Addressing Challenges for Single Microgrids and Networked Microgrids at Large Scales

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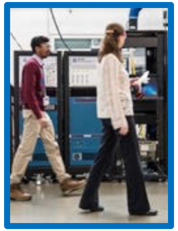
IEEE GreenTech

April 7–9, 2021

Overview

- Microgrid deployments continue, but challenges remain.
- Two case studies:
    1. Single microgrid:
        - Islanding under low-inertia conditions.
    2. Networked microgrids:
        - System restoration impacts.
- Focus on the role of laboratory evaluation.

Energy Systems Integration Facility



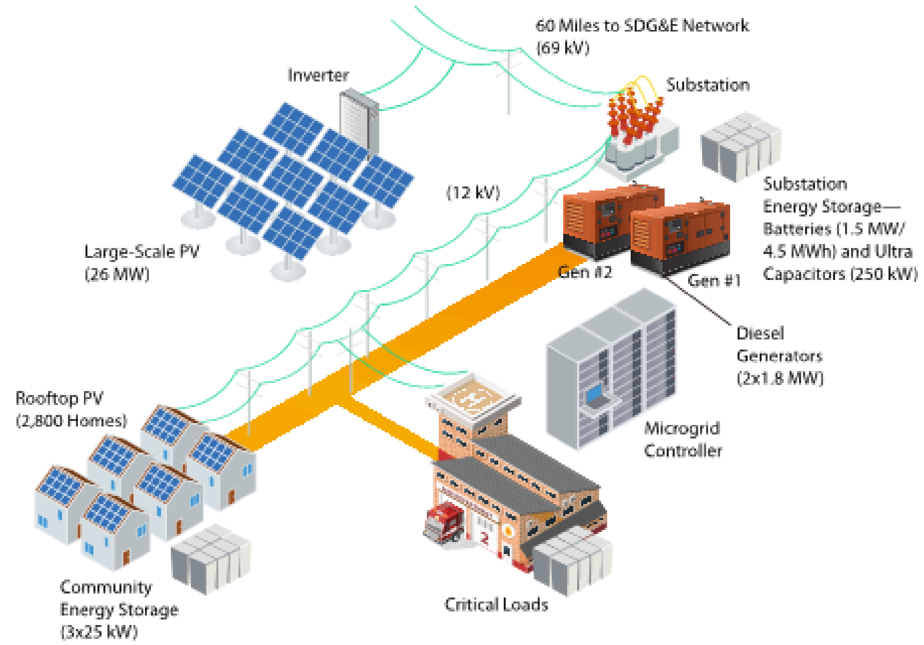
- The Energy Systems Integration Facility (ESIF) is a national user facility located in Golden, Colorado, on the campus of the National Renewable Energy Laboratory (NREL) (http://www.nrel.gov/esif).
- Megawatt-scale controller- and power-hardware-in-the-loop (CHIL/PHIL) capability
- Allows testing of energy technologies at full power in real-time grid simulations to safely evaluate performance.

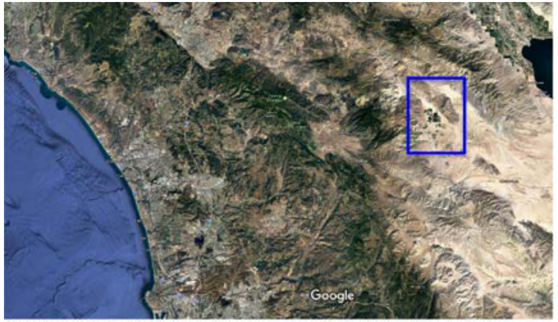
Photos by NREL

High-Penetration Microgrid: SDG&E Borrego Springs

- High concentration of customer-owned solar generation
- Potential for reliability enhancements
- Transmission line thermal limit below maximum net export
- Opportunity to balance supply and demand to be more self-sufficient.

Photo by SDG&E





Borrego Springs Microgrid Assets

Existing:

- ~14-MW native load
- 26-MW photovoltaics (PV)
- 4.5-MW rooftop PV
- 6.5-MW concentrating PV (CPV)
- 1.5-MW/3-h battery energy storage system (BESS) *{future expansion to X MWh}*
- 250-kW ultracapacitor
- 3.6-MW diesel gensets.

