NATIONAL RENEWABLE ENERGY LABORATORY

Grid Modernization Research at NREL

Dr. Murali Baggu, Ph.D.
Laboratory Program Manager - Grid Integration

Utilities State Government Organization
2019 Annual Meeting July 21-24, 2019 Colorado Springs, CO

Topics

NREL at a Glance

1,850

Employees,
plus more than
600
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

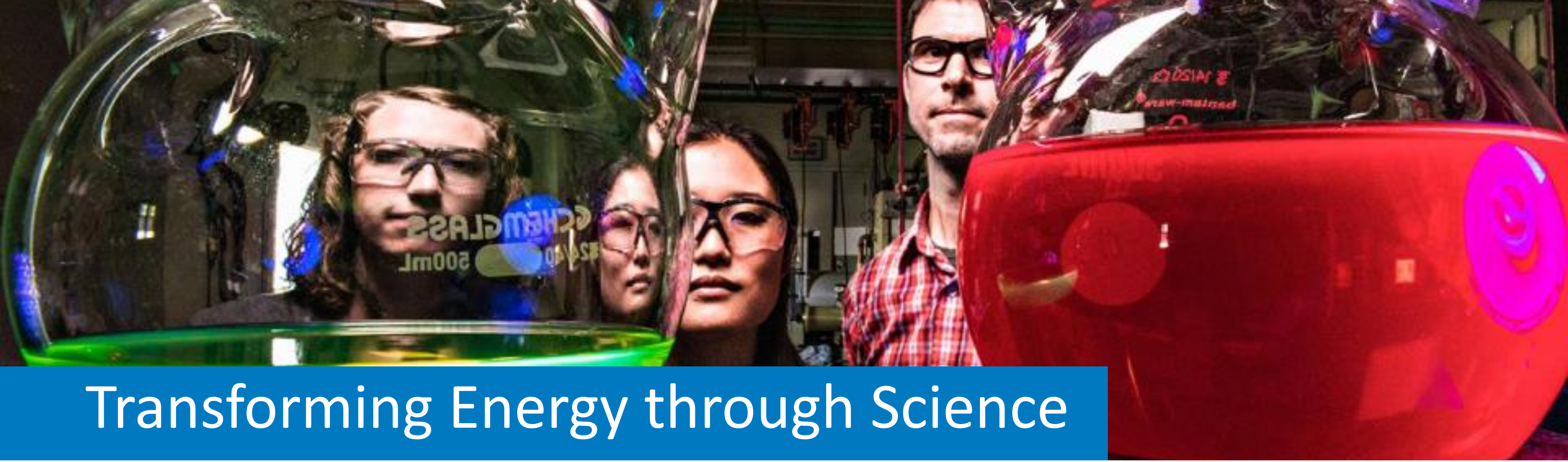
nearly
820

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

$1.1B
annually

National economic impact



Transforming Energy through Science

NREL advances the science and engineering of **energy efficiency**, **sustainable transportation**, and **renewable power technologies** and provides the knowledge to **integrate and optimize energy systems**

NREL's Science Drives Innovation

Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

High-Performance Computing

Data and Visualizations

Energy Systems Integration

Energy Systems Integration Facility

Research Focus Areas

- Renewable electricity to grid integration
- Vehicle-to-grid integration
- Renewable fuels to grid integration
- Battery and thermal energy storage
- Microgrids
- Large-scale numerical simulation
- Cybersecurity and resilience
- Smart home and building systems
- Energy-water nexus
- High-performance computing, analytics, and visualization

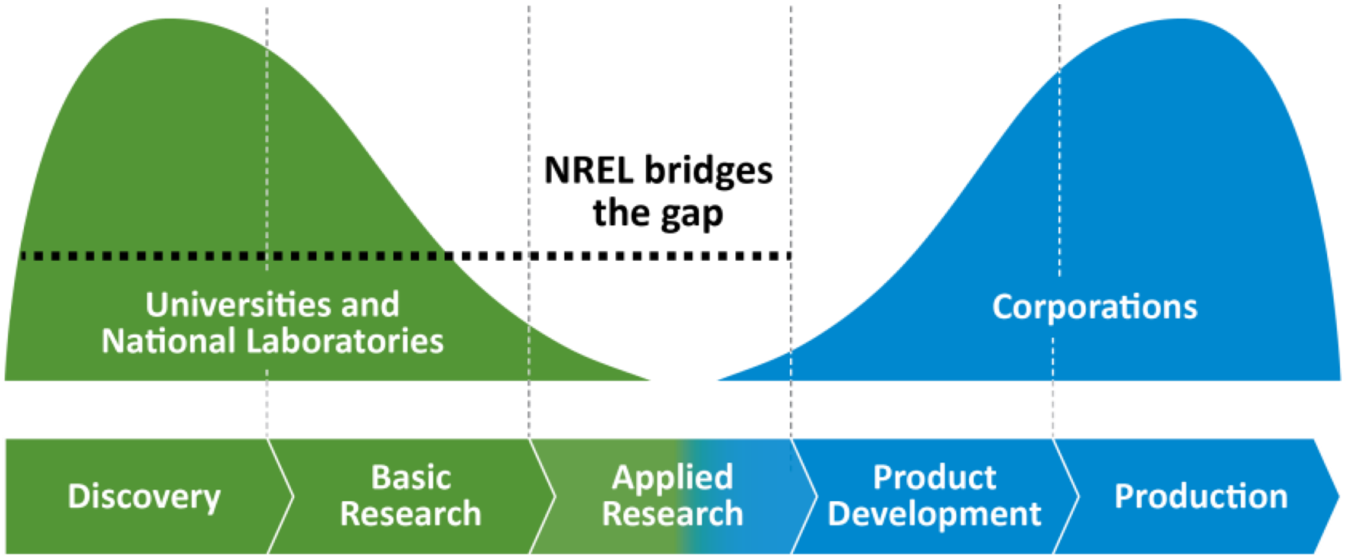
Energy Systems Integration Facility

High-Performance Computing

- Immersive, interactive visualization provides insight into complex systems
- Reduces risks and uncertainties that are often barriers to industry
- Ultra-efficient computer uses warm water for cooling
- Eagle computer, **8 Petaflops**

We Reduce Risk in Bringing Innovations to Market

- NREL helps bridge the gap from basic science to commercial application
- Forward-thinking innovation yields disruptive and impactful results to benefit the entire U.S. economy
- Accelerated time to market delivers advantages to American businesses and consumers

