NREL

Utility and Grid Operator Resources for Future Power Systems Webinar Series

Introduction to Microgrids

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NREL Webinar Series
July 15, 2025

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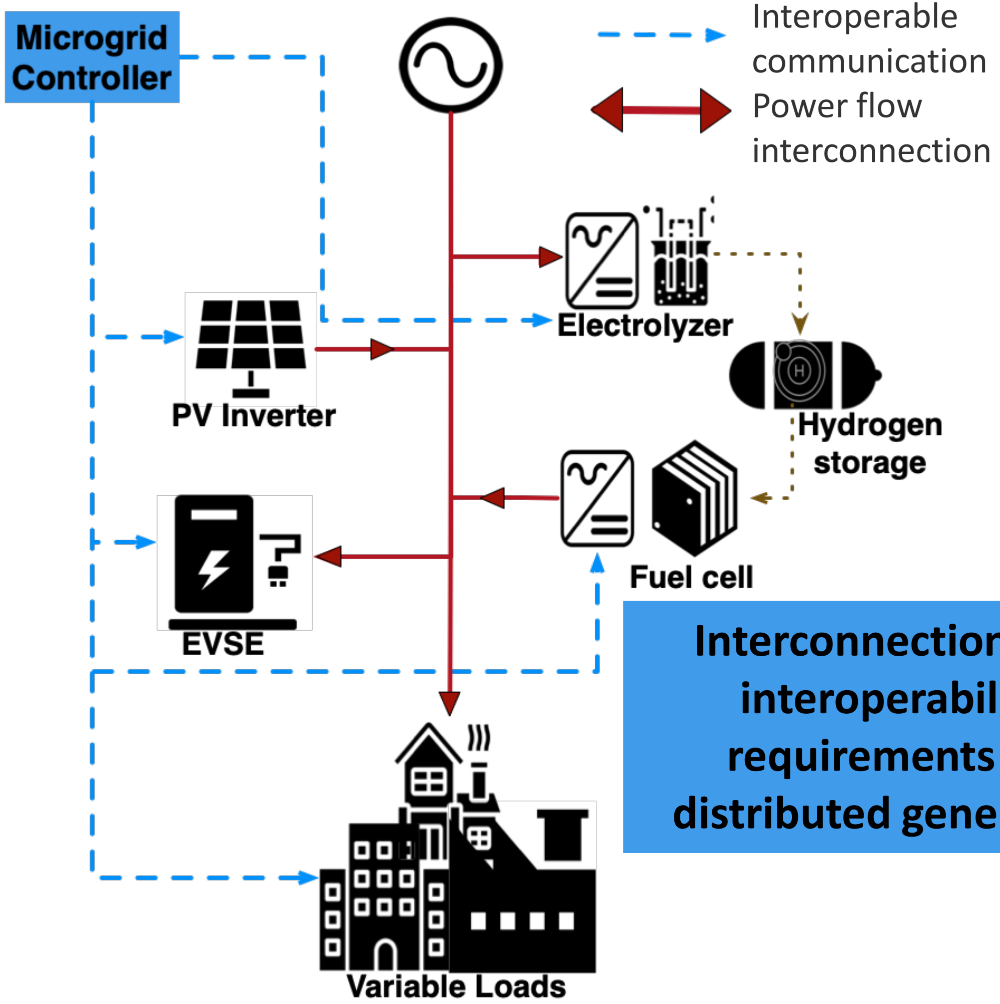
Microgrids



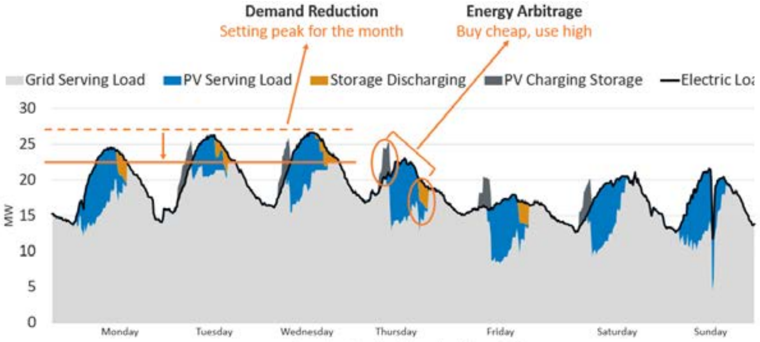
Interconnection and interoperability requirements for distributed generation

