
NREL
NATIONAL RENEWABLE ENERGY LABORATORY
ESIF 2017

Associate Director's Letter

The Energy Systems Integration Facility (ESIF) is the nation's premier facility for the research, development, and demonstration of the integrated technologies and strategies shaping our energy system. It was established in 2013 by the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy on the campus of its National Renewable Energy Laboratory (NREL), and it is a designated DOE user facility.

Now in its fourth year of operation, the ESIF continues to address the key hurdles facing energy systems integration (ESI). At the ESIF, we're examining ways to enable the grid to be more reliable, resilient, secure, and affordable with a diverse generation portfolio including high penetrations of renewable energy. For instance, we're working on several ESIF High Impact Projects, research partnerships with industry that were selected for their potential to impact our ability to provide clean, reliable, and affordable energy nationwide. For Fiscal Year 2017, these projects included advanced integration technologies such as microgrids, advanced inverters, smart buildings and communities, and energy storage.

Modernizing our electric grids will also mean allowing consumers to be active participants on the grid, whether it's by using smart appliances that can provide flexibility during times of peak power consumption, advanced inverters that can provide voltage support to the distribution system, or electric vehicles that coordinate charging times with the grid or serve as power sources through vehicle-to-grid technology. In many ways, these are uncharted territories, requiring new ways to coordinate all of the players to maximize the potential of these technologies for grid reliability and efficiency. All of these projects are helping to solve different aspects of DOE's Grid Modernization Initiative (https://go.usa.gov/xnnM6), a coordinated approach among DOE and the national laboratories to develop the tools and technologies to measure, analyze, predict, protect, and control the grid of the future.

In addition to developing and advancing new technologies, we're making them more secure within the power system. With the increasing use of information technology and operational technology to manage and control the grid and consumer devices such as advanced inverters, smart appliances, and electric vehicles, the grid's cyberattack surface has expanded. Anything connected to the Internet is a potential target for hackers, and diligence to protect the grid is essential because a loss of power can have severe economic, health, and national security impacts. At the ESIF, we're examining not only ways to assess vulnerabilities in the existing system but also ways to improve our energy system's cybersecurity posture going forward.

Award-winning lab space, the most advanced equipment, and specialized scientists and engineers who can help move new technologies forward make the ESIF a unique connecting point where breakthrough research in ESI is happening every day. The best part is, as a DOE user facility, the ESIF is open to partners from utilities to cities, academia to manufacturers. In closing, I extend an invitation, and reiterate the message that has guided the ESIF since it opened more than four years ago: bring us your challenges, and let's solve them together.

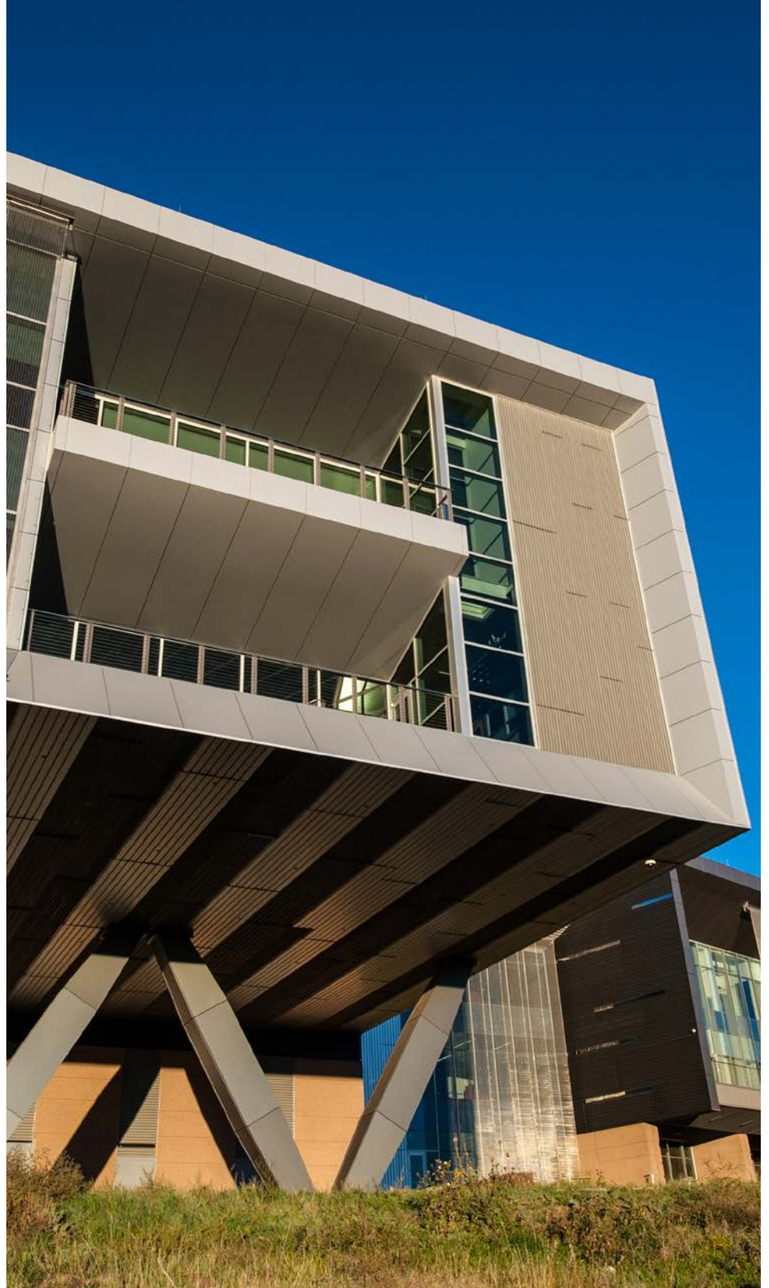
Sincerely,

Juan Torres

Associate Laboratory Director for Energy Systems Integration at NREL

Martha Symko-Davies

Laboratory Program Manager for Energy Systems Integration at NREL



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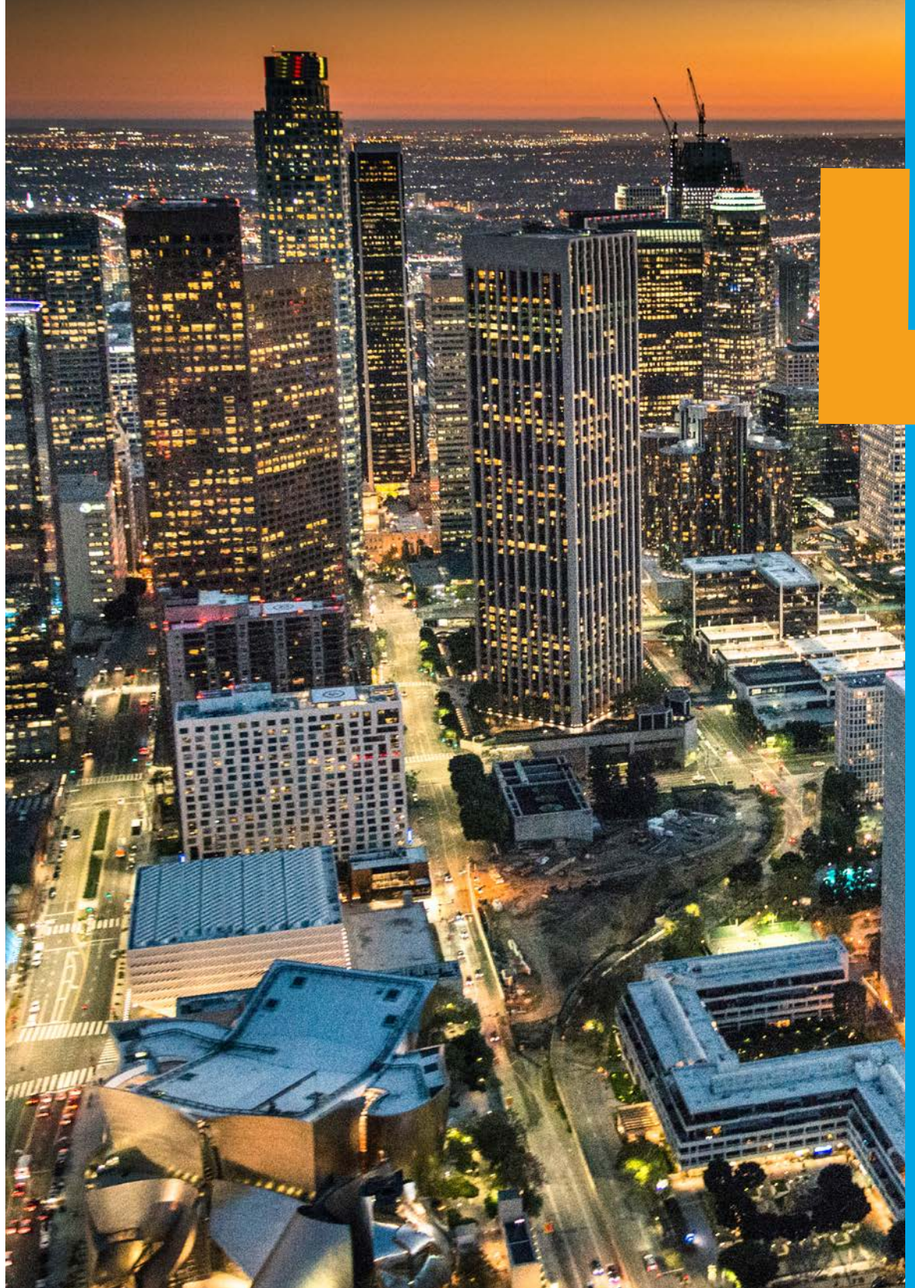
High Impact Projects

Featured throughout this report are the 2017 ESIF High Impact Projects. These industry research partnerships were selected to:

- Demonstrate the use of multiple technologies (such as storage, wind, solar, hydrogen, and buildings)
- Address the challenges outlined in DOE's Grid Modernization Multi-Year Program Plan
- Demonstrate region-wide or company impact as well as national scalability
- Provide lessons that could be implemented across the United States.

Central to the mission of the ESIF is to explore new areas of research that push the boundaries of conventional thinking. The 2017 portfolio of High Impact Projects included two projects that push into important, new mission spaces for DOE. NREL's partnership with Southern California Gas is looking at a new way to convert excess generation from renewable sources into methane gas that can be stored and transported through our existing gas infrastructure. Our work with Panasonic Enterprise Solutions is helping developers, manufacturers, and utilities understand the interrelationships of energy use among buildings, transportation and generation so that they can build communities that are clean, sustainable and "smart." While these projects are forward-looking, they are also timely and practical, solving some of the most complex challenges of modernizing our grid.

Look for the High Impact Project icon throughout the report.



GRID MODERNIZATION

Our extensive, reliable electric grid has fueled U.S. growth since the early 1900s. Access to electricity is such a fundamental enabler for the economy that the National Academy of Engineering named "electrification" the greatest engineering achievement of the 20th century. However, the grid we have today does not have the attributes necessary to meet the demands of the 21st century and beyond.

The traditional grid architecture is based on large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. A modern grid must have:

- Greater resilience to hazards of all types
- Improved reliability for everyday operations
- Enhanced security from an increasing and evolving number of threats
- Additional affordability to maintain our economic prosperity
- Superior flexibility to respond to the variability and uncertainty of conditions at one or more timescales, including a range of energy futures
- Increased sustainability through additional clean energy.

Through its Grid Modernization Initiative (GMI), DOE has identified six technical areas where key developments are needed to modernize the electric grid, and the projects in this report are organized into these six areas.

NREL supports the GMI through the Grid Modernization Laboratory Consortium (GMLC), a strategic partnership between DOE and the national laboratories that brings together leading experts, technologies, and resources to modernize the nation's grid. In FY 2017, NREL supported 23 GMLC projects, 6 of which are led by NREL. NREL also cochairs the GMLC, ensuring efficient program management and execution for the 88 projects under the $200 million GMLC program.

Source: DOE Grid Modernization Multi-Year Program Plan

Devices & Integrated Systems

Project Spotlight

NREL, Bosch, and Bonneville Power Administration Analyze Residential Energy Storage and Sizing

NREL is partnering with Bosch and Bonneville Power Administration to develop cyber-secure home automation algorithms that deliver reliable demand response and allow for cost-effective, easy-to-use, building-integrated battery systems for homeowners. The home automation system integrates controllable air conditioners, water heaters, dishwashers, refrigerators, washing machines, dryers, rooftop solar photovoltaic (PV) systems, and home batteries—allowing homeowners to get better feedback on their home's energy use, manage energy loads, and ultimately save money by right-sizing their battery systems.

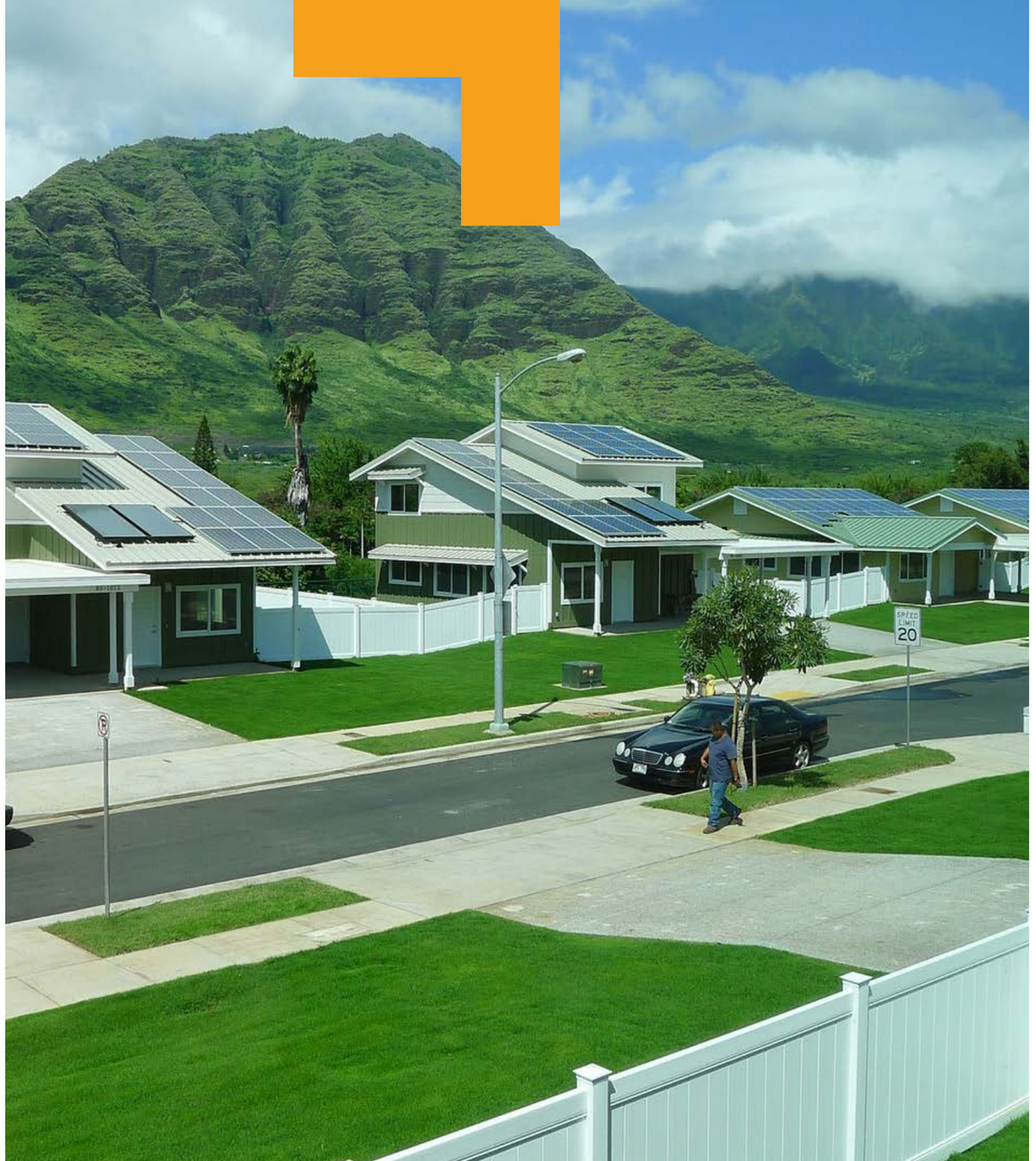
Building-integrated batteries currently have no sizing standards or broad application guidelines. The resulting products are difficult to compare, leading to uncertainty in value proposition and battery life span—which limit market uptake. Establishing practical guidance for sizing, use case expectations (cycling rates, depth of discharge), and economic outcomes could stimulate sales and competition in the home battery systems markets while accelerating energy storage in markets where it could provide immediate value for manufacturers, utilities, and consumers.