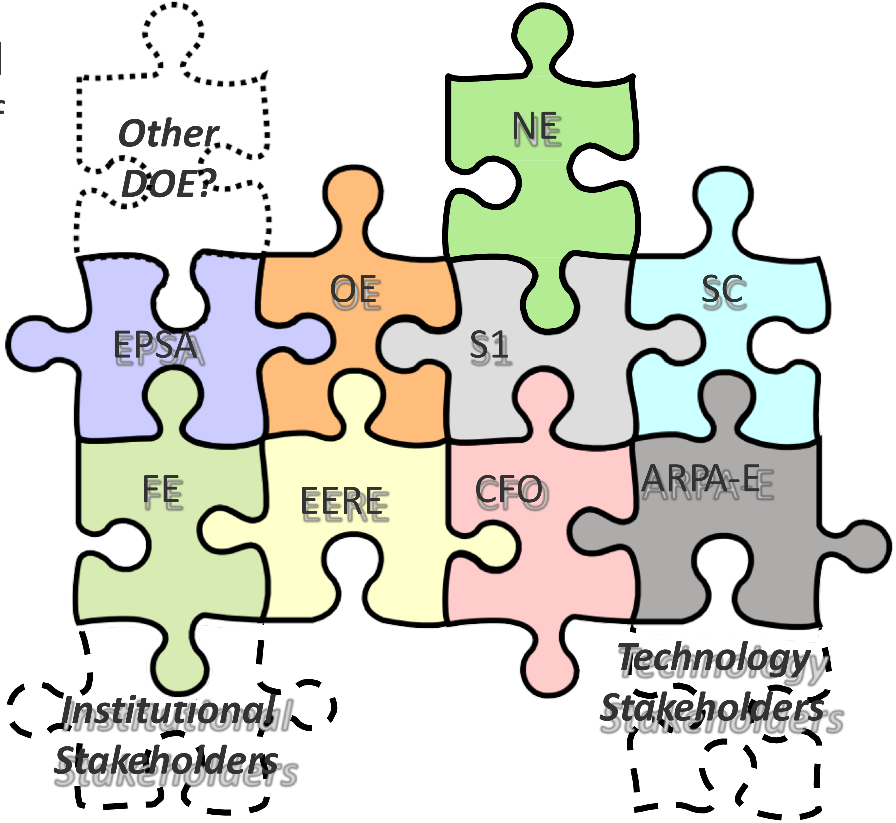


Grid Modernization

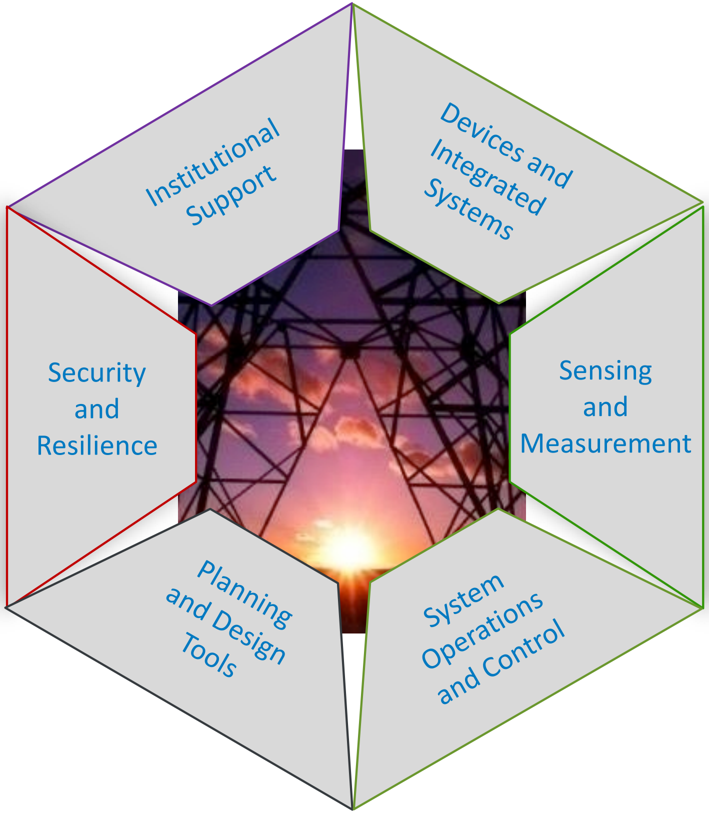
Grid Modernization Initiative -2015

An aggressive and urgent five-year grid modernization strategy for the Department of Energy that includes

- Alignment of the existing base activities among the Offices
- An integrated Multi-Year Program Plan (MYPP)
- New activities to fill major gaps in existing base
- Development of a laboratory consortium with core scientific abilities and regional outreach



Grid Modernization Laboratory Consortium (GMLC)



New Vision for the Grid Modernization Initiative - 2019

- **Fully Integrated Vision:**
  - Focus on a fully integrated vision of the energy system from fuel to generation to load, including interdependent infrastructures.
- **Reliability and Resilience:**
  - Strengthen, transform, and improve the resilience of energy infrastructure to ensure access to reliable and secure sources of energy.
  - Focus on reliable and resilient against all malicious threats, natural disasters, and other systemic risks such as human error or the grid's dependence on other critical systems.
- **Participation:**
  - DOE Offices (the Applied 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).

Topic Areas

Foundational Areas: Multi-lab, holistic proposals are sought that address well-defined foundational platform activities in the six topic areas outlined below.

Resilience Modeling

- Reliability and Resilience Metrics
- Data
- Interdependencies Modeling
- Use Cases
- Visualization

Energy Storage and System Flexibility

- Flexible Distribution System Platforms
- Network Microgrids
- Black Start Capability
- Power Electronics and Controls

Advanced Sensors and Data Analytics

- Crosscut Support
- Robust Sensing System
- Incipient Failure Detection
- Monitoring for Critical Infrastructure Interdependencies
- Detecting and Forecasting Behind-the-Meter Resources

Institutional Support and Analysis

- Resiliency Planning
- Technical Assistance to States and Regions

Cyber Physical Security

- Inherently Secure Field Devices that Provide Observability of Grid Security
- Secure Communications of Information used for Grid Operations, for Normal Operations and/or during Emergency Response
- Malware Analysis Using an AI Approach

Generation

- Hybrid System Portfolio Operations
- Micro and Small-Scale Generation and Supporting Technologies
- Security of Generation, Fuel Supply, and Water Supply
- Environmental Impacts and Critical Functions
- Environmental Resiliency
- Generation Interdependencies