Images by Deepthi Vaidhynathan, NREL

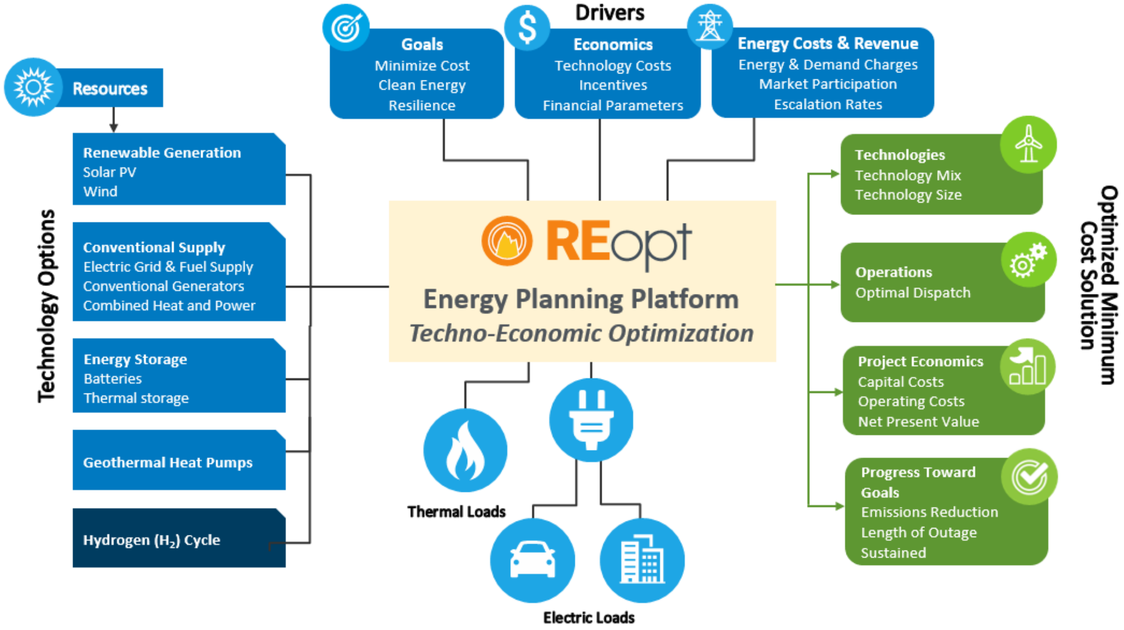
REopt Energy Planning Platform

REopt: A Decision Support Tool

- REopt is a technoeconomic model used to optimize Distributed Energy Resources (DER) sizing and dispatch based on the **site's energy needs and goals.**
- Provides **least cost** solution subject to **resilience.**



Example of optimal dispatch of PV and BESS



REopt considers the tradeoff between ownership costs and savings across multiple value streams to recommend optimal size and dispatch.

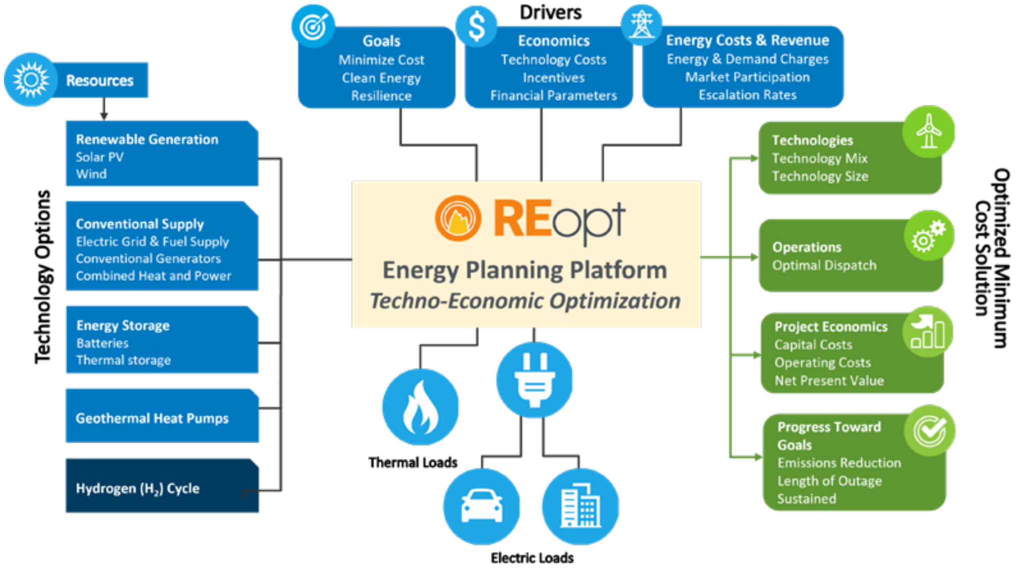
Cutler, Dylan, Dan Olis, Emma Elgqvist, Xiangkun Li, Nick Laws, Nick DiOrio, Andy Walker, and Kate Anderson. 2017. *REopt: A Platform for Energy System Integration and Optimization*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-70022. URL: https://www.nrel.gov/docs/fy17osti/70022.pdf.

Microgrids Planning

Techno-Economic Analysis Tool Development

NREL is working on adding a hydrogen energy storage system (which includes fuel cells, storage tanks, and an electrolyzer) as one of the technology options available in REopt®—a publicly available techno-economic decision-support platform developed by NREL researchers for energy system planning.

