	➢ Ex-post analysis on benefits and costs ; ➢ Allocate value and costs among stakeholders.

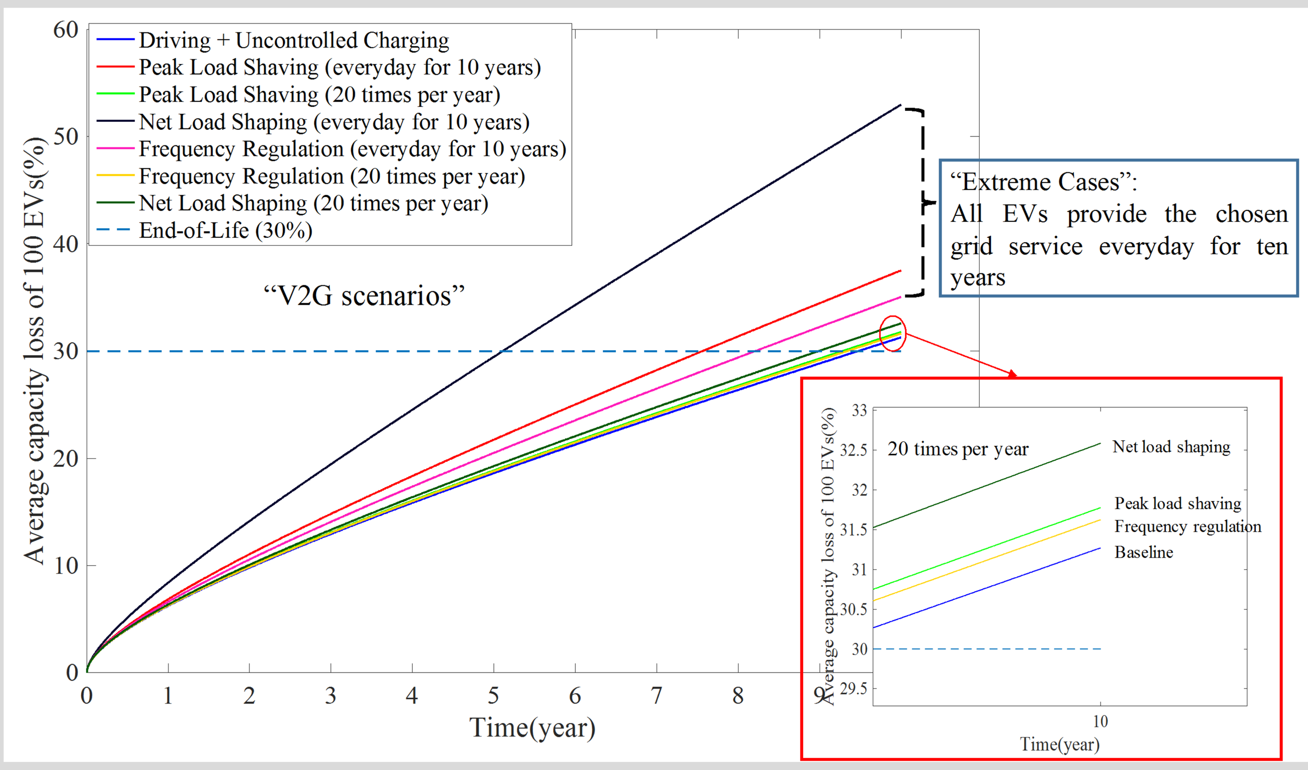
Significant Milestones	Date
Finalized development of case studies and use cases across VTO VGI GMLC projects. Structure for VGISoft framework and integrated sub-models: 1) PEV estimation toolkit, and 2) capacity allocation toolkit) completed.	10/01/2016
Demonstrations, presentation of VGISoft framework to industry advisory panel. Create and integrate the three remaining sub-models into VGISoft framework, namely the delivery optimization, resource allocation, and values estimation toolkits.	04/01/2017
Apply VGISoft for targeted use cases on: 1) Quantifying the feasibility (i.e. cost, value, complexity, risk, etc.) for VGI with collections of vehicles offering many available grid services, 2) Determining how value is distributed amongst stakeholders, including drivers, aggregators, utility shareholders and ratepayers, etc.	10/01/2017

A demonstration on the functionality of VGISoft (100,000EVs)



Capacity Availability Toolkit outputs the power and energy boundaries of aggregate battery. Delivery Optimization Toolkit runs the optimization based on aggregate battery model and outputs the optimal bidding strategy. Resource Allocation Toolkit allocates the total aggregate power into individual vehicles. Value Estimation Toolkit calculates total benefits and costs.

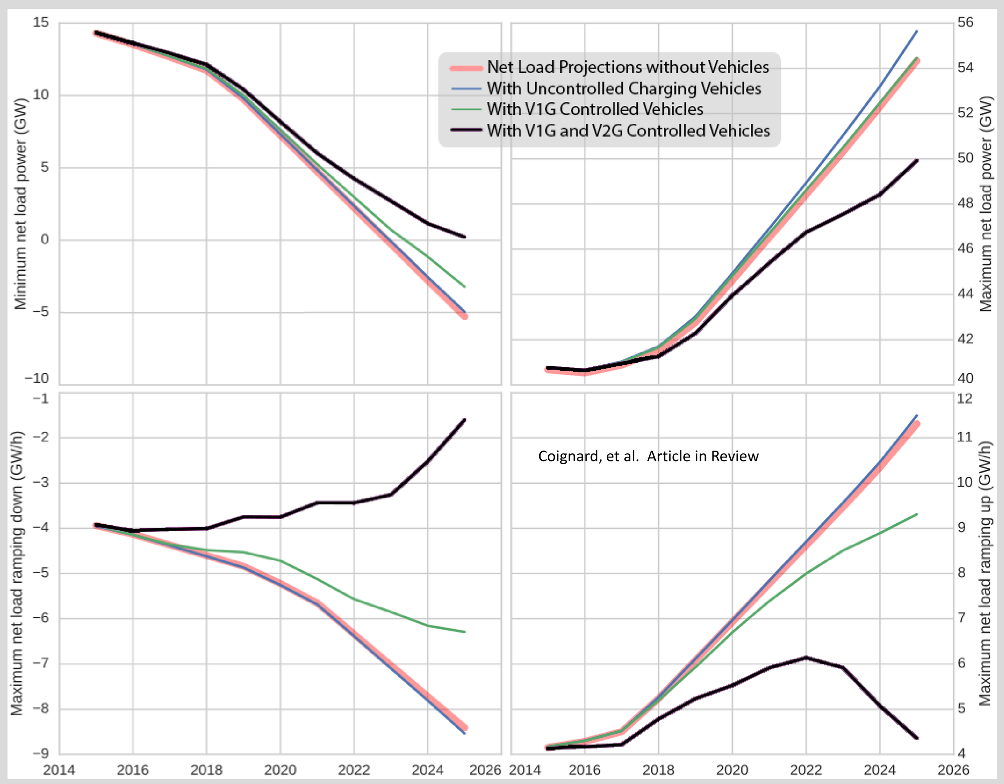
Quantifying EV Battery Degradation from Driving vs. V2G Services



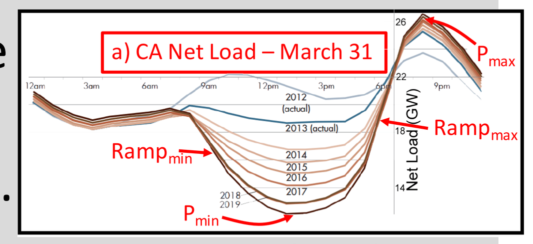
- Simulate average capacity losses of 100 EVs by performing different V2G services for ten years.
- Frequency regulation and peak load shaving do not cause significant degradation.
- Infrequent V2G services have minor impacts on the battery lifetime.

Wang, et al. http://dx.doi.org/10.1016/j.jpowsour.2016.09.116

PEVs for Renewable Energy Integration (“Smoothing the California Duck Curve”)



- We investigate the influence of EVs on California net load projections from 2015-2025.
- Controlled charging has substantial benefits for ramping and day-time valley mitigation.
- V2G can play a significant role in mitigating the sharp up-ramps and down-ramps.



Expected Outcomes

- Outcome 1: Development of open-source toolsets for VGI planning, analysis, and operations.
- Outcome 2: Application of toolsets to address critical knowledge gaps and barriers to VGI

Progress to Date

- Finished development of core toolkits in VGISoft.
- Published “Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services” on *Journal of power sources*.
- Submitted “Clean Vehicles as an Enabler for a Clean Electricity Grid”.

Multi-Lab EV Smart Grid Working Group
(Convened by the DOE Vehicle Technologies Office)

GM0085: Systems Research Supporting Standards and Interoperability

GM0062: Vehicle to Building Integration Pathway

Integrating VGISoft co-simulation framework

(Efforts occur in parallel)

Application of VGISoft across targeted case studies, leveraging real-time aggregator systems

VGI Feasibility Assessment | VGI Renewables Integration Assessment | VGI Battery Health Impacts | Real-time Resource Scheduling

(Application of findings to accelerate VGI deployment)

(Guide research questions, case study investigations, and VGI implementations)

Stakeholder advisory team

U.S. DEPARTMENT OF ENERGY

Multi-Lab EV Smart Grid Working Group
(Convened by the DOE Vehicle Technologies Office)

April 18, 2017

Unified Control of Connected Loads to Provide Grid Services Novel Energy Management and Improved Energy Efficiency

Teja Kuruganti, David Fugate, James Nutaro, Chris Winstead, Brian Fricke – Oak Ridge National Laboratory
Srinivas Katipamula, Jereme Haack – Pacific Northwest National Laboratory
John Wallace - Emerson Commercial and Residential Solutions
Justin Hill, Pradeep Vitta – Southern Company

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Develop a retrofit system for coordinating the operation of multiple loads to - reduce peak demand, reduce energy consumption, and providing transactive energy services to the electric grid.