Renewable Integration

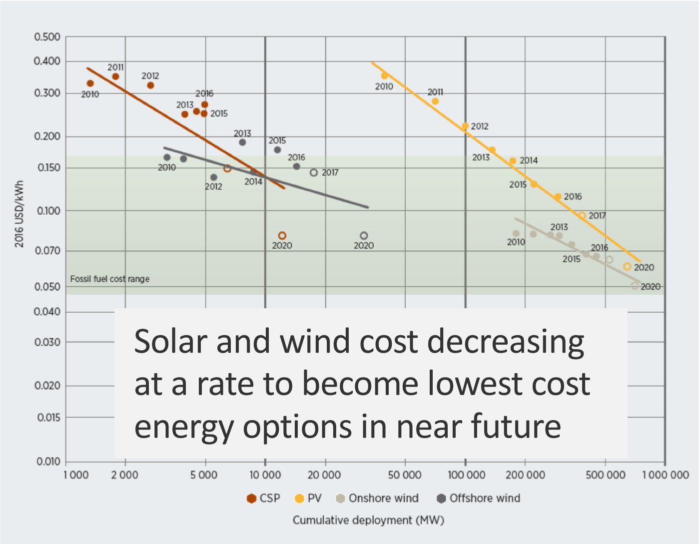
Transformational Electrification

Drivers for Electrification

- Electricity from renewables will soon be consistently cheaper than from fossil fuels
- By 2020, all the power generation technologies that are now in commercial use will fall within the fossil fuel-fired cost range, with most at the lower end or even undercutting fossil fuels
- Decreasing electricity costs from low cost PV and onshore wind projects represent a real paradigm shift in the competitiveness of different power generation options

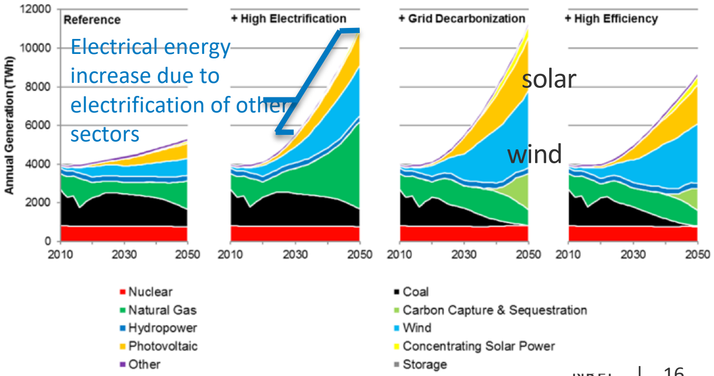
Electrification Path Forward

- Use of wind and solar will drive need for new operations and energy shifting capability (e.g. controls, storage, demand response)
- Building loads, transportation, and industry should migrate to electrification for economic and environmental reasons



Source: IRENA Renewable Cost Database; IRENA Auctions Database; GWEC, 2017; WindEurope, 2017; MAKE Consulting, 2017; and SPE, 2017.

Source: http://www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017



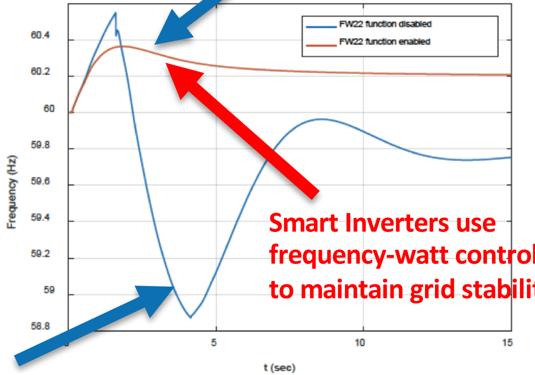
Source: https://www.nrel.gov/analysis/electrification-futures.html

Integrating PV in Hawai‘i

Photo by Ken Kelly, NREL

- In Hawai‘i, PV is cost-effective on residential homes and larger central-station PV plants
- On some of the islands, PV has reached over 50% of the installed generation capacity base
- **Impact: New GMLC research shows smart inverters can maintain stable and safe grid operations**

Overfrequency event causes legacy inverters to trip



Smart Inverters use frequency-watt control to maintain grid stability

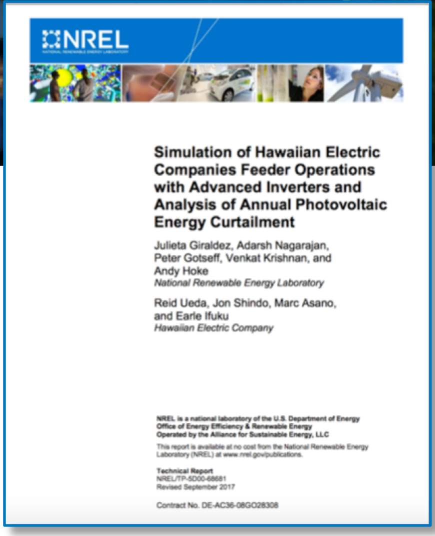
System frequency declines and can cause blackouts

Source: https://www.nrel.gov/docs/fy17osti/68884.pdf

HECO - Voltage Regulation Operating Strategies

- Hawaii has more distributed PV than any other U.S. state and DERs play a major part in the plan for 100% renewables by 2045
- Current levels of PV result in steady-state over-voltage issues
- **Near-term solution:** *use customer-sited resources to increase hosting capacity*

- **Impact :** 1) Activating autonomous inverter-based grid support functions with reactive power priority is recommended to avoid momentary over-voltages, 2) Volt-Var recommended with Volt-Watt to protect the system from high over-voltages, and 3) PV curtailment values from grid support functions are much lower than expected



NREL

Simulation of Hawaiian Electric Companies Feeder Operations with Advanced Inverters and Analysis of Annual Photovoltaic Energy Curtailment

Julieta Giraldez, Adarsh Nagarajan, Peter Gotseff, Venkat Krishnan, and Andy Hoke
National Renewable Energy Laboratory

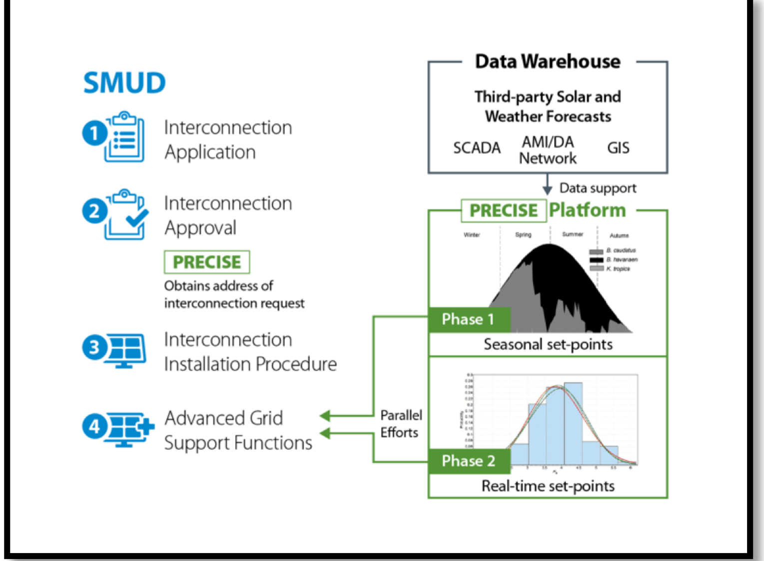
Reid Ueda, Jon Shindo, Marc Asano, and Earle Ifuku
Hawaiian Electric Company

NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

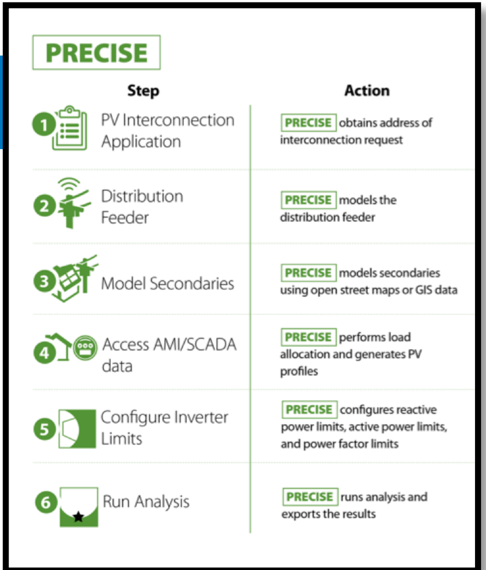
Technical Report
NREL/TP-5D00-68681
Revised September 2017

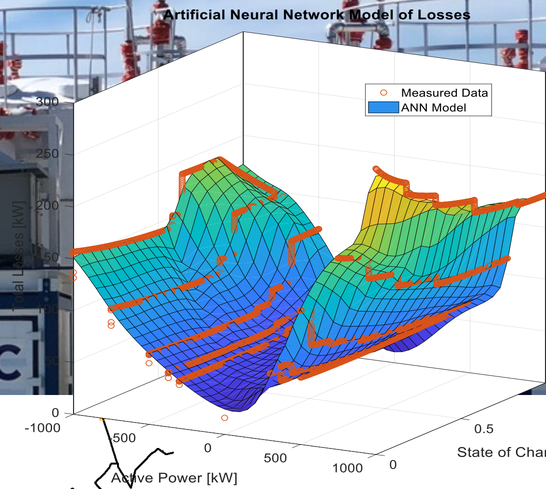
Contract No. DE-AC36-08GO28308

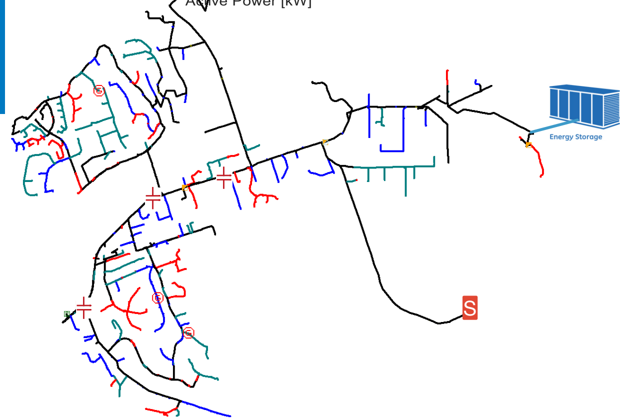


SMUD: Precise

- UL1741 Supplement A and California's Smart Inverter Working Group (SIWG) enabled smart inverters from September 2017
- New 1547-2018 smart inverters are a standard.
- PRECISE will support utilities to preconfigure advanced inverters even before inverters are installed.
- A utility agnostic platform for PREconfiguring and Controlling Inverter Set-points (PRECISE) for of smart-inverters.





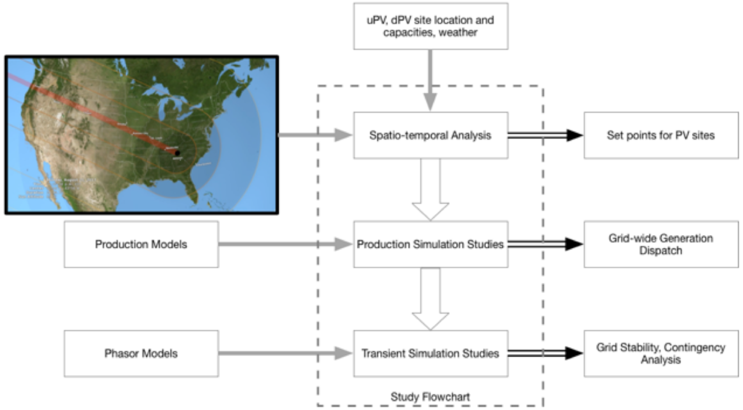


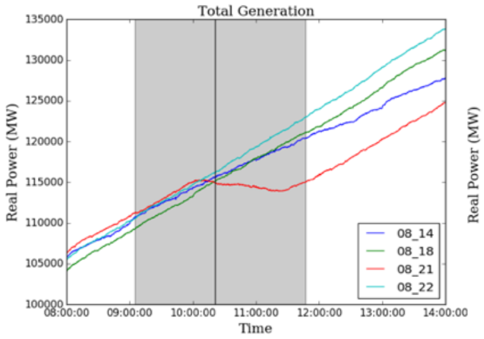
Sumitomo-NREL battery demonstration project

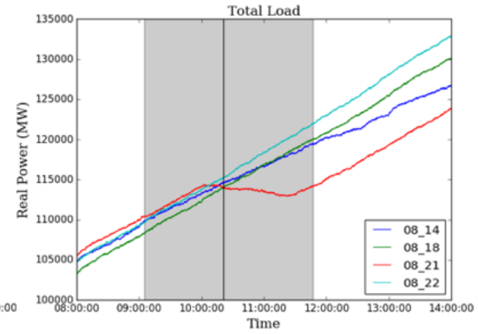
- Economic evaluation based on local distribution grid support
- High fidelity Vanadium flow battery characterization
- Comparison with lithium-ion battery chemistry

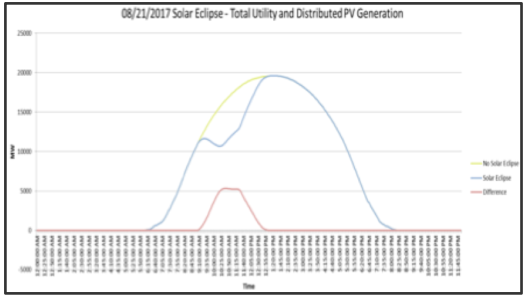
Impact Analysis of Solar Eclipse on WECC

- Framework to study large-area events
  - Spatio-temporal analysis to study PV distribution
  - Production studies to estimate economic generation dispatch
  - Transient studies to analyze grid stability
- Study results used by WECC Reliability Coordinator for preparing for eclipse
- Post-event analysis for further insights