- Integrating a hydrogen energy storage system into REopt will advance the U.S. Department of Energy Hydrogen Program goals through the following project objectives:
  - Identify the optimal sizing of hydrogen fuel cells, electrolyzers, and storage tanks required to achieve a 100% renewable microgrid for Borrego Springs.
  - Quantify the reduction in greenhouse gas emissions and criteria pollutants resulting from (1) replacing on-site diesel generators with a hydrogen storage system, and (2) using hydrogen assets to supply site loads during grid-connected microgrid operations.
  - Improve accessibility of planning for H2 assets for a wide range of REopt users, including developers, researchers, government organizations, and utility and industry partners.



https://www.nrel.gov/reopt/

Cutler, Dylan, Dan Olis, Emma Elgqvist, Xiangkun Li, Nick Laws, Nick DiOrio, Andy Walker, and Kate Anderson. 2017. REopt: A Platform for Energy System Integration and Optimization. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-70022. URL: https://www.nrel.gov/docs/fy17osti/70022.pdf.

Resilience Analysis in REopt

How does REopt evaluate resilience?

REopt identifies the least cost asset portfolio to achieve target resilience (i.e., surviving the site critical loads for the target outage duration).

Energy Resilience Performance (ERP) tool: A post-processing tool that simulates outages at each hour of the year to produce the probability of survival curve.

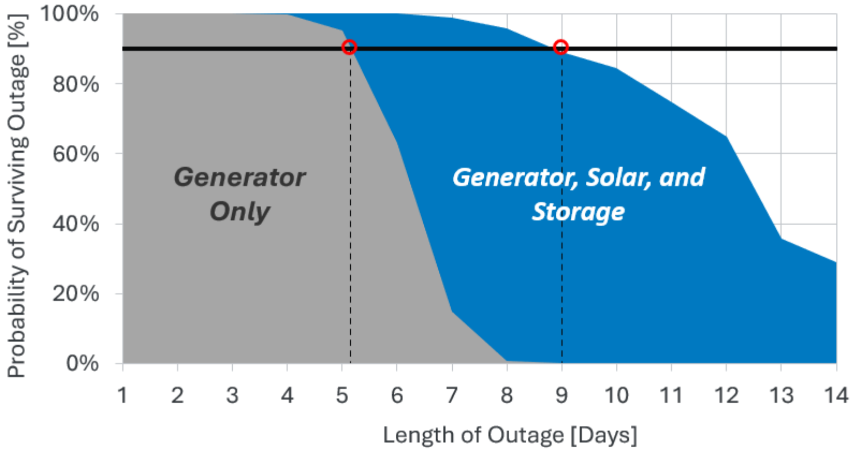


Image from NREL

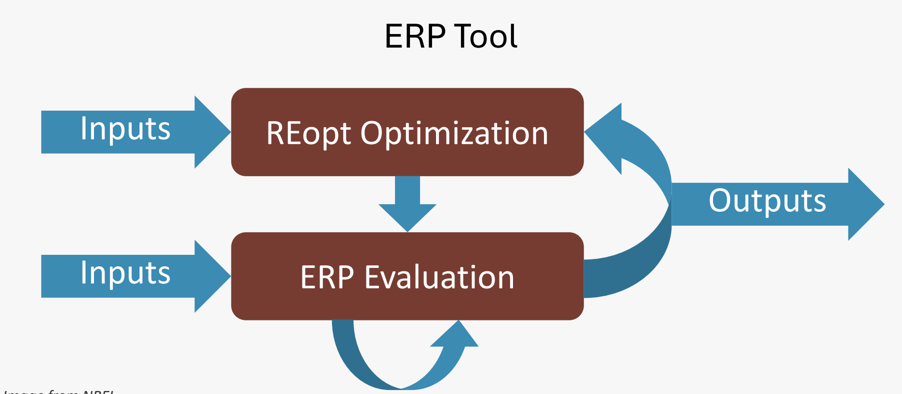


Image from NREL

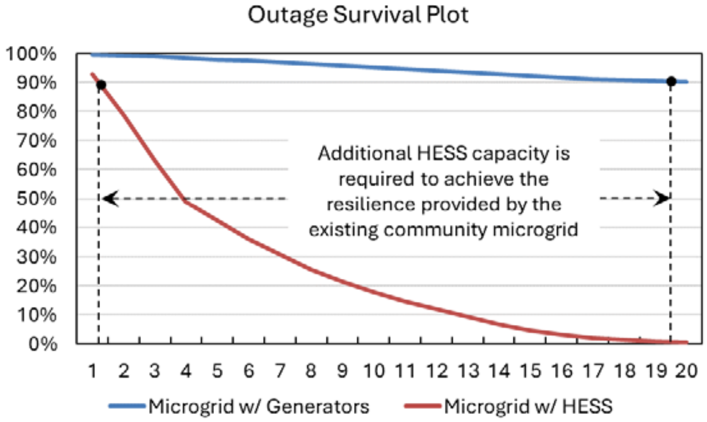
*REopt's ERP tool assesses system resilience after accounting for **reliability** of the DERs and **availability** of fuels. User-refined architectures include number of units, size of the DERs, and redundancy*