NREL's key contributions to this multi-industry challenge include developing foundational machine-learning algorithms for easy-to-operate residential systems, developing innovative strategies for complex modeling situations, and defining methods to bring grid-level cybersecurity and resiliency requirements to residential devices. Leveraging this research, NREL will then develop market guidance for home battery sizing.

Project Spotlight

NREL Assists Hawaiian Electric Companies with Key Standards and Tariff Documents, Boosting Deployment of Grid-Supportive Inverters

NREL helped Hawaiian Electric Companies (HECO) develop a Source Requirements Document (SRD)—a key technical standards document for Underwriters Laboratories (UL) 1741—that allows PV inverter manufacturers to certify grid-supportive inverters for deployment. HECO had required that inverters connected to their electric distribution system provide voltage and frequency ride-through—staying online for a brief period during grid disturbances to help the grid recover quickly—and operate at a fixed power factor of 0.95 absorbing, which assists with voltage control. NREL worked with HECO and its forum of inverter industry stakeholders to develop the SRD, aiming to harmonize requirements with the ongoing revisions to Institute of Electrical and Electronics Engineers (IEEE) 1547 and UL 1741 SA, which will define new interconnection rules for distributed energy resources (DERs).



Project Spotlight

NREL Leads Work on Revised IEEE 1547, a Key Standard for Renewable Energy Integration

A mainstay of the DER standards space, IEEE 1547 was published in 2003 and has since provided criteria and requirements for the interconnection of DERs onto the electric grid. This important standard provides the ability for all DER stakeholders to play by the same rules and expectations, ensuring that a certain technology will maintain the integrity and safety of the electric system and provide smooth transitions under normal and abnormal conditions.

Technology advances and increasing amounts of DERs, however, have led to a need for the standard's reevaluation and revision. Since 2014, when an amendment was introduced to the standard, researchers at the ESIF and industry experts began leading the full revision of IEEE 1547, aiming to specify and harmonize new interconnection requirements for DERs.

In FY 2017, a working group of ESIF engineers and industry representatives completed the revisions to IEEE 1547. With support from DOE, Office of Energy Efficiency and Renewable Energy, and the Office of Energy Delivery and Energy Reliability, NREL also led several subteams, provided direct input to standards working groups as revisions were made, and supported technical positions based on validation tests at the ESIF. The team expects to receive final approval from IEEE by the end of the first quarter in FY 2018. Learn more about the standard's modifications and applications at (http://bit.ly/2yAZHll.)

Project Highlights

NREL-Developed Tool Helps Utilities Fast-Track Interconnection Requests

NREL, in partnership with the Sacramento Municipal Utility District (SMUD), is developing PRECISE, a planning and real-time operation platform that distribution utilities can use to interconnect and integrate high penetrations of customer solar generation. SMUD has an average of 300 interconnection requests each month, and this platform will help cut the application approval time in half, to only 5 days, while ensuring seamless interconnection with the existing grid.

NREL Partners with ORNL and Purdue University on a High-Voltage, Silicon Carbide, 3-D-Printed PV Inverter

To enable better grid integration of solar PV, NREL, Oak Ridge National Laboratory (ORNL), and Purdue University are designing a 50-kW inverter that combines high-voltage silicon carbide with additive manufacturing (3-D printing) and multiobjective magnetic design optimization to achieve better performance and reliability at lower cost. Called AMPVI, the high-power-density inverter design will be prototyped and integration-tested at the ESIF. NREL is leading this project as part of the DOE Solar Energy Technologies Office SunShot National Laboratory Multiyear Partnership (SuNLaMP) program (https://go.usa.gov/xnjnr). For more details, visit the project profile at (https://go.usa.gov/xnD8M).

SuNLaMP Virtual Oscillator Controls Project Advances Inverter-Based Solutions for Low-Inertia Grids

NREL helped develop virtual oscillator controls (VOC) (https://go.usa.gov/xnjn4) for low-inertia grids, and in FY 2016, the DOE Solar Energy Technologies Office SuNLaMP program awarded NREL a $3.85 million, 3-year project (https://go.usa.gov/xnjnj) to further explore VOC and pave the path to a sustainable grid based on electronic inverters. This project has uncovered limitations of conventional controllers and outlined new methods to ease the evolution of the electric grid to an inverter-driven network. Work continued on this project in FY 2017, including demonstrating VOCs' enhanced responsiveness compared to established methods; working with SunPower to incorporate VOC into a multi-inverter system, which ran as a self-sustaining microgrid and powered a load without using any communications; and developing a model order reduction strategy that allows simpler models for complex inverter systems.

New Battery Energy Storage System at NREL Serves as Experimentation Platform for Integrating Storage, Renewables

A 1-MW, 1 MW-h RESolve battery energy storage system (BESS) was installed at NREL in late March 2017 to research ways to optimize the grid for wind and solar power plants. NREL is partnering with several companies, including First Solar, the AES Corporation, Statoil, Pacific Gas and Electric Company, and Renewable Energy Systems Americas Inc.—the system's manufacturer—to test advanced controls for integrating BESS with renewable energy systems. NREL researchers developed a new controller that integrates the BESS with 400-kW PV systems, megawatt-scale turbines, and other grid technologies, forming a dispatchable renewable energy power plant that can provide essential reliability services to the electric grid, including fast-acting primary frequency response, load regulation, voltage support, and ramping control.

Verizon Project Aims to Supply Efficient Backup Power to Cell Phone Towers

Verizon is working with NREL to establish a new topology for cell site power systems based on a PV system and battery energy storage rather than relying on the electric grid. To make this setup operate efficiently, all of the new cell tower equipment and associated cooling systems employ DC power, so the PV and battery power do not need to be converted to AC using an inverter. The prototype system's electronics were installed in an environmental chamber in the ESIF in late June to allow for tests at temperatures from -40°C (-40°F) to 52°C (126°F). At the end of FY 2017, one of seven cooling systems for the electronics had been tested in an ongoing effort to determine which cooling systems work best in each of 17 different climate zones.

Sensing & Measurement

Project Spotlight

New Model Provides Better, Faster Solar Irradiance Values for Solar Applications

NREL researchers developed the Fast All-Sky Radiation Model for Solar Applications (FARMS) and published the results (http://bit.ly/2jczQ0p) in collaboration with an associate at the National Center for Atmospheric Research. Although clear-sky radiative transfer models are fairly straightforward, modeling clouds is relatively difficult and slow, so incorporating clouds into radiation models has always been a difficult task. To get around that problem, the researchers solved the clouds' radiative transfer equations for varying cloud optical thicknesses, cloud particle sizes, and solar zenith angles, creating lookup tables of cloud transmittances and reflectances. The resulting broadband model is more than 1,000 times faster than those currently used in solar resource assessment and forecasting.

In late September 2017, the researchers presented a new spectral model (https://go.usa.gov/xnjn8) at the European PV Solar Energy Conference and Exhibition in the Netherlands. This model, FARMS with Narrowband Irradiances over Tilted Surfaces (FARMS-NIT) yields solar irradiances in many narrow-wavelength bands at any orientation that is useful for PV panels. The capabilities provided by FARMS and FARMS-NIT will be particularly useful to solar developers as they assess the potential power production from any site, including such considerations as the ideal wavelengths to which to tune their solar panels.

Watch: NREL's publicly available solar radiation data support an $84 billion American solar industry. Get an exclusive 360-degree view of the largest continuously operating collection site for that data in the world here (http://bit.ly/2zvK4Nz).

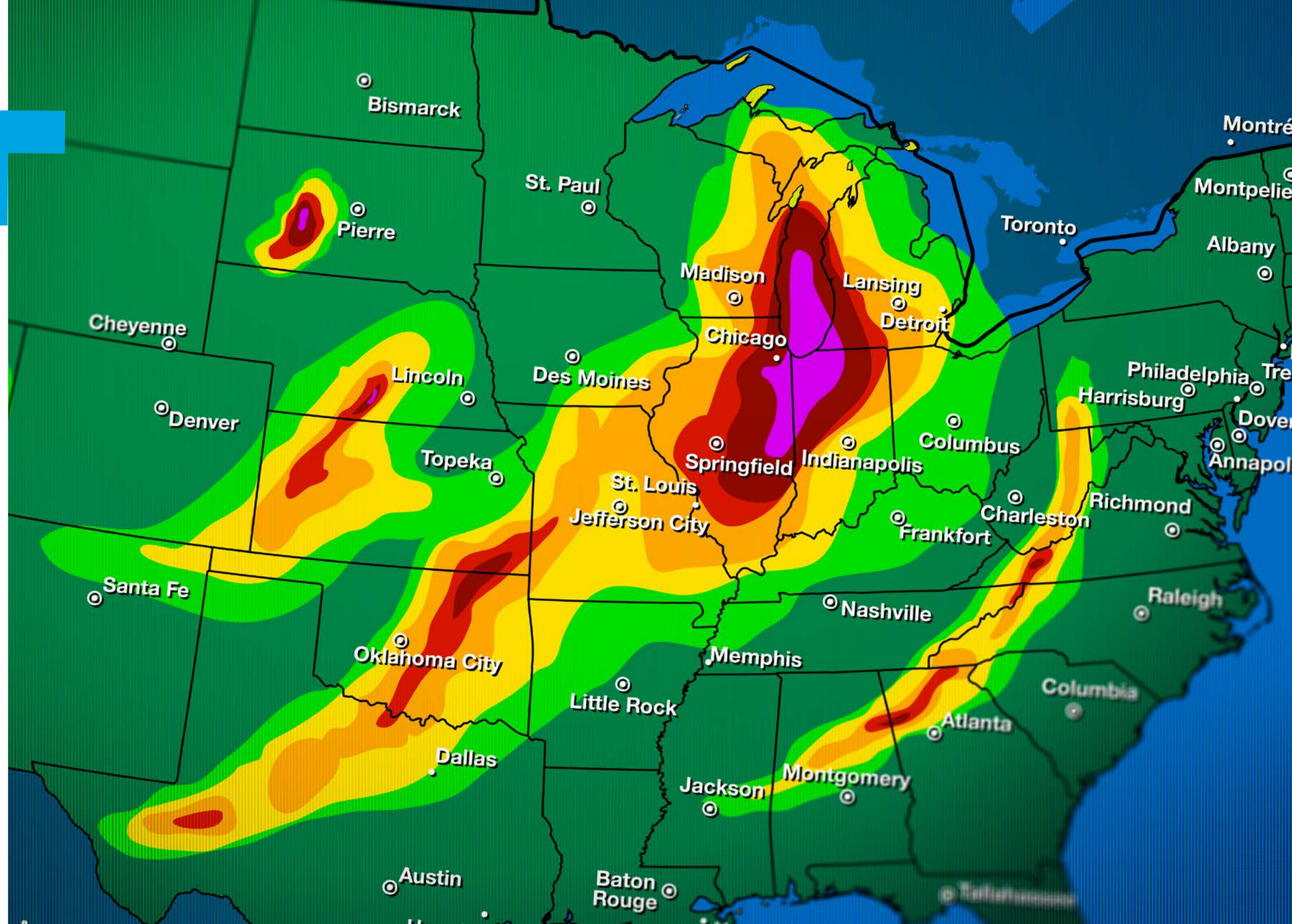
Project Highlights

NREL Develops New, Better Way to Forecast Future Grid Operations

NREL researchers have developed a grid-state forecaster integrated with resource and load forecasting functions. Called the Predictive Analytics for Grid Estimation (PAGE), it can reliably forecast grid conditions such as voltage in 5-minute resolutions with a 30-minute look-ahead window. PAGE uses total sky imagers to monitor clouds for short-term solar forecasts, and then it uses a radiative transfer model for state-of-the-art longer term forecasts. PAGE is the first tool of its kind to directly translate resource and load forecasting to future grid conditions, which can inform immediate actions by system operators.

NREL Contributes to DOE Grid Modernization Project to Identify Gaps in Weather Monitoring and Forecasting

NREL played a vital role in the GMLC 1.2.5 project on sensing and measurement strategy in FY 2017. The multi-lab project team for GMLC 1.2.5 has been leading industry working groups to build a roadmap for developing advanced sensing and measurement technologies. NREL has been leading the working group for weather monitoring and forecasting, which has direct implications on energy consumption and renewable energy forecasting as well as their integration into system operations and planning processes for grid modernization. In FY 2017, the NREL-led working group identified eight major gaps and five additional research needs, including improving the dynamic response of phasor measurement units (PMUs), lowering the cost of PMUs, improving PMU timing reliability and angular resolution, developing advanced phasor calculation algorithms, and improving frequency estimates.