Expected Outcomes

- Whole-building, retrofit, supervisory load control for improving energy efficiency and reducing peak demand by coordinating various building loads – HVAC & R
- Grid-responsive load control technology that can be deployed at large-scale to provide novel grid services
- Platform-driven technology for seamless self-aggregation of building-level loads for providing grid services
- Partnership with a building equipment manufacturer and an electric utility to demonstrate algorithms and techniques developed on an open-source control platform in real building sites

Significant Milestones	Date
Document detailed economic benefit analysis opportunity for small- and medium-sized buildings	12/31/16
Extend control to enable dynamic load shaping and document testing of control with dynamic load	3/31/17
Integrate utility DR signal into the prototypical control systems to perform adaptive load shaping response	6/31/17

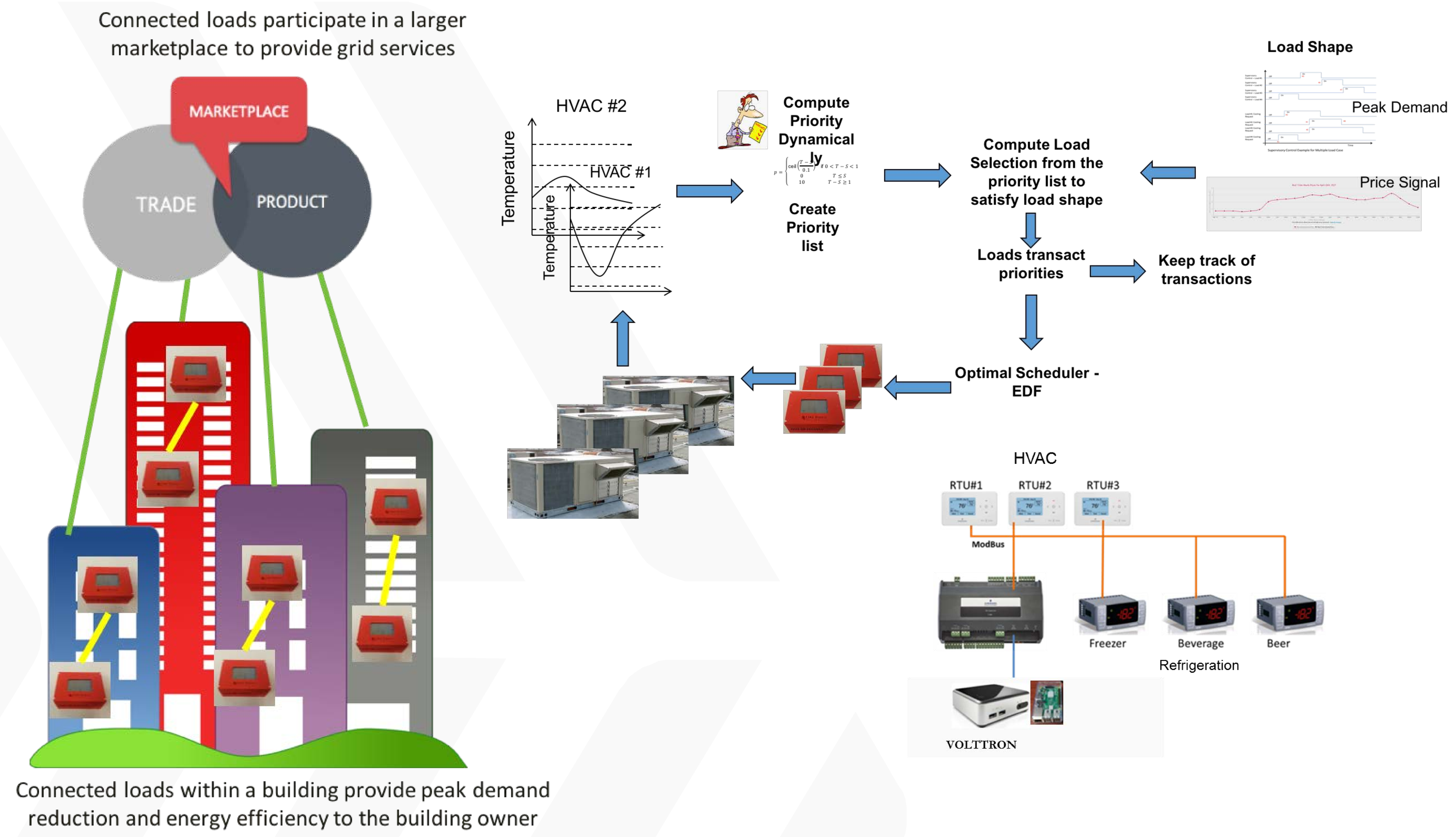


Figure 1: Transactive services enabled by connected loads

Progress to Date

- Supervisory control framework developed to interact with building/store loads to enable grid-responsiveness
- Peak demand reduction developed and tested at real building
- Algorithm for using refrigerated display cases for demand response developed
- Open HW/SW reference of VOLTTRON Thermostat
- Published three conference papers and one journal publication currently under preparation
- Algorithm transitioned to Emerson for field deployment at two Dollar General stores in Florida

VOLTTRON™ Controller for Economic Dispatch: Maximize Return-on-Investment for Building Integrated Fuel Cell CCHP Systems

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

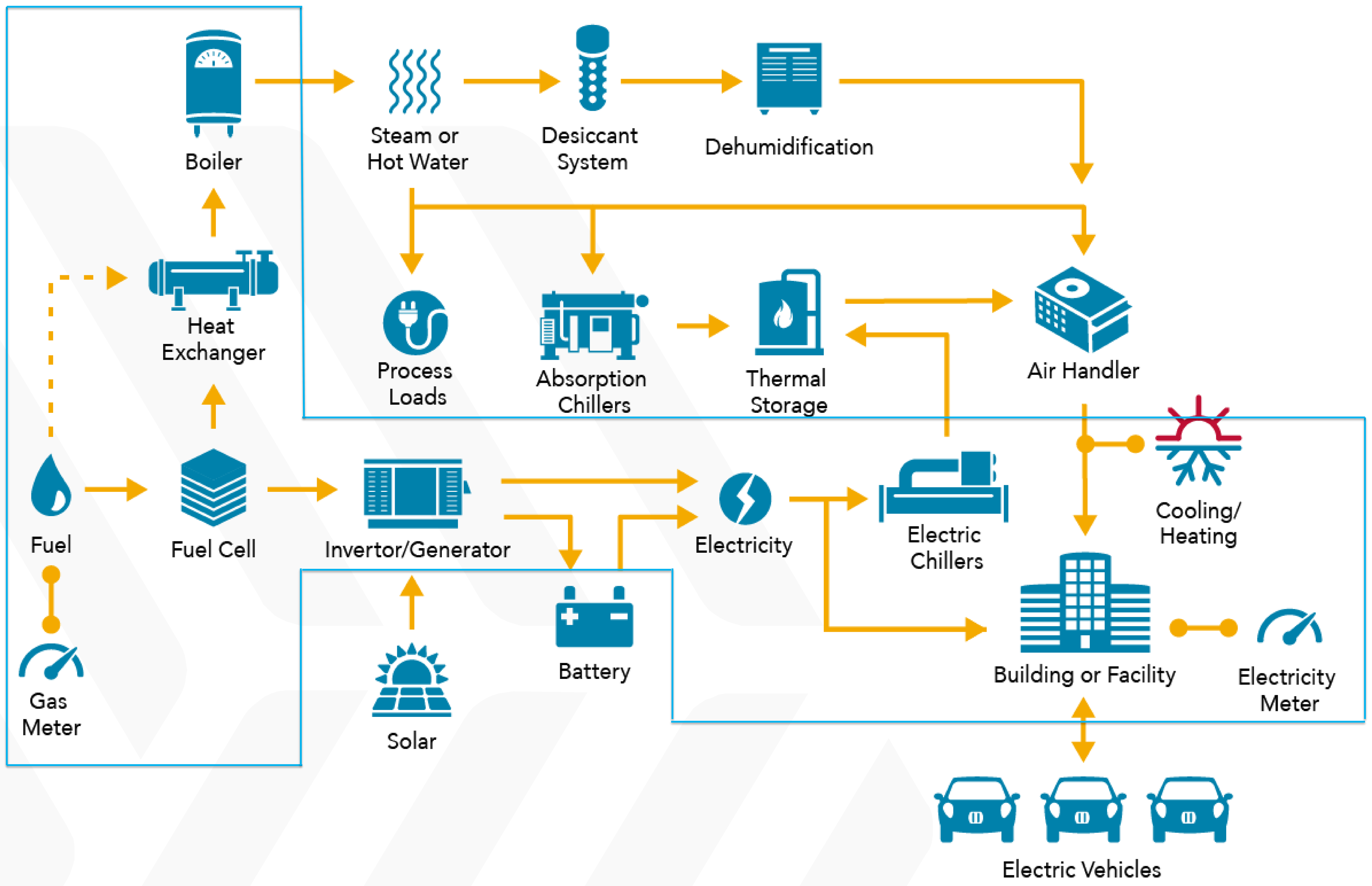
Project Description

This multi-purpose open-source economic dispatch application will ensure automated optimization of fuel cell combined cooling, heating and power (CCHP) systems. The goal is to increase electric grid reliability and hosting capacity of renewable generation assets.

Expected Outcomes

- Maximize return-on-investment of fuel cell CCHP systems (can be leveraged to other CCHP systems)
- Deliver VOLTTRON-compatible real-time control algorithms packaged as a fully functional toolkit
  - Supervisory control and generalized economic dispatch
  - Short-term weather and load forecasting
  - Management of short-term imbalance between local generation and demand
  - Performance monitoring, automated fault detection, and diagnostics
  - Automated continuous commissioning
- **Short-Term (immediate):** Open-source economic dispatch and performance monitoring software
- **Medium-term (<3 years):** One or more energy service providers to commercialize the software and offer as a service to their customers
- **Long-term (>3 years):** Becomes standard implementation methodology for CCHP systems

Significant Milestones	Date
Test algorithms with offline data	3/31/17
Develop integrated software for field testing	9/30/17
Field validation; update controller	12/31/18



Integrated Energy System: System highlighted in blue is the original scope; however, the framework will be general and support the rest of the IES

Progress to Date

- Developed a general economic dispatch VOLTTRON™ software framework
- Adapted solar generation and forecast models
- Developed and tested inverse models for building thermal and electric load and for HVAC systems performance prediction
- Developed economic dispatch and supervisory control algorithms
- Adapted algorithms to mitigate short-term loss of power from renewables or load forecast error
- Converted all models to Python and documented them
- Algorithms validation underway

