Associate Director’s Letter

The Energy Systems Integration Facility (ESIF) has always been a resource that anticipates emerging research needs. With capabilities that continue to advance the impact and scale of leading research, it has attracted partners from around the world whose projects could not be pursued anywhere else.

In Fiscal Year 2018, research at the ESIF adapted and aligned to address the challenges that are shaping the electric grid today and into the future. Because renewable energy and energy-efficiency technologies are now more widespread, improved technologies, tools, and approaches must continue to be developed to enable better integration with the grid and other energy infrastructure.

Among them, cybersecurity has been elevated to a national priority that has crosscutting importance for all grid modernization efforts. We’re investigating how to secure our nation’s infrastructure in light of the increasing attack surface created through the millions of digital devices being integrated into the grid. Another emerging trend is active customer participation in smart load management and energy generation. Our ongoing projects with utilities in Hawaii and California are setting national examples of how to accommodate this shift, with the ESIF playing a major role in simulating and validating new models of customer participation at realistic size and scale—from individual homes and businesses to systems that stretch across the continent.

Our partnerships help us stay at the forefront of changing trends and technologies. In FY 2018 we began a new kind of collaboration with Eaton Corporation, where an Eaton research team joined us on-site at the ESIF for a long-term, close collaboration to expedite the research and commercialization of new energy-related technologies. Directly and collectively pursuing our mutual goals will maximize the use of the ESIF and put us in step with industry priorities. We will also continue to strengthen our collaborations with other national labs. This will allow us to better leverage the extensive knowledge, tools, and capabilities within the national lab complex and bring that to bear on finding solutions to big challenges.

Industry interest in the ESIF is also a testament to our continuing efforts to offer unique and relevant capabilities. Looking forward, our eyes are on Eagle, the National Renewable Energy Laboratory’s (NREL) new supercomputer. Eagle will provide the capability to address the increasingly complex challenges in energy systems integration. We’ll also continue to build out our experimentation capability for advanced distribution management systems, a resource that’s been refined by utility use throughout FY 2018, and our microgrid test bed, a fundamental asset in increasing resilience for at-risk areas across the nation.

It’s clear that we’re facing the largest grid transformation in our nation’s history, and the solutions are spread across domains, industries, technologies, and geographic boundaries. This transformation will require new collaborations and a broad vision, and the big ideas behind our changing energy systems have no better home than here. We are excited to see that the ESIF remains the link that connects leaders in energy systems integration with the capabilities and talent they need to secure and strengthen our nation’s electric grid.

Sincerely,

Juan Torres
Associate Laboratory Director for Energy Systems Integration at NREL

Martha Symko-Davies
Laboratory Program Manager for the Energy Systems Integration Facility at NREL

The ESIF 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 and is a designated DOE user facility.
Celebrating 5 Years of Innovation at the ESIF

In September 2013, the U.S. secretary of energy dedicated the Energy Systems Integration Facility (ESIF) on the National Renewable Energy Laboratory’s (NREL’s) campus in Golden, Colorado. Since the ESIF opened, now more than 5 years ago, it has become the nation’s premier facility dedicated to the research, design, development, and demonstration of the components and systems needed to seamlessly integrate advanced energy technologies into our evolving grid infrastructure. It is a unique facility where the demonstration of scientific discovery can have large-scale industry impact.

The ESIF’s mission was clear. As the cost of renewable and distributed energy technologies decreased and deployments increased, the need to better understand the complexity and interdependencies of our current energy systems and the impact of emerging technologies was apparent. The vision for the ESIF was to bring utilities, technology developers, and grid researchers together to ask the “what if?” questions in a low-risk environment, before new technologies were deployed.

In the 5 years since its dedication, the ESIF’s impact can be seen in the groundbreaking work that the facility has made possible and the innovative partners it continues to attract. As a U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) user facility, it provides the flexibility that partners require to explore projects that they could not execute anywhere else. With a multimegawatt grid simulator, integrated power hardware-in-the-loop (PHIL), high-performance computing (HPC), state-of-the-art visualization capabilities, parallel AC and DC power buses, and configurable evaluation platforms, the ESIF offers a truly unique space for designing, developing, and deploying device- and system-level technologies for a modern grid.

To stay on the leading edge of research, the ESIF will continue to evolve and improve its capabilities in Fiscal Year 2019 and beyond to guide national progress toward a modernized grid. Planned quick-setup, plug-and-play platforms will be highly integrated, flexible, and scalable. They will make it possible to accelerate and push research past existing boundaries while remaining ahead of industry needs.

Projects at the ESIF are categorized as:
- Systems integration (42%)
  - Advanced controls for integrating multiple technologies into an energy system
- Components and devices (43%)
  - Specific devices or components of an energy system
- Advanced materials (15%)
  - Developing new materials for grid devices

Our researchers are focusing on system-level solutions that consider all the complexities and interdependencies of our grid. Looking at devices and solutions in isolation is no longer a viable approach. We will continue to develop research capabilities that take efficiencies and operations of the whole system into account.

As energy producers and energy users become increasingly intertwined, we are leveraging our HPC capabilities to initially influence the design and then evaluate and develop the interface between the producers and consumers, including devices and control systems such as home energy management systems and building energy management systems. We are looking at the integration of mobility, where electric vehicles (EVs) can play a role in the reliable operations of the grid. We are finding a wide variety of ways to store and optimize use renewable energy—from storing it in grid-friendly batteries to converting it to renewable fuels such as hydrogen or natural gas. You will find that the facility truly looks at the key elements supporting research to have impacts on advanced materials development, components and devices, and integrated systems while addressing security and resilience along the way.

The FY 2018 projects in this report present a snapshot of the facility’s research direction—the challenges that face industry, the ideas that drive partners, and all that the ESIF can do to have the largest impacts to help modernize our electric grid.
Central to the mission of the ESIF is exploration of new areas of research that push the boundaries of conventional thinking. In FY 2017, NREL issued a Call for High Impact Projects, seeking partners that demonstrate the use of multiple technologies (such as storage, wind, solar, hydrogen, and buildings), address the challenges outlined in the Grid Modernization Multiyear Program Plan, and provide lessons that could be implemented across the United States. Two of the selected projects push into important, new mission spaces for DOE.

High Impact Projects Overview

Central to the mission of the ESIF is exploration of new areas of research that push the boundaries of conventional thinking. In FY 2017, NREL issued a Call for High Impact Projects, seeking partners that demonstrate the use of multiple technologies (such as storage, wind, solar, hydrogen, and buildings), address the challenges outlined in the Grid Modernization Multiyear Program Plan, and provide lessons that could be implemented across the United States. Two of the selected projects push into important, new mission spaces for DOE.

High Impact Projects Overview

Central to the mission of the ESIF is exploration of new areas of research that push the boundaries of conventional thinking. In FY 2017, NREL issued a Call for High Impact Projects, seeking partners that demonstrate the use of multiple technologies (such as storage, wind, solar, hydrogen, and buildings), address the challenges outlined in the Grid Modernization Multiyear Program Plan, and provide lessons that could be implemented across the United States. Two of the selected projects push into important, new mission spaces for DOE.

High Impact Projects Overview

Central to the mission of the ESIF is exploration of new areas of research that push the boundaries of conventional thinking. In FY 2017, NREL issued a Call for High Impact Projects, seeking partners that demonstrate the use of multiple technologies (such as storage, wind, solar, hydrogen, and buildings), address the challenges outlined in the Grid Modernization Multiyear Program Plan, and provide lessons that could be implemented across the United States. Two of the selected projects push into important, new mission spaces for DOE.
Devices & Integrated Systems

NREL Helps Publish Revision of IEEE 1547

The Institute of Electrical and Electronics Engineers (IEEE) published the revised interconnection standard 1547 in April 2018. With support from DOE’s Solar Energy Technologies Office (SETO), NREL provided critical leadership to revise the standard through technical support to the IEEE 1547 working group while building consensus among hundreds of individuals—including representatives from utilities, equipment vendors and operators, researchers, and independent experts—prior to publication. IEEE 1547-2018 establishes uniform requirements for the interconnection of DERs with the electric power system, and the revisions made will help accelerate the modernization of electric power infrastructure.

IEEE 1547 appears in the majority of interconnection guidance and agreements in the United States. It provides the ability for major participants to play by the same rules and expectations, ensuring utilities that emerging technologies will maintain the integrity of the system and provide smooth transitioning under normal and abnormal conditions. This standard addresses the critical need for a single document that provides uniform technical criteria and requirements for all distributed energy devices connecting to the electric distribution system, and it represents the joint efforts of hundreds of individuals working together to develop a standard that can be adopted across the United States and internationally.

The revised standard is expected to have a significant effect on how the energy industry does business with DERs—and to continue to influence the way electric power systems operate far into the future.

Read the full revised standard (bit.ly/2BAnt4X).

Project Spotlight

NREL Helps Publish Revision of IEEE 1547
Residential buildings use more electricity than any other sector in the United States, including commercial buildings, industrial buildings, and transportation. Heating, air conditioning, water heaters, clothes washers, dryers, and dishwashers are among the most energy-consuming appliances, accounting for about 62% of total energy consumption in the residential sector. NREL researchers are working to automatically sync these appliances and systems using NREL’s home energy management system, foresee™, to coordinate and schedule operation, delivering significantly improved energy savings, comfort, and automation.

As a secure home automation system, foresee choreographs the operation of connected appliances, home batteries, and rooftop solar, satisfying homeowner values and preferences along with utility grid needs. Leveraging machine-learning algorithms to derive data-driven appliance models and usage patterns to predict future energy consumption in homes, foresee enables highly accurate predictions of comfort needs, energy costs, environmental impacts, and grid service availability.