System Operations, Power Flow, & Control

Project Spotlight

SDG&E Collaborates with NREL Researchers to Expand the Borrego Springs Microgrid

Borrego Springs, California, and the utility that serves it, San Diego Gas and Electric Company (SDG&E), both have a challenge: the single, radial transmission line serving the town traverses approximately 30 miles of remote, rugged terrain with elevation changes of 5,000 feet. This desert community, located 90 miles east of San Diego, is subject to frequent monsoonal storms replete with lightning. To reduce the duration of extended outages caused by bad weather and other emergencies, SDG&E built the Borrego Springs Microgrid with the goal to increase the resiliency of the electric service for the 2,800 metered customers who live in Borrego Springs. Thanks to a nearly $5 million grant from the California Energy Commission, SDG&E is now working to expand the microgrid by integrating it with the nearby 26-MW solar power plant to serve the entire town. The microgrid will allow the town to operate in "islanded" mode, separate from the main grid, while potentially running on 100% solar energy, to avoid the impacts of extended power outages. It will also allow SDG&E to defer upgrades to the existing transmission line.

The expanded microgrid will be the largest utility-owned microgrid in the United States. Although it features two 1.8-MW diesel generators as backup power, it is capable of running entirely on solar power through the 26-MW PV facilities and rooftop PV on 2,800 homes in the community. That power supply is backed by two BESS that provide 1.5 MW, 4.5 MWh of storage and 250 kW of ultracapacitors at the local substation as well as three 25-kW BESS distributed throughout the community. The heart of the microgrid is a microgrid controller.

Because this project is in many ways the first of its kind, NREL researchers are supporting it by building a hardware-in-the-loop (HIL) test bed that will integrate the microgrid controller, the diesel generator controllers, and the power hardware, which at the ESIF will consist of a 500-kW PV inverter and a 540-kW BESS inverter. The test bed will also connect NREL's and SDG&E's digital real-time simulators through a remote connection, allowing the utility's grid simulation to interact with NREL's hardware. Once the test bed is ready in early 2018, the system will be operated under four test cases: in grid-connected mode, while disconnecting from the grid, in islanded mode, and while reconnecting to the grid.

Project Spotlight

NREL's ARPA-E Projects Look to the Future of Electric Grids

NREL is currently leading one DOE Advanced Research Projects Agency-Energy (ARPA-E) (https://go.usa.gov/xnWbR) project and supporting another related to the future of the electric grid. ARPA-E is tasked with promoting and funding the research and development of advanced energy technologies. The ARPA-E Network Optimized Distributed Energy Systems (NODES) Program (https://go.usa.gov/xnWbn) aspires to enable renewable generation penetration at the 50% level or more by developing transformational grid control methods that optimize the use of flexible loads and DERs.

As part of NODES, NREL is leading the Real-Time Optimization and Control of Next-Generation Distribution Infrastructure (https://go.usa.gov/xnWbU) project, which will develop a comprehensive distribution network management framework that unifies real-time voltage and frequency control at the DER controller level with network-wide energy management at the utility or energy aggregator level. The distributed control architecture will use real-time feedback control to continuously steer frequencies and voltages toward optimal operating points while dynamically procuring and dispatching synthetic reserves based on the current system state and forecasts of ambient and load conditions. The framework will incorporate intrinsic network physics into the control formulation and process real-time measurements to respond to rapidly changing grid conditions with multiple DERs.

For another NODES project, A Robust Distributed Framework for Flexible Power Grids (https://go.usa.gov/xnWbP), NREL researchers are supporting the University of Minnesota in an effort to address the grid challenges presented by the randomness in widespread renewable power generation. The project will apply concepts from nonlinear and robust control theory to design self-organizing power systems that effectively respond to grid events. The proposed system will enable coordinated response by many local units to adjust consumption and generation of energy, satisfy physical constraints, and provide ancillary services requested by a grid operator. A key feature enabled by the proposed methodology is a flexible plug-and-play architecture wherein devices and small power networks can easily engage or disengage from other power networks or the grid.

Project Highlights

NREL and Pacific Northwest National Laboratory Work to Lower the Cost of Utility Systems Integration with GridAPPS-D

Factors such as an influx of data and smart devices, increasing automation, new market interactions, and a diverse resource mix are driving the need for better-integrated utility systems; however, integrating systems that were designed to operate in silos can be slow and costly. To make this easier, NREL is partnering with Pacific Northwest National Laboratory on a project to create an open-source, standards-based platform for developing advanced distribution system planning and operations applications. The platform, called GridAPPS-D, would reduce the cost to develop, integrate, and maintain future utility systems. NREL's role in this project includes developing an interface between legacy distribution management system (DMS) models and the GridAPPS-D common information model, developing advanced distribution management system (ADMS) applications for the GridAPPS-D environment, and implementing GridAPPS-D using the ESIF's hardware test beds.

NREL Works with Schneider Electric, Xcel Energy to Improve Grid Reliability and Reduce Costs

In partnership with Schneider Electric, ESIF researchers are working with Xcel Energy to modernize its distribution grid in Colorado using Schneider Electric's ADMS platform. The ESIF's ADMS research platform allows the researchers and their industry partners to characterize and refine the performance of an ADMS in a simulated utility environment with the objective of reducing deployment costs and accelerating utility adoption of these advanced grid monitoring and control applications.

Utility-Scale Photovoltaic Plants Increase Their Value by Providing Grid Support

Utility-scale PV power plants can create challenges for grid operators because of the variability of the solar resource, particularly under high penetrations of PV. However, as NREL and a team of partners demonstrated in FY 2017, utility-scale PV plants can also be controlled in ways that counteract this effect, providing essential reliability services to the grid with much faster response times than conventional technologies. Working with the California Independent System Operator (CAISO) and First Solar, NREL showed it was possible to control a 300-MW PV power plant to contribute to system-wide reliability, as documented in a March 2017 report (https://go.usa.gov/xnjnn). The project points the way toward a future grid in which PV plants might employ their controls in a way that provides similar types of essential reliability services to the grid.

Project Highlights

Coordinating Energy, Distribution, and Building System Controls for Next-Generation Grid Management

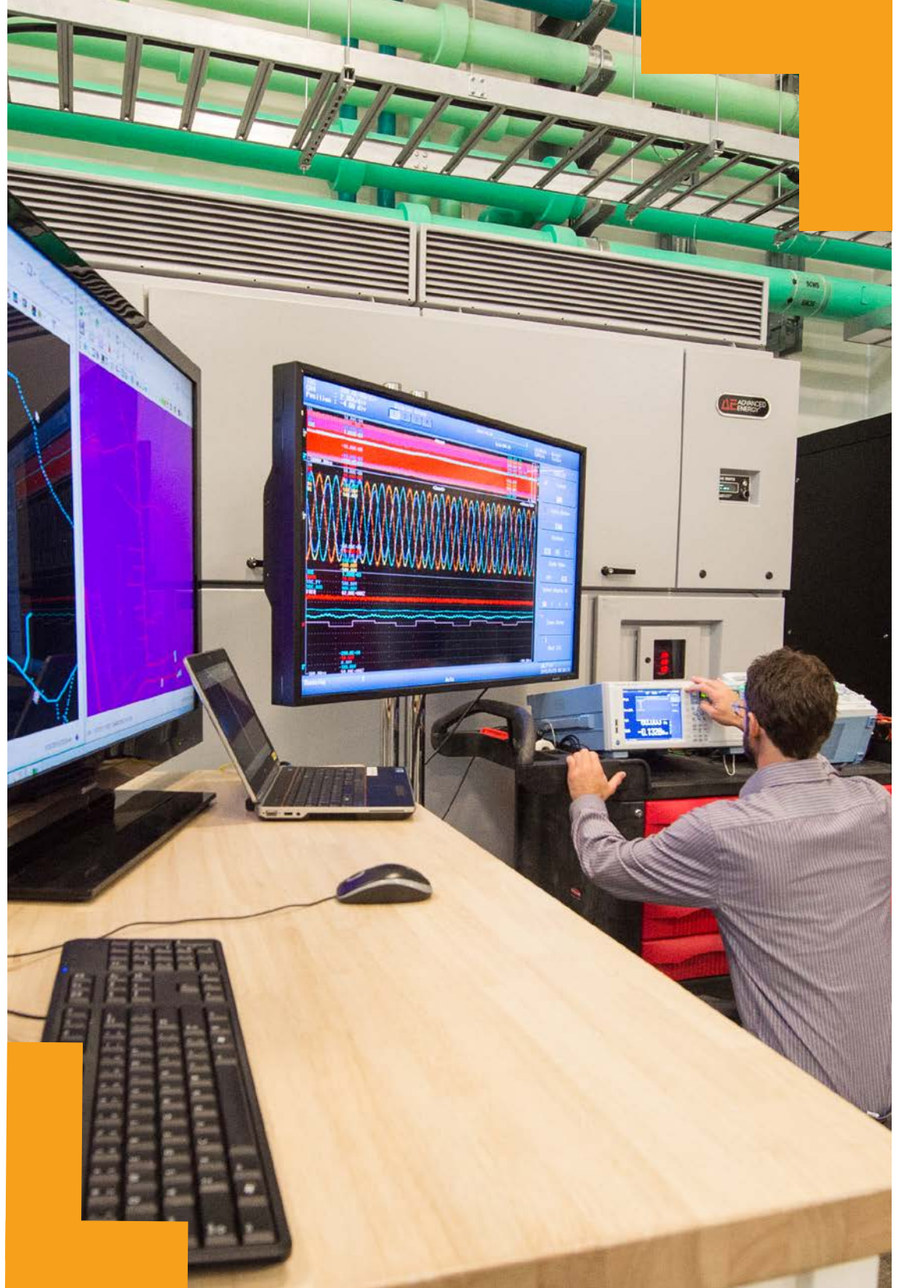
NREL is collaborating with five other national laboratories on a GMLC project to create an integrated grid management framework to allow control systems at all scales to work together seamlessly. The team is developing the framework to coordinate energy management system (EMS), DMS, and building management system (BMS) operations. They will then demonstrate the framework on a complex test system with more than 15,000 transmission substations and a high penetration (more than 50%) of DERs or microgrids. The current approach to power systems operations and controls was developed within narrow functional silos and well before the development of modern computing. This new approach will leverage leading-edge capabilities to transform or extend existing applications while better integrating renewable and distributed generation.

NREL, Sandia Help Vermont Reach Renewable Energy Goals

Ambitious renewable energy targets are rolling out in states and cities across the United States. How to effectively meet those targets without compromising energy reliability is the challenge many utilities are trying to solve. As part of the GMLC, a team from Sandia National Laboratories and NREL is looking at this issue in the Vermont Regional Initiative project. NREL contributed to this project with a detailed report that evaluated and quantified the potential benefits and impacts of reducing peak load through demand response using controllable electric water heaters and batteries on Green Mountain Power's feeders. NREL also performed an analysis that identified gaps and offered improvements for wind forecasting so Vermont utilities could maximize this resource.

Envisioning 80 Percent Renewable Penetration in the Western United States

Frequency response—the ability of the electric grid to correct sudden mismatches between generation and load—is crucial for grid reliability. Traditional, synchronous generators can provide frequency response by adjusting their energy outputs, but renewables—especially PV—generally operate at full capacity and do not provide frequency response. In preparation for a DOE study on how higher PV penetrations could affect frequency response for the Western Electricity Coordinating Council (WECC), NREL researchers developed detailed cases of high renewable penetrations on WECC's system. The team collected data on current and likely future PV capacity, built a model of WECC's frequency response, and developed cases of up to 65% PV and 15% wind energy penetration—even considering 100% instantaneous PV penetration in one WECC region, the most ever considered for WECC.



NREL Evaluates Eaton's Integrated Volt/VAR Control Algorithm

With increasing penetrations of DERs on their distribution feeders, utilities increasingly desire to apply new controls to these feeders to avoid voltage issues. Doing so by using integrated volt/VAR control (IVVC) can overcome overvoltage, reduce voltage fluctuation, save energy consumption, and improve power quality. Eaton, a power management company, has developed an advanced IVVC algorithm that might be applied to a future product. To help evaluate that algorithm, NREL researchers are performing quasi-static time-series simulations on a utility distribution feeder model to compare the performance of the Eaton IVVC algorithm to legacy local controls and traditional IVVC methods. NREL will quantify the impacts of the IVVC algorithm and perform a cost-benefit analysis of operating the feeder with Eaton IVVC in place.

NREL Evaluates Vehicle-to-Home Unit in Partnership with Nichicon, Nissan

NREL worked with Nichicon and Nissan to bring a vehicle-to-home (V2H) unit from Japan to better understand how the system would work with U.S. appliances. Researchers investigated four use cases for the Nichicon V2H emergency response and home energy management system operating with a Nissan electric vehicle: demand charge mitigation, emergency response/black-start capability, solar integration, and home load shifting. This research will provide valuable insight into technology and communications needs for V2H applications, offering the potential for electric vehicles to charge, store, or export energy back to a home according to grid conditions. This work was funded through DOE's Vehicle Technologies Office and Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project.

Watch: NREL, Duke Energy, and GE's Grid Solutions Business collaborated to pinpoint the best voltage control solutions for one of Duke's utility-scale solar power plants. Watch how they did it here (http://bit.ly/2COlacq).

Design & Planning Tools

Project Spotlight

Peña Station NEXT: Developing a Zero-Energy, Transit-Oriented Campus in Denver, Colorado

NREL is collaborating with Panasonic Enterprise Solutions, Xcel Energy, land developer L.C. Fulenwider, and the City and County of Denver through its Denver International Airport to enable the least-cost and most-scalable zero-energy development in the United States. The transit-oriented, 382-acre mixed-use development will feature Xcel Energy's first microgrid in Colorado on a zero-energy campus. Located at the Peña Station on Denver's new light-rail service to the airport, the development has been dubbed Peña Station NEXT.

NREL is developing the foundational software that will enable comprehensive energy district design and planning among cities, land developers, and energy companies. The software will integrate building energy load modeling with distribution system modeling for the first time in a tool that uses URBANopt (https://go.usa.gov/xnKWU)—an NREL-developed advanced analytics platform for high-performance buildings and energy systems in one city area—and OpenDSS (http://bit.ly/2zV4cLB), a simulation tool for power distribution systems, allowing NREL to model the district's interaction with the grid.

NREL will then develop a variety of load and power flow scenarios using a range of technology options, including varying solar PV penetrations, energy-efficiency scenarios, distributed energy storage capacities, and district heating and cooling, possibly using geothermal energy. These will lead to distribution system models that will be verified for feasibility by Xcel Energy and analyzed for cost-benefits by Panasonic. NREL's 2-D and 3-D visualization techniques will be employed to analyze and illustrate the results of the power systems simulations for each URBANopt scenario.

The partners are confident the project holds great promise beyond Peña Station NEXT's borders. Xcel Energy will consider owning and operating the necessary infrastructure to achieve carbon neutrality, potentially expanding the offering to future communities in Colorado. Panasonic is similarly interested in how it might replicate and scale carbon-neutral districts and developments across its other current and future smart city engagements through Panasonic CityNOW. NREL will share its expertise and apply the lessons learned from this project to future developments. See the NREL press release (https://go.usa.gov/xnKjC) and the ESIF partner page for Panasonic (https://go.usa.gov/xnKjr).