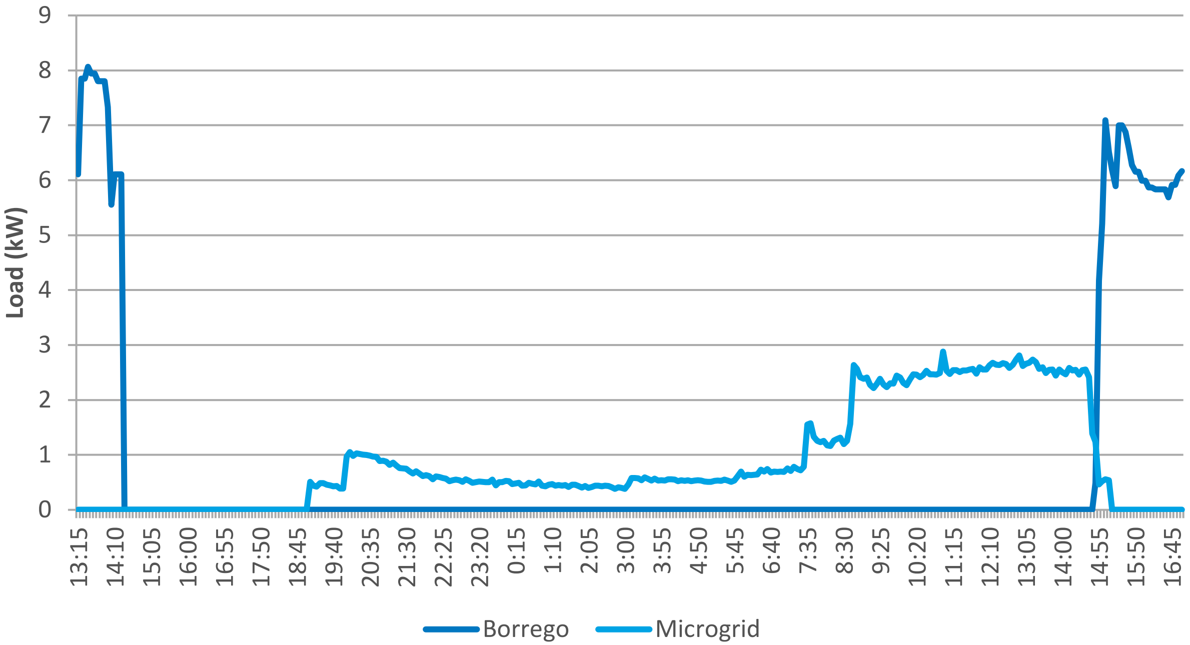
Adding:

- Additional non-conventional resources

Photo by SDG&E

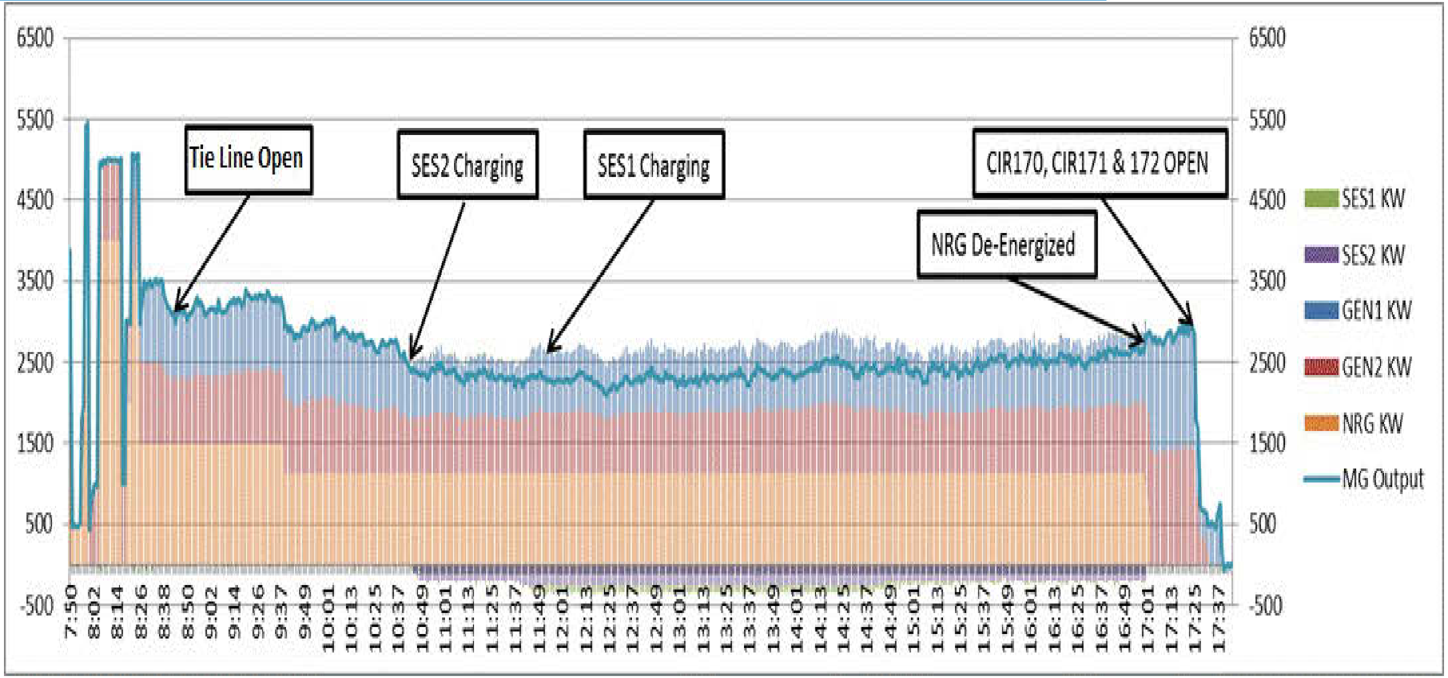
Borrego Outage September 6–7

- At 14:20, a single transmission line to Borrego tripped out.
- Nine transmission and 11 distribution poles were reported down.
- 1,056 customers had power restored during the outage.



Photos by SDG&E

Real-World Experience (Island 3)



May 21, 2015, islanding event

Results provided by SDG&E

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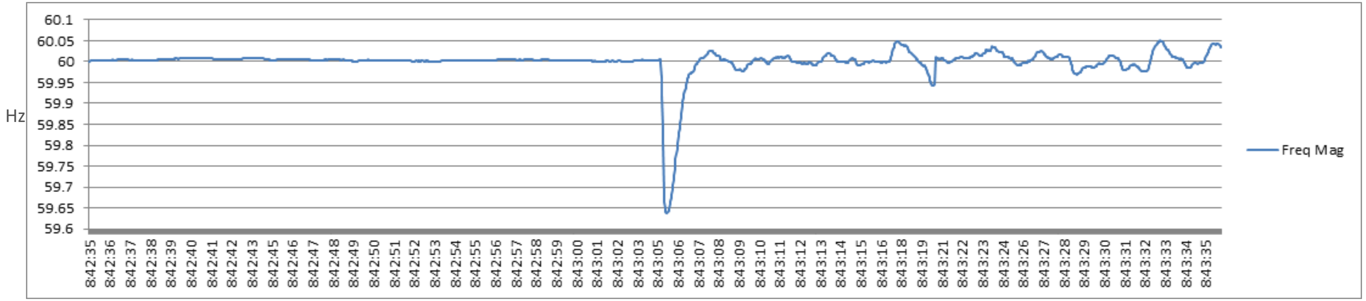

