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ENERGY SYSTEMS INTEGRATION

ESI optimizes the design and performance of electrical, thermal, fuel, and water pathways at all scales.

High Penetration PV: How High Can We Go?

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

"We know how important the option of solar is for our customers. Solving these issues requires that everyone—utilities, the solar industry, and other leading technical experts like NREL—work together. That's what this work is all about. With the highest amount of solar in the nation, our utilities are facing potential reliability and safety issues before anywhere else."

Colton Ching, Vice President for Energy Delivery, Hawaiian Electric

HIGH PENETRATION PV:
How High Can We Go?

With abundant sunshine and a willing population, it's no surprise that Hawaii has some of the highest penetrations of rooftop photovoltaics (PV) in the country. According to the Solar Electric Power Association, 11% of Hawaiian Electric's (HECO) customers have rooftop solar PV compared to a national average of just 0.5%. One of the challenges for HECO—and other utilities with high penetrations of distributed energy resources—is that the customer-owned generation tends to be concentrated in certain areas, or more specifically, on certain feeders in their distribution system.

As the number of rooftop solar systems grew in Hawaii, HECO became concerned that increasing percentages of distributed generation on its grid could lead to instability and damaging conditions. One of HECO's main concerns was the spikes in voltage, called load rejection overvoltage (LRO), that can occur at the customer site with PV generation. The result may be high voltage on the feeder, which would include the customer and perhaps many other local customers. LRO occurs when a portion of a distribution feeder containing more generation than load becomes disconnected from the grid, resulting in a high generation-to-load ratio. The question for HECO became: how high can that ratio safely go with inverter-connected PV?

A Need for Testing

In theory, the new generation of smart inverters—those with fast digital controls, bidirectional communications capability, and robust software algorithms—should be able to react quickly to mitigate the potential harmful effect of LRO. To test this theory and better understand transient overvoltages due to load rejection, HECO collaborated with SolarCity and the National Renewable Energy Laboratory (NREL) to run a series of tests to measure the magnitude and duration of LRO events and demonstrate the ability of advanced PV inverters to mitigate their impacts. Prior to the testing at NREL, no comprehensive LRO test had been performed with advanced inverters.

Testing Protocol

An industry group known as the Forum on Inverter Grid Integration Issues (FIGII), which consists of members from inverter manufacturers, utilities, consultants, and research labs, developed the test plan through a consensus-based process. The LRO tests were completed on five commercially available advanced inverters ranging in size from 3 kilowatts (kW) to 12 kW, and included single-phase inverters, three-phase string inverters, and microinverters. The test plan included 11 different inverter power-to-load power settings, and all tests were performed a total of seven times. The testing took place in the Energy Systems Integration Facility (ESIF) on NREL's campus in Golden, Colorado.

Problem

In the summer of 2013, the Hawaiian Electric Company (HECO) put a moratorium on installing PV systems due to concerns about high penetration impacts on the grid.

Solution

NREL, working with SolarCity and HECO, completed research at the Energy Systems Integration Facility (ESIF) demonstrating the ability of advanced PV inverters to mitigate transient overvoltage impacts.

Result

HECO cleared its interconnection queue, ending the moratorium on solar PV and raising its limit of distributed PV from 120% of minimum daytime load to 250%.

Test Results and What They Mean

The maximum overvoltage did not exceed 200% of nominal level in any test, with typical overvoltage levels significantly lower—and the overvoltage durations were on the order of microseconds to milliseconds, which represents an acceptably short duration. These tests demonstrated that overvoltages were less severe than some utilities feared, and that previous estimates of voltage magnitude and duration were overestimated. A detailed discussion of the test results is included in a report authored by NREL and SolarCity engineers (see the back of this brochure for a list of related reports).