Project Spotlight

In First-of-Its-Kind Study, NREL Weighs Benefits to Utility, Customers of Grid-Supportive Inverter Settings for Distributed PV

Hawai'i's success in adopting renewable energy—especially customer-sited rooftop solar PV systems—has pushed the hosting capacity of many of the islands' distribution circuits past what was thought possible only a few years ago. NREL has been working with HECO for the past several years to help find solutions to safely host more solar PV without compromising reliability.

As part of this ongoing work, in FY 2017, NREL collaborated with HECO, solar experts on the Smart Inverter Technical Working Group Hawai'i, inverter manufacturers, and systems integrators to research how to best implement advanced inverter grid support functions. Using technical guidance and input from the partners, NREL explored different modes of voltage-regulation grid-support functions to better understand the trade-offs between grid benefits and curtailment impacts. In the project's final report (https://go.usa.gov/xnN5z), NREL was able to provide HECO with technically sound recommendations on the initial activation of voltage-regulation grid-support functions that considered Hawai'i's unique feeder characteristics and operations as well as the energy curtailment impacts to solar PV customers.

Using the research findings, HECO launched a pilot project to allow some customers who were waiting on interconnection to connect to the grid if their systems included advanced inverters with specific voltage support functions activated. In collaboration with vendors SolarEdge and Enphase, NREL also developed and deployed an inverter control and data collection system that made it possible to remotely change the inverter grid support settings from the ESIF—a first-of-its-kind achievement—to examine their effects on distribution system voltages and verify the study's findings. As a next step in this project, NREL will add multiple technologies to the existing distribution models, including battery storage, electric vehicles, and load control to understand their potential in providing local voltage support while also estimating their impact on annual PV customer power production.

Project Highlights

NREL Is Developing New Electric Grid Models under ARPA-E Project

NREL is working with the Massachusetts Institute of Technology, Comillas University, and GE's Grid Solutions Business to develop combined distribution-transmission electric grid models. Distribution models will be created using a version of Comillas' Reference Network Model that is adapted to U.S. utilities and based on real data from a broad range of utility partners. The models will be complemented by the development of customizable scenarios that can be used for accurate algorithm comparisons. These scenarios will take into account factors that affect the grid, such as future power generation technologies, varying electrical load, disruptions caused by weather events, and solar and wind data. This project is funded through the ARPA-E Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) project (https://go.usa.gov/xnWjD).

NREL Researchers and Walmart Investigate Energy Savings from Voltage Regulation Systems

ESIF researchers are working with Walmart to explore the energy-saving potential of voltage regulation systems in Walmart stores by investigating, analyzing, and documenting results from Walmart facilities that use these devices. Researchers have analyzed historic energy performance at stores to learn about thermal and electric loading across the Walmart building portfolio, and they will soon monitor and report on the performance of a voltage-reduction technology at four stores in northwestern Arkansas.

NREL Works with the North American Electric Reliability Corporation on Maintaining Grid Reliability with High Penetrations of Distributed Energy Resources

With an ever-increasing number of PV systems interconnected to distribution systems and potentially impacting the reliability of bulk power systems, the North American Electric Reliability Corporation initiated the DER Task Force to consider such impacts and plan a path forward for the continued reliable and resilient operation of the electric grid. The task force consisted of a wide cross section of power system experts, including NREL's DER interconnection and modeling experts. NREL contributed details on the bulk system impacts of DERs with funding from DOE's GMLC.

NREL Technical Assistance Is Helping Aruba Hit 100% Renewable Goal by 2020

Transporting fuel to islands to power their electric grids can be expensive and inefficient, making renewable generation an appealing alternative. The island of Aruba has been pursuing renewable energy and energy-efficiency efforts for more than a decade, and it is targeting a 100% renewable grid by 2020. To make that possible, NREL is working with the island's electric utility, WEB Aruba, to evaluate the technical and economic feasibility of various technologies that will help Aruba reach its goal. Particularly, NREL has been evaluating complementary storage and DER technologies such as ice storage, flywheel storage, underwater compressed air storage, biogas, and smart charging for electric buses that could help integrate higher penetrations of renewables.

Project Spotlight

Partnership with National Electrical Manufacturers Association Inspires New Approach to Secure, Standards-Based DERs

Since April 2016, NREL has been working with the National Electrical Manufacturers Association (NEMA) to develop a secure Internet of Things protocol that can be applied to DER systems. With a growing need to securely integrate DER assets as they are interconnected with the electric grid, NEMA sought help from NREL's cybersecurity research team at the ESIF to evaluate and successfully demonstrate security specifications for the DER portion of the International Electrotechnical Commission (IEC) standard 61850 for substation automation.

After developing a validation guidance document, however, the NREL team identified a problem. Vendors had been developing DER technologies that employ a range of standards requirements, such as Modbus TCP or Distributed Network Protocol, instead of those in IEC 61850. Considering this, NREL's cybersecurity research team proposed a solution that could be applied to a multitude of DER technologies. Instead of expecting every vendor and device manufacturer to employ one common set of standards into their product, the team designed a certification procedure that would allow vendors of different DER technology standards to ensure consistent security specifications.

During the last few months of FY 2017, NREL's cybersecurity research team outlined 26 verification test cases with a detailed test plan for each to prevent DERs from common cyberattack and vulnerabilities, such as eavesdropping, spoofing through security certificates, replay attacks, and man-in-the-middle attacks. The team is now sharing the document with a number of security working groups in the DER standards community as well as with major vendors to receive feedback on each of the detailed test plans.

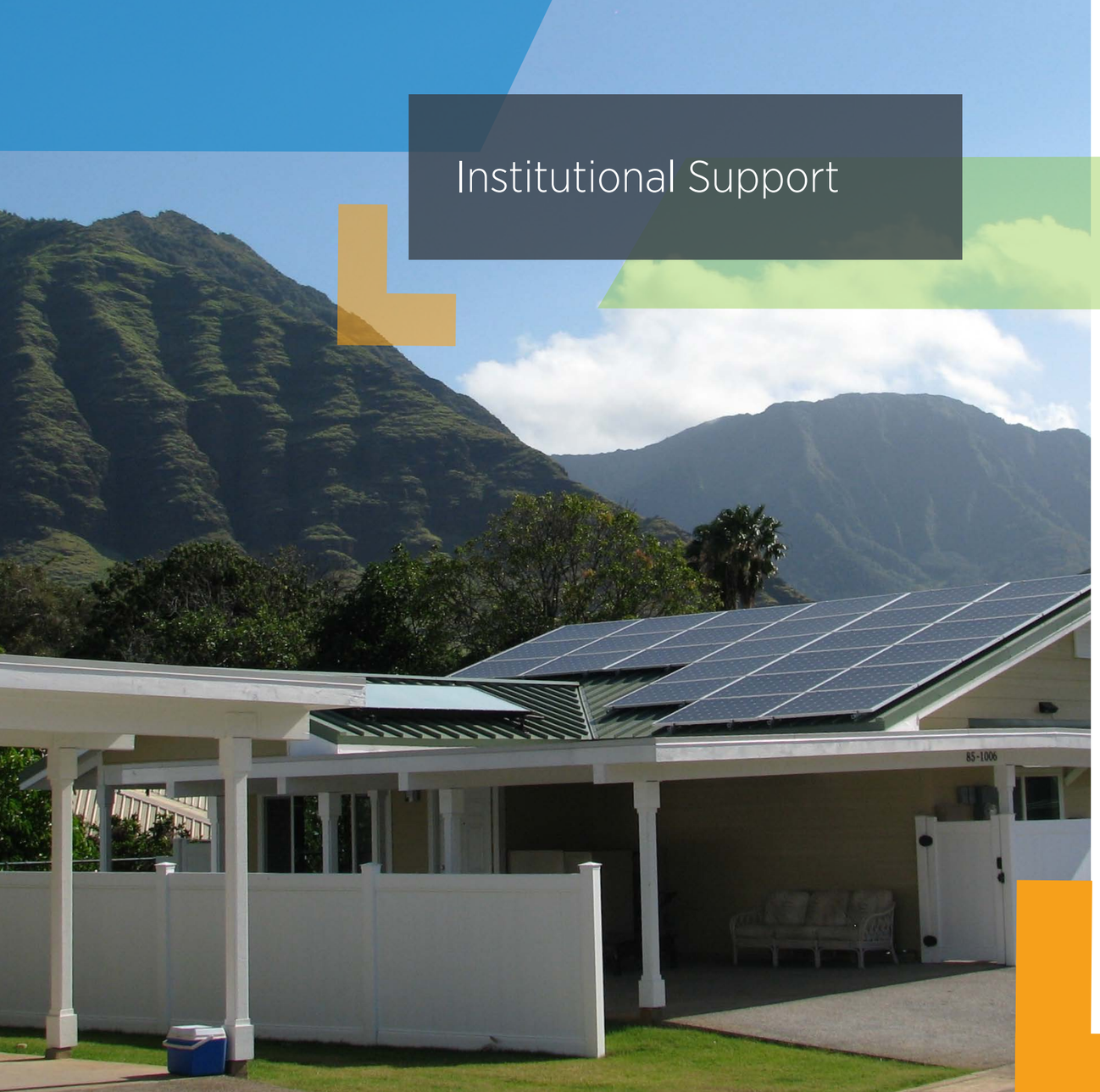
Project Highlights

Securing Communications Across Public Networks with Dispersive Technologies and CAISO

Redirecting data in transit offers an effective way to secure network communications while lowering the cost for information exchange between utility companies and DER asset owners. Under a partnership with Dispersive Technologies and CAISO, NREL researchers are providing configuration, evaluation, and data collection on the company's Critical Infrastructure Software-Defined Network. The team has been working to validate the technology for its effectiveness in deflecting information packets to eliminate the potential for hackers to receive continuous data streams on a single path. As industry moves to a more distributed generation model in which various hubs will require the ability to exchange information, such technologies are required to secure reliable communications across low-cost public networks.

Governance Assessments Lead to New Partnerships and Research

NREL's cybersecurity research team conducted nine cyber-governance assessments for U.S. utilities in FY 2017 that included the National Institute of Standards Technology's Cybersecurity Framework and DOE's Cybersecurity Capability Maturity Model. The team developed a customized framework for each utility that offers tangible metrics for its cybersecurity posture, providing each of the nine utilities with a list of prioritized action items for their strategic investments in cybersecurity. These assessments led to a number of future engagements and interest in NREL's cybersecurity evaluation services.



Institutional Support

Project Spotlight

HECO Grid Modernization Project Informed by ESIF Research

The Hawai'i Public Utilities Commission (PUC) approved on July 17, 2017, a Power Supply Improvement Plan (PSIP) submitted by HECO to upgrade its five island power grids. The plan describes the scope and estimated cost to update the energy networks of Hawaiian Electric, Maui Electric, and Hawai'i Electric Light in the next 5 years and how it will help the companies achieve a consolidated renewable portfolio standard of 48% by 2020 (relative to a mandate of 30%) and 100% by 2040, 5 years ahead of schedule. The PSIP was informed by NREL research on advanced inverters and renewable resource potential in Hawai'i.

To achieve the plan's goals, HECO will acquire nearly 400 MW of new renewable resources by 2021. HECO's plan anticipates continued growth of rooftop solar and describes the work needed to expand and upgrade grid infrastructure using the newest generations of inverters, control systems, and energy storage to help reliably integrate an estimated total of 165,000 rooftop systems by 2030, more than twice today's total of 79,000. See the HECO press release (http://bit.ly/2A4aFRZ).

Meanwhile, on August 29, 2017, HECO submitted a related strategy to modernize its electric grids, allowing for increased use of renewable resources, improved reliability, and more customer choice. Now under consideration by the Hawai'i PUC, the plan was also informed by ESIF research that examined the performance of advanced inverters on HECO's distribution grids. The PUC opened the plan for public comment from August 30 to September 13, 2017. See HECO's Grid Modernization Strategy (http://bit.ly/2hMpNeA) and the ESIF web page on NREL's work on advanced inverters (https://go.usa.gov/xnKu8) for HECO.

Project Highlight

NREL Report Helps Improve the Interconnection Process in New York State

NREL collaborated with the New York State Energy Research and Development Authority to develop new methods to make the interconnection process in New York State quicker and easier. The project resulted in an NREL-developed guide for utilities and developers called *Supplemental Information for New York State Standardized Interconnection Requirements* (https://go.usa.gov/xnKWX). Focusing on key technical issues that have accounted for the majority of concerns when connecting PV systems, the guide provides background, guidance, and mitigation measures. In addition to the guide, NREL developed a white paper comparing and contrasting New York interconnection requirements with requirements and "fast screens" in other states such as California, Hawai'i, and Massachusetts. Partners on the project included the New York Department of Public Service, the New York Power Authority, and New York investor-owned utilities.

Advanced Buildings Research

Project Spotlight

NREL and iUnit: Leading Research and Design for Zero Energy Building Multifamily Construction

Approximately 38 million people in the United States live in buildings that contain five or more units—totaling almost 18.5 million households. Demand is growing, but designers and builders still face a number of challenges in bringing advanced, zero energy building construction to multifamily housing. NREL researchers are working with Denver developer iUnit to overcome these challenges with an innovative pilot test at a 380-ft^2 modular apartment installed in the ESIF.

The ESIF's smart home HIL research capabilities and energy modeling tools are helping to enhance energy efficiency in the modular multifamily pilot apartment while creating a development platform for construction. The team is working to understand how a reduction in apartment energy loads combined with energy storage can be scaled up to whole-building energy management. Researchers are also investigating energy storage opportunities that might be available to optimize PV integration at a whole-building scale.

The innovative solutions that the iUnit team is evaluating at the ESIF will be incorporated into their planned Champa Flats community in Denver. If applied on a large scale, energy-efficiency efforts in multifamily housing such as iUNIT could save $3.4 billion annually.

Tech to Market

NREL, Wells Fargo Help Start-Ups Bridge the Gap with Innovation Incubator

NREL worked with Wells Fargo to develop the Innovation Incubator (IN^2) program, designed to accelerate the tech-to-market pipeline for early-stage entrepreneurs. These projects offer scalable, clean-technology solutions designed to reduce the energy impact of commercial buildings. Selected companies receive $250,000 in funding from Wells Fargo as well as access to NREL's world-class facilities and researchers who will test, validate, and incubate the companies' technologies to help them meet critical validation milestones on the path to market.

Teams Working in the ESIF

Go Electric

Customer-facing microgrid solution, which reduces typical building energy costs.

LiquidCool Solutions

Energy-efficient computing cooling technology.

Whisker Labs

Peel-and-stick energy metering technology, which might reduce metering costs by 90%. Following testing at NREL, Whisker Labs was purchased by Earth Networks, and its metering technology is being readied for commercial release.