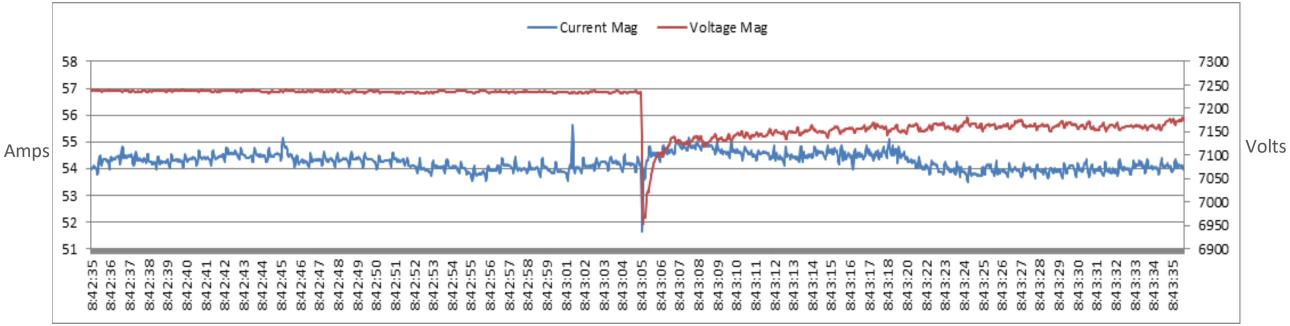

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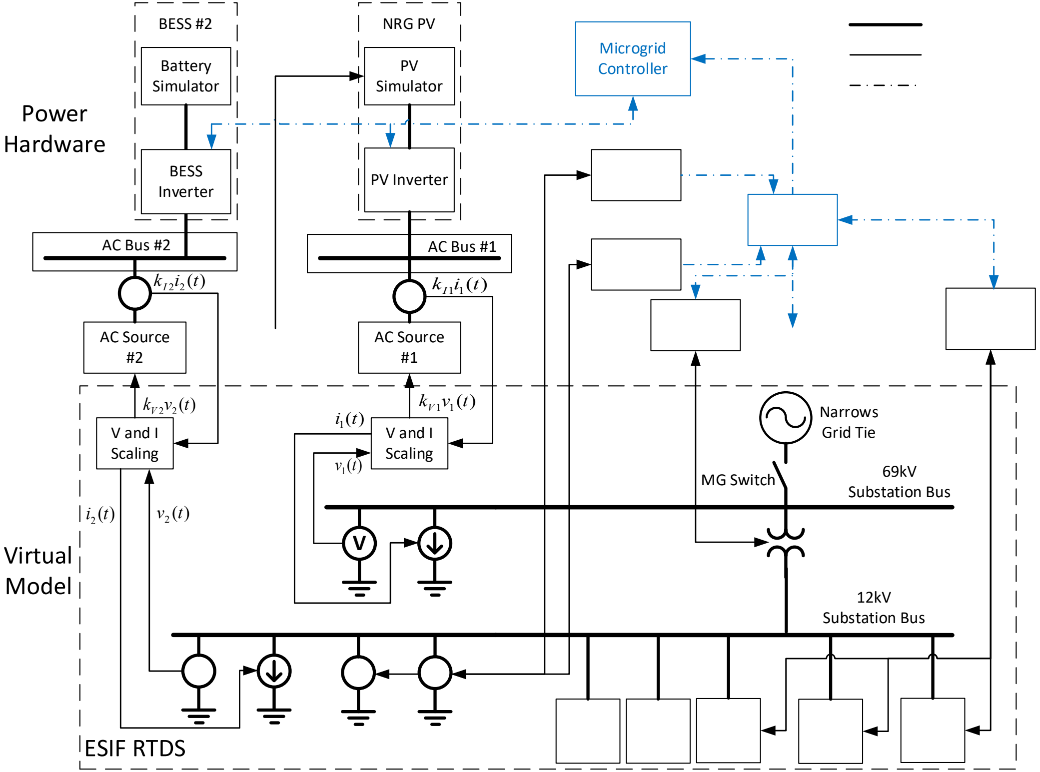
Results provided by SDG&E

Islanding with 100% Renewables

- U.S. Department of Energy (DOE) Solar Energy Technologies Office-funded project, led by San Diego Gas & Electric Company (SDG&E)
- Scope:
  - Add advanced grid-forming inverter and microgrid controller.
- Objectives :
  - Validate, via laboratory and field tests, innovative microgrid technologies that enable distributed energy resources (DERs), including multiple smart PV inverters and a grid-forming battery inverter, to contribute to grid stability and resilience by establishing frequency and maintaining voltage magnitude during transient conditions, especially during microgrid islanding.
  - Advance the state of the art in grid-forming inverter controls through field deployment of an advanced grid-forming BESS and using this BESS to provide fast frequency response during islanding.
  - Advance the state of the art of demonstrating how intelligent control of distributed assets can improve local system reliability and resilience and reduce PV curtailment due to islanding operations.
  - Attempt to island the Borrego Springs Microgrid with 100% renewable resources and black-start without fossil generators.