Foresee adjusts to high and low energy demands and sends/receives energy forecast signals and price signals via two-way communications with the utility. By coordinating energy use and shifting appliances to run at off-peak times, foresee can reduce stress on the electric grid and help consumers see reduced energy bills by participating in existing demand-response and time-of-use programs. By monitoring utility prices and weather forecasts, analyzing power consumption, and monitoring connected appliances and systems, foresee schedules the operation of connected systems to best achieve the priorities identified by the homeowner.

Using the Systems Performance Laboratory in the ESIF, recent results indicate that foresee can provide homeowners between 5% and 12% whole-home energy savings while delivering a homeowner-defined balance of comfort, convenience, energy cost reduction, and grid benefits. If foresee were used in every U.S. home, NREL researchers estimate that more than 1 quadrillion BTU of primary energy could be saved each year, which equates to about $10 billion in energy bill savings. This is roughly equivalent to saving all of the energy used by every household in Alaska, Delaware, Hawaii, Idaho, Maine, Montana, New Hampshire, North Dakota, Rhode Island, South Dakota, Vermont, and Wyoming combined.

The innovation behind foresee was developed as a result of an ESIF high-impact project among NREL, Colorado State University, ETAL-EISCRYPT, and Robert Bosch, LLC, with funding support from the Bonneville Power Administration and DOE. This project enabled design approaches for connected home energy systems (e.g., home batteries) that are applicable to developers, appliance manufacturers, regulators, and utilities nationwide as home automation is adopted. In addition, the researchers developed a preliminary method for sizing home batteries and studied how coordinating multiple instances of foresee can provide local grid services/benefits.

The project team received an R&D 100 award at the November 2018 awards ceremony for this outstanding innovation. Presented annually by R&D Magazine, the awards, known as the “Oscars of innovation,” honor the 100 most innovative technologies of the past year.
NREL Study Inspires New Research on Photovoltaic Inverter Response to Grid Disturbances

In August 2016, the San Bernardino County Blue Cut Fire burned 37,000 acres of land, including more than 100 homes and several other structures. Several photovoltaic (PV) inverters connected to residential solar systems tripped offline, which is often the result of inverters sensing frequencies that are either too high or too low for their voltage ride-through capabilities. In collaboration with Southern California Edison, NREL sought to further evaluate the inverters’ behavior and validate the findings of the North American Electric Reliability Corporation task force through laboratory testing at the ESIF. Researchers found that there were large deviations in PV inverter frequency measurement, indicating that the trip behavior was not largely influenced by high- or low-frequency ride-through capabilities but rather by a misapplication of frequency measurement methods. Results of the NREL study on “Laboratory Testing of a Utility-Scale PV Inverter’s Operational Response to Grid Disturbances” were shared at the IEEE Power &Energy Society General Meeting in August 2018, triggering discussion among industry, standards organizations, and product vendors on the effectiveness and consistency of frequency measurement methods for PV inverters.

Virtual Oscillators Stabilize Large-Scale Grids with Low-Inertia Controls

Extending NREL’s previous work evaluating virtual oscillator controls (go.usa.gov/xnjn4), with support from SETO, NREL and project partners are developing models of low-inertia power systems to study the dynamics of low-inertia, large-scale grids. Virtual oscillator controls refer to grid stabilization methods that will allow inverters to play a critical role previously performed by synchronous machines. In FY 2018, the team—with project partners from Lawrence Berkeley National Laboratory, Sandia National Laboratories, the University of Washington, and the University of Wisconsin-Madison—focused on developing a comprehensive framework for analyzing the stability of low-inertia grids, specifically characterizing the tipping point of complex grid systems as a function of inverter penetration level. NREL’s work has scoped the behavior of low-inertia grids, providing an analytical foundation for grid-forming inverters entering large power systems.

Ocean Renewable Power Company to Provide More Than 50% of Electricity Needs for Alaskan Village

In partnership with the Ocean Renewable Power Company, Inc., NREL evaluated the performance of the generator and power conversion components of the company’s RivGen Power System. The power system will be deployed in the Kvichak River, Alaska, in Igiugig, whose residents rely on diesel generators as their primary power source. NREL researchers are performing assessments to (1) validate system and component compatibility and (2) test the DC-to-AC power converter in a microgrid configuration, replicating the system’s in-field configuration. The RivGen generator and power conversion equipment will operate in parallel and will be synchronized with diesel generators to supply power to variable loads.

Walmart Improves Energy Savings with Voltage Regulation Device at the ESIF

NREL is helping Walmart evaluate a voltage regulation system that could provide energy savings across its stores. Using the ESIF’s grid simulator and load bank capabilities, engineers are studying how Beovista’s Beolec Mark 5 unit, an autotransformer that regulates voltage independently on each phase, will perform for typical electrical demands in Walmart stores. The researchers are evaluating the device by varying the grid simulator across Walmart’s anticipated range of voltage and power while measuring the Mark 5 unit’s performance. The autotransformer will be useful in reducing, balancing, and regulating incoming electric supply for downstream electrical equipment.
With funding from SETO’s Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE) program, NREL is developing an efficient and scalable means of measuring and controlling rooftop solar and other DERs. The goal of the platform, named GO-Solar, is to do more with less. GO-Solar uses only a few measurement points to produce a short-term forecast of grid conditions. This machine-learned forecast is then used for control. GO-Solar dispatches control outputs to a subset of devices that include both new and legacy DERs.

Together with the Hawaiian Electric Companies (HECO), the GO-Solar development team is demonstrating the control scheme on data from Oahu’s feeders. The team will use PHIL testing in the ESIF to validate hardware before scaling up the simulation to manage more than 1 million test nodes from actual HECO data. This large-scale simulation benefits from both the ESIF’s supercomputing capabilities and the advent of the Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS), a DOE-sponsored, NREL-developed co-simulation platform.

The GO-Solar platform extends beyond utility control of DERs. It can be adapted to work through distributed control or for use by third-party aggregators. The software has also been developed for application in the mainland. It is being tested on realistic power system simulations generated by NREL’s Synthetic Models for Advanced Realistic Testing of Distribution systems and Scenarios (SMART-DS) (go.usa.gov/xPsNj), a tool developed under DOE’s Advanced Research Projects Agency-Energy (ARPA-E): Generating Realistic Information for the Development of Distribution and Transmission Algorithms (GRID DATA) program.

The research, development, and demonstration of GO-Solar is only one example that highlights the success of collaborations among DOE offices, agencies, and consortia, including SETO, GMLC, and ARPA-E.
NREL and San Diego Gas & Electric Company Unlock Grid-Edge Data with Advanced Metering Infrastructure

After investing more than $5 billion to deploy advanced metering infrastructure (AMI), the utility industry is looking to use the resulting data set for operational insights. A surge in DER adoptions is putting new emphasis on AMI infrastructure. In light of these changes, NREL and SDG&E initiated a collaboration to unlock insights from AMI data and apply them to real-time grid operations.

NREL is using the data to develop advanced algorithms to capture important grid parameters, such as phase identification, which will help grid operators with more precise AMI controls. With access to the ESIF’s software tools and hardware-in-the-loop capabilities, the team can effectively model the utility’s distribution circuits to develop and evaluate such algorithms. The algorithms will account for high PV penetration levels in SDG&E’s system.

Following an evaluation of AMI technology, in FY 2019 NREL will provide SDG&E with an accurate simulation of AMI controls, allowing the utility to leverage grid-edge data from smart meters and potentially achieve significant cost and energy savings. The proposed solutions from the data analysis will uncover additional value for utility operations and improve operational efficiencies, such as enabling faster outage recovery times and managing high DER penetrations. With more than 3.6 million customers, SDG&E’s ratepayers stand to benefit from this reuse of AMI data by unlocking increased value from existing infrastructure.

Project Highlight
System Operations, Power Flow, & Control

NREL’s Autonomous Energy Grid Research Looks at Control Solutions for Highly Complex Grids

From home appliances and EVs to PV inverters and energy storage, the number of controllable devices being connected to the grid is skyrocketing. At the current pace, the number could easily reach the hundreds of millions. Although this is great news in terms of making our energy supply more resilient and cleaner, it presents a new challenge: how can we control and optimize a grid with this much complexity?

In comparison, current grid systems—even the largest systems—typically control about 10,000 points. If the number of these devices increases by several orders of magnitude, existing techniques to monitor, control, and optimize them will be inadequate.

To proactively address these challenges, NREL is investigating and realizing the concept of autonomous energy grids (AEGs) (go.usa.gov/xPAtM). This approach takes emerging concepts such as autonomous systems and applies them to electric grids. By focusing on basic research in optimization theory, control theory, big data analytics, and complex system theory, the NREL-led research team aims to develop a flexible planning and operation framework that can keep pace with the complexity of modern grids.

A key aspect of this research is developing mechanisms for distributed grid control and optimization. Unlike current systems that rely on centralized computing platforms for grid control, AEGs could self-organize and control themselves at the grid edge using advanced machine learning and simulation. To do this, AEGs would rely on scalable cellular blocks that are able to act similarly to microgrids, self-optimizing when islanded and participating in optimal operation when interconnected to a larger grid.

In FY 2018, the NREL team developed and tested a number of algorithms that produced advances in the optimization and control of networked systems and significantly reduced the time of the optimization. The team also developed a novel distributed optimization technique called Networked Short-term Forecast (NEST) that has been applied to wind power plants. NEST is able to incorporate measurements from multiple turbines so each individual turbine can get a better estimate of wind direction, leading to better performance. These same techniques can be applied to buildings, grids, and transportation. Finally, this project focused on the preliminary integration of grid, buildings, vehicles, and wind models. During the next 2 years of this project, these models will be scaled to show the limitations of centralized control and the advantages of a hierarchical, highly distributed system that uses distributed optimization.