VOLTTRON Common Data Model

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

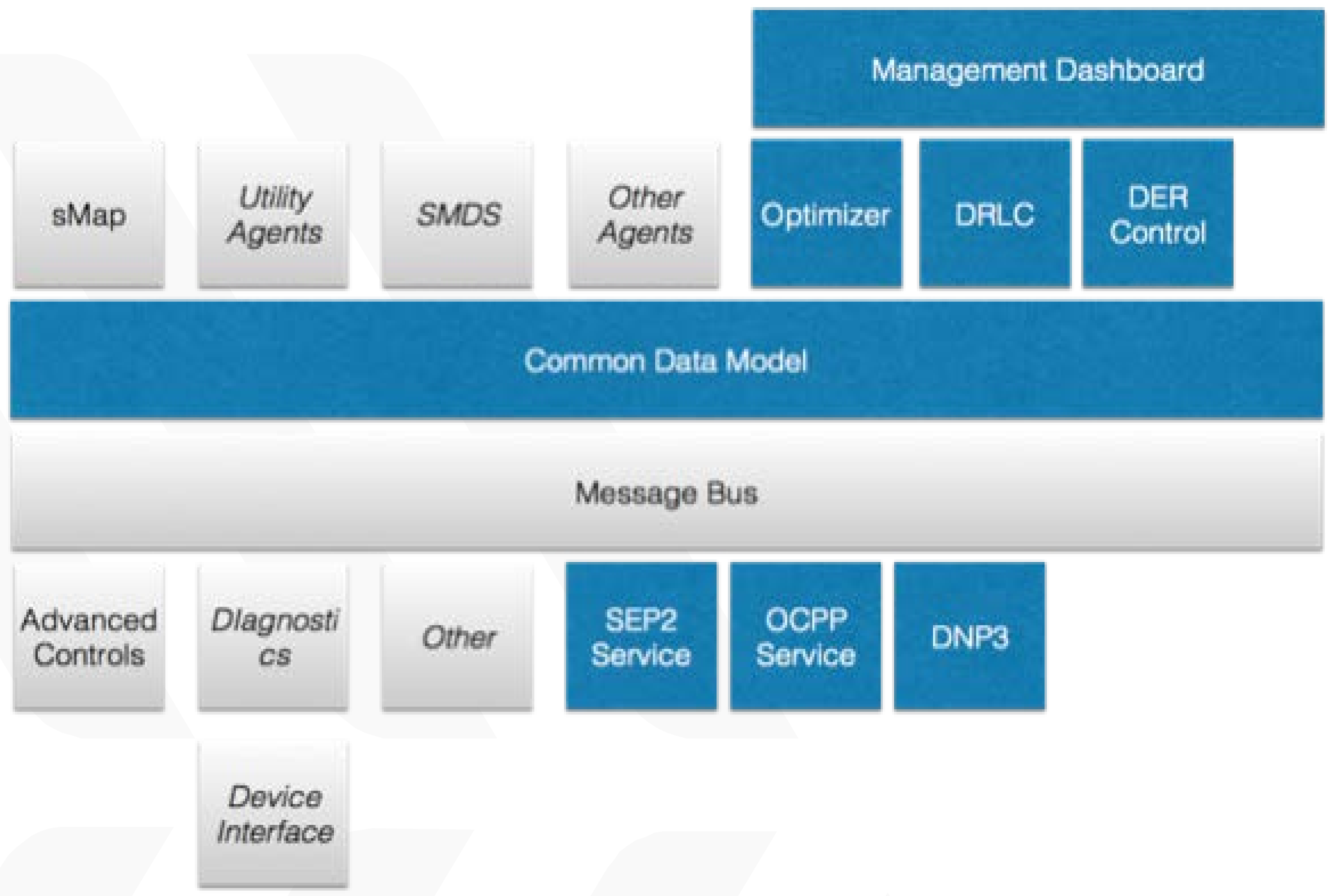
Project Description

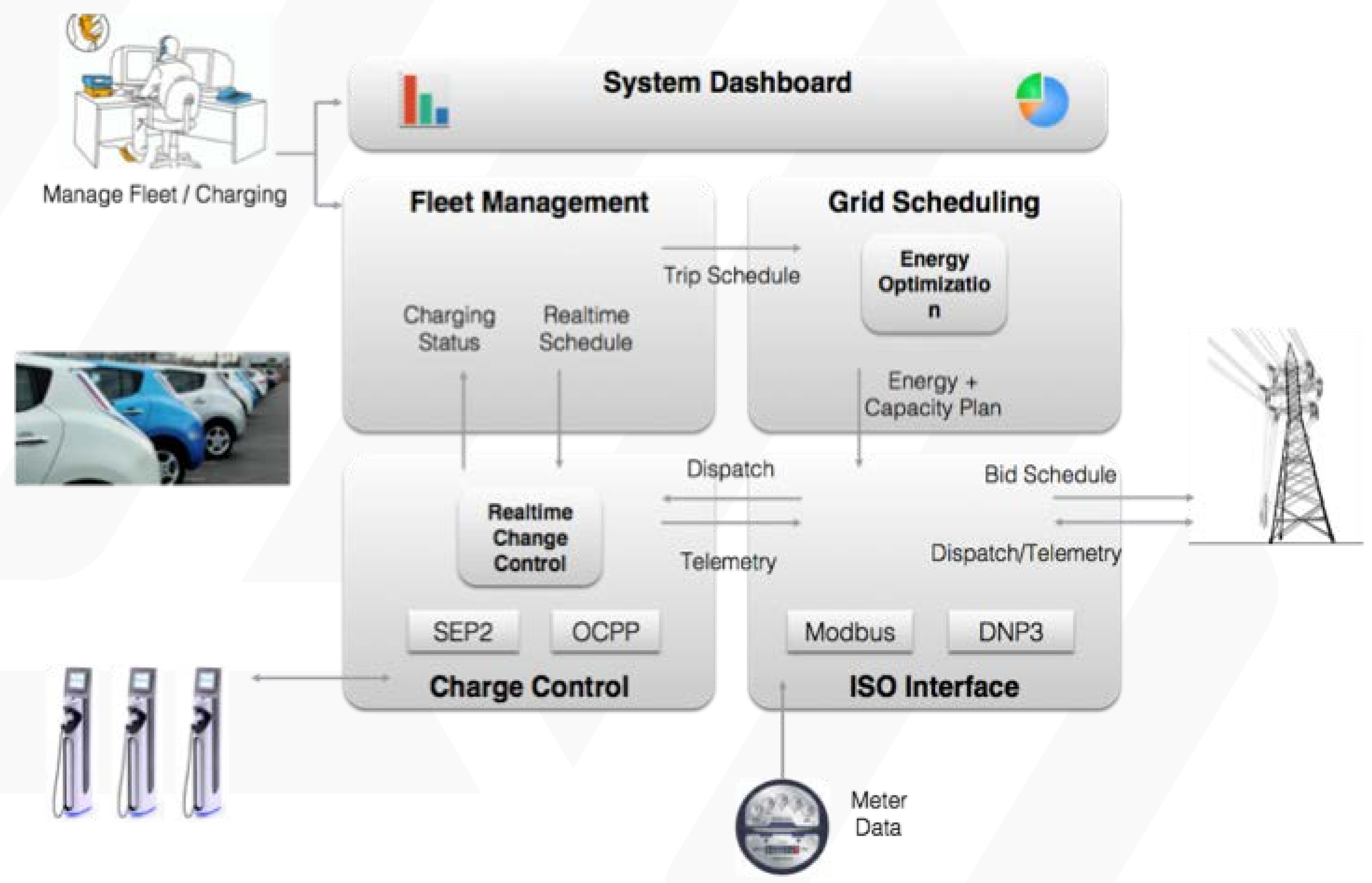
This project adds DER management capabilities to VOLTTRON by implementing support for common DER protocols and mapping the data onto the the VOLTTRON message bus using the SunSpec information model (based in IEC61850). Agents will be developed for commonly used protocols and functions, such as SEP2, DNP3 and the ChargePoint EV API. We will deploy a regional reference implementations at SLAC's GISMo Laboratory, NREL's ESIF and LBNL's FLEXLAB that are connected to live loads, energy resources and storage.

Expected Outcomes

- **Integration of DER and smart meters**: The protocols and data mapping will support use cases that include: device monitoring (inverter, etc.), demand response/load control, EV charging and DER energy optimization.
- **Open Source Interfaces to key protocols**: SEP2 (IEEE 2030.5) functions sets will be implemented as agents to support DRLC and DER use cases. A DNP3 agent will support grid control of Volttron connected DERs. A ChargePoint API device driver will enable smart charging of EVs across the largest network in the US.
- **Develop open source transactive power optimizer software**: A DER optimization agent will serve as a template for integrating with the newly supported protocols and facilitate its adoption by systems integrators.
- **Embed in low cost platforms:** The project with provide design specifications and regional demonstrations for the systems integrator community.

Significant Milestones	Date
ChargePoint EV API	11/30/16 (DONE)
SEP2 DRLC Function Set	05/30/17
SunSpec Mapping	08/01/17
SEP2 DER Function Set	11/20/17
Microgrid Control Demonstration	03/01/18
DNP3	04/01/18
Microgrid Optimization & Analytics	08/01/18





Progress to Date

- Chargepoint API Completed
  - First production use in GM0062: V2B Integration Pathway
- SEP2 Demand Response Load Control
  - Design spec published and reviewed with VOLTTRON core dev team
  - Development in progress and on schedule

Community Control of Distributed Resources for Wide Area Reserve Provision

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Team

- DOE Labs: Lawrence Berkeley National Laboratory (lead), National Renewable Energy Laboratory, Sandia National Laboratories
- Industry / Utility: Smarter Grid Solutions, Riverside Public Utilities