HIL Evaluation Platform at NREL



PHIL:

BESS inverter (actual ABB 100-kW); grid-forming

PV inverter (actual SMA 500-kW); grid-following

CHIL:

PXiSE microgrid controller

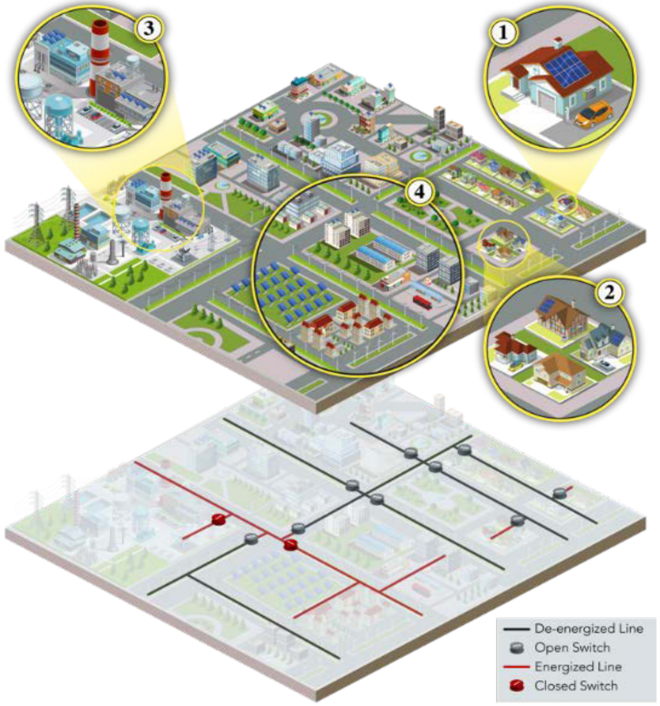
EasyGen diesel generator controllers

Load tap changer and capacitor bank controllers

Photos by NREL

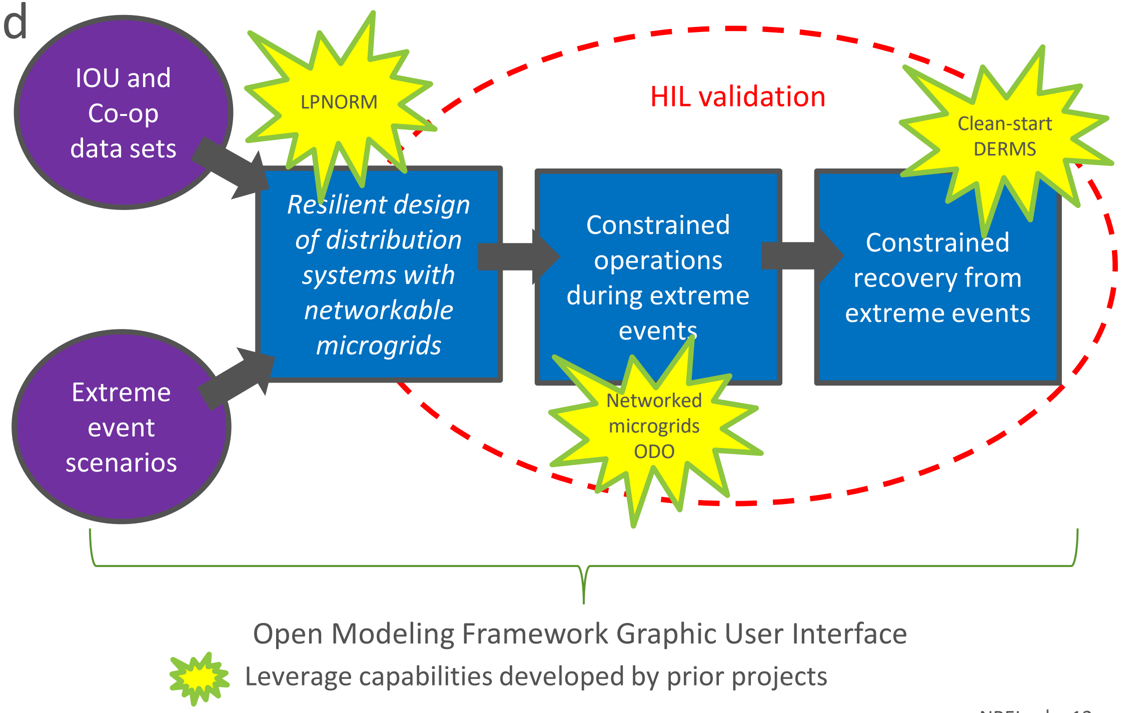
System Restoration with Networked Microgrids

- Individual microgrids have proven their ability to increase reliability and resilience, but at a high cost.
- Networked microgrids can further increase reliability and resilience and mitigate the high costs.
- Networked microgrids provide the following:
  - Resilience (to extreme events)
  - Reliability and security (normal/single failures, e.g., N-1)
  - Economics (combined investment and operations)
  - Efficiency (operating at efficiency points).
- Networked microgrids can exist in many variations.