Transportation & Hydrogen Systems Center Research

Project Spotlight

NREL and SoCalGas Launch First U.S. Power-to-Gas Pilot Project

Southern California Gas Company (SoCalGas) and Electrochea have joined with NREL to launch a demonstration project to create and test a carbon-free, power-to-gas system for the first time ever in the United States. The technology takes excess electricity and converts it to hydrogen, which can be used, stored, or further converted to renewable natural gas. This last step in the process is achieved via a bioreactor that houses hardy bacteria. The hydrogen is combined with carbon dioxide and fed to the bioreactor where the bacteria produce renewable natural gas (methane). With minor filtration, the methane meets pipeline quality and can be injected into existing natural gas infrastructure.

This innovative technology could provide North America with a large-scale, cost-effective solution for storing excess energy produced from renewable sources. The pilot project will be used to determine the commercial viability of this power-to-gas approach to energy storage and provide insights into megawatt-scale system designs. By combining these insights with renewable energy resource data, the research team will identify optimal locations in California and the western half of the United States where this grid-scale energy storage would be the most economical.

Watch: Get a quick overview of the NREL-SoCalGas power-to-gas project and watch the 25-foot-tall bioreactor being installed (http://bit.ly/2Aw9lav).

HySteP Update

In FY 2016, NREL and Sandia National Laboratories contracted with Powertech Labs to produce the first Hydrogen Station Equipment Performance (HyStEP) (https://h2tools.org/h2first/HyStEP) device, designed to be used by certification agencies to measure the performance of hydrogen dispensers with respect to fueling protocol standards. In FY 2017, the CSA Group—a Canadian-based standards and certification organization—used those designs to build a second device that is now in Massachusetts for its first station commissioning.

Project Highlights

NREL Researchers Investigate Approaches for Scaling Up the Use of Renewable Hydrogen

As technologies mature and costs drop, potential uses for hydrogen in the energy system are expanding from power generation and transportation to grid services and industrial processes. The H2@Scale initiative—a collaboration among DOE and 14 national laboratories, including NREL—is looking at ways hydrogen can support our future energy system. At the ESIF, NREL researchers and partners from national laboratories and industry are pursuing H2@Scale by advancing hydrogen technologies in a number of areas, including low-temperature electrolysis; storing excess solar and wind energy by producing renewable natural gas from hydrogen and carbon dioxide; and reducing the cost, improving the reliability, and increasing the availability of hydrogen fueling stations.

NREL Researchers Achieve Milestone in Fuel Cell Catalyst Development

NREL's Extended Thin-Film Electrocatalytic Structures project achieved a key fuel cell performance and durability target established by DOE. The NREL-led team successfully demonstrated an electrocatalyst mass activity of more than 440 mA/mg_{Pt} at 900 $mV_{IR\text{-}free}$ in fuel cell tests while meeting membrane electrode assembly durability targets. Improvements in the performance and durability of fuel cells pave the way for the broader adoption of hydrogen technology in vehicle and grid-support applications.

Improving Hydrogen Dispenser Reliability

Hydrogen dispensers are the leading cause of maintenance events at retail hydrogen stations. Through DOE's Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) project, NREL is working with manufacturers to lessen downtime by improving hydrogen dispenser component reliability. NREL researchers built a prototype test skid that simulates the inner workings of eight hydrogen dispensers to test reliability in highly accelerated life testing. Hydrogen is produced at the ESIF and dispensed through the test skid into a tankless vehicle simulator to evaluate hydrogen dispenser components during continuous refueling.

Improving Quality and Lowering Costs of Fuel Cell Membranes

NREL and W.L. Gore & Associates set out to clarify manufacturing quality requirements for fuel cell membranes. NREL's suite of real-time inspection techniques and research web line allows researchers to establish a baseline for the quality of GORE-SELECT Membrane materials by mapping characteristic nonuniformities. NREL will also use its unique spatial cell performance tools to better understand the performance and lifetime impact of nonuniformities. The project will contribute to the goal of continuously improving the quality and reducing costs of Gore's proton-conducting membrane, which is used in commercially available fuel cell vehicles.

Improving Optical Inspection Methods to Detect Fuel Cell Membrane Defects

NREL is assisting Mainstream Engineering Corporation in developing and validating a device to optically inspect fuel cell membranes. Mainstream is prototyping a full-scale inspection device based in part on NREL-developed technology. NREL, along with partners at Georgia Institute of Technology, is conducting studies to understand the effects of membrane inhomogeneities on fuel cell performance and quantify how those defects lead to accelerated cell degradation. This project aims to identify thresholds of detection based on defect size and type and demonstrate Mainstream's commercialization-ready system on several roll-to-roll membrane manufacturing lines.

Collaboration with EasyMile to Boost Research in Intelligent and Autonomous Electric Vehicles

NREL's research on electric vehicle grid integration examines the interactions among electric vehicles, building energy systems, utility electric grids, and renewable energy sources. In an important step toward furthering intelligent, efficient, and autonomous electric vehicles, transportation researchers at NREL plan to partner on research-and-development efforts with EasyMile, a smart mobility solutions company. The collaboration (https://go.usa.gov/xnjnR) will explore opportunities for how wireless charging can enable intelligent load management in various grid and campus load scenarios.

High-Performance Computing & Visualization

Project Spotlight

ESIF Testing Confirms the Water Savings of Thermosyphons

NREL and Sandia National Laboratories have partnered with Johnson Controls to investigate the use of the company's BlueStream Hybrid Cooling System(https://go.usa.gov/xnKWN), which adds a thermosyphon upstream of evaporative cooling towers to reduce water consumption. The thermosyphon was installed on the ESIF roof and started operating in August 2016 for NREL's High Performance Computing Data Center (HPC). After monitoring the system for a year, ESI researchers have confirmed that the system cut water use by nearly half, saving more than 1 million gallons without any negative impacts on the data center's efficiency. Sandia National Laboratories will apply the data from the ESIF's installation to their own cooling needs.

High-Performance Computing Usage Information

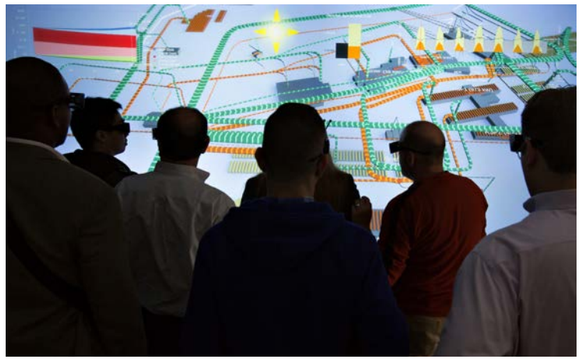
Area	No. of Projects	Node Hours Used
Advanced manufacturing	2	137,228
Bioenergy	3	5,594,418
Buildings	4	16,951
Computational science	5	188,017
Energy systems integration	8	900,190
Exascale computing	2	29,818
Geothermal	3	5,524
Grid modernization	6	56,938
Hydrogen and fuel cells	6	2,315,663
Solar energy	13	4,324,516
Vehicles	10	1,058,729
Water	1	232,534
Wind	11	2,802,657
TOTAL	74	17,663,183

Watch: Did you know that NREL's HPC is the engine that powers the lab's 3-D visualizations? These visualizations give researchers never-before-seen insights that help advance research in new ways. Step into some 3-D visualizations here (http://bit.ly/2BonqWz).

Project Highlights

New ESIF High-Performance Computing Data Management and Analysis Capabilities

In FY 2017, the ESIF's high-performance computing system added ESIF Relay, a real-time data streaming service that supports a range of functions, from HIL experiments to lab-wide metering data management. In addition, an application programming interface allows secure data accessibility and standardized programming access to data stored within the ESIF's Research Data System; Tanager, a new graphics processing unit cluster, enables enhanced visualization, image analysis, and machine learning; and the Big Data Analytics Platform provides access to the ESIF's HPC or—for external collaborations—the cloud, allowing scientists to explore massive data sets efficiently.



NREL completed a campus renewable energy planning proof-of-concept, which combines techno-economic optimizations from REopt simulations, whole building simulations from URBANopt, and power flow simulations from OpenDSS. Users can interactively explore the complex parameter space by defining new simulation scenarios and launching those scenarios on the HPC resources. The Peña Station NEXT project used the framework to couple and interactively visualize scenarios from whole building energy simulations and distribution power flow simulations.

PARTNERS

NREL continues to forge new partnerships among industry, academia, and government to leverage the expert staff and exceptional resources that the ESIF offers. Below are partners with active agreements in FY 2017.

3M Company

Advanced Energy Industries

Argonne National Laboratory

Bonneville Power Administration*

Bosch

California Energy Commission

Caterpillar, Inc.*

CenterPoint Energy, Inc.

CenturyLink

Chinese Academy of Sciences

CPS Energy

Cogent

Colorado School of Mines

Commonwealth Edison

CSIRO*

Dispersive Technologies

Duke Energy

Eaton

Electric Power Research Institute*

Element One, Inc.

El Paso Energy

First Solar

Florida Power & Light*

GE Energy Solutions

General Motors

Giner, Inc.

Go Electric

Green Charge Networks

Hawaiian Electric Company, Inc.*

Heila Technologies

Hyperlight Energy

Ibis Networks

Idaho National Laboratory

Ingersoll Rand

Intel Corporation

Leviton Manufacturing

Mainstream Engineering Corp.

National Electrical Manufactures Association

New York State Energy Research & Development Authority*

Northrop Grumman Corp.

OMNETRIC Group

Panasonic

PDC Machines

Peak Reliability

Peroxygen Systems, Inc.

Pika Energy

Rijksdienst voor Ondernemend

Sacramento Municipal Utility District

SafeConnect Solar

San Diego Gas & Electric*

Schneider Electric

Schweitzer Engineering Labs

Shell Global Solutions

Smarter Grid Solutions

Southern California Edison

SolarCity

Southern California Gas Company*

Sumitomo Corporation

Tokyo Electric Power Company

Toyota

University of Delaware

University of Illinois Urbana-Champaign

U.S. Department of Defense

U.S. Navy*

Western Electricity Coordinating Council

Verizon

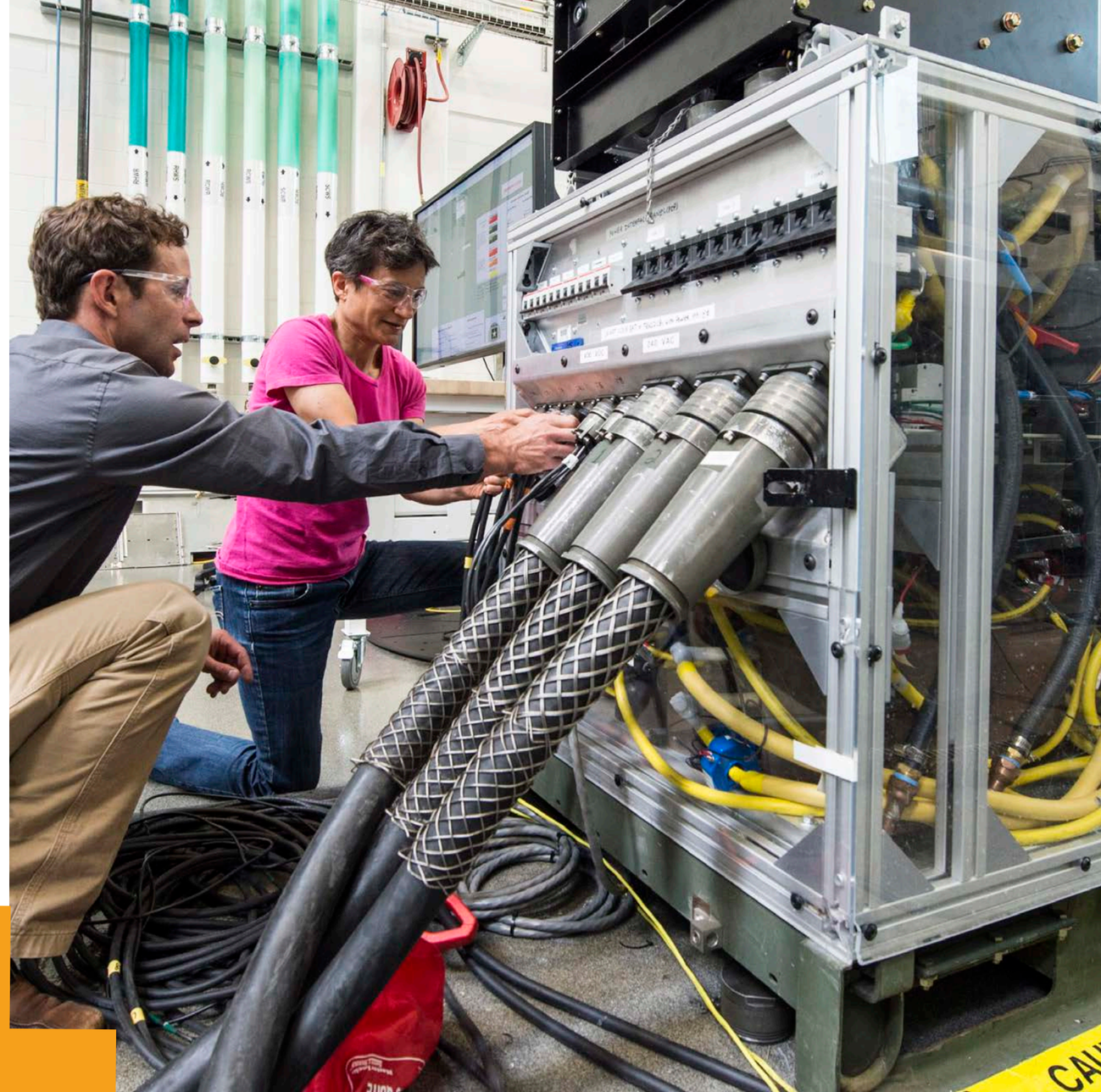
W.L. Gore & Associates

Walmart, Inc.

Xcel Energy

XTRLS

*These partners have more than one project.