Project Description

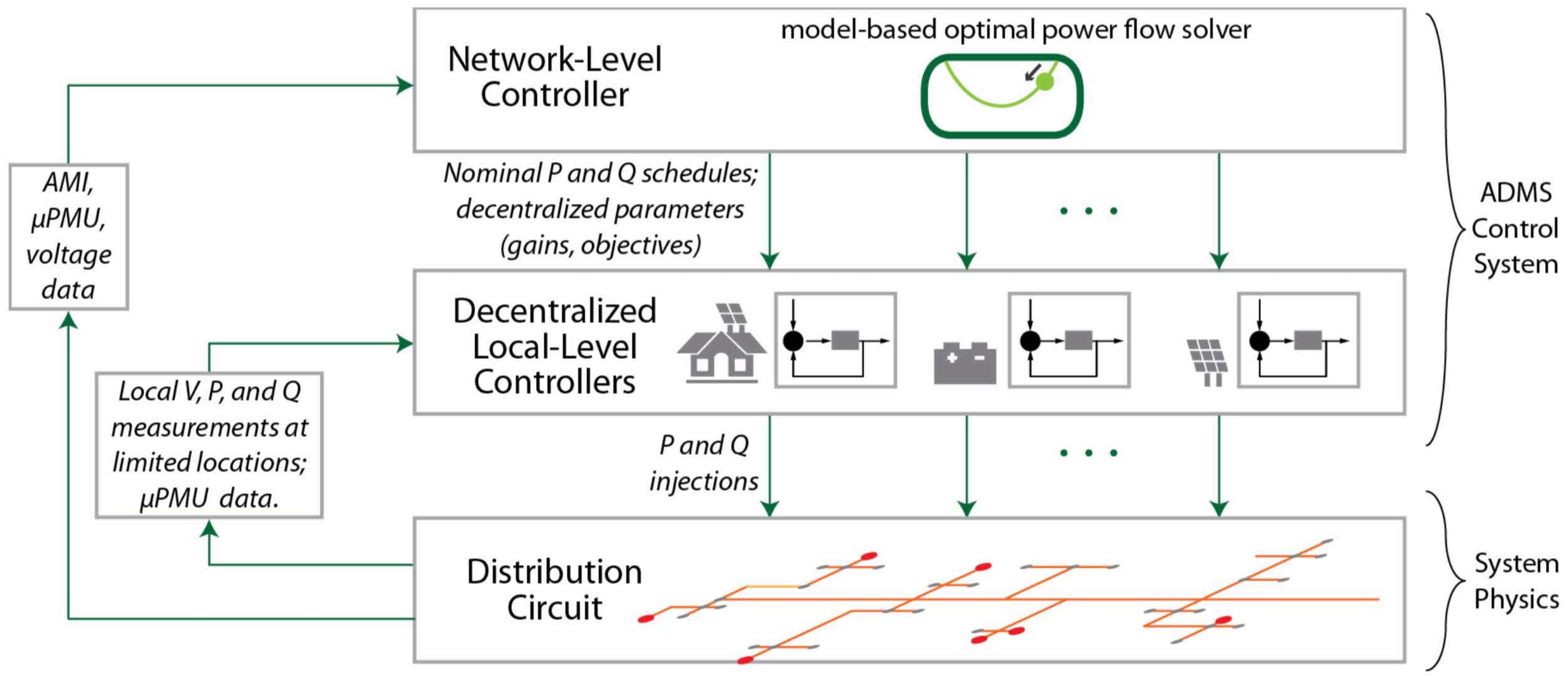
Our goal is to develop and demonstrate an advanced distribution management system (ADMS) that allows DERs to improve distribution system operations and simultaneously contribute to transmission-level services. In short, we envision (1) elevating load buses to the level of generator buses with respect to the degree of control authority they present to system operators and (2) simultaneously optimizing distribution-level measures such as resistive losses and nodal voltage deviations.

Expected Outcomes

- Tools for spatiotemporal forecasting of DER output
- New distribution system operations planning, including battery state of charge management
- New real time decentralized optimization tools
- Hardware-in-the-loop tests of PV and battery systems for network management
- Implementation on industry partner's existing DER management platform
- Assessment of value for volt-VAR optimization and delivery of transmission level services

Benefits to:

- **Electricity consumers**: reduce costs and improve power quality
- **Distribution companies**: provide new network and DER management products and opportunities to reduce costs in or even profit from transmission-level markets
- **Transmission operators**: Facilitates greater penetration of variable renewable generation
- **Industry**: Open-source algorithms for distribution network management products

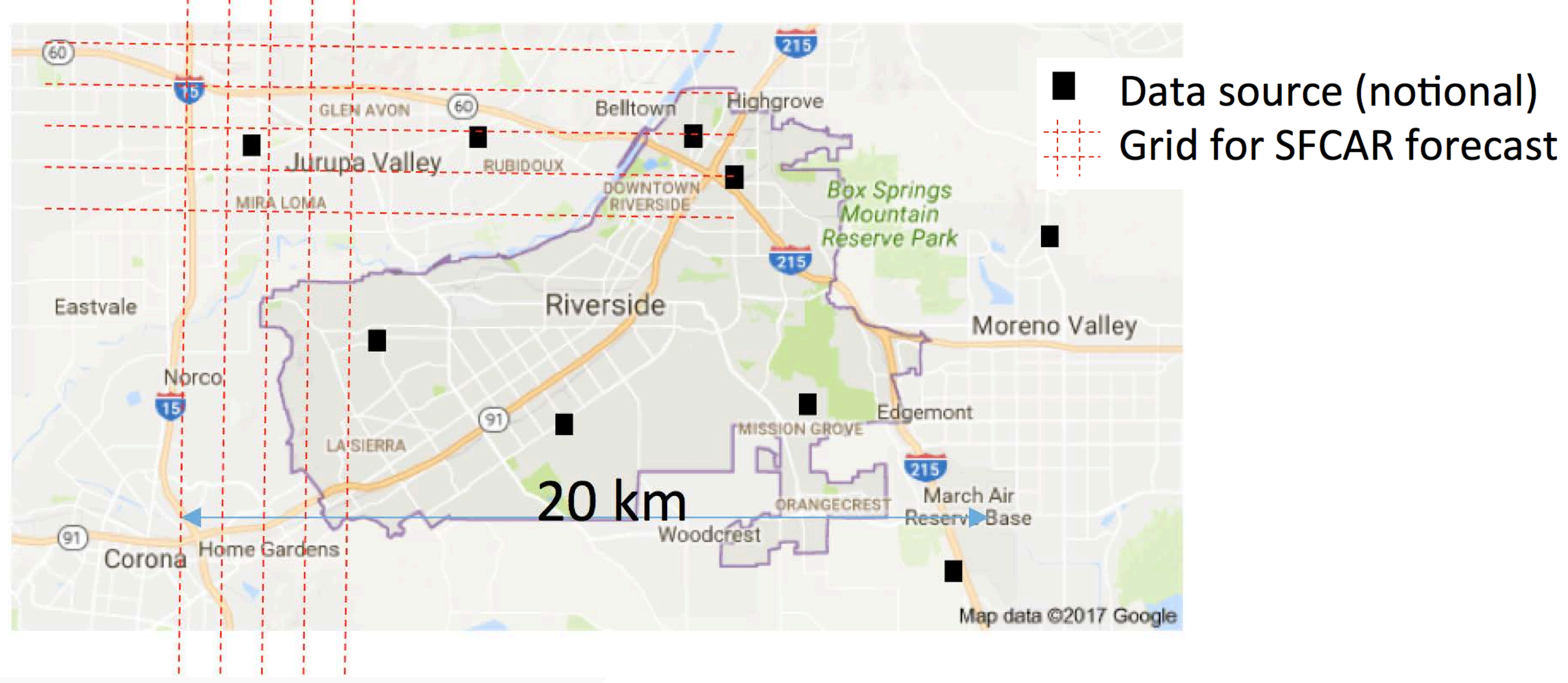


Hierarchical control solution schematic

Significant Milestones	Date
Initial implementation of decentralized control for voltage support complete and simulated.	April '17
Optimization and forecasting algorithms implemented in simulation	April '18
Hardware in the loop (HIL) tests designed, small simulations demonstrated	April '18
Integration of control algorithms and data streams into SGS platform for HIL demonstration.	April '19
Transmission- and distribution-level benefits quantified	April '19

Progress to Date

- Two new decentralized control tools developed and accepted in journals or conference proceedings
- Initial decentralized control hardware in the loop tests completed and to appear in conference proceedings
- Several conference presentations scheduled
- PV forecasting toolset developed, to be distributed in open-



U.S. DEPARTMENT OF ENERGY

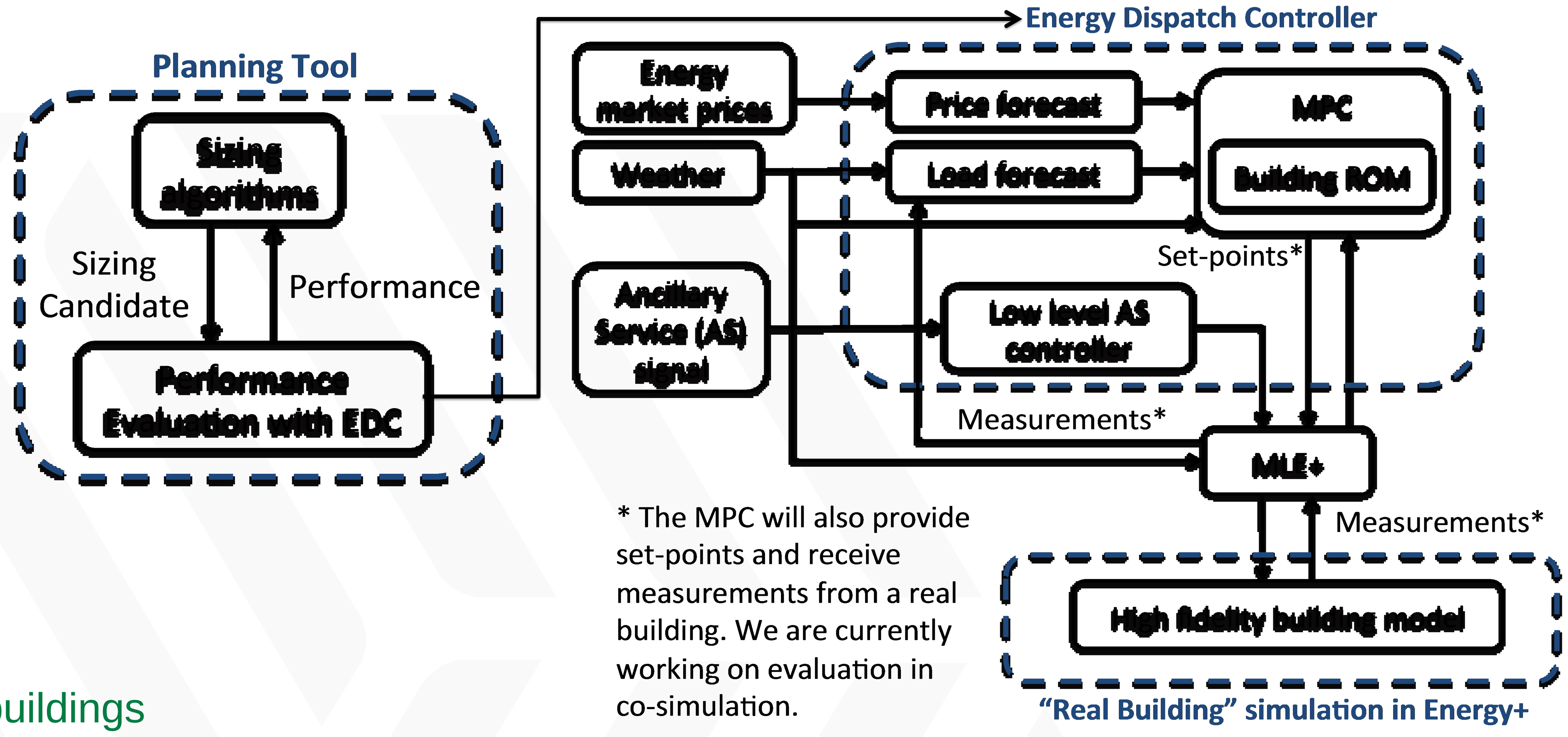
Optimal Stationary Fuel Cell Integration and Control (Energy Dispatch Controller)

Genevieve Saur (NREL), Zhiwen Ma (NREL), Annabelle Pratt (NREL), Yashen Lin (NREL), Dustin McLarty (Washinton State University), William Livingood (NREL), Luigi Gentile Polese (NREL), Brian Ball (NREL), Jereme Haack (PNNL), Gregor Henze (University of Colorado – Boulder)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

- Create an open-source novel **energy dispatch controller** (EDC) which will provide optimal dispatch for fuel cells and other CHP generators, controllable building elements and components, thermal and electrical storage, renewables, and transactive communication for participation in ancillary grid services.
- Integrate aggregated annual summary knowledge of the optimal dispatch into a **planning tool** for building component sizing.