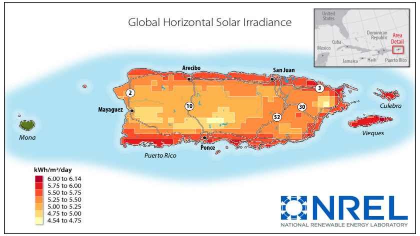


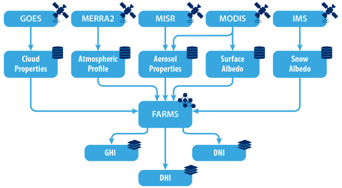


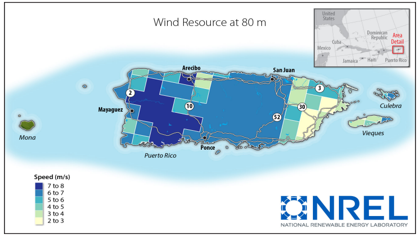




Multi-Lab Support Effort to PREPA







NREL contributions to Phase 1 activities:

- Support transition to 100% renewable grid in Puerto Rico by 2050
- Initial characterization of potential for Solar and Wind power
- Minimum technical requirements for interconnecting utility-scaler PV and wind generation
- Recommendations on use cases for energy storage for reliability and resiliency services
- PSCAD model of PREPA grid
- Storage demonstration project with AES using 12 MW BESS in Puerto Rico

Multi-Lab Grid Modeling Support for Puerto Rico Phase II

Murali Baggu, Elizabeth Doris

Project Summary

Ultimate goal is to provide Puerto Rico with useful tools and skills which will enable them to plan and operate its electric power grid with more resilience against future disruptions.

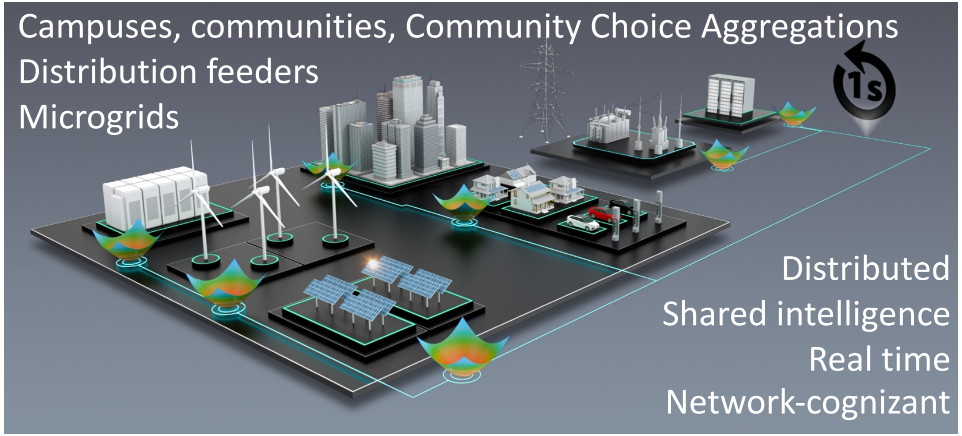
Project Impacts

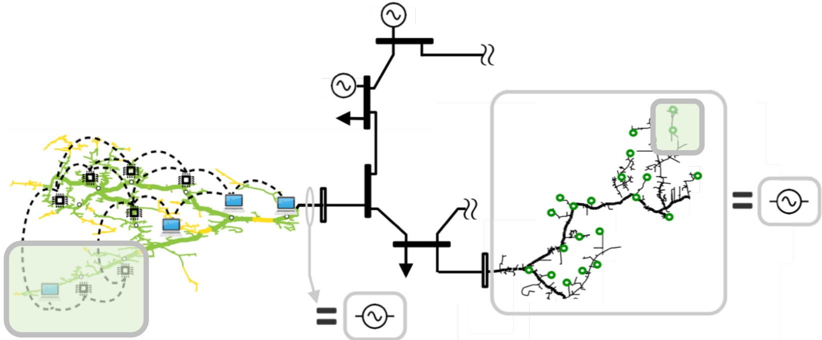
- Support the long-term recovery of Puerto Rico's electric power grid in the most secure and resilient way. A resilient electric grid is vital to Puerto Rico's security, economy, and way of life and will provide the foundation for essential services that people and businesses on the island rely on every day.
- Enable Puerto Rico stakeholders to develop strong technical rational for energy investment decisions.
- Work with a wide variety of stakeholders to identify data and tools needed to continue capacity development for self-sufficiency of the energy sector. Execute training and train-the-trainer on data and tools

Control and Optimization Theory

Real-time optimization and control of next-generation distribution infrastructure

CHANGING WHAT'S POSSIBLE

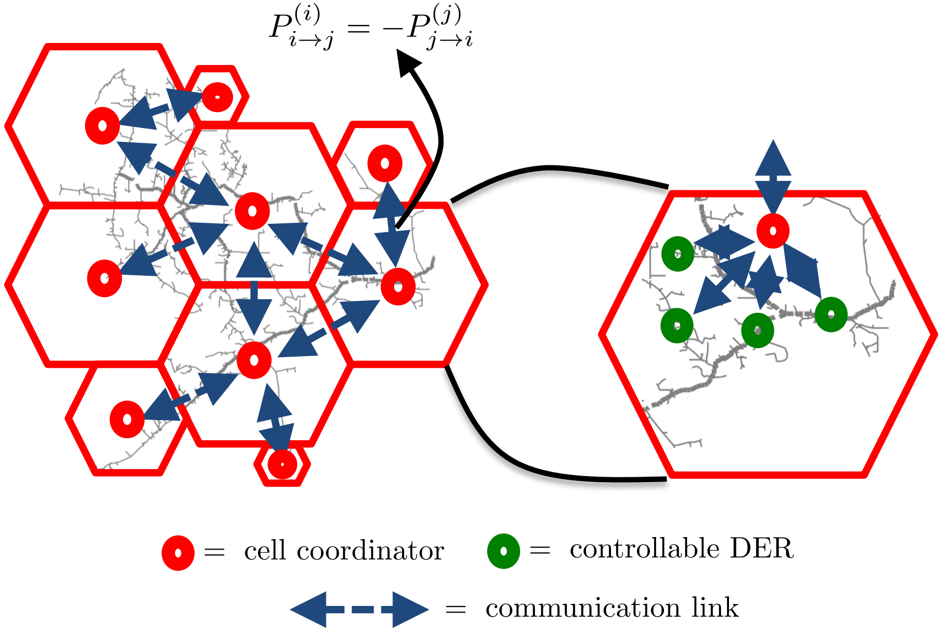




A real-time, distributed, and plug-n-play optimization platform to enable massive integrations of DERs, ensure voltage and power quality 100% of the time, maximize social welfare, and realize the virtual power plant vision.