DOE PROGRAM RESEARCH

ARPA-E

Network Optimized Distributed Energy Systems (NODES)

- RONIN
- ROBUST

Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA)

- SMART-DS: Synthetic Models for Advanced & Realistic Testing of Distribution systems and Scenarios

Buildings

Home Battery System

Fuel Cell Technologies Office

GMLC Category 1 Projects:

DER Siting and Optimization Tool for California

700 bar Hydrogen Dispenser Hose Reliability Improvement

Advanced Ionomers and Membrane Electrode Assemblies for Alkaline Membrane Fuel Cells

Automotive Fuel Cell Material and Manufacturing Development (cooperative research and development agreement with GM, cost-shared with the Fuel Cell Technologies Office [FCTO])

Collaboration on SBIR/TTO Phase II Project for Optical QC Device (FCTO-funded SBIR with Mainstream Engineering)

Demonstration of Hydrogen Tube-Trailer Consolidation for Reducing Refueling Station Cost

Dispenser Reliability Component Testing

Dynamic Modeling and Validation of Electrolyzers in Real-Time Grid Simulation

ElectroCat (Electrocatalysis Consortium): Membrane Electrode Assembly (MEA) Diagnostic, Segmented Cells

Extended-Surface Electrocatalyst Development (ETFECS)

Fuel Cell Bus Evaluations (National Fuel Cell Technology Evaluation Center [NFCTEC])

Fuel Cell Electric Vehicle Evaluation (NFCTEC)

Fuel Cell Membrane Electrode Assembly Manufacturing Research and Development (FCTO AOP)

Fuel Cell Technology Status: Degradation (NFCTEC)

FC-PAD: Fuel Cell Consortium for Performance and Durability—Advanced Integration, Contaminants, Electrode Layers

H2@Scale

High-Efficiency Tandem Absorbers for Economical Solar Hydrogen Production

HydroGEN Advanced Water Splitting Materials Consortium

Hydrogen Component Validation

Hydrogen Meter Benchmark Testing

Hydrogen Sensor Testing Laboratory

Hydrogen Station Data Collection and Analysis (NFCTEC)

Improved Hydrogen Liquefaction through Heisenberg Vortex Separation of Para- and Orthohydrogen

Integrated Research Facility for Advancing Hydrogen Infrastructure (HITRF)

Materials Performance Testing (technical services agreement with W.L. Gore & Assoc., cost-shared with FCTO)

Material-Process-Performance Relationships for Roll-to-Roll Coated PEM Electrodes (FCTO AOP)

National Codes and Standards Deployment and Outreach

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

Renewable Electrolysis Integrated System Development and Testing

Technical Assistance in Fabrication and Testing of MEAs (FCTO-funded SBV with Altergy)

Grid Modernization

GMLC Category 1 Projects:

1.1 Foundational Analysis for GMLC Establishment

1.2.1 Grid Architecture

1.2.2 Interoperability

1.2.3 GMLC Testing Network

1.2.4 Grid Services and Technologies Valuation Framework Development

1.2.5 Sensing and Measurement Strategy Methodology

1.3.05 DER Siting and Optimization Tool for California

1.3.10 Vermont Regional Partnership Enabling the Use of DER

1.3.21 Alaska Microgrid Partnership

1.3.29 Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii

1.3.33 Midwest Interconnection Seams Study

1.4.01 Standards and Test Procedures for Interconnection and Interoperability

1.4.02 Definitions, Standards and Test Procedures for Grid Services

1.4.04 Advanced Sensor Development

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

1.4.10 Control Theory

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

1.4.15 Development of Integrated Transmission, Distribution, and Communication Models

1.4.17 Extreme Event Modeling

1.4.18 Computational Science for Grid Management

1.4.25 Distribution System Decision Support Tools

1.4.26 Development and Deployment of Multi-Scale Production Cost Models

1.4.29 Future Electricity Utility Regulation

GMLC Category 2 Projects:

GM0061 Virtual Battery-Based Characterization and Control of Flexible Building Loads Using VOLTTRON

GM0062 Vehicle to Building Integration Pathway

GM0063 Development of an Open-Source Platform for Advanced Distribution Management Systems

GM0085 Systems Research Supporting Standards and Interoperability

GM0086 Modeling and Control Software Tools to Support V2G Integration

GM0094 Measurement-Based Hierarchical Framework for Time-Varying Stochastic Load Modeling

GM0163 Diagnostic Security Modules for Electric Vehicle to Building Integration

GM0172 VOLTTRON Message Bus Protocol Adapter

GM0187 Community Control of Distributed Resources for Wide Area Reserve Provision

GM0229 Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources

GM0237 Advanced Distribution Management System Testbed Development

GM0252 Optimal Stationary Fuel Cell Integration and Control (DG-BEAT)

SI-1545 Rapid QSTS Simulations for High-Resolution Comprehensive Assessment of Distributed PV Impacts

SI-1583 Stabilizing the Power System in 2035 and Beyond: Evolving from Grid-Following to Grid-Forming Distributed Inverter Controllers

SI-1586 Opportunistic Hybrid Communications Systems for Distributed PV Coordination

SI-1631 Assessing the Value of Concentrating Solar Power in a Sunshot Future

SI-1639 System Advisor Model

SI-1689 Additively Manufactured PV Inverter

SI-1695 Accelerating Systems Integration Codes and Standards

SI-1728 Solar Resource Calibration, Measurement, and Dissemination

WGRID-04 Providing Ramping Service with Wind to Enhance Power System Operational Flexibility

WGRID-05 Power System Reliable Integration Support to Achieve Large Amounts of Wind Power (PRISALA)

WGRID-35 Market and Reliability Opportunities for Wind on the Bulk Power System

WGRID-38 North American Renewable Integration Study (NARIS)

WGRID-49 Understanding the Role of Short-Term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power

WGRID-59 WindView: An Open Platform for Wind Energy Forecast Visualization

Office of Electricity Delivery and Energy Reliability

GMLC Category 1 Projects:

1.1 Foundational Analysis for GMLC Establishment

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GM0163 Diagnostic Security Modules for Electric Vehicle to Building Integration

GM0172 VOLTTRON Message Bus Protocol Adapter

GM0187 Community Control of Distributed Resources for Wide Area Reserve Provision

GM0229 Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources

GM0237 Advanced Distribution Management System Testbed Development

GM0252 Optimal Stationary Fuel Cell Integration and Control (DG-BEAT)

Solar Energy Technologies Office

SuNLaMP Prime Projects (GMLC Category 2):

30356 Additively Manufactured PV Inverter

30359 Solar Resource Calibration, Measure, and Dissemination

30360 Improve and Validation of the System Advisor Model

30361 Assessing the Value and Impact of Dispatchable CSP

30362 Opportunistic Hybrid Comms Systems for Dist PV Coordination

30363 Accelerating Systems Integration Standards (ACCEL)

30364 Stabilizing the Power System in 2035 and Beyond

SuNLaMP Subrecipient Projects (NREL as Subrecipient):

Oak Ridge National Laboratory Prime: Frequency Response of Three Major U.S. Power Grids—Zhang

Sandia National Laboratory Prime: Distribution System Modeling—Mather

Argonne National Laboratory Prime: An Integrated Tool for Improving Grid Reliability—Zhang

GMLC Category 1 Projects:

1.1 Foundational Analysis for GMLC Establishment

1.2.1 Grid Architecture

1.3.21 Alaska Microgrid Partnership

1.4.01 Standards and Test Procedures for Interconnection and Interoperability

1.4.15 Development of Integrated Transmission, Distribution, and Communication Models

1.4.25 Distribution System Decision Support Tools

1.4.29 Future Electricity Utility Regulation

1.3.29 Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii

1.4.04 Advanced Sensor Development

Other Direct Projects:

31105 U.S. representation for IEA PVPS Task 14

31797 Demonstration of Ancillary Services by Large PV Plant in CA

32402 North American Renewables Integration Study (NARIS)

32887 PV Plant and Battery Energy Storage Integration

32314 Solar Technology Cost Modeling and Competitive Analysis

32918 Eclipse Peak

INTEGRATE Projects (Collaborative)

Southern California Gas

ENERGISE Projects

NREL Primes:

Grid Optimization with Solar (GO-Solar)

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

NREL Subs:

Scalable/Secure Cooperative Algorithms and Framework for Extremely-high Penetration Solar Integration (SolarExPert)

Electric Access System Enhancement (EASE)

Vehicle Technologies Office

GMLC Category 1 Projects:

1.4.02 Definitions, Standards, and Test Procedures for Grid Services

1.4.10 Control Theory

Wind Power Technologies Office

GMLC Category 1 Projects:

1.3.33 Midwest Interconnection Seams Study

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

1.4.26 Development and Deployment of Multi-Scale Production Cost Models

GMLC Category 2 Projects:

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WGRID-05 Power System Reliable Integration Support to Achieve Large Amounts of Wind Power (PRISALA)

WGRID-35 Market and Reliability Opportunities for Wind on the Bulk Power System

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WGRID-49 Understanding the Role of Short-Term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power

WGRID-59 WindView: An Open Platform for Wind Energy Forecast Visualization

Water Power Technologies Office

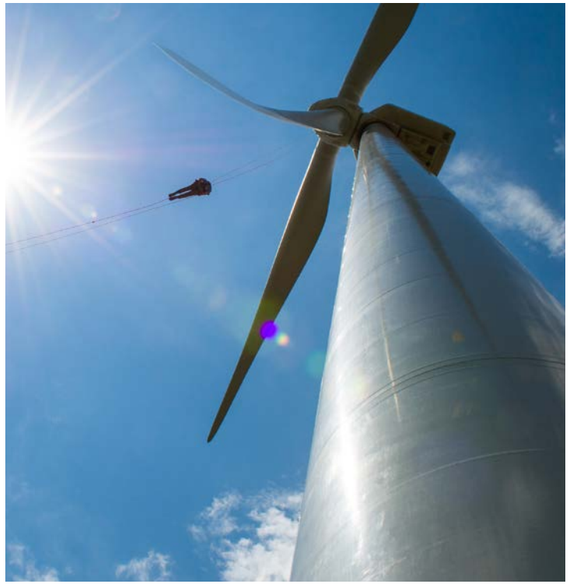
North American Grid Integration Study (NARIS)

Pumped Storage and Hydropower Value Consortium (HVC)

Ternary PSH Design and Evaluation

Obermeyer PSH Valuation

FY2017 Small Business Voucher—Natel



KNOWLEDGE SHARING

Leading the Next Generation of Energy Systems Researchers

Internships at the ESIF present students with the unique opportunity to establish long-term relationships with NREL researchers while being exposed to the breadth of dynamic topics in NREL's ESI research portfolio. In FY 2017, the ESIF offered nearly 100 internships to graduate and undergraduate students who have a variety of backgrounds in science and technology from universities across the United States.

Several types of internships are offered at the ESIF, including the Science Undergraduate Laboratory Internships, opportunities through NREL's Research Participant Program, the Office of Energy Efficiency and Renewable Energy Robotics Internship Program, the National Science Foundation, and the ESI Summer Graduate Internship Program.

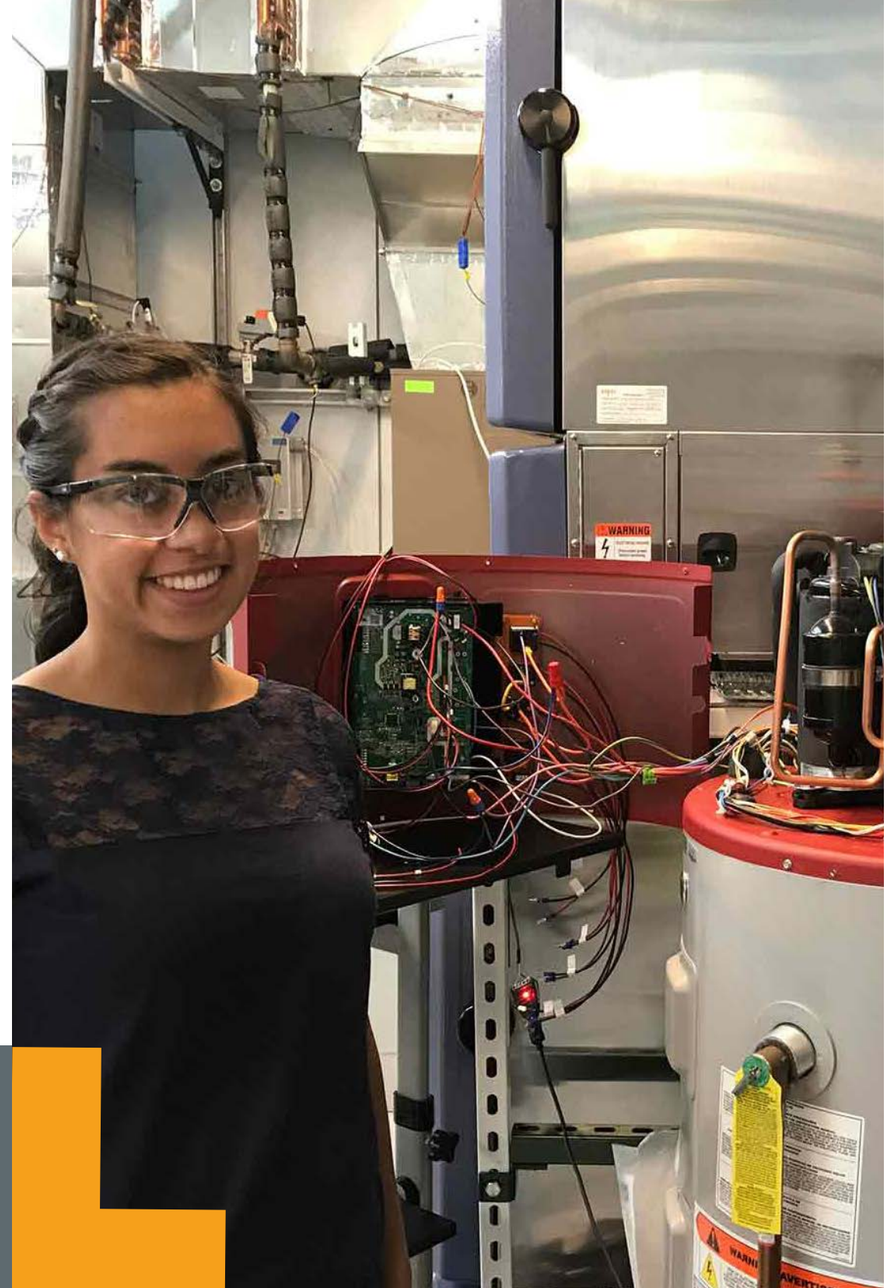
Webinars

Webinar Series: Competitive Procurement for Microgrid Controller Technology—November 10, 2016–May 5, 2017

Call for High-Impact Projects—January 17, 2017

Demonstration of Essential Reliability Services by 300-MW PV Power Plant: An NREL, California Independent System Operator, and First Solar Study—April 27, 2017

Did you know? The ESIF hosts thousands of visitors each year from the United States and around the world.



Workshops & Conferences

Enabling High Pen PV through Next-Generation Power Electronic Technologies—October 11, 2016

U.K.-U.S. Grid Modernization Collaboration Workshop—February 28, 2017

Siemens-OMNETRIC Industry Day—March 22, 2017

EPRI-Schneider Electric Industry Day—March 29, 2017

Fourth International Grid Simulator Testing Workshop—April 25, 2017

Autonomous Energy Grids Workshop—September 13, 2017

Smart Grid Educational Series

NREL hosts an ongoing series of educational webinars on smart grid-related topics featuring speakers from the lab and the energy industry. Recordings of the 11 Smart Grid webinars NREL hosted in 2017 can be found at https://www.nrel.gov/esif/sges-webinars.html.