The **energy dispatch controller** would provide energy management for an integrated building and be able to participate in grid ancillary service markets. The **planning tool** would provide design assistance for integrating other generation and storage components into the building.

Expected Outcomes

- Fills need for better energy management of integrated buildings
  - Allows the wealth of information provided by distributed sensing technology throughout a building to be used for cost savings and grid support. Not currently well-used.
- Increases benefit of distributed energy resources (DER) in integrated buildings
  - Reduces energy bills and emissions
  - Improves on-site energy reliability and security
  - Maximizes benefits of CHP, heat capture, storage, and other renewable generation
- Expands grid supportive features of smart buildings and distributed energy resources for grid modernization.
  - Increases grid reliability and security using a flexible, dispatchable energy resource
  - Supports local deployments of variable DER (i.e., wind and solar)
- Supports fuel cell market development
  - Quantifies economic benefit of integrated CHP
  - Provides reliable system design
  - Informs the industry of favorable transient characteristics for the dynamic performance of fuel cells

Significant Milestones	Date
Feedback on GUI functionality	6/30/17
Verify source code runs on two operating systems	6/30/17

Progress to Date (First Year Objectives FY17)

- EDC Optimization (Model Predictive Control (MPC))
  - Select and complete initial algorithm formulation of MPC
  - Complete initial testing in co-simulation of one model building
  - Verify source code can be run on multiple OS
- GUI
  - Complete initial GUI screens to provide interface for testing and feedback
- Building Design Framework
  - Create interface for providing building specification and design that can be used for reduced order building models (ROM) and Planning Tool component sizing
- Co-simulation Environment
  - Create a functioning co-simulation environment for evaluation and testing of EDC

Operational and Strategic Implementation of Dynamic Line Rating for Optimized Wind Energy Generation Integration

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Provide industry stakeholders with a Dynamic Line Rating (DLR) solution that is state of the art as measured by cost, accuracy, and dependability; enable human operators to make informed decisions and take appropriate actions without human or system overloading and impacting the reliability of the grid.

Expected Outcomes

- Research will extend IEEE and CIGRE DLR standards to "True" Dynamic Line Rating (TDLR) to provide utilities forecast capabilities and improved situational awareness for optimization and risk.
- Conductor Optimization Tool is an industry partner-informed application to choose the most economical transmission line conductor and route for new siting and upgrading of transmission assets considering DLR.
- Best implementation of additional control room data such that operator performance is enhanced rather than increasingly burdened.

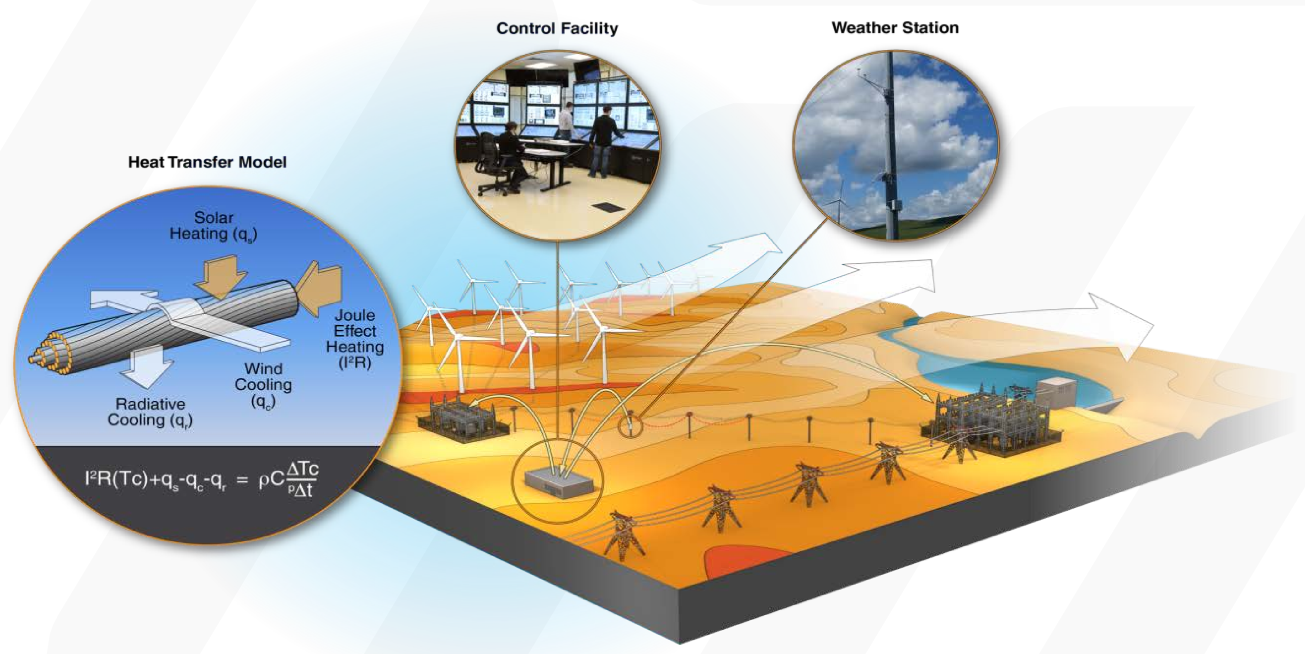


Figure 1. Illustration of sensing, CFD transferred weather conditions, dynamic line rating computations, and communication to SCADA/EMS for system planning and operations.

Significant Milestones	Date
Phase I CRADA completed with AltaLink, LLC in Alberta	Q3 FY16
GLASS Rev 1.0 Copyright assertion approved	Q4 FY16
Go-No-Go integration of DLR software at Idaho Power Co.	Q4 FY17

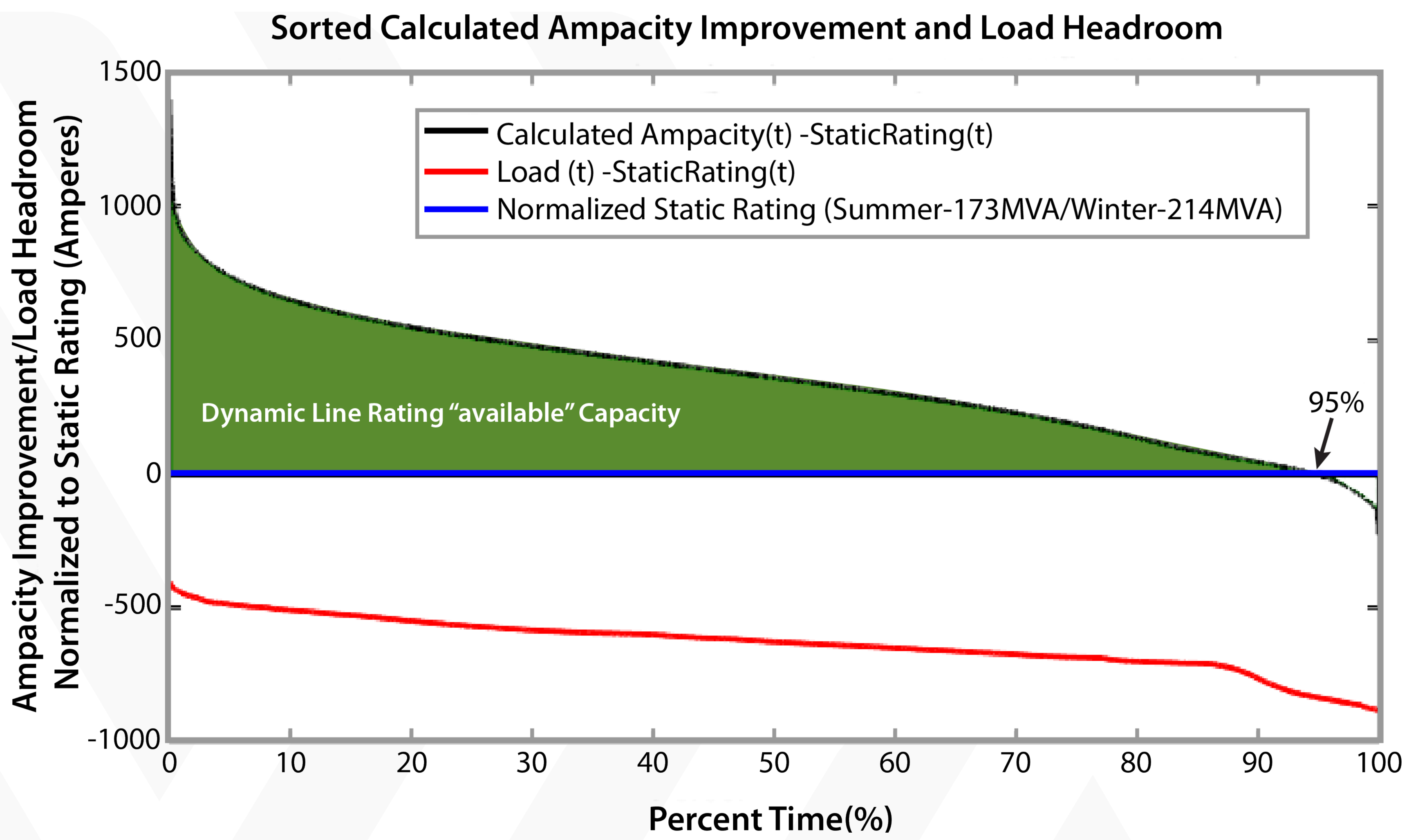


Figure 2. Results from a case study with AltaLink (Alberta, Canada) reporting improvement in capacity of Wind Energy connected transmission (4 line miles, 85 miles^2). Similar results from Idaho Power pilot studies over two regions with a total of 480 line miles over an area of 3,400 miles^2.