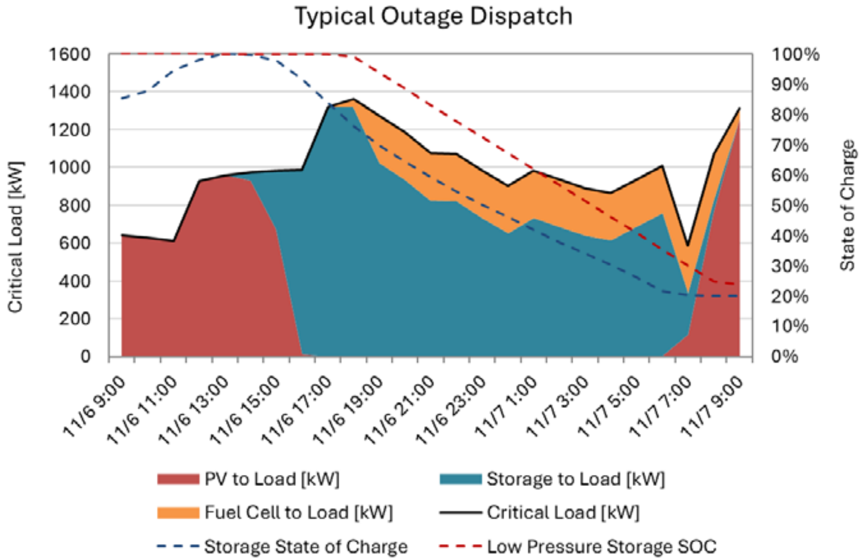
National Renewable Energy Laboratory. "Reopt for Resilience." URL: https://www.nrel.gov/reopt/curriculum/reopt-for-resilience

Example Results - Scenarios 1 and 2

Resilience from planned hydrogen assets (scenarios 1 and 2):

- The existing microgrid offers up to **20 hours** of resilience, whereas the planned hydrogen energy storage system (HESS) will offer up to **1 hour** of resilience.
- The planned hydrogen asset sizing does not provide enough resilience because:
  - The state of charge for both the battery energy storage system and HESS are depleted during the night.
  - The critical circuit rooftop photovoltaic (PV) capacity available is too small to recharge the battery energy storage system and HESS as well as to supply loads during t



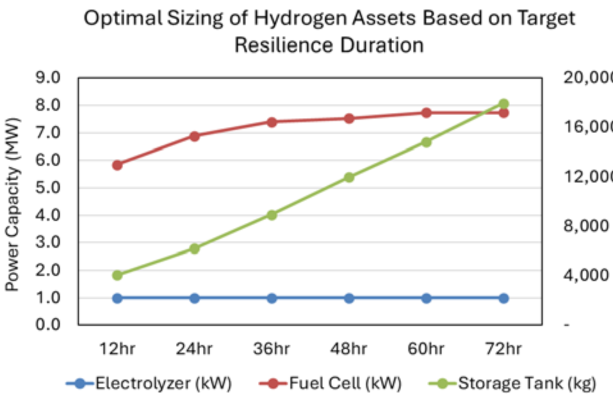


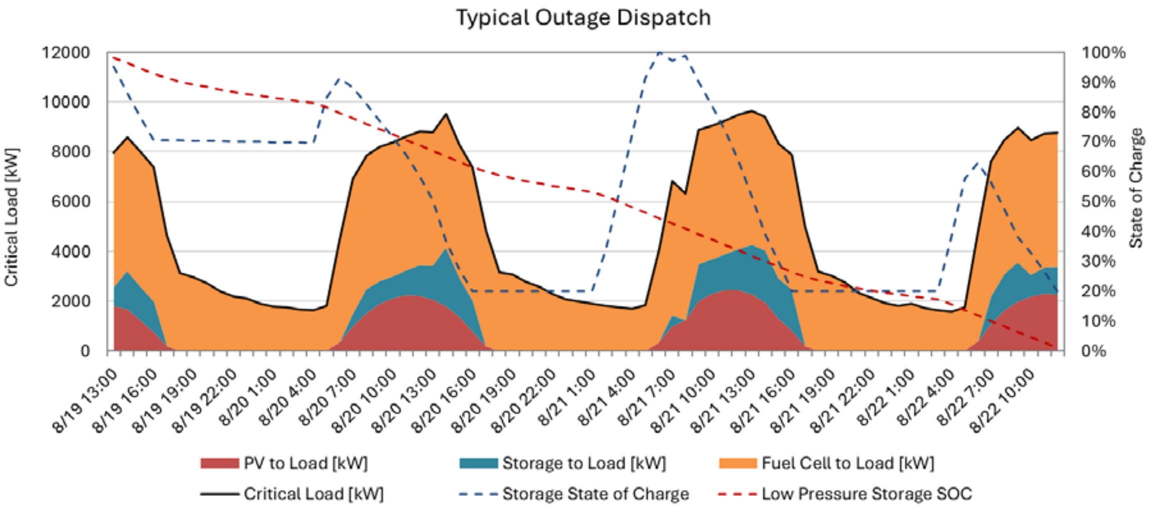
Preliminary NREL Analysis Results: Do Not Cite