USER FACILITY UPDATES

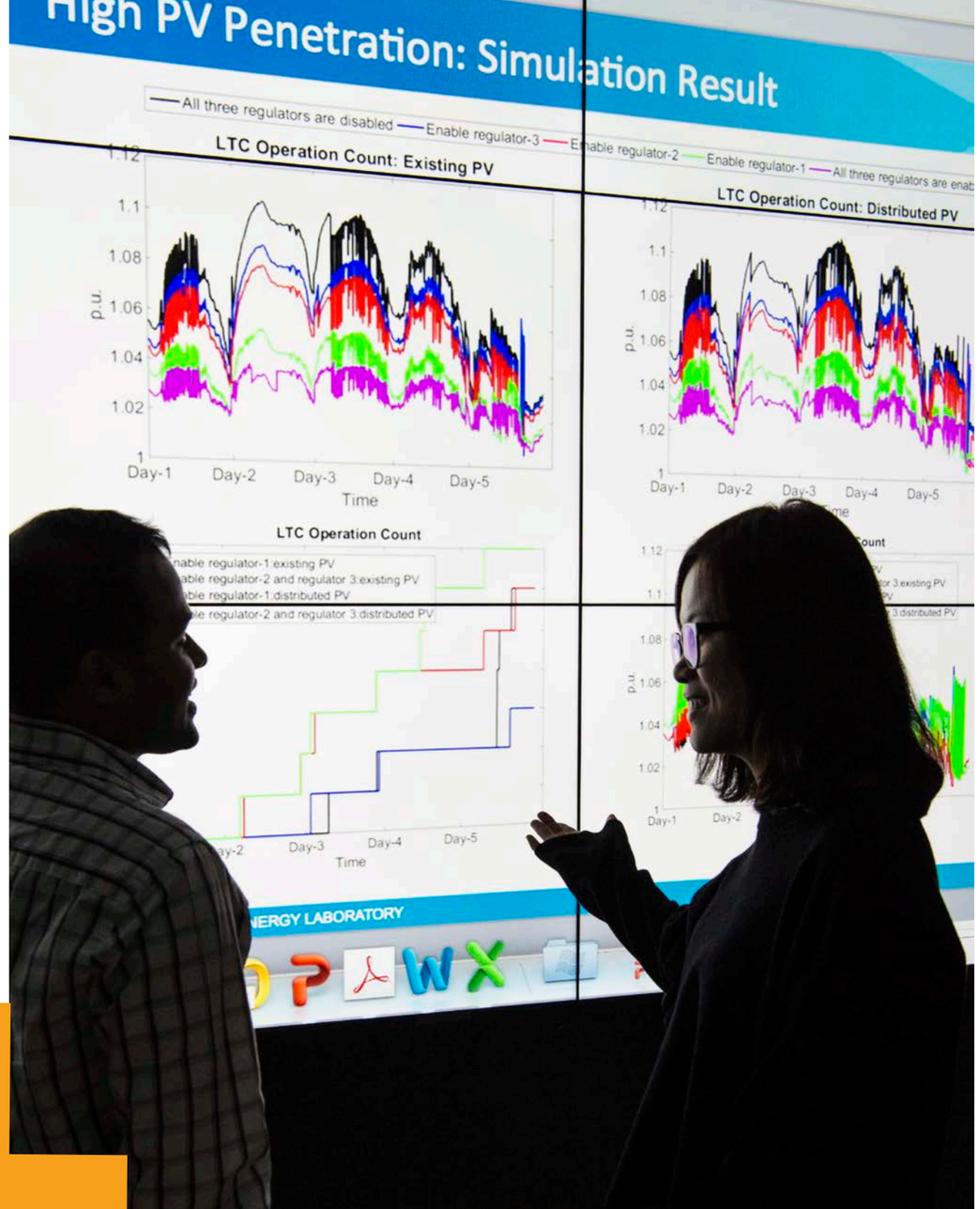
Hardware-in-the-Loop Capabilities Get Upgrades in Response to Increasing Demand

As the demand for power-hardware-in-the-loop (PHIL) and controller-hardware-in-loop (CHIL) research continues to grow, ESIF engineering staff have responded with upgrades and new capabilities. A new state-of-the-art Novacore system for real-time digital simulation has been installed as well as several connectivity upgrades to support distributed fiber-optic controls and communications across the facility. Also, significant horsepower has been added to the Opal-RT systems, including high-node-count phasor simulation, processing core updates, and distributed control capabilities. Finally, a multimode fiber-optic network for fast control and communications capabilities among several large energy laboratories is now operational. Upgrades will continue as demand and research needs increase.

Video: Power hardware-in-the-loop is a key research tool for evaluating new grid technologies safely in the lab before they are connected to the actual grid. Get the details on how it works here (http://bit.ly2hmvUtq).

Competitive Procurement for Microgrid Controller Technology

For the first time, NREL conducted a dual-stage competitive procurement, offering five technology vendors the opportunity to compete at the ESIF's state-of-the-art research laboratories between June and December 2017. The dual-stage Competitive Procurement for Microgrid Controller Technology required selected teams to demonstrate their controller's functionality in a CHIL test bed and a PHIL test bed at the ESIF in addition to receiving a cybersecurity evaluation. The top-performing microgrid controller will be purchased and integrated into the ESIF's permanent microgrid research test bed.



Grid Simulator Capacity Doubles to 2 MW

The ESIF's 1-MW bidirectional grid simulator is the most requested piece of equipment at the facility. This asset is central to large-scale PHIL experiments and is the workhorse for advanced grid studies. To meet increasing demand and advanced research needs, NREL and DOE have installed a second 1-MW system, bringing the total asset size to 2 MW comprising eight individual 250-kW simulators. Individual simulators can be paralleled in various combinations to provide flexible grid simulation power levels tailored to each activity. To optimize the use of this valuable system and minimize downtime, the ESIF also entered into a service agreement with Ametek, the manufacturer of the grid simulator system, to streamline maintenance and repairs.

Real-Time Connections to Other National Laboratories, Industry Amplify ESIF's Impact

NREL is collaborating with Idaho National Laboratory, Sandia National Laboratories, and five U.S. and two European university partners on the Real-Time Super Lab project. The goal of this project is to maximize geographically separated testing capabilities by connecting them in real-time simulations via the Internet. The implications are broader than testing, however. Whereas the current approach is limited to regional electricity sharing, the team sees the potential to exchange electricity among continents, improving the resiliency of electric grids. NREL's contributions to this project included accurately estimating communications delays, addressing latency issues, and improving available bandwidth. In addition, NREL has established real-time links to industry partners to make it possible to run experiments virtually by linking assets at partner facilities to the advanced research equipment at the ESIF. Links have been established with SDG&E, Australia's Commonwealth Scientific and Industrial Research Organization, and Rijksdienst voor Ondernemend in the Netherlands.

SYSTEM & TECHNOLOGY RESEARCH PLATFORMS

NREL enables utility partners, technology vendors, potential system owners, and researchers to evaluate existing and future use cases under different scenarios for a variety of energy control and management systems at the ESIF's national, vendor-neutral research platforms. The ESIF research platforms cover microgrids, smart homes, cybersecurity, and ADMS.

Microgrid

Cities, utilities, businesses, universities, and the military are increasingly interested in the flexibility, quick response, and security of microgrids. At the ESIF, new technologies and configurations are assessed at full power against a realistic replica of the actual location. Laboratory validation improves performance and mitigates anomalies before bringing these systems into the field. The ESIF also adds a cybersecurity communications layer, connecting power systems via realistic control networks using actual industry protocols. The megawatt-scale cyber-physical platform for microgrids reduces risks of deployment and helps optimize the successful performance of microgrid hardware, communications, and security.

NREL researchers ran a grid simulation using industrial-scale inverters to model a microgrid that **San Diego Gas & Electric** is expanding in Borrego Springs, California. Other partners that have used the microgrid research platform include **Caterpillar, EaglePicher, Honeywell, and Raytheon**.

Smart Home

NREL's smart home research platform advances technology to make our homes more comfortable and convenient while saving energy and being more grid friendly. Researchers simulate real-world conditions in a controlled laboratory environment incorporating power generation, energy storage, electric vehicles, and end loads in a space that connects sensors and analytics, appliances, a home, or even a community. Using HIL technology, researchers evaluate all aspects of intelligent building ecosystems—from smart appliances to cyber-secure home EMS—to tie into the dynamic grid of the future.

Researchers work with a home battery that integrates with a solar inverter and other controlled appliances as part of a home EMS available in the smart home research platform. This project is jointly funded by **Bonneville Power Administration, Bosch**, and the U.S. Department of Energy Building Technologies Office. Other partners that have worked in the smart home research platform include **AO Smith, ecobee, Eguana, Electric Power Research Institute, ESCRYPT, Fronius, Green Mountain Power, Hawaiian Electric Companies, Intwine, Leviton, LG Chem, Nissan, Pentair, Toyota, Trane,** and **Whisker Labs/Earth Networks**.

Cybersecurity

NREL's cybersecurity research platform employs a nine-layer cybersecurity architecture that effectively protects any multinode Internet protocol network. NREL demonstrates this by protecting distribution grid management use cases against insider threats and external hackers. Compared to traditional approaches to cybersecurity, which rely on costly updates to fixed legacy systems, the nine-layer architecture separates the power, communications, and cybersecurity systems—allowing each of these to be modular and evolve according to the business needs of a given use case. This method presents a systemic approach to protecting critical infrastructure without a need for forklift upgrades or additional security at the end device and protocol level. By leveraging lessons learned via NREL's cybersecurity research platform, asset owners can save significant amounts of capital investments in cybersecurity while meeting regulatory requirements.

NREL researchers work through different scenarios to evaluate the security of new technologies that are being introduced to the electric grid. The nine-layer architecture that the research platform employs is applicable to any multisite information system in any industry that uses real-time transactions (such as generation, transmission, and distribution) between users and/or systems. NREL's cybersecurity researchers worked with several industry partners in FY 2017 to evaluate the cybersecurity for a number of technologies—from online energy devices to electric vehicles, wind turbines, home energy networks, thermostats, and demand response systems.

Advanced Distribution Management System

NREL and the DOE's Office of Electricity Delivery and Energy Reliability have developed a vendor-neutral advanced distribution management system (ADMS) evaluation platform and are expanding the platform's capabilities. For low-cost, low-risk evaluation, utilities can use the platform at the ESIF to assess the performance of an ADMS that has been deployed or will be deployed. The platform uses actual grid-scale hardware, large-scale distribution system models, and advanced visualization to simulate real-world conditions. Among the many use cases evaluated in the ADMS research platform are the integration of transmission-to-building operations, incorporation of high penetrations of DERs into utility operations, and coordination among traditional utility assets and islandable microgrids. An industry advisory board consisting of representatives from partners from across the country ensures that developed capabilities meet industry requirements. Learn more about this capability and the types of research questions that the ADMS evaluation platform can answer here (https://go.usa.gov/xnAqF).

For a project with **Duke Energy**, researchers study feeder topography of a distribution management system electric grid in the ESIF's collaboration room. Other partners that have used the ADMS research platform include **Xcel Energy, EPRI, GE Grid Solutions, Schneider Electric,** and **Opal-RT**.

INVENTIONS

Records of Invention

Title	Primary NREL Center	NREL Number
A Modular and Scalable Power Architecture for Medium-Voltage Power Conversion	5D00 - Power Systems Engineering	ROI-17-74
A Short-Term and High-Resolution Distribution System Load Forecasting Approach	5D00 - Power Systems Engineering	ROI-17-98
ACES Investigator	2C00 - Computational Sciences	SWR-17-28
AMReX	2C00 - Computational Sciences	SWR-17-29
Class Object Attribute Data (COAD) for PLEXOS	2C00 - Computational Sciences	SWR-17-31
Commercial Distribution Management Systems (DMS) model to Common Information Model conversion	2C00 - Computational Sciences	SWR-17-37
Data-Driven Decision Support for Renewable Curtailment	5D00 - Power Systems Engineering	ROI-17-45
Decentralized Interleaving of Parallel-Connected Converters in DC Microgrids	5D00 - Power Systems Engineering	ROI-17-64
DSS2ePHASOR ("OpenDSS" files to "ePHASOR-SIM" interface files converter)	5D00 - Power Systems Engineering	SWR-17-14
FARMS-NIT (Fast All-sky Radiation Model for Solar applications with Narrowband Irradiances over Tilted surfaces)	5D00 - Power Systems Engineering	SWR-17-48
HELICS (High-Performance Transmission Distribution Communication Market Co-Simulation Framework)	5D00 - Power Systems Engineering	SWR-17-32
Heterogeneous Network Topology Manager	5D00 - Power Systems Engineering	ROI-17-95
Integrated PV Module and Lights	5D00 - Power Systems Engineering	ROI-17-23
LibIsopach	2C00 - Computational Sciences	SWR-17-05
Load-Flow in Multiphase Distribution Networks: Existence, Uniqueness, and Linear Models	5D00 - Power Systems Engineering	ROI-17-40
Low-Voltage Electric Vehicle Power Distribution System	5D00 - Power Systems Engineering	ROI-17-37
Measurement-Based Hidden PV Estimation	5D00 - Power Systems Engineering	ROI-17-67
Network-Aware Decentralized Voltage Control for Distribution Grids	5D00 - Power Systems Engineering	ROI-17-28
PeleC	2C00 - Computational Sciences	SWR-17-35
PelePhysics	2C00 - Computational Sciences	SWR-17-36
PQScal (Power Quality Score Calculation for Distribution Systems with DER Integration)	5D00 - Power Systems Engineering	SWR-17-06
pywtk (Python WindToolKit)	2C00 - Computational Sciences	SWR-17-26
Remote Sensing of Transmission Line Operating Environment for Dynamic Line Ratings	5D00 - Power Systems Engineering	ROI-17-43
Single-Phase Battery Charger for EV With No Energy Storage Requirements	5D00 - Power Systems Engineering	ROI-17-38
Transmission Distribution Simulation Visualizer (TDSVis)	2C00 - Computational Sciences	SWR-17-18
Travelling Wave Based Protection Scheme to Detect and Identify Faults in a Distribution System With High Penetration of Inverter Based Distribution Energy Sources	5D00 - Power Systems Engineering	ROI-17-77
Use of Embedded Optical Fibre in Transmission Cable Wrapping for Conductor Temperature Sensing	5D00 - Power Systems Engineering	ROI-17-44
Variable Time-Step Solution Method for Quasi-Static Time-Series Power Flow Analysis	5D00 - Power Systems Engineering	ROI-17-16
Volttime	2C00 - Computational Sciences	SWR-17-33
WPP_Observer_IR	5D00 - Power Systems Engineering	SWR-17-12