- ❑ Large-scale power hardware-in-the-loop experiments
- ❑ High-fidelity feeder models with 100 controllable DERs
- ❑ More than 100 physical DERs

Autonomous Energy Grids



Objective:

- Formulate new classes of optimization problems for Autonomous Energy Grids
- Develop computationally affordable solution approaches for non-convex problems associated with real-time operation of AEGs
- Develop distributed algorithms for real-time optimization of AEGs with various message-passing

Autonomous energy grids (AEGs): scalable, reconfigurable, and self-organizing information and control infrastructure that promises ***extreme enhancements in terms of resiliency, security, and reliability***

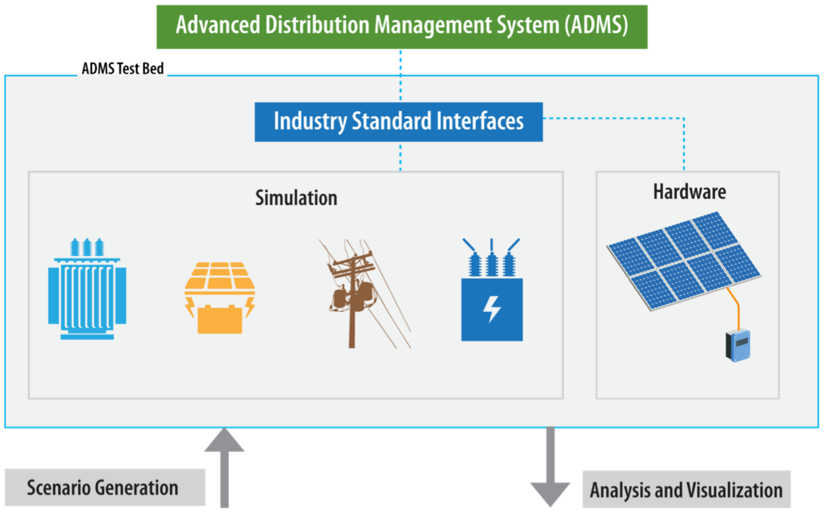
Grid Research: Distribution Automation

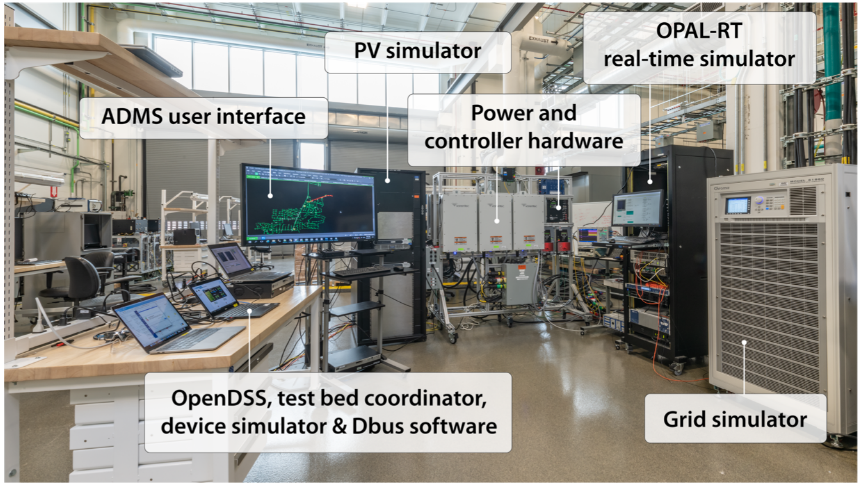
ADMS Testbed Development

Project Description

- Model large scale distribution systems for evaluating ADMS applications
- Integrate distribution system hardware in ESIF for PHIL experimentation
- Develop advanced visualization capability for mock utility distribution system operator's control room.

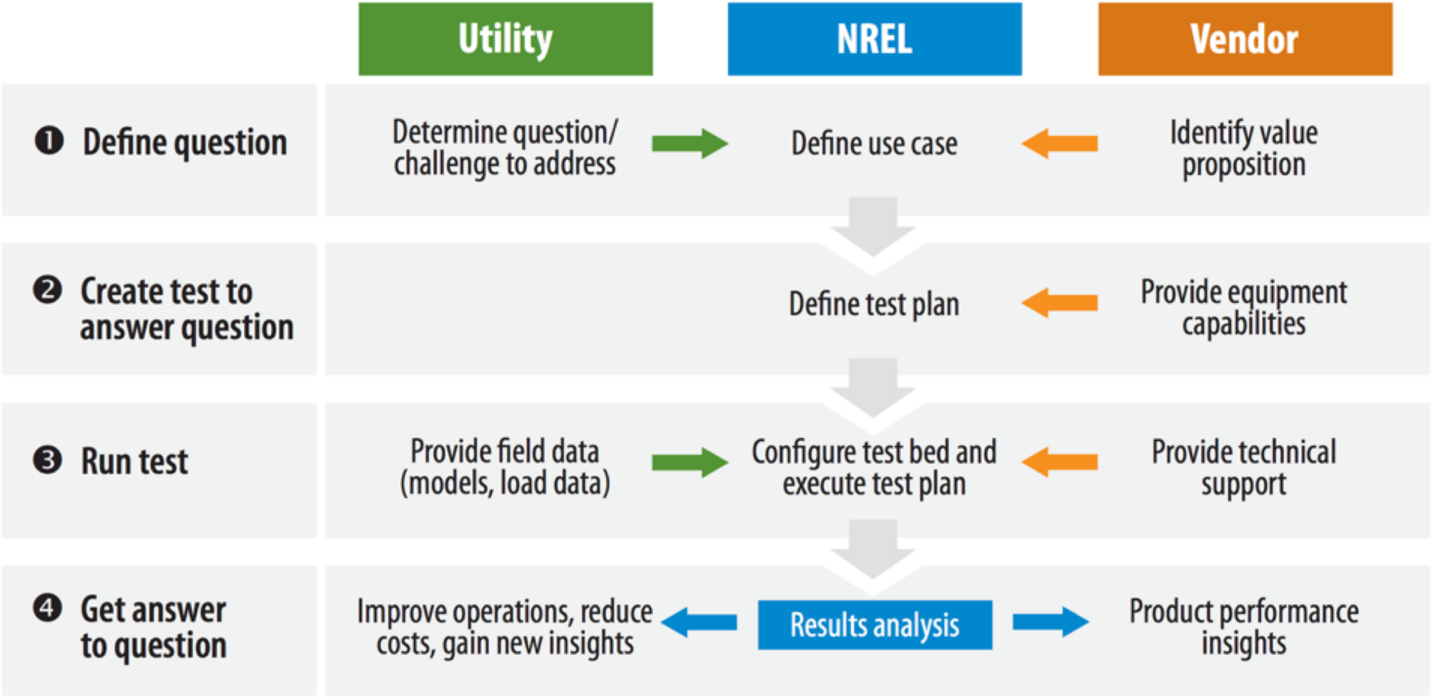
Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY





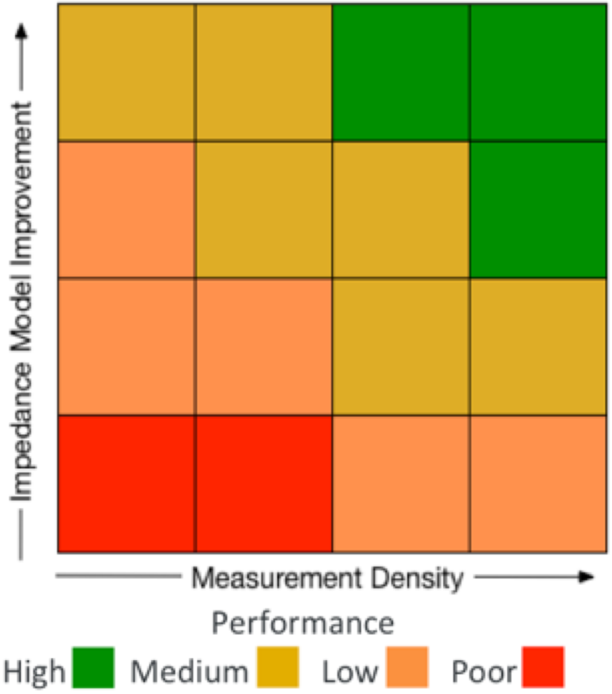
Use Case Selection

Advanced Grid Research
OFFICE OF ELECTRICITY
US DEPARTMENT OF ENERGY



ADMS Use Case 1: Model Improvement

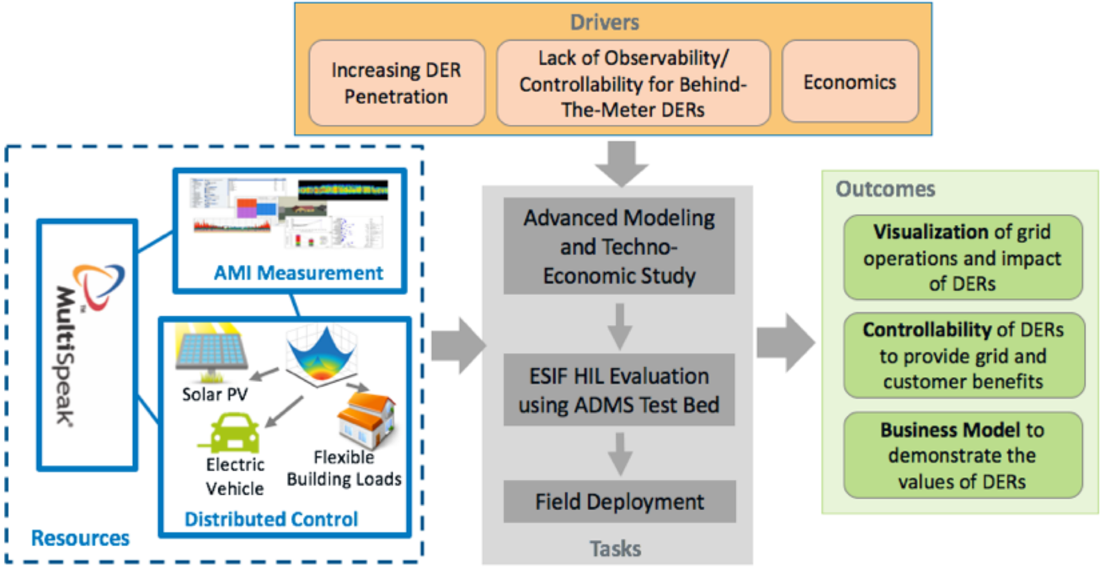
Goal: Identify a trade-off between the depth of remediation needed and the density of measurements to implement various advanced distribution management applications like Fault Location, Isolation and Service (Supply) Restoration (FLISR), Integrated Volt-VAR Optimization (IVVO) and Fault Location Prediction (FLP) on their system



Use Case 2: Enabling Distribution System Observability and Control for High DER

Goal: Develop and validate new grid visualization, control paradigms, and business models for cooperatives and municipally-owned utilities through integration of grid-friendly intelligent DER assets

- Model HCE's network and define use cases.
- Evaluate advanced voltage regulation mechanisms using hard-ware-in-the-loop (HIL) experiments.
- Perform **first-of-a-kind pilot field deployment**
- Analyze techno-economic cost-benefit of use cases.
- Disseminate best practice through NRECA and NISC



Project Team: NREL, Holy Cross Energy, Survalent, NRECA

Enhanced Control, Optimization, and Integration of Distributed Energy Applications (Eco-Idea)

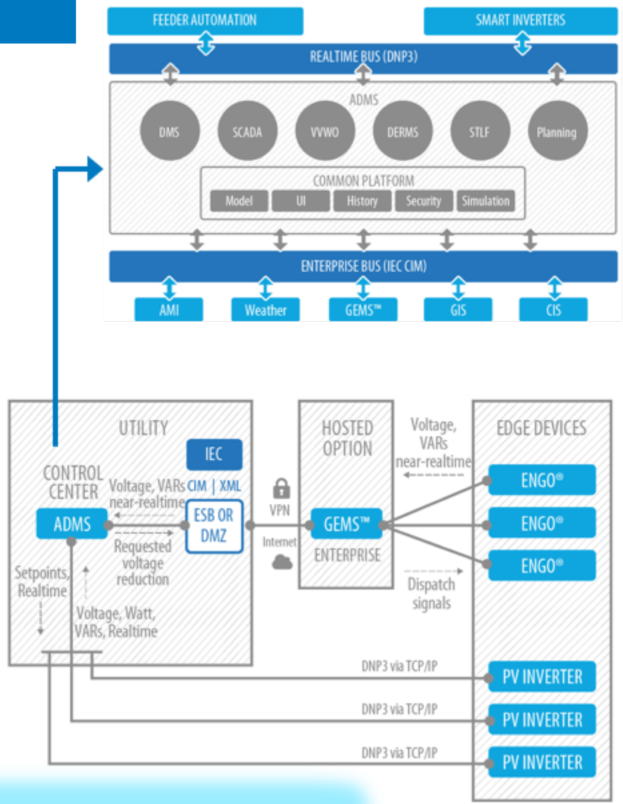
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Partners: NREL, Schneider Electric, Varentec Inc., Xcel Energy, Austin Energy, and EPRI

Technology Summary

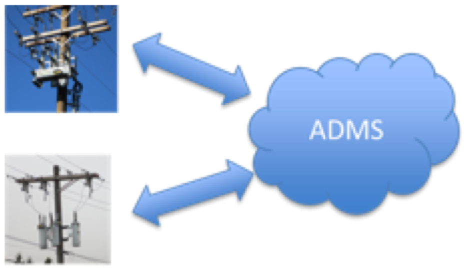
Develop, *validate*, and *deploy* an innovative Data-Enhanced Hierarchical Control (DEHC) architecture that:

- Comprehensively resolves the deficiencies of current operational settings.
- Enables an efficient, reliable, and secure operation of distribution systems with massive penetration of solar energy.
- Seamlessly integrates multiple voltage-regulation technologies to achieve a reliable and efficient system-wide operation at multiple spatio-temporal scales in the face of volatile ambient conditions.
- As a first-of-its-kind deployment of the proposed DEHC platform, provides ample evidence of the effectiveness of the proposed approach.