Example Results – Scenario 3

Optimal hydrogen asset sizing for target resilience (Scenario 3):

- Hydrogen asset sizing based on target resilience duration is shown below. The target resilience hours is an important determinant in sizing the hydrogen assets for the microgrid.
- The critical circuit rooftop PV capacity available during an outage is not sufficient to recharge the storage as well as supply loads during the day. This forces the stored hydrogen at the start of an outage required to be sufficient to sustain critical loads for the duration of the outage. Therefore, allowing the additional existing PV to replenish the hydrogen storage will significantly reduce the storage sizing.





Preliminary NREL Analysis Results: Do Not Cite

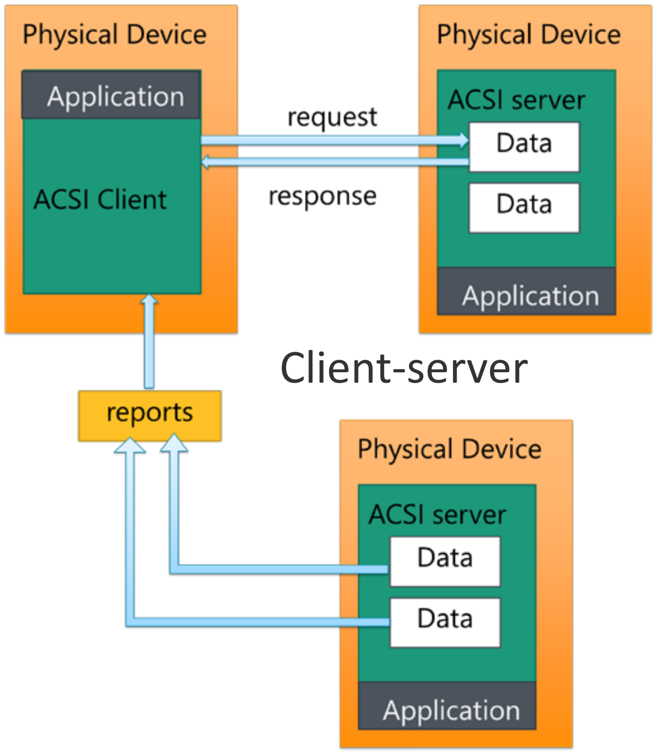
Microgrids Standards

Interconnection and Interoperability Standards & Importance for Distributed Generation in Microgrids

- IEEE 1547- (recent 2023). IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- UL 1741 Supplement SA: Grid Support Utility Interactive Inverters and Converters, Underwriters Lab, 2016
- CSA C22.3 No. 9: Interconnection of distributed energy resources and electricity supply systems [Draft]," Canadian Standards Association (CSA), Mississauga, 2019
- Few national grid codes in European Union.
- IEC 61850 Communication networks and systems for power utility automation –Part 7-420: Basic communication structure – Distributed energy resources and distribution automation logical nodes
- DNP3 Application Note AN2018-001 – DNP3 Profile for Communications with Distributed Energy Resources
- P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads

Last 10 years has seen updates every two or three years

Communication Architectures



Client-server

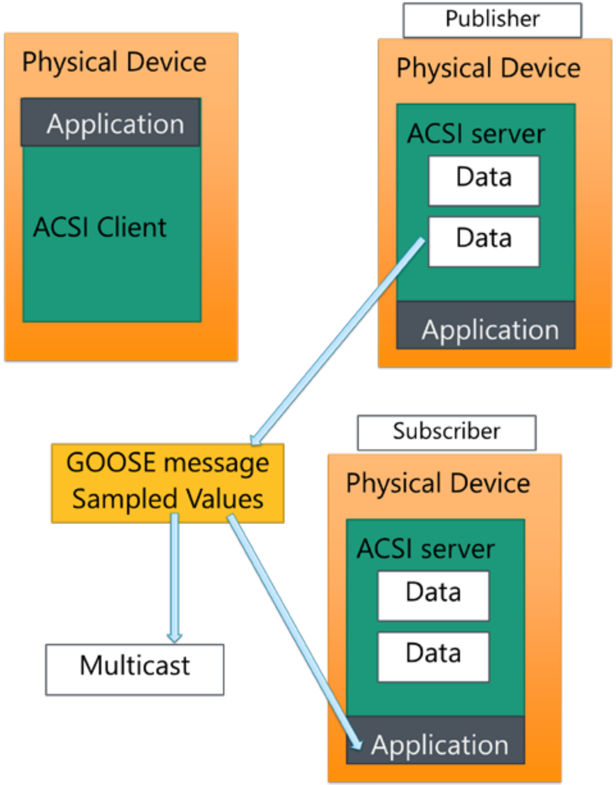
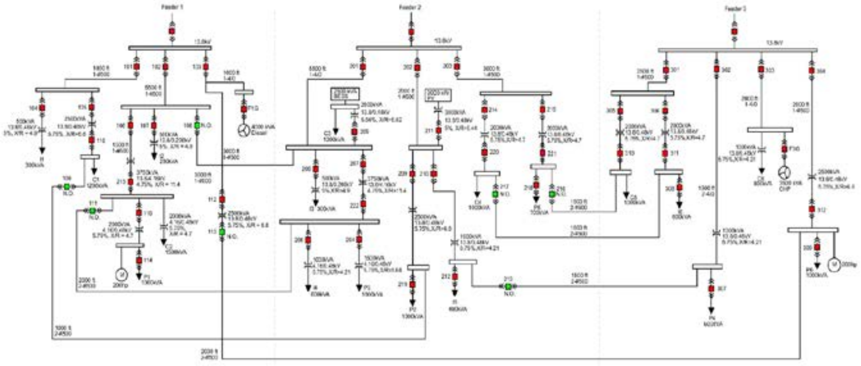


Image from NREL

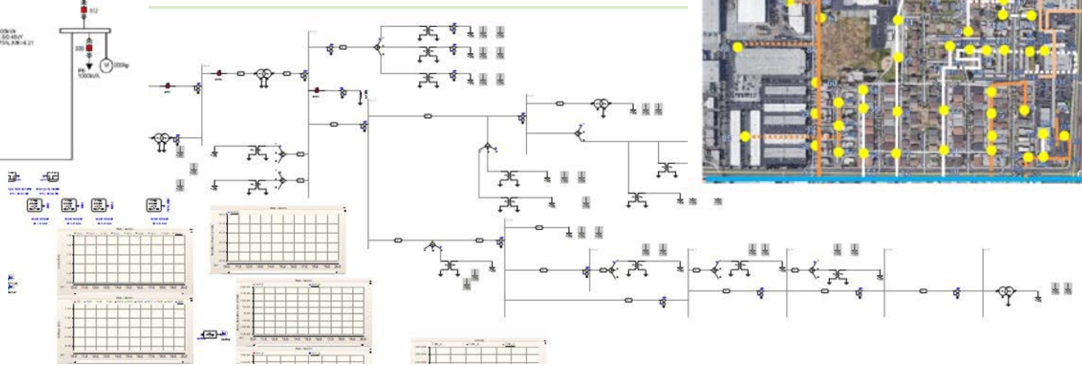
Publisher-subscriber

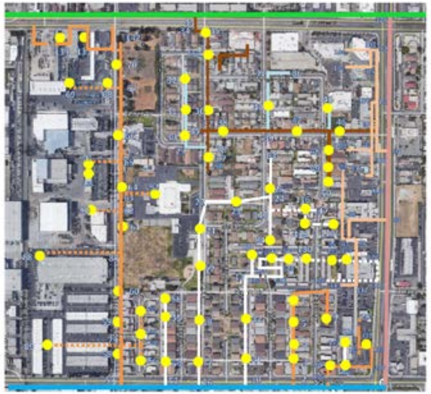
ACSI: Abstract Communications Services Interface
GOOSE: Generic Object-Oriented Substation Event

