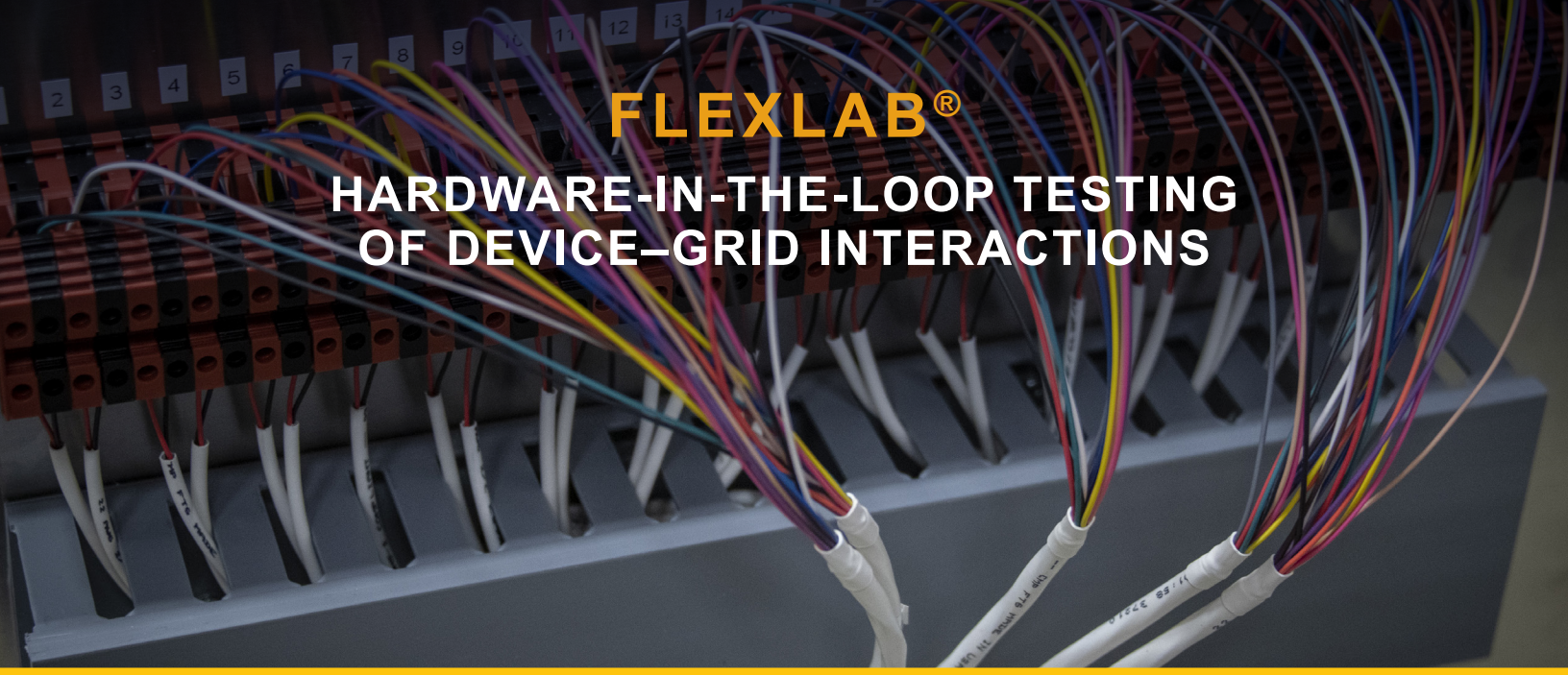

FLEXLAB®

HARDWARE-IN-THE-LOOP TESTING OF DEVICE–GRID INTERACTIONS

This Advanced Research Projects Agency-Energy (ARPA-E) project enabled users to conduct hardware-in-the-loop testing using real devices.