In addition to the advantages AEGs offer in terms of grid operations, they provide considerable benefits to resilience by eliminating single points of failure in monitoring and controlling the grid. This ensures that system operations are secure against attacks and resilient to outages, contingencies, and natural disasters. This work is funded through NREL’s Laboratory Directed Research and Development (LDRD) program.
Some of the most beautiful and geographically diverse locations in the United States are also marked by extreme weather occurrences, which can create disturbances on the electric grids that supply them with power. Borrego Springs, California, is one of those places. To help address these conditions, SDG&E operates a microgrid there.

NREL is working with SDG&E to better understand how a microgrid controller with advanced technology could perform with the Borrego Springs microgrid. NREL is able to explore this safely at the ESIF, which houses NREL’s megawatt-scale microgrid test platform. The platform allows utilities such as SDG&E to connect their microgrids and run a variety of simulations. This type of research and testing is critical to de-risk the deployment of new grid-connected technologies. It allows utilities and device manufacturers to answer “what if” questions in the context of a connected system with multiple devices rather than looking at single devices in isolation.

As part of its generation mix for this microgrid, SDG&E is able to leverage the 3 MW of rooftop solar in Borrego Springs and a 26 MW array owned and operated by a third party. Longer term, SDG&E’s goal is to transition from generators to a renewable-based microgrid. Part of what NREL is simulating in the test with the Borrego Springs microgrid is the number of DERs, including rooftop PV, for the high-penetration renewable generation environment.

ESIF high-impact projects, like this collaboration between NREL and SDG&E, produce much more than only a road map for a single utility to expand a microgrid. They serve the entire industry and advance important technologies in new ways, generating data and ideas that other researchers can use. Lessons learned from this project have helped establish the first set of IEEE standards around microgrid controller testing and gave the NREL team reassurance for future projects of similar scale.
NREL’s Advanced Distribution Management System Test Bed Provides Utilities with Low-Risk Evaluation

With support from DOE’s Office of Electricity Delivery and Energy Reliability Advanced Grid Research and Development program, NREL researchers are developing a vendor-neutral advanced distribution management system (ADMS) test bed, aiming to accelerate industry adoption of ADMS technologies for the next decade and beyond. The test bed allows NREL and industry partners to evaluate unique ADMS features in a controlled laboratory environment by presenting a realistic model of an electric distribution system that can be interfaced with an ADMS.

The test bed offers a multi-timescale simulation environment that can be interfaced with actual grid-scale hardware. Additionally, the test bed provides integrated data collection and real-time visualization capabilities, allowing researchers to more effectively observe experiments as they are executed and store data for further analysis. Upon completion of the ADMS test bed buildout, NREL will evaluate the impact of improvements to the distribution system model data for Xcel Energy’s ADMS on the effectiveness of the ADMS’s volt/volt-ampere reactive (VAR) optimization (VVO) application. The data will inform Xcel and other utilities on the level of accuracy that is required of models to achieve an optimal trade-off between VVO application performance and costs for model improvement.

This investment in NREL’s ADMS test bed is now being applied to other NREL projects, such as the SETO-funded ENERGISE Enhanced Control and Optimization of Integrated Distributed Energy Applications (ECO-IDEA) project, a collaboration among NREL, Schneider Electric, Varentec, the Electric Power Research Institute, and Xcel Energy. The NREL-led team will leverage the ADMS test bed to develop, validate, and deploy a hierarchal architecture wherein a fast-acting layer of control can interact with a centralized ADMS system to manage their distribution networks.

Holy Cross Energy and NREL Grid Study Brings Big Results to Smaller Utilities

HCE and NREL are working with ADMS developer SurvalentONE, the National Rural Electric Cooperative Association (NRECA), and Heila Technologies to empower distribution management systems (DMS) and DER management systems (DERMS) for rural cooperatives and municipally owned utilities. The study leverages support from DOE’s ARPA E, EERE, and the Advanced Grid Research and Development program within DOE’s Office of Electricity.

A major outcome of the work will be new control paradigms and business models for managing the millions of DERs that are entering the grid. The spread of technologies—from rooftop solar and batteries to smart appliances and EVs—can be used as assets toward energy resilience and reliability for both large and small utilities across the country. This work shows how HCE can optimize its operation of these technologies using NREL’s real-time optimal power flow (DERMS) control and SurvalentONE’s supervisory control and data acquisition system and AMI.

Much of the research is taking place in NREL’s ADMS test bed, where real data from HCE’s grid is being used to test algorithms and communications protocols such as NRECA’s MultiSpeak. NREL researchers will use hardware-in-the-loop testing at the ESIF to demonstrate advanced control of DERs. By building on common tools from SurvalentONE and NRECA, this project will become a useful example for cooperatives and municipal utilities, paving the way for non-wires alternatives for utilities to better manage their distribution networks.

NREL Lab-Directed Project Develops Approach to Optimize Multi-Energy Systems

Through NREL’s LDRD program, researchers have designed a new approach to managing multi-energy systems that considers power, water, and district heating systems—traditionally planned and operated separately—in a way that intelligently couples their operation and creates a roadmap for optimal use. In general, joint optimization of multiple systems is largely unexplored, but the researchers took a close look at a variety of challenges associated with this approach and formalized an optimal power-water-heating system (OPWHF) problem. This OPWHF problem ensures that controllable assets across the power, water, and heating systems are working together and in the most efficient way possible. For example, tanks and pumps are optimally managed to satisfy water demand while improving electric grid operations; and for the power network, an AC optimal power flow formulation is augmented to accommodate the controllability of water pumps and combined heat and power (CHP) plants.

Results show that this approach to optimizing multiple systems across a district can save significantly more energy and reduce operational costs of the interconnected multi-energy system as a whole than the separate operation of each network.
Project Spotlight

ARPA-E Projects Look at New Frameworks to Optimize Control of Distributed Energy Resources

Throughout FY 2018, NREL continued its contributions to DOE’s ARPA-E program Network Optimized Distributed Energy Systems (NODES). NREL is leading one project—Real-Time Optimization and Control of Next-Generation Distribution Infrastructure—to develop a comprehensive distribution management framework that dynamically controls DER operations in accordance with network-wide energy management and forecasts. The control architecture will use real-time feedback control to continuously steer voltages toward optimal operating points while procuring and dispatching synthetic reserves based on current system states and forecasts. This framework is being developed with support from the California Institute of Technology, the University of Minnesota, Harvard University, and Southern California Edison.

A second project, Enabling the Grid of the Future, is being led by the University of Minnesota with support from NREL, the University of Illinois, Dynapower, and the University of Tennessee. The research team is designing and implementing an advanced control framework that enables the coordinated response from many local units to adjust consumption and generation of energy, satisfy physical constraints, and provide ancillary services requested by a grid operator.

Both projects are leveraging the ESIF’s real-time PHIL simulation capabilities as well as HPC to validate and demonstrate the novel control technology. NREL researchers have successfully demonstrated the benefits of the developed control solutions using up to 30 physical DERs and embedded controllers connected at power to a simulated real-world power distribution grid. In FY 2019, the NREL team will conduct an additional large-scale demonstration, with more than 100 powered DERs and flexible loads. NREL’s NODES research will result in a more reliable and resilient grid, protecting U.S. businesses from costly power outages and brownouts.

Project Highlights

NREL and Columbia University Study Grid Forecasting in Lab-Directed Research

Columbia University and NREL have begun a 2-year collaboration to advance the foundations of estimation and forecasting in networked systems. The research is centered on developing scalable algorithms for estimating and forecasting grid operations for real-time grid control. Both projects are leveraging the ESIF’s real-time PHIL simulation capabilities as well as HPC to validate and demonstrate the novel control technology. NREL researchers have successfully demonstrated the benefits of the developed control solutions using up to 30 physical DERs and embedded controllers connected at power to a simulated real-world power distribution grid. In FY 2019, the NREL team will conduct an additional large-scale demonstration, with more than 100 powered DERs and flexible loads. NREL’s NODES research will result in a more reliable and resilient grid, protecting U.S. businesses from costly power outages and brownouts.
Project Highlights

New Approach to Power Systems Operations and Controls Boosts Collaboration Across National Labs

NREL is collaborating with five other national laboratories on the GMLC project, multi-scale integration of control systems, to create an integrated grid management framework to allow transmission, distribution, and building-level control systems to work together seamlessly. The project will develop and demonstrate an open framework to coordinate EMS, DMS, and building management system (BMS) operations. As part of this project, NREL researchers successfully integrated a DMS at NREL with an EMS and BMS at the PNNL. Working closely with PNNL, the team defined the communications structure for the EMS-BMS-DMS link and tested the information exchange among the systems. New applications will also be added that would transform or extend the EMS and BMS capabilities, such as probabilistic risk-based operations, forecasting data integration, and decision support.

Reducing Barriers for Advanced Distribution Management Systems: GridAPPS-D Contributes Platform for Application Development

Within a utility’s ADMS, there is a need for preconfigured applications that manage data- and device-rich distribution grids. As part of the GMLC, DOE’s Office of Electricity is supporting NREL and PNNL in developing an open-source, standards-based ADMS application development platform. The platform, GridAPPS-D, is similar to an operating system for a mobile phone: it allows developers to create applications and deploy them with minimal customization. In FY 2018, the GridAPPS-D development team created ADMS applications for the optimal energy dispatch of DERs, short-term grid forecasting, and solar forecasting. The development platform will shift ADMS costs away from integration efforts and will free utilities to focus on functions that provide the utility with quantifiable benefits.