Microgrid Models Under Evaluations



Preliminary NREL Analysis



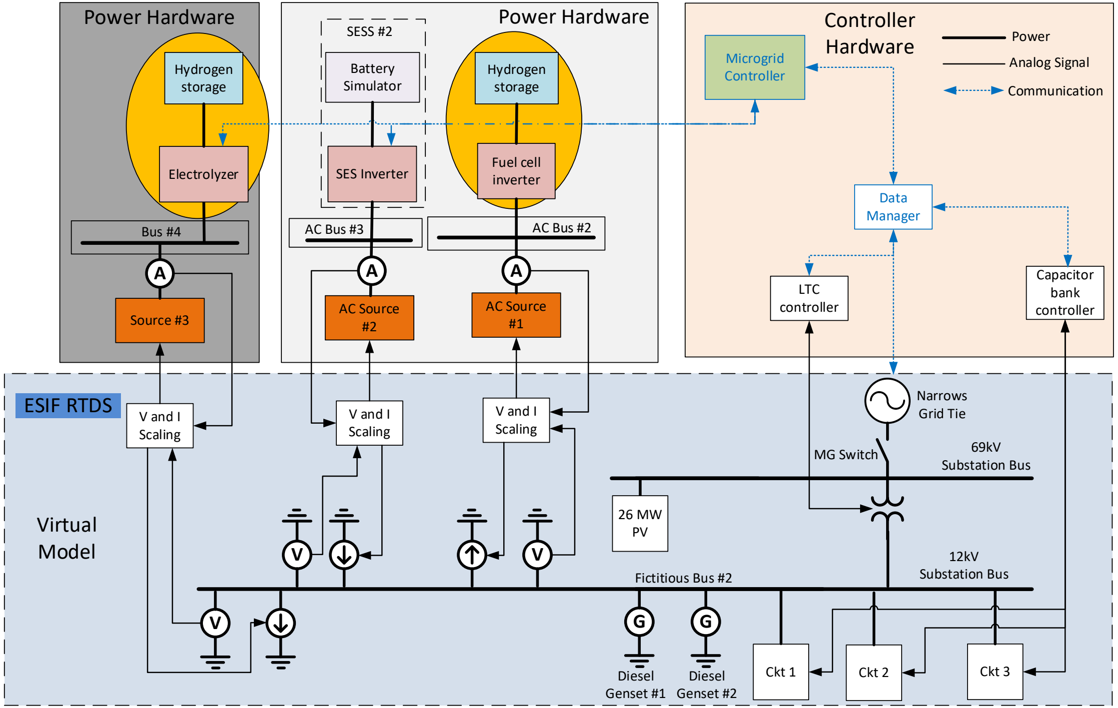


Completed and working on the following microgrid models:

- Banshee microgrid model, imaginary microgrid model
- Oak View Community, Huntington Beach, California – with aging electrical infrastructure and a critical city water pumping station
- Real microgrid in North Carolina
- Igiugig, Alaska – isolated microgrid power system
- And many more

Lab Demonstration

- Use Advanced Research on Integrated Energy System assets to run Power Hardware-in-the-Loop (PHIL) and controller hardware-in-the-loop experiments to de-risk field deployment.



RTDS: Real-time Digital Simulator

Images by NREL

Lab Demonstration

- Currently hosting PXiSE Energy Solutions' microgrid controller under a different project along with the Borrego Springs model in the controller
- The digital real-time simulation model of Borrego Springs is running at NREL's Energy Systems Integration Facility with the battery energy storage asset in PHIL and the PXiSE microgrid controller in controller hardware-in-the-loop.
- The PHIL setup with battery energy storage inverter is operational and reliable.