THE CHALLENGE

Enabling real-time modeling of transmission and distribution network interactions with controllable devices

The proliferation of dynamic loads and distributed energy resources on the electrical grid is changing the ways transmission and distribution (T&D) networks operate. It is essential to gain a better understanding of the nature of these changes, but conventional modeling tools only model and analyze each network separately, so the real-time dynamics between controllable devices and these systems have not been revealed. No method had been able to produce high-fidelity, real-time simulations of the effect of dynamic end use devices on grid performance.

THE SOLUTION

In this ARPA-E funded project, researchers turned to the U.S. Department of Energy's FLEXLAB® facility to demonstrate and evaluate a hardware-in-the-loop (HIL) system to evaluate demand response (DR). The project involved a partnership of four institutions and was led by principal investigators Adilson Motter and Takashi Nishikawa from Northwestern University's Institute for Sustainability and Energy (ISEN). The system allowed direct integration of physical devices into a real-time model of the power systems, which enabled users to control and capture the true response of dynamic devices. By analyzing these dynamic interactions, users were able to better evaluate the performance of grid and device control algorithms.

> **"FLEXLAB® had the right combination of capabilities that allowed us to simultaneously control a large number of hardware devices, measure their power consumption, and interface with real-time simulation of large-scale power distribution and transmission systems, which were all essential in testing the optimization and control algorithms developed in our project."**
>
> **Takashi Nishikawa, Research Professor, Northwestern University**

Northwestern University

THE BOTTOM LINE

The test validated the performance of the HIL system and controllers

The real-time power systems model interacted and communicated well with the devices in FLEXLAB®. The team directly controlled some devices, and an asynchronous process from the real-time simulator was used to communicate with devices using TCP/IP-based custom communications. The HIL-based DR test was conducted successfully with the integrated T&D model, hierarchical controllers, and real devices, validating the HIL testbed approach and control algorithms. The HIL testbed could also be used to validate a broad range of grid service applications, including voltage management, frequency responses from distributed energy resources, and controllable loads.

THE EXPERIMENT

- The team configured a large, integrated T&D model with approximately 10,000 nodes to run in real-time, using phasor-domain ePHASORSIM software, connected to 100 controllable devices at FLEXLAB. The testbed featured 4 HVAC pumps, 2 HVAC fans, 3 photovoltaic (PV) plus battery-connected inverters, 31 heaters, and 60 blower motors.
- The integrated T&D models were configured to run in two different subsystems, so the model could run in parallel in different CPU cores.
- The test model ran optimization for the transmission network and a building controller, an integrated T&D network with controllers, and a building controller. Two data acquisition (DAQ) systems were used—one for the inverters and one for the other devices and circuits in the testbeds.
- The FLEXLAB setup used one optimization module for the transmission network and one for the building controller. Because optimization processes must be iterative, they were run outside of the real-time simulator.
- To validate communications, individual devices were subjected to test targets a building controller would generate, and the aggregated response was analyzed.
- A hierarchical control structure was used to test the DR; control signals for the FLEXLAB devices were generated to improve the small-signal stability at the transmission level.
- To demonstrate the large-scale HIL setup, the team performed a DR test that included all the devices. Preliminary tests found the devices exhibited different response times, errors in characterization, and nonlinear power consumptions, so the building controller was modified to account for these factors while generating targets to the individual devices.

THE RESULTS

- The HIL-based DR test was conducted successfully with the integrated T&D model, hierarchical controllers, and real devices, validating the HIL testbed and control algorithms.
- The preliminary test showed that the communication setup between the T&D model and DAQ systems at FLEXLAB worked well.
- All the devices at the testbed were fully controllable individually. The building controller also was able to disintegrate the overall target into individual targets for all 100 devices at FLEXLAB, and to control them to meet the power target.
- The study showed that the HIL testbed provides flexibility. It can be used in the future to validate a variety of grid service applications such as voltage management, frequency responses from distributed energy resources, and controllable loads.

flexlab.lbl.gov
ieeexplore.ieee.org/abstract/document/9087705

BERKELEY LAB ENERGY TECHNOLOGIES AREA