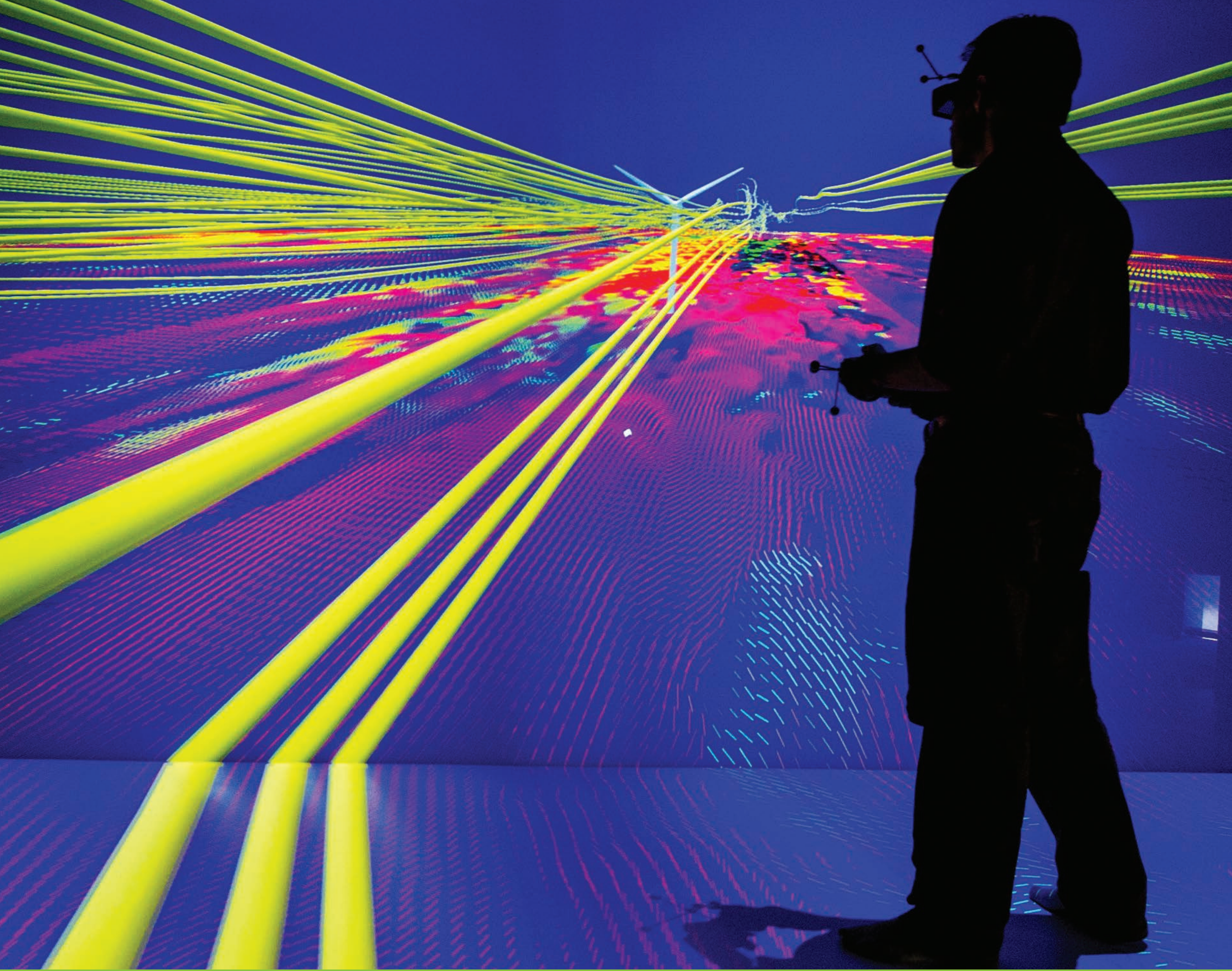
Following the testing at NREL, HECO cleared its interconnection queue and raised its limit of distributed PV from 120% of minimum daytime load to 250%, specifically citing NREL's report as a reason for this change in policy. In addition, HECO is now allowing inverter manufacturers to self-certify for LRO using the test methods used by NREL. Key members of IEEE and UL working groups are now moving to incorporate LRO testing into the IEEE 1547 and UL 1741 standards to address the issue nationwide.

Overcoming Clean Energy integration Challenges

While HECO is out in front, it is not alone in facing challenges related to higher penetrations of interconnected solar generation. Other utilities are experiencing increasing customer requests for interconnection of distributed solar or wind generation and are seeking high-quality, quantitative research studies to guide their operational decisions and use new technology to enhance reliability.

Research and development at the ESIF are focused on overcoming the challenges of integrating new energy efficiency and renewable energy technologies into today's energy infrastructure. Application and technology challenges addressed span the entire energy system—from buildings, campuses, and fleets, to regional- and national-scale energy distribution systems.

This work was performed under a 50-50 cost-share CRADA. Funding came from SolarCity and the DOE Solar Energy Technologies Office.



UNIQUE CAPABILITIES OF THE ESIF

Connected by common infrastructure, ESIF laboratories offer the following unique capabilities:

Hardware-in-the-Loop at Megawatt-Scale Power: Researchers and manufacturers can conduct integration tests at full power and actual load levels in real-time simulations and evaluate component and system performance before going to market.

Research Electrical Distribution Bus (REDB): The ultimate power integration circuit, made up of two AC and two DC ring buses, connects multiple sources of energy and "plug-and-play" testing components in key ESIF labs.

Supervisory Control and Data Acquisition (SCADA) System: Integrated throughout the ESIF, a SCADA system monitors and controls the Research Electrical Distribution Bus operations and safety and gathers real-time, high-resolution data for collaboration and visualization.

High Performance Computing and Data Center: Petascale computing using Peregrine—NREL's high performance computer—enables unprecedented large-scale numerical modeling, including the simulation of material properties, processes, and fully integrated systems that would otherwise be too expensive, too dangerous, or even impossible to study by direct experimentation.

Data Analysis and Visualization: Analysis and visualization capabilities at the ESIF go beyond what is found in a typical utility operations center. The ESIF's fully integrated visualization tools allow researchers and NREL partners to see and understand complex systems and operations in a completely virtual environment.

Related Reports

These and many other research reports are available at no cost on *www.nrel.gov/publications.*

1. Nelson, A., A. Hoke, S. Chakraborty, J. Chebahtah, T. Wang, and B. Zimmerly. 2015. *Inverter Load Rejection Over-Voltage Testing: SolarCity CRADA Task 1a Final Report*. *http://www.nrel.gov/docs/fy15osti/63510.pdf*.

2. Hoke, A., A. Nelson, S. Chakraborty, J. Chebahtah, T. Wang, M. McCarty. 2015. *Inverter Ground Fault Overvoltage Testing*. *http://www.nrel.gov/docs/fy15osti/64173.pdf*.

Partner With Us

Manufacturers, utilities, microgrid operators, and other research organizations can partner with NREL to take advantage of the ESIF's unique capabilities.

Visit *www.nrel.gov/esi/working_with.html* or contact the ESIF User Program at 303-275-3027 or *userprogram.esif@nrel.gov* to discuss opportunities.

Learn more about the ESIF and see a list of current partners at *www.nrel.gov/esi/partnerships.html*.

For complete details on the ESIF's capabilities, tools, research focus areas, and user facility opportunities, please visit *www.nrel.gov/esif*.

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