Hawaiʻi Natural Energy Institute Research Highlights

Grid Integration

Holistic Optimization of Microgrids

<u>Objective and Significance</u>: This project advances an optimization framework for microgrids that integrates multiple distributed energy resources (DERs), including photovoltaic (PV) systems, battery energy storage systems (BESS), fuel cells, electrolyzers, and hybrid energy storage systems (HESS), to identify cost-optimal and resilient configurations (Figure 1).

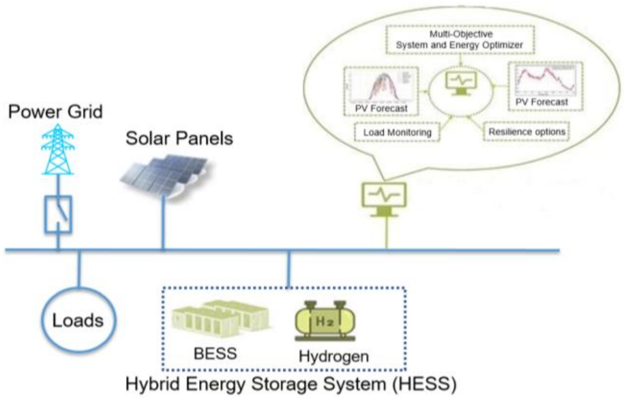

Figure 1. System architecture of a microgrid with HESS.

<u>Background</u>: Microgrids and distributed renewable systems are increasingly central to building reliable and resilient energy systems. However, most conventional commercial optimization platforms, such as HOMER Pro, offer limited flexibility for modeling hybrid systems that combine both electrical and hydrogen-based energy storage. These limitations restrict the ability to capture realistic operational dynamics, cost interactions, and the temporal variability inherent to renewable generation and load behavior.

Our method uses a two-stage mixed-integer linear programming (MILP) formulation designed for precision, scalability, and realism. The first stage compresses annual high-resolution data into representative daily profiles for efficient computation, while the second stage refines component sizing and dispatch using the full-year time series. This structure enables accurate assessment of renewable resource penetration, operational cost, and grid interaction under diverse scenarios. Ultimately, this work supports Hawaiʻi's transition toward 100% renewable and zero-emission energy systems by advancing flexible, data-driven design tools for microgrid development.

<u>Project Status/Results</u>: Building on earlier work that explored a hybrid MILP-particle swarm optimization (PSO) approach, this phase advances to a fully MILP-based optimization model that enhances computational transparency, solution accuracy, and integration of detailed operational constraints. The updated model employs a two-stage MILP structure that efficiently manages large time-series datasets while accurately representing the coupling among generation resources, storage systems, and grid interaction.

By integrating high-resolution data and physical models for PV, BESS, electrolyzers, fuel cells, and hydrogen tanks, the model enables precise evaluation of system sizing, dispatch strategies, and economic performance. This capability supports a wide range of microgrid and hybrid energy applications.

The updated two-stage MILP model has been successfully developed and validated for optimal microgrid sizing and operation. The model integrates PV systems, BESS, electrolyzers, fuel cells, and HESS within a unified optimization environment.

In the first stage, the representative-day optimization efficiently reduces computational complexity by condensing annual 15-minute resolution data into monthly weekday, weekend, and peak-day profiles. The second stage refines component capacities and dispatch schedules using the full-year dataset to capture seasonal and operational variability with high fidelity.

Preliminary results demonstrate the model's capability to determine cost-optimal configurations that minimize grid dependence and enhance renewable utilization while maintaining operational reliability. Comparative testing indicates improved accuracy and scalability relative to conventional commercial tools. This enhanced model also provides a foundation for future resilience-focused applications, including outage management, critical load support, and carbon-neutral microgrid design in both grid-connected and islanded modes.

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