Patent Filings

Title	Primary NREL Center	NREL Number
Real-Time Voltage Regulation Through Father and Broadcast Techniques	5D00 - Power Systems Engineering	16-35
Distribution Infrastructure Optimization and Control	5D00 - Power Systems Engineering	PROV/16-124
Determining Load Flow in Multiphase Networks	5D00 - Power Systems Engineering	PROV/17-40
Network-Cognizant Voltage Droop Control	5D00 - Power Systems Engineering	PROV/17-28
Mitigating Latency Errors in Distributed Systems	5D00 - Power Systems Engineering	16-31
Virtual Oscillator Control	5D00 - Power Systems Engineering	PCT/16-74
Virtual Oscillator Control	5D00 - Power Systems Engineering	16-74
Decentralized Control	5D00 - Power Systems Engineering	PROV/17-64
Modular Scalable Power Conversion	5D00 - Power Systems Engineering	PROV/17-74

PUBLICATIONS

Most Downloaded Publications

The following were the most downloaded FY 2017 ESIF publications on NREL.gov:

1. *Clear Sky Probability for the August 21, 2017, Total Solar Eclipse Using the NREL National Solar Irradiation Database*
2. *Greening the Grid: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid, Vol. I—National Study*
3. *The Economic Potential of Three Nuclear-Renewable Hybrid Energy Systems Providing Thermal Energy to Industry*
4. *Demonstration of Essential Reliability Services by a 300-MW Solar Photovoltaic Power Plant*
5. *Feeder Voltage Regulation with High-Penetration PV Using Advanced Inverters and a Distribution Management System: A Duke Energy Case Study*
6. *Evaluation of the National Solar Radiation Database (NSRDB): 1988–2015*
7. "ESIF 2016: Modernizing Our Grid and Energy System"
8. *A Prospective Analysis of the Costs, Benefits, and Impacts of U.S. Renewable Portfolio Standards*
9. *Quality Assurance Framework for Mini-Grids*
10. "Grid Integration Science," NREL Power Systems Engineering Center

PUBLICATIONS

Conference Papers (Preprints)

Baggu, M., K. Smith, A. Friedl, T. Bialek, M.R.. Schimpe. 2017. "Performance and Health Test Procedure for Grid Energy Storage Systems: Preprint." Presented at the 2017 IEEE Power & Energy Society General (PES GM) Meeting, Chicago, Illinois, July 16–20, 2017.

Baker, K., X. Jin, D. Vaidhynathan, W. Jones, D. Christensen, B. Sparn, J. Woods, H. Sorensen, and M. Lunacek. 2017. "Short Paper: Frequency Regulation Services from Connected Residential Devices: Preprint." Presented at BuildSys '16: 3rd ACM International Conference on Systems for Energy-Efficient Built Environments, Palo Alto, California, November 16–17, 2016.

Bernstein, A., and E. Dall'Anese. 2017. "Linear Power-Flow Models in Multiphase Distribution Networks: Preprint." Presented at the 7th IEEE International Conference on Innovative Smart Grid Technologies (ISGT Europe 2017), Torino, Italy, September 26–29, 2017.

Bloom, Aaron; Novacheck, Josh. 2017. "The Eastern Renewable Generation Integration Study: Insights on System Stress: Preprint." Presented at the 6th International Workshop on Integration of Solar Power into Power Systems, Vienna, Austria, November 14–15, 2016.

Buttner, W.J., C. Rivkin, R. Burgess, E. Brosha, R. Mukundan, J.C. Will, and J. Keller. 2016. "Overview of the U.S. DOE Hydrogen Safety, Codes and Standards Program. Part 4: Hydrogen Sensors; Preprint." Presented at the 6th International Conference on Hydrogen Safety (ICHS), Yokohama, Japan, October 19–21, 2015.

Carter, T., Z. Liu, D. Sickinger, K. Regimbal, and D. Martinez. 2017. "Thermosyphon Cooler Hybrid System for Water Savings in an Energy-Efficient HPC Data Center: Modeling and Installation: Preprint." Presented at the 2017 ASHRAE Winter Conference, Las Vegas, Nevada, January 28–February 1, 2017.

Chamana, M., K. Prabakar, B. Palmintier, and M. Baggu. 2017. "Conversion and Validation of Distribution System Model from a QSTS-Based Tool to a Real-Time Dynamic Phasor Simulator: Preprint." Presented at the IEEE Green Technologies Conference, Denver, Colorado, March 29–31, 2017.

Cruickshank, R.F, G.P. Henze, R. Balaji, B.-M. Hodge, and A.R. Florita. 2017. "Empirical Investigations of the Opportunity Limits of Automatic Residential Electric Load Shaping: Preprint." Presented at the IEEE Green Technologies Conference, Denver, Colorado, March 29–31, 2017.

Cui, M., Z. Wang, J. Zhang, Q. Wang, A. Florita, V. Krishnan, and B.-M. Hodge. 2017. "Probabilistic Wind Power Ramp Forecasting Based on a Scenario Generation Method: Preprint." Presented at the IEEE Power and Energy Society General Meeting, Chicago, Illinois, July 16–20, 2017.

Gevorgian, V., and B. O'Neill. 2017. "Demonstration of Active Power Controls by Utility-Scale PV Power Plant in an Island Grid: Preprint." Presented at the 15th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Vienna, Austria, November 15–17, 2016.

Gevorgian, V., and Y.C. Zhang. 2017. "Wind Generation Participation in Power System Frequency Response: Preprint." Presented at the 15th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Vienna, Austria, November 15–17, 2016.

Gevorgian, V., P. Koralewicz, R. Wallen, and E. Muljadi. 2017. "Controllable Grid Interface for Testing Ancillary Service Controls and Fault Performance of Utility-Scale Wind Power Generation: Preprint." Presented at the 15th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Vienna, Austria, November 15–17, 2016.

Gruchalla, K., J. Novacheck, and A. Bloom. 2016. "Visualization of the Eastern Renewable Generation Integration Study: Preprint." Presented at SC16: International Conference for High Performance Computing, Networking, Storage and Analysis, Salt Lake City, Utah, November 13–18, 2016.

Harris, T., A. Nagarajan, M. Baggu, and T. Bialek. 2017. "Cost Benefit and Alternatives Analysis of Distribution Systems with Energy Storage Systems: Preprint." Presented at the 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC), Washington, D.C., June 25–30, 2017.

Husain, T., I. Hasan, Y. Sozer, I. Husain, and E. Muljadi. 2017. "Design Considerations of a Transverse Flux Machine for Direct-Drive Wind Turbine Applications: Preprint." Presented at the 2016 IEEE Energy Conversion Congress and Exposition, Milwaukee, Wisconsin, September 18–22, 2016.

Jiang, H., F. Ding, Y.C. Zhang. 2017. "Short-Term Load Forecasting Based Automatic Distribution Network Reconfiguration: Preprint." Presented at the 2017 IEEE Power & Energy Society General Meeting (PES GM), Chicago, Illinois, July 16–20, 2017.

Johnson, B., M. Rodriguez, M. Sinha, and S. Dhople. 2017. "Comparison of Virtual Oscillator and Droop Control: Preprint." Presented at the IEEE COMPEL 2017, Stanford, California, June 9–12, 2017.

Lin, Yashen; Johnson, Brian; Gevorgian, Vahan; Purba, Victor; Dhople, Sairaj. 2017. "Stability Assessment of a System Comprising a Single Machine and Inverter with Scalable Ratings." Presented at the IEEE North American Power Symposium, September 17–19, 2017, Morgantown, West Virginia.

Maitra, A., T. Hubert, J. Wang, R. Singh, N. Kang, X. Lu, J. Reilly, A. Pratt, and S. Veda. 2017. "DMS Advanced Applications for Accommodating High Penetrations of DERs and Microgrids: Preprint." Presented at the 24th International Conference on Electricity Distribution, Glasgow, Scotland, June 12–15, 2017.

Mather, B. 2017. "Fast Determination of Distribution-Connected PV Impacts Using a Variable Time-Step Quasi-Static Time-Series Approach: Preprint." Presented at the 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC), Washington, D.C., June 25–30, 2017.

Miller, N., and K. Clark. 2017. "Impacts of High Levels of Distributed PV and Load Dynamics on Bulk Power Transient Stability: Preprint." Presented at the CIGRE International Colloquium on the Evolution of Power System Planning to Support Connection of Generation, Distributed Resources and Alternative Technologies, Philadelphia, Pennsylvania, November 2–3, 2016.

Nagarajan, A., A. Nelson, K. Prabakar, A. Hoke, M. Asano, R. Ueda, and S. Nepal. 2017. "Network Reduction Algorithm for Developing Distribution Feeders for Real-Time Simulators: Preprint." Presented at the 2017 IEEE Power and Energy Society General Meeting, Chicago, Illinois, July 16–20, 2017.

Nelson, A., G. Martin, and J. Hurtt. 2017. "Experimental Evaluation of Grid Support Enabled PV Inverter Response to Abnormal Grid Conditions: Preprint." Presented at the Eighth Conference on Innovative Smart Grid Technologies (ISGT 2017), Washington, D.C., April 23–26, 2017.

Nelson, A., K. Prabakar, A. Nagarajan, S. Nepal, A. Hoke, M. Asano, R. Ueda, and E. Ifuku. 2017. "Power Hardware-in-the-Loop Evaluation of PV Inverter Grid Support on Hawaiian Electric Feeders: Preprint." Presented at the Eighth Conference on Innovative Smart Grid Technologies (ISGT 2017), Washington, D.C., April 23–26, 2017.

Palmintier, B., D. Krishnamurthy, P. Top, S. Smith, J. Daily, and J. Fuller. 2017. "Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework: Preprint." Presented at the 2017 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Pittsburgh, Pennsylvania, April 21, 2017.

Pratt, A., M. Ruth, D. Krishnamurthy, B. Sparn, M. Lunacek, W. Jones, H. Wu, S. Mittal, and J. Marks. 2017. "Hardware-in-the-Loop Simulation of a Distribution System with Air Conditioners under Model Predictive Control: Preprint." Presented at the 2017 Power and Energy Society General Meeting. Chicago, Illinois. July 16–20, 2017.

Purba, V., S. Jafarpour, B.B. Johnson, F. Bullo, and S. Dhople. 2017. "Reduced-Order Structure-Preserving Model for Parallel-Connected Three-Phase Grid-Tied Inverters: Preprint." Presented at the IEEE Workshop on Control and Modeling for Power Electronics, Stanford, California, July 9–12, 2017.

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Smith, K., A. Saxon, M. Keyser, B. Lundstrom, Z. Cao, and A. Roc. 2017. "Life Prediction Model for Grid-Connected Li-ion Battery Energy Storage System: Preprint." Presented at the 2017 American Control Conference, Seattle, Washington, May 24-26, 2017.

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Wang, X., W. Gao, J. Wang, Z. Wu, W. Yan, V. Gevorgian, Y.C. Zhang, E. Muljadi, M. Kang, M. Hwang, and Y.C. Kang. 2017. "Assessment of System Frequency Support Effect of PMSG-WTG Using Torque-Limit-Based Inertial Control: Preprint." Presented at the 2016 IEEE Energy Conversion Congress and Exposition, Milwaukee, Wisconsin, September 18–22, 2016.

Wang, X., W. Gao, W. Yan, J. Wang, E. Muljadi, V. Gevorgian, and A. Scholbrock. "Evaluation of the Inertial Response of Variable-Speed Wind Turbines Using Advanced Simulation: Preprint." Presented at the IEEE Power & Energy Society General Meeting, Chicago, Illinois, July 16–20, 2017.

Wu, Y., J. Wei, and B.-M. Hodge. 2017. "A Distributed Middleware Architecture for Attack-Resilient Communications in Smart Grids: Preprint." Presented at the IEEE International Conference on Communications 2017 SAC Symposium Communications for the Smart Grid Track, Paris, France, May 21–25, 2017.

Xie, Y., M. Sengupta, and C. Deline. 2017. "Recent Advancements in the Numerical Simulation of Surface Irradiance for Solar Energy Applications: Preprint." Presented at the 2017 IEEE 44th Photovoltaic Specialists Conference (PVSC), Washington, D.C., June 25–30, 2017.

Yang, R., and Y.C. Zhang. 2017. "Three-Phase AC Optimal Power Flow Based Distribution Locational Marginal Price: Preprint." Presented at the IEEE Eighth Conference on Innovative Smart Grid Technologies (IEEE ISGT 2017), Arlington, Virginia, April 23–26, 2017.

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Zhang, C., S. Santhanagopalan, M.J. Stock, N. Brunhart-Lupo, and K. Gruchalla. 2016. "Interpretation of Simultaneous Mechanical-Electrical-Thermal Failure in a Lithium-Ion Battery Module: Preprint." Presented at SC16: International Conference for High Performance Computing, Networking, Storage and Analysis, Salt Lake City, Utah, November 13–18, 2016.

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Afrin, S., J. Dagdelen, Z. Ma, and V. Kumar. 2017. "Application of Sol-Gel Method as a Protective Layer on a Specular Reflective Surface for Secondary Reflector in a Solar Receiver." In *Proceedings of the ASME 2016 10th International Conference on Energy Sustainability*. New York, NY: American Society of Mechanical Engineers.

Ainsworth, N., A. Hariri, K. Prabakar, A. Pratt, and M. Baggu. 2017. "Modeling and Compensation Design for a Power Hardware-in-the-Loop Simulation of an AC Distribution System." Proceedings of the 2016 North American Power Symposium (NAPS). Piscataway, NJ: Institute of Electrical and Electronics Engineers.

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Habte, A., M. Sengupta, A. Andreas, I. Reda, and J. Robinson. 2017. "Shortwave Radiometer Calibration Methods Comparison and Resulting Solar Irradiance Measurement Differences: A User Perspective." In *Proceedings of the 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC)*. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Hasan, I., T. Husain, Y. Sozer, I. Husain, and E. Muljadi. 2017. "Analytical Model-Based Design Optimization of a Transverse Flux Machine." In *Proceedings of the 2016 IEEE Energy Conversion Congress and Exposition (ECCE)*. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Husain, T., I. Hasan, S. Iftekhar, Y. Sozer, I. Husain, and E. Muljadi. 2017. "Cogging Torque Minimization in Transverse Flux Machines." In *Proceedings of the 2016 IEEE Energy Conversion Congress and Exposition (ECCE)*. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Kroposki, B., P. Skare, R. Pratt, T. Kim, and A. Ellis. 2017. "Grid Modernization Laboratory Consortium - Testing and Verification." In Proceedings of the 2017 Ninth Annual IEEE Green Technologies Conference (GreenTech). Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Lundstrom, B., S. Chakraborty, G. Lauss, R. Brundlinger, and R. Conklin. 2017. "Evaluation of System-Integrated Smart Grid Devices using Software- and Hardware-in-the-Loop." In *Proceedings of the 2016 IEEE Power and Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

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NREL/BR-5C00-70906 • February 2018