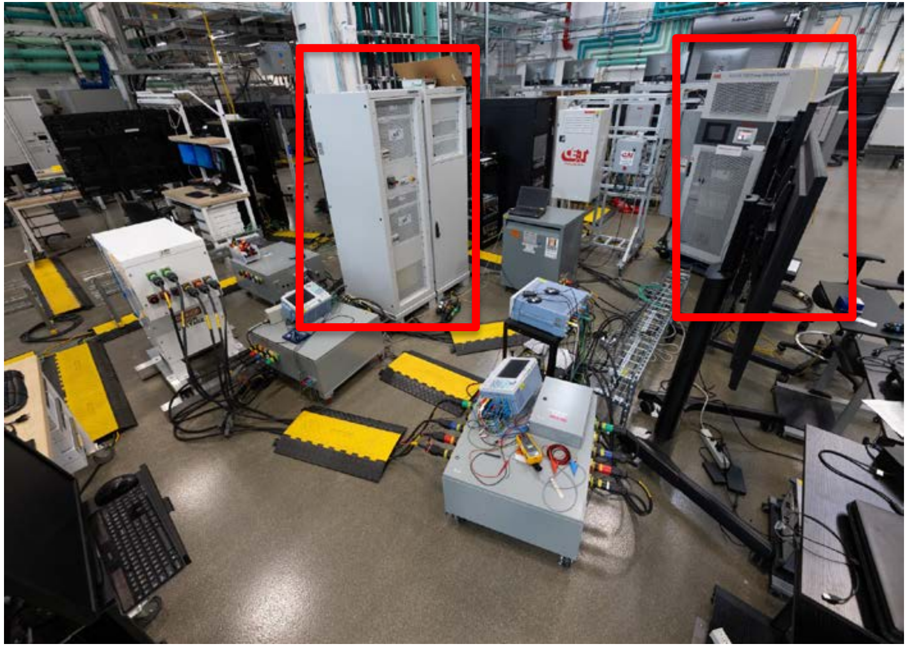
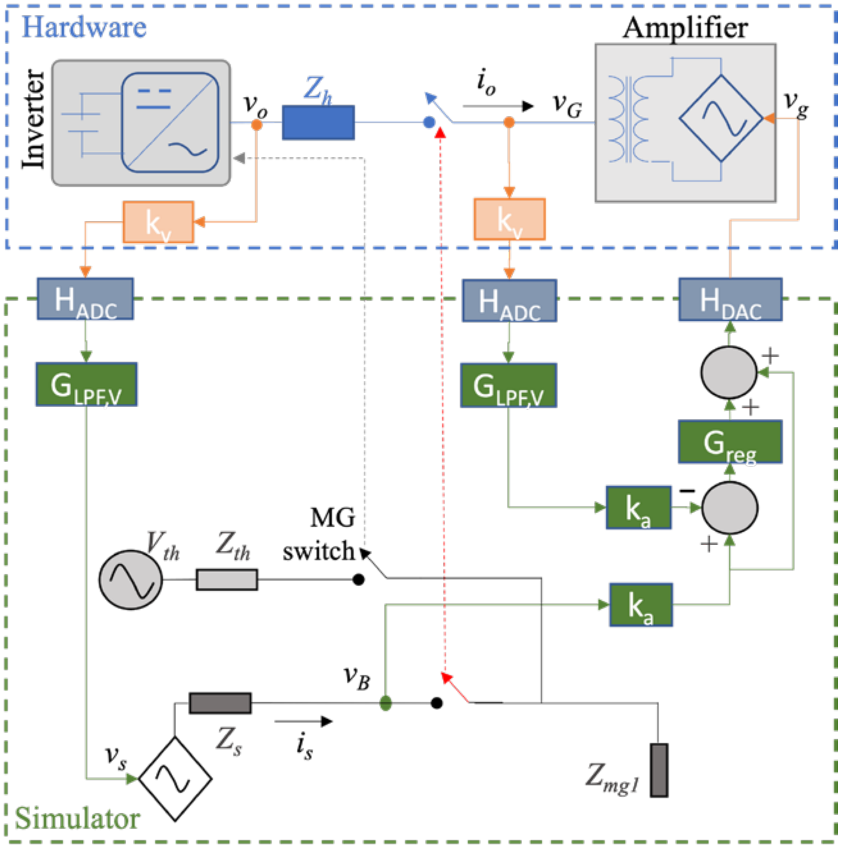
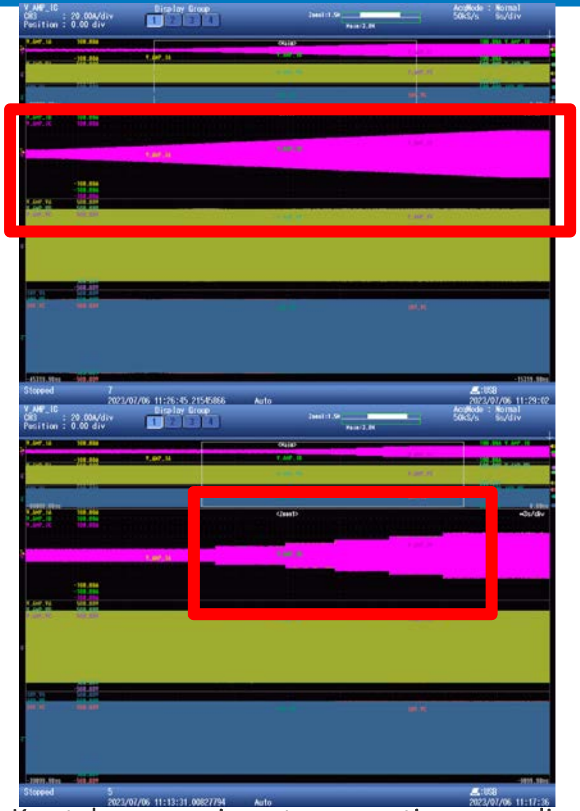


Photo by NREL

Initial PHIL Results from Grid-Forming Inverters





Scope capture of the inverter dispatch change in grid-connected operation showing the (top) current, (middle) the amplifier voltage, and (bottom) inverter voltage.

Scope capture of the load step change in islanded operation showing the (top) current, (middle) the amplifier voltage, and (bottom) inverter voltage.

Key takeaway – inverter operating according to sequence of operations

A. Pratt, K. Prabakar, S. Ganguly and S. Tiwari, "Power-Hardware-in-the-Loop Interfaces for Inverter-Based Microgrid Experiments Including Transitions," *2023 IEEE Energy Conversion Congress and Exposition (ECCE)*, Nashville, TN, USA, 2023, pp. 537-544

Summary

- REopt – useful planning tool for microgrid studies
- Controller hardware-in-the-loop and power hardware-in-the-loop are meaningful approaches to de-risking field deployment of microgrids.

Thank You

www.nrel.gov

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NREL/PR-5D00-92848

This work was authored by NREL for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding for the technical work provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. Funding for the webinar preparation provided by the U.S. Department of Energy Office of Policy. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.