Microgrid Control Work Informs Industry Standards

Behind the curtains of microgrid operation lie its control systems, autonomously dispatching DERs—including diesel and natural gas generators, PV systems, wind turbines, storage devices, and controllable loads—to meet the objectives of the microgrid. The control system also determines when and how to disconnect from and reconnect to the grid to provide the most affordable and reliable power possible to microgrid customers, even when the larger grid is down. As a result of NREL’s work with SDG&E for their microgrid in Borrego Springs and a competitive procurement for a microgrid controller at the EDI, NREL is developing control algorithms and evaluating industry controllers within NREL’s microgrid research test bed. NREL also participated in standardization efforts for microgrid controllers, including IEEE standards 2030.7 and 2030.8, which define the functions of microgrid controllers and the method for evaluating them, respectively.
As part of the GMLC project to develop integrated transmission, distribution, and communications models, NREL researchers worked as part of a tight-knit development team with PNNL, Lawrence Livermore Laboratory, and other national labs to debut a powerful grid modernization software named HELICS (bit.ly/2P1S8eU).

HELICS is an HPC framework for linking multiple off-the-shelf simulation tools to act as a single unified model, exchanging data at each time step. It is open source (github.com/GMLC-TDC/HELICS-src), cross-platform, and scalable from laptop to HPC environments. Its support for combining cyber (e.g., communications, control) and physical domains of energy systems provides a modular platform for simulations not previously possible, such as bringing together multi-energy systems simulations from buildings, grid, transportation, and water or testing the performance and scalability of novel autonomous energy system controllers, algorithms, and architectures. Other use cases include large-scale integrated transmission-distribution simulation and cybersecurity and resilience evaluation.

Several projects have already benefited from the technology, including those from collaborations across the national lab network as well as from industry. For example, the NREL-HECO GO-Solar project leverages the unique capabilities of HELICS to validate the performance and scalability of novel algorithms for monitoring and controlling high-solar grids. The GO-Solar simulation includes a high-fidelity electric model of the entire island of Oahu from the level of bulk generation and transmission, through every distribution feeder, down to individual customers, collectively representing more than 1 million electrical nodes. At the same time, HELICS is providing the project team with early-stage, systems-level cybersecurity evaluation. This provides the ability to address cybersecurity concerns early on, resulting in design improvements for increased energy resilience.

HELICS will also be used to simulate the integrated transmission-distribution system for millions of customers as part of NREL’s collaboration with the Los Angeles Department of Water and Power, which aims to help the utility meet their renewable energy targets. Further, the software is being used to support the SETO-funded Artificial Intelligence Driven Smart Community Control project, enabling researchers to validate a foreseen-based solar, building, and storage controller prior to deployment.

The technology is an exciting development that enables high-performance co-simulation to combine best-in-class tools for breakthrough energy systems integration analysis, design, simulation, validation, and testing.
NREL and Sacramento Utility Optimize Solar Photovoltaic Interconnection with PRECISE

A platform developed by NREL and SMUD is enabling the autonomous operation of distributed energy from advanced inverters, allowing utilities to maximize the cost-effective use of installed solar systems. The tool, PRECISE (go.usa.gov/xPs5s), is a technology that evolved from NREL’s high-impact project work with HECO, which was inspired by the surge in customer interest to connect home-installed solar to Hawaii’s grid.

Likely HECO, in 2016 SMUD began to see a surplus in PV interconnection applications from residents in Sacramento, challenging the utility’s ability to respond to each request quickly while considering voltage control and grid reliability. During this time, NREL researchers began to explore the idea of preconfiguring advanced inverters based on residents’ locations, clusters, and seasonal weather patterns.

With support from SMUD, in FY 2018 NREL developed a real-time operation platform that allows distribution utilities to optimize the many DERs that are now running smoothly among the islands.

Learn more by reading the article on our work with HECO in Solar Today (bit.ly/2Oe8B7).
Project Highlights

NREL and Sumitomo Assess Benefits and Value Streams of Utility-Scale Storage with Vanadium Redox Flow Battery

In FY 2018, NREL initiated research to identify value streams offered from a utility-scale vanadium redox flow battery at a substation with high PV penetration. In collaboration with Japanese manufacturer Sumitomo Electric, NREL studied the energy storage system’s economic benefits to the distribution grid in the form of energy arbitrage, voltage support, and peak shaving. SDG&E contributed feeder data to the collaboration where the battery is physically located, and the distribution feeder model was used to accurately identify value streams from the utility-scale battery energy storage system. Following its simulated performance, the vanadium redox flow battery was deployed for field-testing on SDG&E’s host feeder. Using NREL’s Renewable Energy Integration and Optimization (REopt™) software (reopt.nrel.gov), researchers identified value streams for the vanadium redox flow energy storage system. The research will help utilities better understand the value streams of energy storage from local grid use as well as the charging and discharging requirements for a large-scale storage system at the substation level.

Researchers Generate Realistic, Synthetic Data Sets for Innovation in Power System Studies

Future innovation in the electric power industry depends on restricted data because real distribution system data are often unavailable to researchers as a result of security and privacy concerns. A DOE ARPA-E project is hoping to remedy that with the introduction of synthetic grid models, which are realistic but not real models that mimic actual grid characteristics. For NREL’s part, a 3-year award has allowed researchers to contribute multiscale distribution models that are adapted to U.S. utilities and based on data from a range of utility partners.

In its second year of the ARPA-E project, NREL built on Comillas’s Institute for Research in Technology Reference Network Model to produce SMART-DS (go.usa.gov/xPsNj): electric grid models of real cities that account for real geography and realistically depict future grid systems in those cities. The NREL team has also integrated customizable scenarios into the models so that researchers can accurately test advanced algorithms and control architectures. These data building tools account for unknown factors affecting the grid, such as future generation technologies, increased DERs, varying electrical loads, and disruptions caused by weather.

The first models from SMART-DS are already available in the project’s repository (bettergrids.org), and the project team—with support from the Massachusetts Institute of Technology, CYME International, and Electrical Distribution Design—has already gone beyond its original commitment by developing supporting software tools, such as a conversion tool to switch between popular distribution system software tool formats.
NREL is investigating how the security and resilience of the electric power system can be measured, evaluated, and visualized to help utilities, government agencies, and communities prepare for a variety of potential scenarios. With support from laboratory-directed funding, researchers are developing a decision support tool that incorporates value metrics and use case modeling to optimize the cost, security, and resilience of energy systems.

The project is one of several new research efforts included within NREL’s Energy Security and Resilience program, which focuses on improving the security and resilience in systems that employ advanced energy technologies, configurations, and business models. In developing resilience metrics, researchers considered the temporal evolution of disruptive events—from both cyber and physical disruptions—and how different event types are distinguished. By combining these metrics with data from historical outages and showing what individuals are willing and able to pay for resilience planning, the team developed a framework to determine economic asset losses over time after an unpredictable event. Using these metrics, the team developed an integrated simulation model to evaluate adaptable and scalable energy system architectures, including power, communications, and market layers. The model allows researchers to modify test scenarios for various system types and scales while isolating variables.

The team is now visualizing results of the model in 3-D to explore the costs and benefits of different energy systems and control architectures. With further evaluation and analysis still underway, this capability will allow researchers to demonstrate security and resilience performance as well as the interdependencies among power systems, cost structures, and communications flows in an immersive 3-D environment. The team hopes to provide campuses, cities, island communities, and regions with an effective tool to help make informed decisions about technology and cost trade-offs for more secure and reliable energy systems.
Fast, Secure, Peer-to-Peer: NREL and BlockCypher Demonstrate Autonomous Energy Exchange with Blockchain Technology

NREL researchers have successfully demonstrated a secure, peer-to-peer energy market with blockchain technology. In partnership with blockchain Web services provider BlockCypher, researchers at NREL have applied the disruptive and decentralizing technology to energy markets, demonstrating the viability of two homes participating in an autonomous energy exchange.

In the project's preliminary demonstration, two homes with real residential loads were emulated in the ESIF’s Systems Performance Laboratory. Each home’s energy use was managed by NREL’s foresee software, which directed the purchase and sale of energy according to a predetermined contract established on a blockchain network, facilitated by BlockCypher. A blockchain energy market carries the hope of near-instantaneous transactions and more accurate price signaling, and it will leverage underused DERs for more flexible load shifting. The work fits into a broader vision of transactive energy in which energy is exchanged dynamically and efficiently between energy producers and consumers.

NREL’s early demonstration of peer-to-peer energy exchanges has gained enough momentum to fund future work in the blockchain energy space. The development team will look to scale up their work to a distribution grid, determining how such a market can contribute to resilience and cybersecurity.

Project Highlights

Visualizing Energy Resilience for U.S. Military Bases

In collaboration with the U.S. Department of Defense, NREL researchers modeled a power system and communications system in 3-D to visualize the systems’ interdependencies for a military base, leveraging the ESIF’s Insight Center capabilities. Researchers simulated several backup energy system architectures, including backup diesel generators for specific buildings and a microgrid. The NREL team evaluated the survivability and cost of each energy architecture as well as how failures in the power system could impact the communications system. Future work will also evaluate impacts on the water system. Researchers are using the results from this study to inform decision-makers as they determine how to improve energy resilience and prioritize resilience investments for military bases across the country.