DLR Accomplishments to Date

Standards – Significant participation in IEEE and CIGRE standards groups. PI is one of two U.S. Delegates on CIGRE Working Group B2.59: Forecasting Variable Line Ratings.

Publications – 7 peer reviewed journals, **16** conference proceedings, **50+** invited presentations, Best Conference Paper on Markets, Economics, and Planning (IEEE PES GM).

Commercialization – Copyright asserted, DOE EERE Lab Corps commercialization strategy.

Workshop – INL | DOE | UVIG hosting the Dynamic Line Rating Workshop November 7-9, 2017 in Idaho Falls, ID.

Interactions w/ Industry & Academia – 15+ Non-Disclosure Agreements, **1** SPP agreement executed, **2** CRADA projects underway, more than **$1M** invested by industry/academia partners.

INL/MIS-17-41553

Dynamic Building Load Control to Facilitate High Penetration of Solar PV Generation

Teja Kuruganti, David Fugate, James Nutaro, Yaosuo Xue, Jin Dong, Mohammad Olama, Isha Sharma, Roderick Jackson, Arjun Shankar - Oak Ridge National Laboratory (ORNL)
Justin Hill, Pradeep Vitta – Southern Company
Seddik Djouadi, Ouassim Bara – University of Tennessee, Knoxville
Godfried Augenbroe – Georgia Tech

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

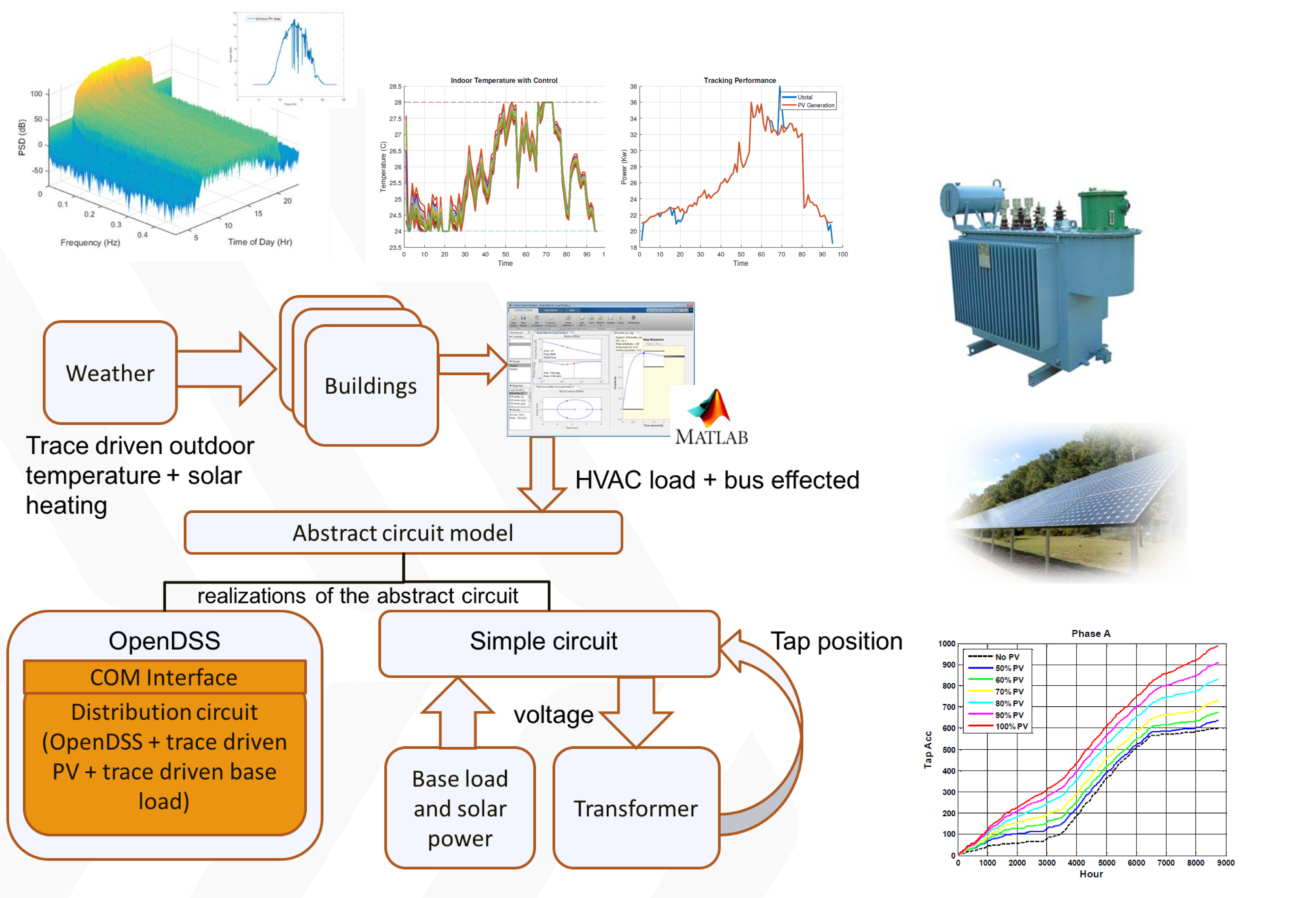
Project Description

Enable responsive building loads that can be controlled temporally and spatially to minimize the difference between demand and PV production to minimize voltage variation and reduce two-way power flow

Expected Outcomes

- Low-cost, low-touch control retrofits to distributed PV and building loads that enable load-shaping response in order to facilitate high-levels of renewable penetration
- Open-source software and hardware specification of the control platform to enable load integration and deployment

Significant Milestones	Date
Integrate models into an example configuration and simulate to study interactions without any controlled coordination to determine a baseline	10/31/16
Simulate various combinations of distributed PV and building loads to determine the effect and sensitivity of the combinations on the distribution grid stability	1/31/17
Report that documents the effect of varying levels of PV (10-100% of peak load) in the standard IEEE test case without any coordinated load control	1/31/17



PV Power Output Time-Frequency PSD for One Summer Day

Progress to Date

- Novel method using spectral analysis of PV generation to determine optimal utilization of loads as distributed energy resource
- Analysis of impact of high PV penetration using steady state and quasi steady state feeder voltages, and operation of LTCs due to PV power variability by using QSTS simulations with year long real data
- End-to-end open-source modeling and simulation package to enable PV responsive load control
- Adaptive load control for coordinating multiple buildings' loads to enable high penetration of PV
- Seven publications published/accepted. Two publications under preparation

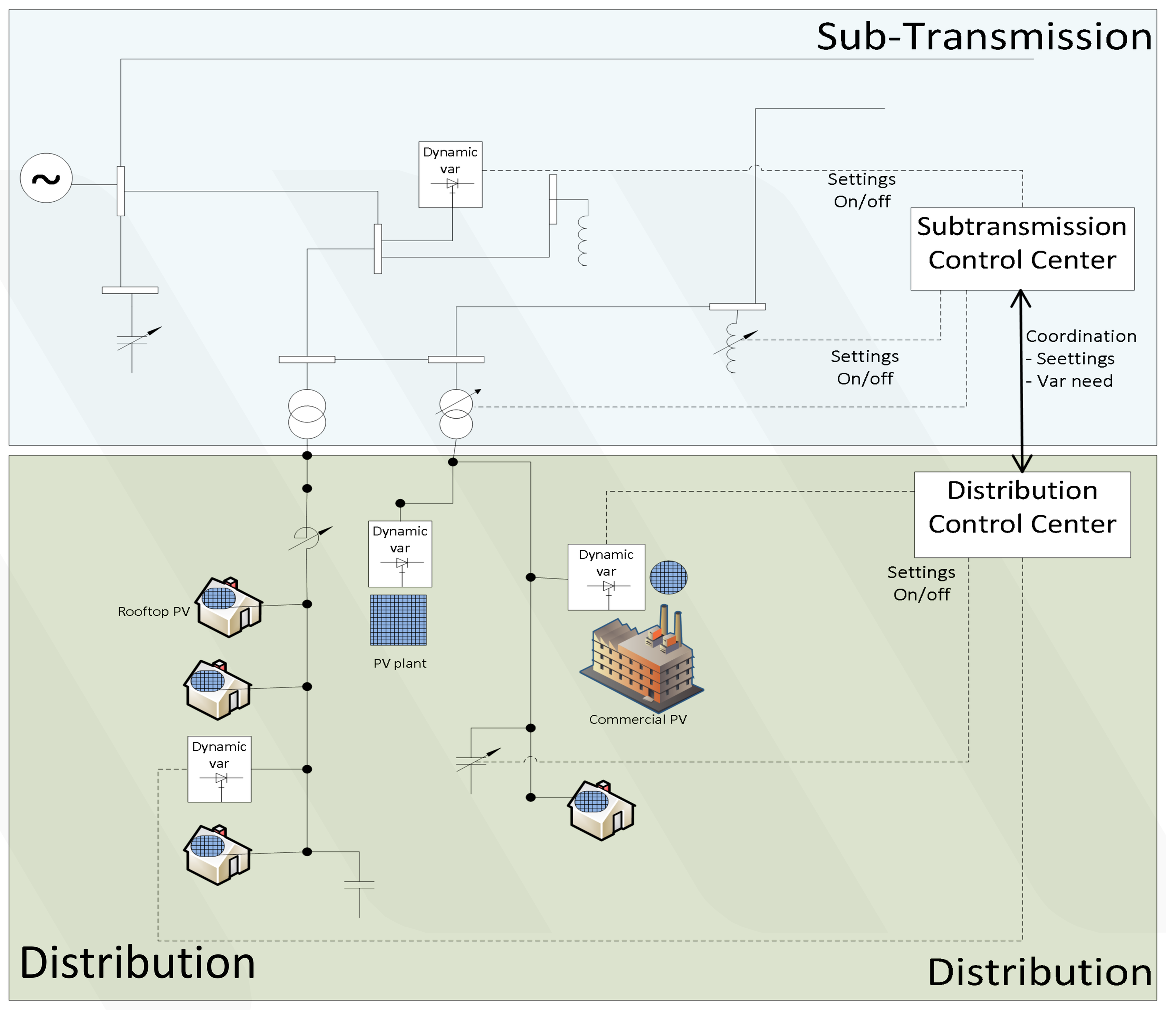
Enabling High Penetration of Distributed PV through the Optimization of Sub-Transmission Voltage Regulation