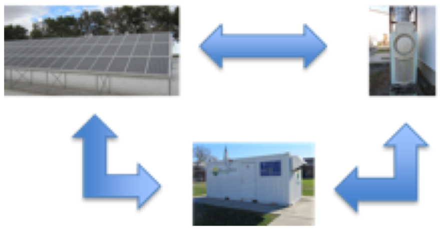
Seamless system-wide, fast, and secure coordination among heterogeneous devices to achieve optimal and reliable operation of distribution systems with massive PV penetration.

Increasing distribution system resiliency using flexible DER and Microgrid Assets Enabled by OpenFMB



Centralized

+



Decentralized

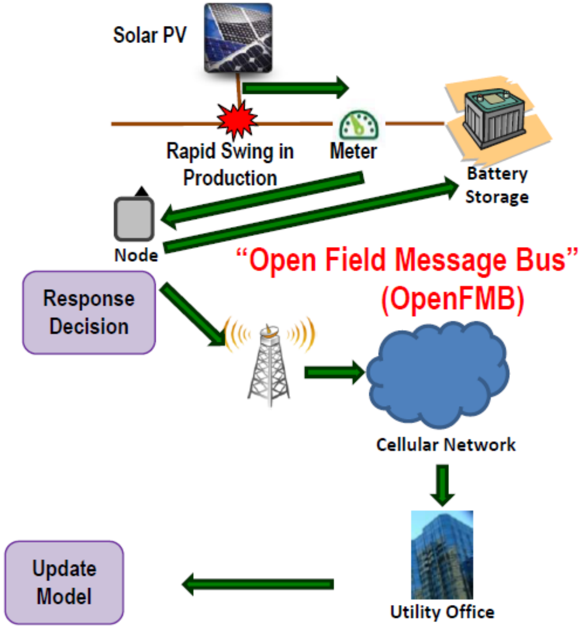
- A 20% increase in distribution feeder resiliency through the active engagement of DERs and microgrids as resiliency resources in flexible segmented distribution system operations.

Expected Outcomes

- A 20% increase in distribution system resiliency.
- The ability to coordinate the operations of centralized utilities systems and decentralized non-utility systems using OpenFMB.
- The ability to implement a segmented operational strategy.
- The ability to actively engage distributed DERs and microgrids as active operational assets.

Regional Progress

- The initial deployment will focus on operating FLISR in a segmented scheme with high penetrations of DERs and microgrids.
- The developed capabilities can be applied in any region where there are centralized and decentralized control systems that could be integrated to achieve global goals.



San Diego Gas & Electric- AMI for Operations

Impact: Real measured data as opposed to models will demonstrate how SDG&E service territory is currently and forecasted to be impacted for High Pen PV and EVs., applicable directly to other utilities.

Description: Data analysis optimized design for real-time controls and systems for high PV penetration in its service territory as well as determine the effectiveness of technology solutions such as energy storage, EV's, smart inverters, flexible loads et cetera to mitigate any issue with High Pen PV. Leverage its existing AMI infrastructure to provide a foundational, pervasive secondary voltage monitoring network and a phase identification system.

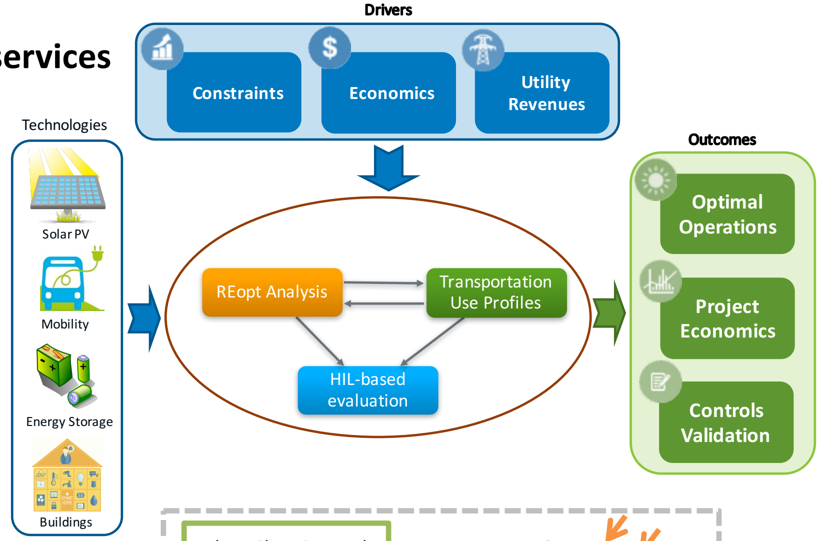
ESIF Activity: ITRON AMI system will collect data from SDG&E and will then develop and propose algorithms through ESIF's remote hardware in the loop (RHIL) for data analysis to be able to provide metrics back to SDG&E such as voltage regulation, fault location.

Project Team:

Evaluating site control strategies for grid services

Goal: Optimizing mobility, solar, buildings and storage for grid services

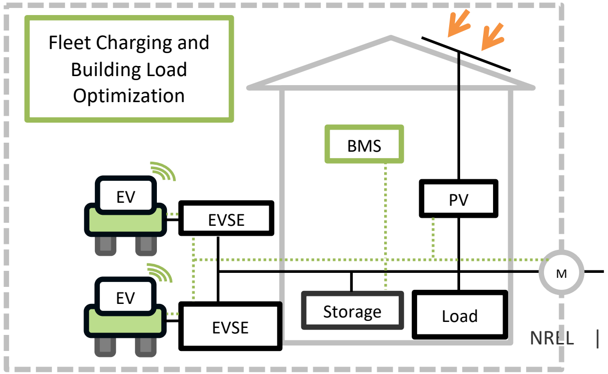
Description: Electrification of transportation fleets provide an opportunity for optimizing multiple DER technologies. Synergistic site controls unlock additional value streams and accelerate technology adoption.



ESIF Activities

- Detailed regional analysis for California, PJM and New York
- FleetDNA data analysis to develop transportation and battery use profiles
- HIL evaluation for controls validation
- Cost-benefit analysis

Impact: Optimal integration of mobility with other DER technologies



Project Team

EATON

conEdison

Thank you

www.nrel.gov

Murali.Baggu@NREL.gov