Site Security Assessments Lead to Development of New NREL Cybersecurity Evaluation Tool

Researchers with NREL’s cybersecurity group have conducted more than 23 security site assessments for utility partners, providing each with a score that reflects cybersecurity posture based on both the National Institute of Standards and Technology cybersecurity framework and DOE’s Cybersecurity Maturity Model framework. NREL’s ongoing work in site security assessments provides utility partners with a detailed analysis of policies and business processes that can be strengthened to improve cybersecurity. In FY 2018, the team’s success in this work led to a Federal Energy Management Program award to further expand NREL’s assessment tool and create a new cybersecurity framework specifically to evaluate the cybersecurity posture of DER technologies. The development of this tool is a first step toward evaluating real DER hardware and its security from potential cyberattacks.

Watch: By understanding how to secure today’s electric grid, researchers at NREL are working to design and secure the grid of the future. Watch this video (bit.ly/2Qk9QPj) to hear from NREL’s Juan Torres on his vision for cybersecurity research at NREL.

Watch: NREL, in partnership with BlockCypher, has laid the groundwork to help make peer-to-peer energy transactions possible. See how this technology (bit.ly/2r5PHhO) leans on NREL-developed foresee, an innovative user-centric home energy management system.
Institutional Support

Peña Station NEXT Project Visualizes a Zero Energy Campus, Informs Rate Design

NREL, Panasonic, and Xcel Energy are collaborating on a project to enable the least-cost and most scalable zero-energy infrastructure development in the United States. The transit-oriented Peña Station NEXT district in Denver, Colorado, will feature a microgrid on the zero energy campus. The 400-acre zero energy district includes storage, building, and transportation technologies working together with what will be Denver’s first microgrid, located along the city’s light-rail route.

With funding from DOE’s Vehicles Technologies Office, in FY 2018 the research team implemented mobility into this project to better understand impacts on the grid. The new analyses considered scenarios in which 50% of vehicles are electric, increasing peak demand by 40% more than that of existing buildings. More than 7,000 node hours of HPC computations were used in evaluating 2,500 different power system design scenarios with EV loads. NREL researchers implemented a new modeling approach using EVI-Pro with travel profile data to build representative loads that were modeled as part of 100 individual buildings on the campus using UrbanOpt. Likewise, researchers used OpenDSS to understand power systems operations driven by UrbanOpt-generated loads and the forecasted solar production.

NREL’s simulation results shed light on the value of EV charging algorithms to align with local generation and reduce the number of grid voltage violations that a distribution circuit would encounter. The project demonstrates that intelligent charging approaches can enhance grid operations. In addition, the team identified opportunities to reduce PV curtailment by 80% and voltage violations by 65% in a zero energy design scenario that includes 50% EVs versus another scenario without EVs. A key outcome resulted in NREL’s collection of load-shaping scenarios and fast-charge load shapes that can be integrated into future grid impact analyses.

Peña Station NEXT will model the interaction of the district with the grid under a variety of load and power flow scenarios using a range of technologies, including varied solar PV penetration levels, energy-efficiency scenarios, DER storage capacities, and district heating and cooling. Xcel Energy plans to verify the feasibility of these distribution system models, and Panasonic will perform cost-benefit analyses. Analysis from this project will be used to inform the Colorado Public Utilities Commission to determine the optimal rate design for the Peña Station NEXT district.

Watch: NREL researchers are using advanced modeling and visualization tools to help create the planned zero energy district Peña Station NEXT. See it here: bit.ly/2TI55Q6.
H2@Scale Partnerships Accelerate Hydrogen Production, Infrastructure Technology Advancements

NREL is working with multiple industry partners through competitively selected H2@Scale projects (go.usa.gov/xPHtd) to accelerate the development of affordable technologies for the wide-scale production and use of hydrogen. These partners, which range from small businesses to large corporations, are leveraging NREL’s unique capabilities and expertise to address key early-stage research and development (R&D) challenges in a number of areas, including hydrogen infrastructure, low-temperature electrolysis, and energy storage.

Partners including Honda, RIX Industries, Shell, Tatsuno, and a consortium of California agencies are using experimental capabilities at the ESIF to develop and validate new hydrogen compression and cooling strategies; identify component failures and fixes through accelerated life testing; improve the accuracy of hydrogen metering devices under real-world conditions; and develop hydrogen station innovations for light-, medium-, and heavy-duty fueling. NREL is also working with Frontier Energy to use data generated at the ESIF to develop a hydrogen systems fueling model that can be used by industry to understand and improve hydrogen station reliability, capacity, and performance.

Other H2@Scale partners are working with NREL to research and validate electrolyzer systems at both small and large scales. For example, Giner ELX is using NREL’s large electrolyzer stack test platform to validate the stack efficiency, membrane lifetime, catalyst performance, and cell component durability of its megawatt-scale electrolyzer stack, and GTA is using NREL’s lab-scale in situ electrolysis cell test capabilities to benchmark the performance of its low-temperature water electrolysis system.
Since the project's inception, in 2014, Southern California Gas Company (SoCalGas) and Electrochaea GmbH have worked with NREL to design, fabricate, and commission a first-of-its-kind, pressurized, power-to-gas, electrolytic hydrogen biomethanogenesis system. The two-step process uses low-cost or otherwise curtailed renewable electricity to produce hydrogen, which can be used, stored, or further converted to renewable natural gas. Step two in the conversion process is achieved in a bioreactor that houses microorganisms that consume hydrogen and carbon dioxide. These single-celled microbes (archaea) efficiently convert these gases into methane while producing heat. With minor filtration and dehydration, the methane meets pipeline quality standards and can be injected into existing natural gas infrastructure.

In FY 2018, DOE's Bioenergy Technologies Office provided additional funding to examine this biomethanation technology using biogas sources, such as those from wastewater treatment plants or dairy farms, instead of pure carbon dioxide. Such gas streams primarily comprise methane and carbon dioxide; if the gases are bubbled through the bioreactor with hydrogen, the organisms will convert the carbon dioxide to methane and result in a very high (> 98%) final methane concentration. With the new funding, NREL is also developing a small-scale, mobile version of the pressurized SoCalGas bioreactor to allow researchers to operate the biomethanation system with actual biogas sources from California to New York City. This will shed light on how robust the process is in converting a variety of waste streams to methane under conditions that change with location and season.

Additionally, in 2018 the team commissioned the system and produced the first molecules of methane in the 700-L, 18-bar bioreactor outside the ESIF. The goal of this effort is to improve the cost and integration of the electrolyzer and bioreactor—an advancement that could accelerate market acceptance and deployment of the long-duration, grid-scale energy storage process. Electrolytic hydrogen based energy storage could enable increased penetrations of variable generation and grid stability issues while providing high-value hydrogen. Initial results from both analysis and hardware experiments show that at high renewable penetration levels, a network of electrolyzers in a distribution circuit can reduce power fluctuations by about 65%, use 4.74 MWh of renewable energy that would have otherwise been curtailed, and reduce the number of voltage violations by 48%–65% for a sample day.

NREL is collaborating with HyET Hydrogen to develop membrane electrode assembly (MEA) manufacturing automation technology for electrochemical hydrogen compression (EHC). EHC has the potential to replace mechanical compression in some hydrogen end-use applications, but the high-pressure conditions require specialized MEAs that have been fabricated only at the lab scale. The team is using roll-to-roll equipment and unique metrology test beds to develop new inks and roll-to-roll coatings of EHC electrodes. NREL is also working with HyET to develop real-time inspection techniques to detect defects and measure uniformity of EHC membranes and electrodes during high-volume manufacturing.

As part of the HydroGEn Advanced Water Splitting Materials consortium, NREL provides capabilities and expertise to help industry and academic partners accelerate advanced water splitting materials R&D. Through a collaboration with Proton Onsite (now Nel Hydrogen), NREL is providing catalyst and membrane characterization, electrode ink development, and alternative methods to manufacture and inspect low-temperature electrolysis materials. Using NREL's on-site electrolysis cell characterization capabilities, Proton demonstrated that its high-activity catalyst exceeded DOE's near-term performance targets and is on a path toward meeting the ultimate efficiency and cost goals.
As part of Eaton Corporation’s extended collaboration with NREL, the project teams are evaluating control strategies for managing medium- and heavy-duty EV fleets for grid services. Coordinated control of electrified fleets with other DER technologies will result in cost savings for the fleet owner, operational benefits for the utility, and scalable insights into how new grid devices can support each other. Eaton and NREL have launched a high-impact project to understand these benefits by developing a co-optimization platform for integrating e-mobility with other DER technologies.

Researchers are performing analyses to identify grid services and the U.S. regions where these services will yield the most benefit. To date, the team has identified three scenarios that represent varied use of the EV fleet being evaluated. A transportation use analysis will help yield realistic transportation and battery use profiles, enabling researchers to develop real-time control strategies for the use profiles, such as maximum benefit or maximum battery life-cycle strategies. The control strategies will then be evaluated under realistic scenarios with hardware-in-the-loop simulations at the ESIF, using Eaton’s Power Xpert Energy Optimizer (PXEO) controller within the developed platform. The team has so far completed an integration demonstration of the PXEO controller while interacting with a simulated school site in real-time. The simulation results will be used in techno-economic comparisons of the control strategies.

This project leverages tools that were developed by NREL, including REopt (reopt.nrel.gov), Battery Lifetime Analysis and Simulation Tool (BLAST) (go.usa.gov/xPsnE), Electric Vehicle Infrastructure Projection Tool (EVI-Pro) (go.usa.gov/xPsnw), and PVWatts (pvwatts.nrel.gov), among others. As a result of this project, these tools have been upgraded to include mobility as an additional type of DER, enabling even more nuanced simulation capabilities for future research.