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

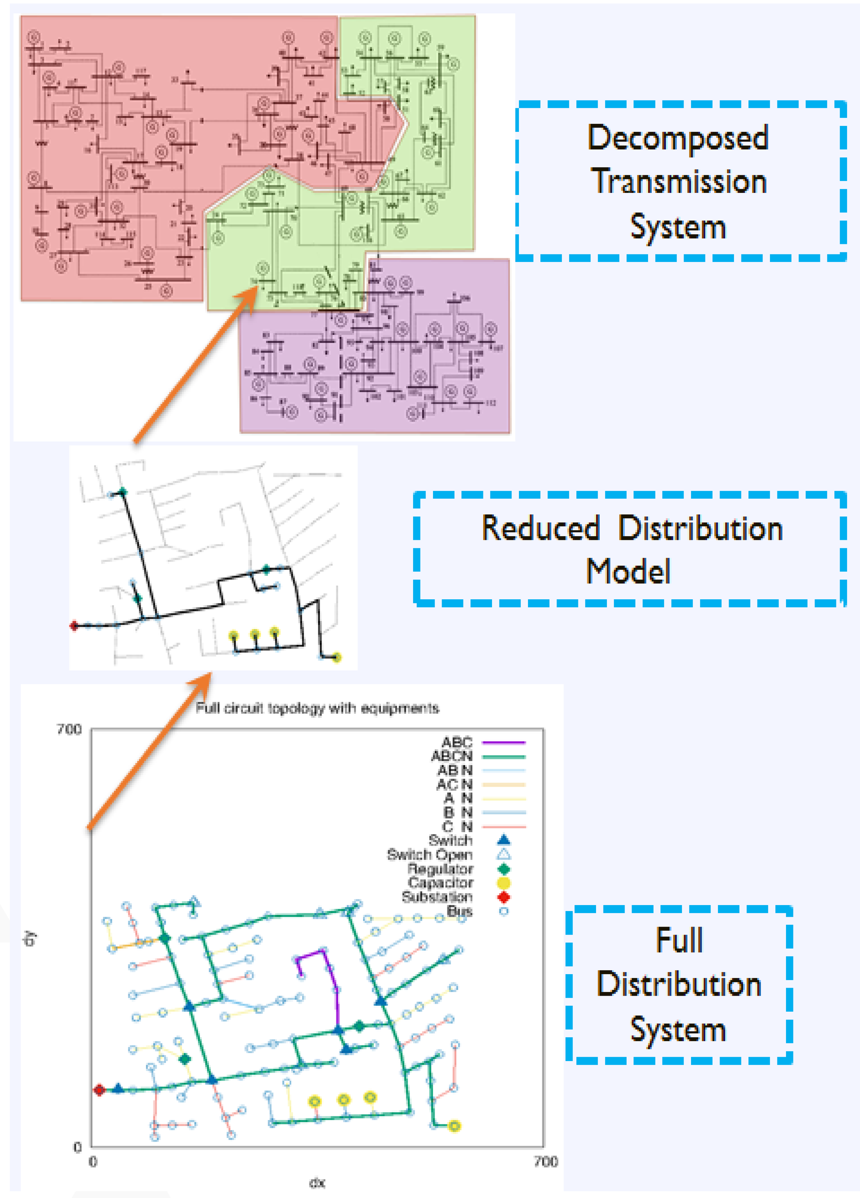
PNNL: Nader Samaan, Marcelo Elizondo, Yuri Makarov, Bharat Vyakaranam, Siddharth Sridhar, Xinda Ke, Renke Huang, Mallikarjuna Vallem, Jesse Holzer;
NCSU: Alex Q. Huang and Ning Lu **OCC:** Gregory T. Smedley **GE Global Research:** Yazhou Jiang **Duke Energy:** Brant Werts

Project Description

- Grid was not historically designed for bi-directional power flow, and again was not designed for controlling as many devices as are connecting today. Hence this project is advancing an integrated, coupled technologies approach, all the way from advanced, grid edge solar PV inverters, to distribution feeder equipment, to sub-transmission systems. Improvement to help PV will also help improve utilization of those grid assets for all generation types.
- The team is developing a Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT) to optimize the use of reactive power control devices and stabilize voltage fluctuations caused by intermittent PV, and a related Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT) for planning.



Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT) architecture

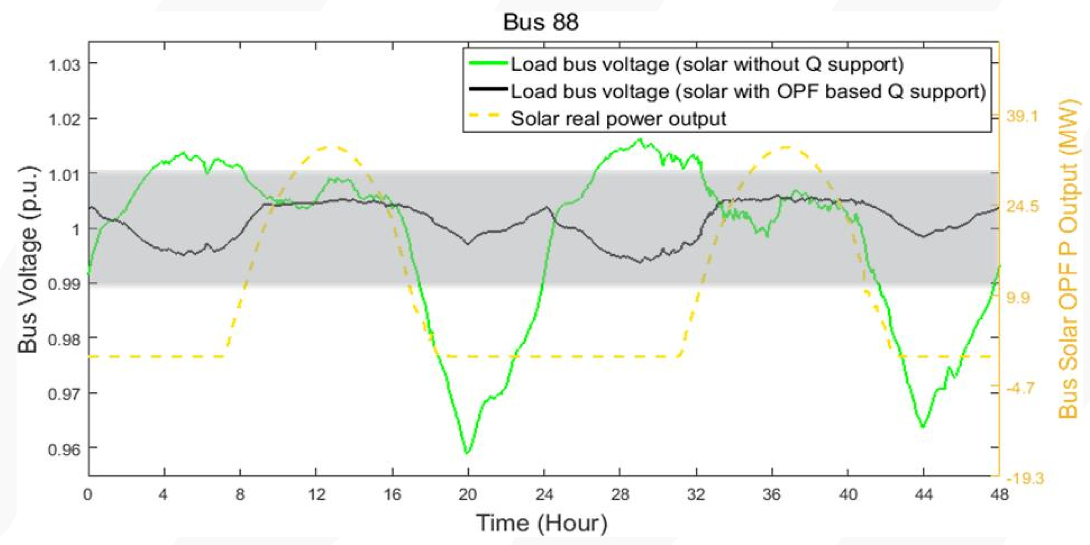


Scalability of the solution

Co-optimization of transmission and distribution Voltage

Expected Outcomes

- Successful implementation, demonstration, and commercialization of an operational tool to coordinate voltage regulation
- Development of planning tool (OFuST-VPT) to help utilities optimize investment in reactive power compensation to facilitate increased PV penetration
- Combined operation and planning tools will seamlessly interface with utility systems to help plan for and manage high PV penetration



Optimal control of substation voltage uses PV smart inverter functionality

Impact

- Enable high penetration of PV – up to 100% of substation peak load while meeting ANSI, IEEE and NERC standards
- Reduce interconnection approval time and cost

Significant Milestones	Date
Demonstrate prototype of CReST-VCT on IEEE testbed with 30% PV penetration	3/31/2017
Simulate performance of CReST-VCT on Duke Energy Carolinas system model and develop prototype of OFuST-VPT	3/31/2018
Field demonstration on Duke Energy testbed	3/31/2019

Progress to Date

- Demonstrated CReST-VCT on IEEE 118-bus test system
- Completed advanced synchronous generator capable PV inverter control models and integrated into CReST-VCT
- Developed and tested via simulation load-side control options for full IEEE 123-node system and two Duke Energy distribution feeders in OpenDSS
- Wrote white paper summarizing characteristics of reactive power compensation devices to be modeled in CReST-VCT
- Finalized prototype of distribution system model reduction tool
- Five (5) peer-reviewed articles accepted for publication

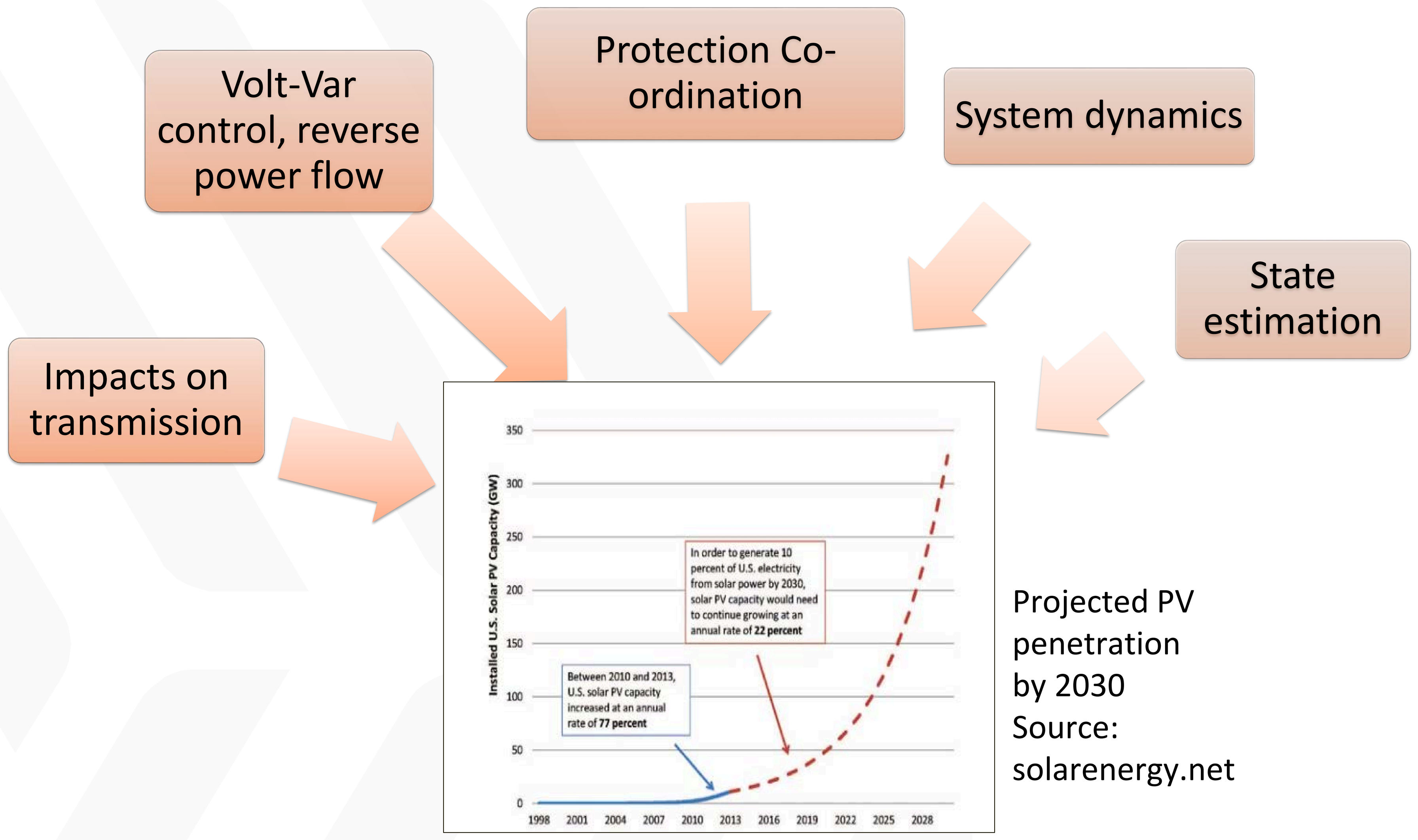
A Tool-Suite for Increasing Performance and Reliability of Combined Transmission-Distribution under High Solar Penetration

