FLEXLAB®

SAFE, RELIABLE MANAGEMENT OF DISTRIBUTED GENERATION ON THE GRID

This California Energy Commission project identifies solutions for managing renewables and battery storage, effectively saving customers money and improving grid performance.

THE CHALLENGE

Incorporating renewables and storage while maintaining grid safety and reliability

California's electrical distribution grid, originally designed for a unidirectional power flow from large centralized power plants, must now adapt to large-scale deployment of distributed renewable generation such as photovoltaics (PV) and co-located battery storage. Power delivery from many intermittent sources distributed along the grid can result in issues such as critical voltage variability, if not properly handled, and can adversely modify load profiles. Customers are interested in accessing clean renewable power for their homes and businesses, optimizing energy use, and lowering their operating costs. For California to achieve successful integration of distributed generation (DG) technologies, grid design and operation must include new predictive, diagnostic, and control capabilities that reduce customer energy consumption and cost while improving electrical distribution grid reliability.

THE SOLUTION

In this California Energy Commission EPIC funded project, Lawrence Berkeley National Laboratory (LBNL) researchers turned to the U.S Department of Energy's FLEXLAB® facility to address grid impacts while optimizing the customer benefits. LBNL investigated solutions to enable high levels of DG in the electricity system. The research team designed and built a central testing facility to evaluate DG technology in California, and used it to study its impact on the grid. Novel control systems were designed and field-tested in the controlled and flexible environment of the FLEXGRID facility. The team also developed and validated simulation models based on the facility's hardware, to rapidly evaluate many different scenarios before testing with the hardware. The researchers developed a controller for combined PV and storage systems to mitigate the steep ramping known as the "duck curve," provide benefits to building owners by maximizing their revenue, and provide grid operators with voltage stabilizing functionality.

THE BOTTOM LINE

Available technologies facilitate renewable integration and cost savings

Use of controllers and innovative inverters can increase predictability and control of power flows from distributed renewable resources, providing improved operations and cost savings for customers, and grid reliability and financial benefits to utilities and ratepayers alike. Simulations showed that an annual electricity bill could be reduced by as much as 35 percent, with about a six-year payback period of the investment in battery storage—significantly shorter than the manufacturer's 10-year warranty.

THE EXPERIMENT

The project included four steps:

Development and construction of the FLEXGRID test facility, a full-scale testbed for renewable DG. The 1,000 square foot PV installation with 15 kilowatts (kW) of peak power provided the local renewable power supply, while three household-scale batteries offered 19 kilowatt-hours (kWh) of storage. The high-fidelity sensing micro-synchrophasor measurement unit devices provided readings of 120 samples per second to accurately evaluate and analyze power conditions during operation. The team used the facility to study the impact of renewables on the power grid, with the sensing equipment recording variations in supply voltage during periods with and without PV generation. The measured voltage violations were stored in a digital library of grid events and used to prototype an algorithm to predict the severity of these very short-lived events and inverter controls, to mitigate grid impacts. The resulting online library provides access to academia, researchers, and industry.

Simulation models, for grid planning and controls evaluation. Data recorded at FLEXGRID was used to create a simulation model of grid performance and test various DG and controls scenarios. Additional simulation studies included component and system models of PV, batteries, inverters, and the power grid. Researchers used simulation models to study different levels of deployment and combinations of various DG equipment, and to quantify their impacts.

Development of an optimized control of a smart inverter that can actively regulate power generation in accordance with locally observed quantities. The functionalities are based on California Rule 21, to allow more flexibility and adaptability of DG. The objective was to determine the best control setpoints for various smart inverters connected within the electrical grid. This project investigated the use of dynamic setpoints that depend on location and season. Optimizing these parameters can lead to reductions in the levelized cost of electricity, especially for grid networks with high PV penetrations.

Optimal control to mitigate the "duck curve," for a deeper dive into DG capabilities. The team analyzed the combination of distributed PV and battery storage and optimized the controller's operation. It was implemented as a model predictive control, where an internal mathematical model is evaluated and solved to a global optimum at each controller time step. Forecasts of weather data, PV generation, and load for the upcoming 24 hours were input. The team sought to maximize the revenue for the generating asset owner while providing additional services to the grid. The controller was evaluated in annual simulations and in a field test conducted at FLEXGRID.

THE RESULTS

During the field test for the model predictive controller for PV and battery storage, the controller responded to changing environmental conditions and provided near optimal control of the storage system for a time-varying electricity price.

The simulation indicated cost savings of up to 35 percent, with a payback time of about 6 years—significantly shorter than the manufacturer's 10-year warranty.

The installation of a battery storage system can financially benefit residential and commercial ratepayers, as well as grid operation and reliability.

The capacity of the inverter could be decreased while providing the same generation output, which would decrease the levelized cost of electricity for DG. Under high PV penetration, it would be even more advantageous to use variable control setpoints by preventing curtailment of PV generation during peak hours.

Ratepayers would see improved grid reliability compared to the current situation.

- FLEXGRID will continue to be a central base for testing new renewable technologies and their integration issues in California, allowing evaluation of novel control systems in a controlled, emulated environment and enabling real-time comparisons between end-user demand, renewables, inverters, and storage.
- The simulation models (which include PV, battery, smart inverter, and the power grid component and system models) are generic and can be combined and parameterized to reflect other systems. The package is available online and can help stakeholders, regulators, and researchers make sound investment and planning decisions.
- The micro-synchrophasors installed at FLEXGRID recorded ~4 terabytes of data over roughly two years. The event detection algorithm developed and applied resulted in detection of 27 voltage events over the study. The events were stored in a digital library, and when used to perform short-term forecasting revealed that the initial slope of a voltage event is a good parameter to predict the event's severity and duration. This information can be vital for inverter settings, in accordance with California Rule 21, with the overall objective to improve grid reliability.
- The simulation models are not domain-specific and allow simulation of full grids, to enable researchers and stakeholders to make informed decisions.
- All developed simulation models, the grid event library, and the model predictive controller are open-source and available online.

flexlab.lbl.gov
https://flexlab.lbl.gov/publications/photovoltaic-and-behind-meter-battery
https://flexlab.lbl.gov/publications/hybrid-approach-short-term-pv-power
https://flexlab.lbl.gov/publications/open-pmu-event-dataset-detection-and

PG&E BERKELEY LAB ENERGY TECHNOLOGIES AREA