Eaton and NREL are also working closely with an industry advisory board, representing stakeholders that span a variety of expertise—including utilities, fleet owners, vehicle original equipment manufacturers, and consultants—to engage in broad discussions on the challenges associated with fleet integration. The collaboration concerns an important and upcoming line of work: how can co-optimized energy devices support each other and the grid? The end product of this work, a framework for co-optimizing mobility with other DER technologies, will have crosscutting impact, with applications to mobility, storage, PV, and building technologies.
New Science of Safety Facility Supports Comprehensive Evaluation of Advanced Battery Chemistries

The next generation of Lithium-ion batteries includes new chemistries and increased size to meet the demands of longer range for vehicles and increased penetrations of power packs for stationary applications. With an increase in energy density for these advanced battery chemistries (e.g., with the use of lithium metal anodes or sulfur cathodes), there is also a need to effectively understand their safety. The most effective way to meet this challenge is through basic research that combines theoretical tools and advanced characterization tools to study batteries under complex abuse scenarios. This includes research into capabilities to simultaneously track the thermal, mechanical, electrochemical, and chemical response of multiple components within a battery cell under a variety of abuse scenarios, including overcharge, nail penetration, mechanical crush, and storage at extreme temperatures.

A new Science of Safety Facility located in the Materials Characterization Laboratory at the ESIF bridges a long-standing gap between NREL’s world-class computational models and the niche space of the thermal evaluation of batteries that NREL is known for within DOE’s Vehicle Technologies Office portfolio. This will enable further abuse characterization by integrating comprehensive, real-time, multiscale, multidomain models with state-of-the-art experimental characterization capabilities.

This facility integrates NREL’s HPC capabilities with state-of-the-art characterization tools to facilitate studies of multiple failure modes across multiple lengths and timescales. These integrated capabilities will enable the evaluation of the fundamental phenomena governing battery safety in both conventional and previously unexplored cell architectures; support several DOE programs, including SEISta and XFC; and enhance engagement with industry.

Project Highlights

State-of-the-Art Computed Tomography Scanner Offers High-Precision, Nondestructive Analysis for Fuel Cells, Batteries, and Power Electronics

The ESIF became 5 tons heavier after a cutting-edge, industrial computed tomography scanner from North Star Imaging was delivered to the Materials Characterization Laboratory on the third floor. Acquired through General Purpose Investment funding from DOE, it serves applications across the lab, including energy storage, power electronics, PV, hydrogen, basic sciences, and beyond.

The new capability allows for nondestructive, high-precision, and high-speed analysis capabilities and is critical for assessing the performance degradation of fuel cells, batteries, power electronics, and other devices. The system can be configured to scan for defects on the single-micron level, and it can also completely inspect a battery module or a solar panel with a single scan. It has already been used to detect defective bypass diodes for solar panels and formation voids in hydrogen flow fields as well as for quality inspection of interfaces in power electronics and lithium-ion batteries.

NREL Establishes Remote Communications Link with Argonne National Laboratory for Electric Vehicle Charging

Using Mosquito software, NREL deployed a Message Queuing Telemetry Transport (MQTT) client on a control computer located on the EV supply equipment setup to allow for communications to Argonne National Laboratory’s (ANL) MQTT broker. The team successfully demonstrated basic communications to the MQTT broker to publish and subscribe to a test topic setup by ANL and determined that an average latency for the round-trip communications to and from the ANL MQTT broker is about 500 ms.

High-Performance Computing and Data-Driven Analytics Deliver Rich Visualizations of Travel Behavior for 76 Million Trips

As part of the Technologist-in-City initiative with Smart Columbus and in collaboration with the Ohio Department of Transportation, NREL’s mobility systems team employed the ESIF’s HPC and advanced analytical capabilities to visualize travel behavior from a real-world data set comprising more than 76 million trips. The resulting heat map—nicknamed the Buckeye Blaze—reflects travel patterns in Columbus, Ohio, based on millions of individual trip records. Because the large size of the data set made normal computer processing unwieldy, the team used the Spark Big Data Analysis Cluster, which enables the efficient analysis of massive data sets. This resource—which contains 48 nodes with 40 cores, 43 terabytes of storage, and 250 gigabytes of RAM per node—supplements the Eagle and Peregrine supercomputers for dedicated, data-driven analytics. Spark ran the necessary queries for the heat map in a matter of seconds, delivering rich visualizations of travel behavior and prompting ongoing collaboration among transportation researchers and HPC experts.
High Performance Computing & Visualization

Project Spotlight

The Eagle Has Landed: NREL Welcomes New, More Powerful High-Performance Computing System

In January 2019, NREL will put into production its new, more powerful supercomputer, Eagle. HPCs, such as Eagle, allow researchers to run increasingly detailed models that simulate complex processes, systems, and phenomena, enabling the researchers to gain new insights and drive innovations in energy-efficiency and renewable energy technologies.

The Hewlett Packard Enterprise supercomputer includes the latest Intel Xeon processors and boasts a peak performance of 8.0 petaflops, meaning it can carry out 8 million-billion calculations per second. This equates to an approximately threefold increase in the amount of scientific computing capability relative to Peregrine, NREL’s current supercomputer.
Thermosyphon Dry-Cooling Technology Keeps Data Center Cool with 50% Less Water

NREL’s new supercomputer, Eagle, is warm-water, liquid-cooled and generates a great deal of heat. To manage this heat, the Computational Science Center routes water through multiple loops that are designed to capture, reuse, and otherwise dissipate heat. One loop terminates at a bank of evaporative coolers. The center decided to use evaporative coolers instead of chillers because they are energy efficient and less expensive. These evaporative coolers, mounted to the roof of the data center, eject waste heat, but because they evaporate water, this method is not very water-efficient. To rectify this, the center, in collaboration with Sandia National Laboratories and key input from Johnson Controls—the thermosyphon developer—turned to the thermosyphon dry-cooling system.

The NREL thermosyphon dry cooler, the first of its kind installed in a data center, cut water usage by 50%. It works by modulating between evaporative cooling when necessary and dry cooling when weather conditions are conducive to the process. Air-cooled heat exchangers, such as the thermosyphon, make use of ambient air to cool liquid of a higher temperature.

In 2018, DOE awarded NREL and project partners Sandia National Laboratories and Johnson Controls with Federal Energy and Water Management Awards. Annually, these Federal Energy Management Program awards recognize individuals and organizations that have made significant contributions to energy and water efficiency within the federal government.

Water is not relatively expensive, but it is not readily available in every environment. As a result, improving water efficiency in data centers is important to sustainability. NREL has taken the lead in this area, and its groundbreaking work is paving the way for others to follow suit.

Data Center Showcases Sustainability and Demonstrates Hydrogen Fuel Cell

NREL’s ESIF has tested a Daimler AG Mercedes-Benz, 65-kW hydrogen fuel cell, which will move into the data center to provide power directly to the two racks of information technology equipment. Daimler, in addition to NREL, collaborated with Hewlett Packard Enterprise and Power Innovations to make use of its automotive fuel cells in nontransportation sectors. Fuel cells provide resilience and can serve as either the primary or backup energy supply for the data center.

NREL Unlocks Insights from City Data with Visualization Platforms

Seventy percent of all energy is consumed in cities globally, emphasizing the need for resources to help cities make strategic energy decisions. Cities Leading through Energy Analysis and Planning (Cities-LEAP) (go.usa.gov/xPsQm), a project supported by DOE’s Office of Strategic Programs, investigated how cities are currently using data, revealing that many lack access to energy data and that most lack the sophistication to analyze it. During the past 4 years, Cities-LEAP developed a city energy profile with 15 data sets for every U.S. city. By multiple accounts, this new data set is the best available, but it still lacked a representation to help cities comprehensively understand their energy use when compared to other cities. Through the Advanced Energy Systems Design initiative, NREL researchers used the HPC Data Center to synthesize the 15 data sets, representing data for more than 23,400 U.S. cities. NREL’s visualization team then created platforms to help cities navigate the data: a 2-D dashboard approach allows cities to be compared on a range of metrics; and the 3-D visualization in the ESIF’s Insight Center further extends flexibility in viewing correlations, trends, and stratification in the data.
**Engineering Low-Cost Magnesium for Lightweight Vehicles**

NREL is modeling how magnesium behaves at the atomic scale to determine how to make rollable sheets for the auto industry. The work involves quantum-mechanics-based simulations to understand how magnesium deforms and how it changes in different chemistries. NREL researchers are leveraging the power of HPC to examine plastic deformation and inform changes in composition. The data are being used not only to inform the broader project but also could be used for future modeling. Industry can use NREL data in finite-element modeling to investigate how this sheet metal will perform.

**Improving Wind Farm Controls**

NREL is using HPC to model the wake interactions in wind farms, or how air flows through turbines and affects performance. The modeling focuses on wake steering, a form of wind control in which an upstream turbine intentionally offsets its yaw angle to generate a deflection in its wake away from downstream turbines and improve wind farm performance. The models allow researchers to adjust turbine controls to determine how an upstream turbine can minimize wake losses downstream and produce better overall power. The research aims to reduce the cost of wind energy by producing more wind farm energy from the same capital investment.

**Informing Optimal Pathways for Renewable Integration**

In FY 2018, NREL researchers used the Resource Planning Model—an optimization model that helps inform investment decisions for conventional energy, distributed energy, and storage—to run a set of forward-looking scenarios with high PV penetrations. The results from the model are being used to probe ways in which current planning methods fall short when it comes to PV penetration. Examples could include regions that are overbuilt or underbuilt from a peak demand perspective or where ramping needs could be more sufficiently captured and subsequently met by the planned build-out. Researchers are working to publish the FY 2018 results to help city planners improve their planning tools and better manage high PV penetration scenarios. The City of Los Angeles is currently using the model with technical assistance from NREL to examine pathways to reach its renewable energy goals.