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Shrirang Abhyankar, Ning Kang, Karthikeyan Balasubramaniam (Argonne National Laboratory)
Yingchen Zhang, Bryan Palmintier, Ibrahim Krad, Dheepak Krishnamurthy (National Renewable Energy Laboratory)
Alexander Flueck (Illinois Institute of Technology)
Sandro Aquiles-Perez (Electrocon International Inc.)

Project Description

Develop a suite of software tools that imparts a holistic understanding of the steady-state and transient behavior of transmission-distribution interaction under high PV penetration levels along with real-time monitoring of the distribution system and integration of system protection.



Project objective: Address grid challenges impeding high solar integration

Expected Outcomes

Steady-state analysis Tool
- Combined transmission-distribution modeling
- New models of subtransmission/distribution substation
- Quasi-static analysis (less than 5 second time-step)
- Tool publicly available at end of 2018

Dynamics and Protection Tool
- Combined transmission-distribution modeling
- Integration with protection models
- New solar PV models using dynamic phasors

Distribution state estimation Tool
- Unbalanced distribution system state estimation
- Inclusion of AMI, PMU, and other sensor measurements
- Semi-definite programming based approach

Significant Milestones	Date
Set up Utility Advisory Group with three participating utilities (HECO, PG&E, and SPP)	Oct 2016
A total of five use-cases, to understand the different challenges the utilities are facing today or expecting in the future, have been prepared for the three proposed tools.	Jan. 2017
Developed steady-state transmission & distribution analysis tool interfacing ANL's transmission system simulator PFLOW with NREL's IGMS tool	Jan. 2017
Verified initialized network states of combined "unbalanced three-phase everywhere" T&D network model and implemented single-phase induction motor model with stall capability.	Mar. 2017
Verified unbalanced three-phase distribution system state estimates from semi-definite programming approach with noisy and missing measurements.	Mar. 2017

Progress to Date

- Utility Advisory Group (UAG): Hawaiian Electric Company (HECO), Pacific Gas & Electric (PG&E), SouthWest Power Pool (SPP)
- Use cases (five in total) for analyzing reliability and improving of combined transmission-distribution under high solar penetration.
- Preliminary functionality demonstration of the three tools
- Publications/Presentations:
  - B. Palmintier et al., "Experiences integrating transmission and distribution simulations for DERs with the Integrated Grid Modeling System (IGMS)", in Proceedings of the 19th Power Systems Computation Conference (PSCC' 16) Genoa, Italy 2016.
  - A. Flueck, "A Tool-Suite to Improve Reliability and Performance of Combined Transmission-Distribution under High Solar Penetration", presented at the CAPE Users group meeting, Ann Arbor, Michigan 2016.
  - K. Balasubramaniam and S. Abhyankar, "A Combined Transmission and Distribution System Co-Simulation Framework for Assessing Impact of Volt/VAR Control on Transmission System", to appear in IEEE PES general meeting 2017.
- Supporting GMLC project 'Development of Integrated Transmission, Distribution, and Communication Platform' by developing complementary use cases.

Providing Ramping Service with Wind to Enhance Power System Operational Flexibility

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

This project aims to develop an innovative, integrated, and transformative approach to mitigate the impact of wind ramping by providing flexible ramping products from wind power.

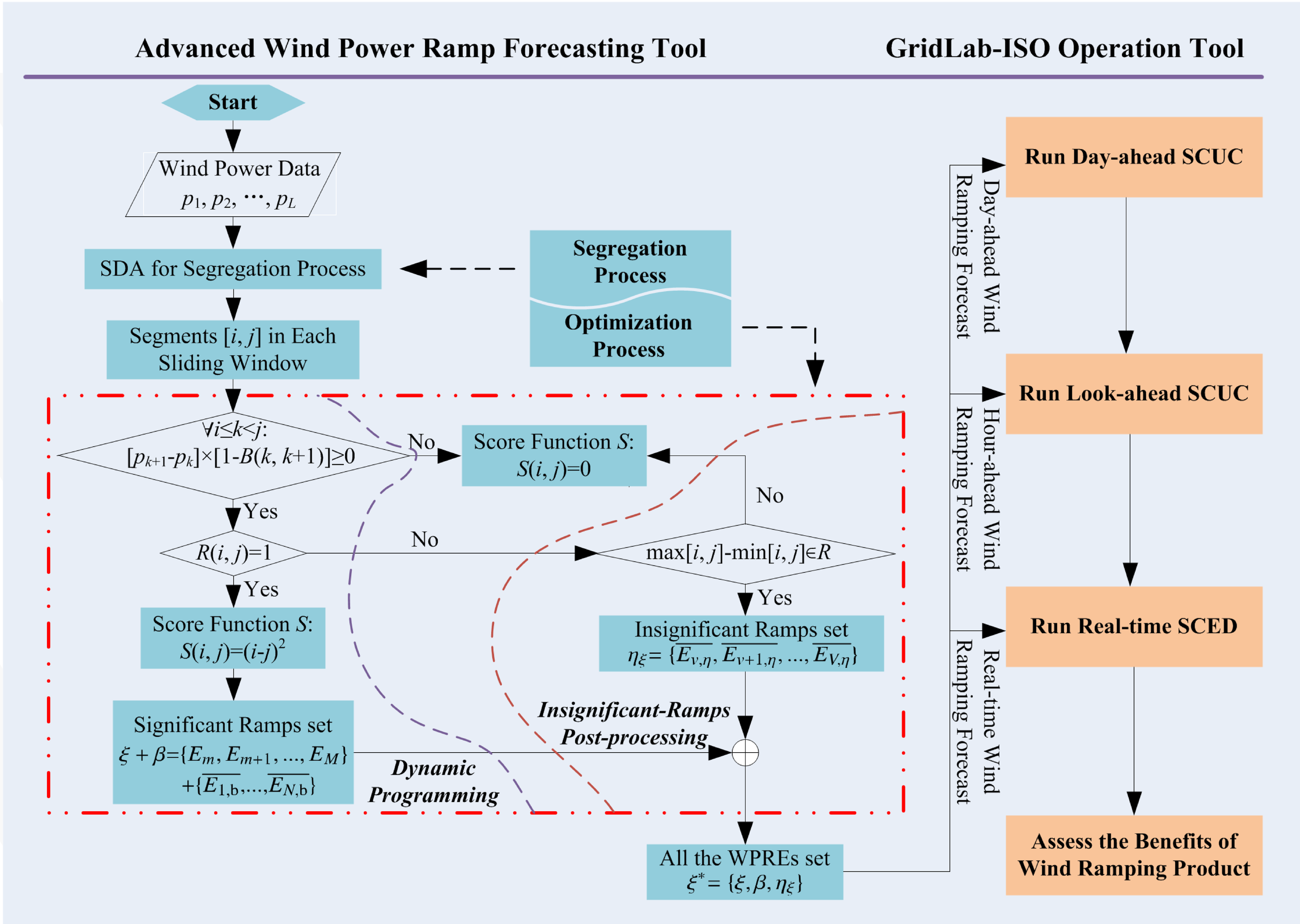
Expected Outcomes

- ❑ A new design to transform a negative characteristic of wind power, specifically "ramping", into an advantageous one.
- ❑ Advanced techniques for mid-term and short-term wind power ramp forecasting.
- ❑ New tools, concepts, and techniques that can be licensed to utility companies for testing the benefits of using wind to providing ramping service.
- ❑ Collaborate with industry to test and validate the methodology, taking into account economic and reliability goals, by integrating the proposed methodology into the operations of ISOs.

Impacts:

- ❑ The proposed project will significantly contribute to the reduction of wind integration costs by making wind power dispatchable and allowing the efficient management of wind ramping characteristics.
- ❑ The new market simulation tool we design in this project will be open-sourced to all DOE labs and be licensed to U.S. utilities and ISOs per their requests.

Significant Milestones	Date
Develop new techniques for short-term (e.g. 5-min) wind power ramp forecasting.	12/31/2016
Assess wind ramping forecast at different forecasts horizons.	3/31/2017
Design the wind-friendly flexible ramping products.	6/30/2017
Enhance the open source electricity market simulation tool.	9/30/2017
Simulation of the proposed approach on an actual bulk system	3/31/2018
Analyze the benefits of the proposed wind-friendly ramping product to the power grid	9/3012018



The Wind Power Ramp Forecasting and Electricity Market Simulation Tool Framework

Progress to Date

- Finished developing mid- and short- term wind power ramp forecasting algorithm and tool.
- Finished the design of the electricity market simulation tool.
- Peer-reviewed articles
  - One conference paper on 2017 IEEE PES General Meeting.
  - One journal paper published on IEEE Transactions on Sustainable Energy.
  - One journal paper under review by IEEE Transactions on Smart Grid.
  - One extended abstract submitted to IEEE Transactions on Power Systems.

U.S. DEPARTMENT OF ENERGY

P.I.: Bri-Mathias Hodge, National Renewable Energy Laboratory
Team members: Qin Wang, Venkat Krishnan (NREL)
External Partners: The University of Texas at Dallas

April 18, 2017