---

<table>
<thead>
<tr>
<th>AY 18 Nov  Dec  Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Usage Effectiveness</td>
</tr>
<tr>
<td>1.037 1.030 1.032 1.032 1.030 1.030 1.039 1.030 1.033 1.041 1.043 1.041 1.034</td>
</tr>
</tbody>
</table>

The ESIF’s HPC Data Center averaged a power usage effectiveness rate of 1.037, more than achieving the target of 1.1.
ESIF Laboratories Updates & Advanced Capabilities

ESIF Operations Demonstrate Continued Dedication to Safety, Quality, and Customer Service

The ESIF demonstrated leadership in environmental, safety, health, and quality (EHS&Q) with best-in-class results for FY 2018. The facility continues to hold accreditations for environmental (International Organization for Standardization [ISO] 4001), safety and health (Occupational Health and Safety Assessment Series 18001), and quality (9001). The ESIF’s workflow processes were recognized as strengths and best practices, demonstrating an ongoing commitment to safety, quality, and customer service through continuous improvement and excellent performance. The ISO 9001:2015 audit during FY 2018 transitioned the EHS&Q procedures from system-based to process-based, increasing efficiencies and reducing redundancy for staff and users. The ESIF team was recognized for outstanding performance in engineering design processes for research equipment during the FY 2018 audit.
Microturbines at the ESIF Expand Integration Research

The ESIF has acquired two C-200S Capstone Turbine Corporation microturbines with CHP that will be connected to and available for integration experimentation at the ESIF. These microturbines have inverters to interface with the electric grid, allowing versatile grid support services such as voltage and frequency support. The units can run in parallel with a healthy grid, or they can be disconnected to create their own local, independent power system. The units are outfitted with advanced control and communications interfaces, allowing researchers to leverage them for a variety of applications in advanced microgrids, autonomous energy grids, CHP applications, and grid support functions.

GHOST Model Sets New Standard for Microgrid Controller Evaluation

NREL has set a new standard for microgrid evaluation with the release of the Grid Hardware Open-Source Test Bed (GHOST), the highest fidelity model available for microgrid testing. GHOST enables users to test and quantify a controller’s performance across multiple criteria, reflecting realistic performance trade-offs in categories such as economic operation, resilience, and reliability.

GHOST is the product of NREL’s Microgrid Controller Procurement Program (go.usa.gov/xPsQv), which used GHOST’s test sequences to select a top-performing microgrid controller for the laboratory’s expanded microgrid test bed. GHOST’s criteria for evaluation was informed by professionals in the microgrid domain and was trialed on commercially available controllers. The GHOST model represents an important step toward standardizing the testing of microgrid controllers, helping to bring consensus to a fast-moving technology.

ESIF Expands Fabrication and Testing Capabilities for Electrolyzer and Fuel Cell Materials

NREL developed new fabrication and testing capabilities for fuel cells and electrolyzers, including advancing roll-to-roll processing techniques, developing electrolysis test stations and advancing segmented cell test capabilities, upgrading fuel cell test stations, and developing high-throughput membrane conductivity characterization.

Infrastructure Capabilities Exceed State-of-the-Art Gaseous Capabilities

New hydrogen infrastructure capabilities supporting R&D funded by both DOE’s Fuel Cell Technologies Office (FCTO) and industry:

• The addition of dual-dispense capabilities and autonomous fueling for accelerated reliability experiments at various temperature levels
• Increased flow capacity
• A recirculation system
• The robotic hose test assembly was upgraded to expand the scope of testing and add high flow through rates that recycle hydrogen back into the station to maximize test rates while minimizing impacts to station availability.
In 2018, NREL and Eaton Corporation launched a new kind of partnership in the ESIF. In addition to access to the facility’s lab space, a team of Eaton researchers are now co-located at the ESIF to perform a long-term, close collaboration with NREL on research that involves the integration of EV fleets with the grid and new energy technologies. As an EERE user facility, this type of partnership could be the start of many at the ESIF—offering long-term access to our labs and offices—with strategic collaborators.
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
Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors (CIRCUITS)
• A High-voltage, High-reliability Scalable Architecture for Electric Vehicle Power Electronics
Saving Energy Nationwide in Structures with Occupancy Recognition (SENSOR)
• Battery-free RFID Sensor Network with Spatiotemporal Pattern Network Based Data Fusion System for Human Presence Sensing

Buildings
Home Battery System
GMCL Category 1 Projects:
Advanced Sensor Development
Sensing and Measurement Strategy Methodology
Interoperability
Integrated Multi-Scale Data Analytics and Machine Learning for the Grid Distribution System

Fuel Cell Technologies Office
700 bar Hydrogen Dispenser Hose Reliability Improvement
Advanced Ionomers and Membrane Electrode Assemblies for Alkaline Membrane Fuel Cells
Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks (sub to Ivy, Inc.)
Collaboration on SBR/TTO Phase II Project for Optical QC Device (FCTO-funded SBR with Mainstream Engineering)
Demonstration of Hydrogen Tube-Trailer Consolidation for Reducing Refueling Station Cost
Dispenser Reliability Component Testing
Dynamic Modelling and Validation of Electrolyzers in Real-Time Grid Simulation
ElectroCat (Electrocatalysis Consortium):
• Membrane Electrode Assembly (MEA) Diagnostic, Segmented Cells
• Electrochemical Compression at 875 bar
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
FC-PAD: Fuel Cell Consortium for Performance and Durability—Electrode Layer Integration Grid Integration and Hydrogen Energy Storage
HighScale
• California Hydrogen Infrastructure Research Consortium

High-Efficiency Tandem Absorbers for Economical Solar Hydrogen Production
Highly Accessible Catalysts for Durable High-Power Performance (sub to GM)
HydroGEN Advanced Water Splitting Materials Consortium
Hydrogen Component Validation
Hydrogen Sensor Testing Laboratory

- Experimental Characterization of Durability of Advanced Electrolyzer Concepts in Dynamic Loading
- Holistic Fuel Cell Electric Vehicle/ Hydrogen Station Optimization Model
- Hydrogen-Component Performance Diagnostic Testing
- Megawatt-Scale Polymer-Electrolyte-Membrane-Based Electrolyzers for Renewable Energy System Applications
- Membrane Electrode Assembly Manufacturing Automation Technology for the Electrochemical Compression of Hydrogen
- Optimizing an Integrated Renewable-Electrolysis System
- Scalable Electrolytic Systems for Renewable Hydrogen Production
- Tatsuno Coriolis Flow Meter Development Testing in High-Pressure Hydrogen
- Validating an Electrolysis System with High-Output Pressure
- Validation of Hydrogen Technology on the Electric Grid Using Production Modeling
Grid Modernization

GMLC Category 1 Projects:
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
1.2.6 Grid Architecture
1.2.7 GMLC Testing Network
1.2.8 Interoperability
1.2.9 Grid Services and Technologies Valuation Framework Development
1.2.10 Vermont Regional Partnership Enabling the Use of DER
1.2.11 Multi-Scale Integration of Control Systems (EMS/DMS/BMS)
1.2.12 Control Theory
1.2.13 Extreme Event Modeling
1.2.14 Computational Science for Grid Management
1.2.15 Development of Integrated Transmission, Distribution and Communication Models
1.2.16 Development of Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle and Grid Resources
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
1.4.21 Laboratory Valuation Analysis Team
1.4.22 Distribution System Decision Support Tools
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:
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
1.4.02 Definitions, Standards, and Test Procedures for Grid Services
1.4.04 Advanced Sensor Development
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
1.4.21 Laboratory Valuation Analysis Team
1.4.22 Distribution System Decision Support Tools
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 Resilient Distribution Systems Projects:
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
1.4.21 Laboratory Valuation Analysis Team
1.4.22 Distribution System Decision Support Tools
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

Office of Electricity Delivery and Energy Reliability

GMLC Category 1 Projects:
GM0063 Development of an Open-Source Platform for Advanced Distribution Management Systems
GM0081 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)

GMLC Resilient Distribution Systems Projects:
Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB
Laboratory Valuation Analysis Team

Solar Energy Technologies Office
SuNLaMP Prime Projects (GMLC Category 2):
30356 Additively Manufactured PV Inverter
30359 Solar Resource Calibration, Measurement, and Dissemination
30360 Improvement and Validation of the System Advisor Model
30361 Assessing the Value and Impact of Dispatchable CSP
30362 Opportunistic Hybrid Comms Systems for Distributed 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
San Diego National Laboratory Prime: Distribution System Modeling—Marin
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
1.4.39 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 (Bio-Idea)

NREL Subs:
- Scalable/Secure Cooperative Algorithms and Framework for Extremely High Penetration Solar Integration (SolarBoxPrt)
- Electric Access System Enhancement (EASE)
- Solar Forecasting 4 Projects

NREL Primes:
- Probabilistic Cloud Optimized Day-Ahead Forecasting System Based on Weather Research and Forecasting Solar System
- Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)

NREL Subs:
- Advancing the Weather Research and Forecasting Solar Model to Improve Solar Irradiance Forecast in Cloudy Environments

Water Power Technologies Office
North American Grid Integration Study (NARIS)
Pumped Storage and Hydropower Value Consortium (HVC)
Ternary PSH Design and Evaluation
Dbermeyer PSH Valuation
FY 2017 Small Business Voucher – Natel Dehlsen

Vehicle Technologies Office
Visualizing Net Zero Energy District with Panasonic

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/EMS)
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 energy systems integration research portfolio. In FY 2018, the ESIF offered nearly 60 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, DOE’s EERE Robotics Internship Program, and the National Science Foundation.

ESIF Steering Committee Meeting Held June 23, 2018, in Washington, D.C.

As the ESIF has evolved into a robust facility with both public and private users, EERE formed an independent steering committee to help guide ESIF research direction and required capabilities for the future. The committee ensures that the facility is appropriately maintained, operated, and resourced—and made broadly available to meet stakeholder needs as a national user facility. In addition, the ESIF Steering Committee provides advice and recommendations to the ESIF’s management team on any topics it deems appropriate. High-level recommendations were provided by DOE for FY 2018 and future R&D around the world.

WORKSHOPS, CONFERENCES, & EVENTS

The following table includes a snapshot of the workshops, conferences, and events held in the ESIF in 2018.

<table>
<thead>
<tr>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Cybersecurity &amp; Resilience Workshop</td>
<td>October 12–13, 2017</td>
</tr>
<tr>
<td>ASHRAE Workshop</td>
<td>October 26, 2017</td>
</tr>
<tr>
<td>International Conference for Energy Systems Integration</td>
<td>December 5–6, 2017</td>
</tr>
<tr>
<td>High-Performance Computing: Open-Source Code Workshop</td>
<td>February 12–13, 2018</td>
</tr>
<tr>
<td>Long-Term Visions for Wholesale Electricity Markets Workshop</td>
<td>February 27, 2018</td>
</tr>
<tr>
<td>Climate Leadership Conference</td>
<td>March 2, 2018</td>
</tr>
<tr>
<td>21st International Conference for Condensed Matter Nuclear Science</td>
<td>June 6, 2018</td>
</tr>
<tr>
<td>Third U.S.-China Smart Grid Workshop</td>
<td>June 20, 2018</td>
</tr>
<tr>
<td>Cybersecurity Workshop for Distributed Energy Resources</td>
<td>July 17, 2018</td>
</tr>
<tr>
<td>Idaho National Laboratory and National Energy Technology Laboratory Workshop</td>
<td>July 25, 2018</td>
</tr>
<tr>
<td>21st International Conference on Ternary and Multinary Compounds (ICTMC-21) Conference</td>
<td>September 12, 2018</td>
</tr>
<tr>
<td>Workshop on Modeling &amp; Simulations for ADMS</td>
<td>September 26, 2018</td>
</tr>
</tbody>
</table>
## INNOVATIONS

The ESIF delivered 411 technical outputs, including journal articles, records of invention, software, and conference papers.

<table>
<thead>
<tr>
<th>Title</th>
<th>Primary NREL Center</th>
<th>NREL Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTEM-DB API Examples</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-04</td>
</tr>
<tr>
<td>Wind Toolkit HSDS API Examples</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-05</td>
</tr>
<tr>
<td>Enabling DNP3 communication for dSPACE boards controlling PV inverter DNP3, dSPACE-comm</td>
<td>1D00 - Power Systems Engineering</td>
<td>SWR-18-09</td>
</tr>
<tr>
<td>Matrix Completion for Low-Observability Voltage Estimation</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-26</td>
</tr>
<tr>
<td>Distribution Transformation Tool (DITTo)</td>
<td>1D00 - Power Systems Engineering</td>
<td>SWR-18-16</td>
</tr>
<tr>
<td>Design of a Robust Current Controller for PV inverters to reject grid impedance uncertainty using D decomposition</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-31</td>
</tr>
<tr>
<td>Wind Plant Performance Project (WPP) Benchmarking</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-18</td>
</tr>
<tr>
<td>Grid Services from PV GSPV</td>
<td>1D00 - Power Systems Engineering</td>
<td>SWR-18-22</td>
</tr>
<tr>
<td>Snow Melting PV Inverters</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-33</td>
</tr>
<tr>
<td>PRE-configuring and Controlling Inverter Settings (PRECISE) Tool</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-39</td>
</tr>
<tr>
<td>Decentralized Interfacing for Cascaded Converters</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-42</td>
</tr>
<tr>
<td>PyDSS PyDSS</td>
<td>1D00 - Power Systems Engineering</td>
<td>SWR-18-24</td>
</tr>
<tr>
<td>Improving productivity through increased hydrogen mass transfer in anaerobic gas fermentation systems</td>
<td>1B00 - Energy Systems Integration Facility</td>
<td>RDI-18-48</td>
</tr>
<tr>
<td>Real-Time Feedback-Based Optimization of Distribution Grids</td>
<td>1D00 - Power Systems Engineering</td>
<td>SWR-18-27</td>
</tr>
<tr>
<td>Harmonic/Interharmonic Inverter-Based Generation Faulted Condition Communication for Protective Relaying</td>
<td>1D00 - Power Systems Engineering</td>
<td>RDI-18-51</td>
</tr>
<tr>
<td>The ESIF delivered 411 technical outputs, including journal articles, records of invention, software, and conference papers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Title</td>
<td>Primary NREL Center</td>
<td>NREL Number</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>WindView</td>
<td>5D00 - Power Systems Engineering</td>
<td>SWR-18-51</td>
</tr>
<tr>
<td>Network Reduction Algorithm for Developing Distribution Feeders for Real-time Simulators</td>
<td>5D00 - Power Systems Engineering</td>
<td>SWR-18-54</td>
</tr>
<tr>
<td>Co-optimization of fuels and engines (Co-Optima) Co-optimizer (CoOptimaOptimizer)</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-57</td>
</tr>
<tr>
<td>Grid Synchronization Method for Inverter-Based Grids</td>
<td>5D00 - Power Systems Engineering</td>
<td>ROI-18-100</td>
</tr>
<tr>
<td>Parameter Optimization Toolbox for n-s POT-NLS-NLP Parameter Optimization Framework</td>
<td>5D00 - Power Systems Engineering</td>
<td>SWR-18-60</td>
</tr>
<tr>
<td>Hardware and Software System for Monitoring Residential Power Quality</td>
<td>5D00 - Power Systems Engineering</td>
<td>ROI-18-105</td>
</tr>
<tr>
<td>Renewable Energy Planner tool kit</td>
<td>5D00 - Power Systems Engineering</td>
<td>ROI-18-110</td>
</tr>
<tr>
<td>Real-time distributed energy resource energy dispatch using distributed control N/A</td>
<td>5D00 - Power Systems Engineering</td>
<td>SWR-18-62</td>
</tr>
<tr>
<td>Lenns-XRD: Rapid-Phase Decomposition of Diffraction Spectra</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-68</td>
</tr>
<tr>
<td>Network island detector ND</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-70</td>
</tr>
<tr>
<td>Parallel Fenics Implementation of Block School CFltis</td>
<td>2C00 - Computational Sciences</td>
<td>SWR-18-71</td>
</tr>
<tr>
<td>Distribution Infrastructure Optimization and Control</td>
<td>5D00 - Power Systems Engineering</td>
<td>PROV/18-124A</td>
</tr>
<tr>
<td>Heterogeneous Network Topology Manager</td>
<td>5D00 - Power Systems Engineering</td>
<td>PROV/17-95</td>
</tr>
<tr>
<td>Magnetocaloric Refrigeration</td>
<td>5B00 - Energy Systems Integration Facility</td>
<td>PRD/16-91</td>
</tr>
<tr>
<td>Real-Time Feedback-Based Optimization of Distributed Energy Resources</td>
<td>5D00 - Power Systems Engineering</td>
<td>PCT/16-124</td>
</tr>
<tr>
<td>Real-Time Feedback-Based Optimization of Distributed Energy Resources</td>
<td>5D00 - Power Systems Engineering</td>
<td>16-124</td>
</tr>
<tr>
<td>Matrix Completion for Low-Obsevability Voltage Estimates</td>
<td>5D00 - Power Systems Engineering</td>
<td>PRD/18-26</td>
</tr>
<tr>
<td>Optimized Device Cooling</td>
<td>5C00 - Energy Systems Integration</td>
<td>PRD/16-79</td>
</tr>
<tr>
<td>Network-Cognizant Voltage Droop Control</td>
<td>5D00 - Power Systems Engineering</td>
<td>17-28</td>
</tr>
<tr>
<td>Image-Based Solar Estimates</td>
<td>5D00 - Power Systems Engineering</td>
<td>PRD/18-56</td>
</tr>
<tr>
<td>Modular Scalable Power Conversion</td>
<td>5D00 - Power Systems Engineering</td>
<td>PROV/17-74A</td>
</tr>
<tr>
<td>Coordinated Net-Load Management</td>
<td>5D00 - Power Systems Engineering</td>
<td>PROV/18-59</td>
</tr>
<tr>
<td>Decentralized Control</td>
<td>5D00 - Power Systems Engineering</td>
<td>17-64</td>
</tr>
<tr>
<td>&quot;Renewable Power to Renewable Natural Gas Using Biological Methane Production&quot;</td>
<td>5B00 - Energy Systems Integration Facility</td>
<td>PRD/18-48</td>
</tr>
<tr>
<td>&quot;Renewable Power to Renewable Natural Gas Using Biological Methane Production&quot;</td>
<td>5B00 - Energy Systems Integration Facility</td>
<td>PRD/18-48A</td>
</tr>
</tbody>
</table>
Most Downloaded Publications

The following were the most downloaded FY 2018 ESIF Publications on NREL.gov:

2. "ESIF 2017 Annual Report"
6. Marginal Cost Pricing in a World without Perfect Competition: Implications for Electricity Markets with High Shares of Marginal Cost Resources
7. "Distributed Energy Resource (DER) Cybersecurity Standards"
10. "Performance of Existing Hydrogen Stations."

Conference Papers (Preprints)