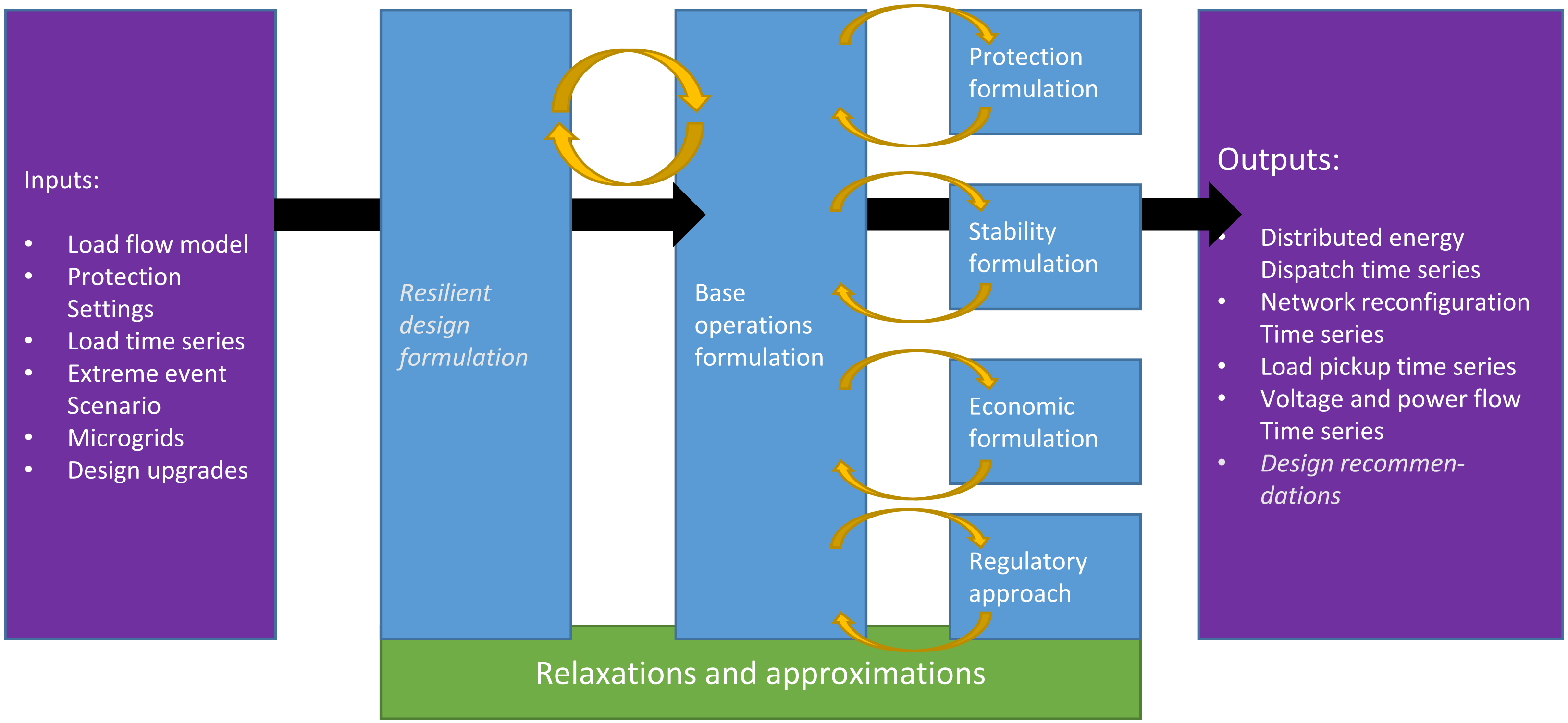


Resilient Operations of Networked Microgrids

- DOE Office of Electricity microgrids program invested in several networked microgrids projects.
- Also, the DOE Grid Modernization Laboratory Consortium, e.g., Citadels
- Focus here on Resilient Operations of Networked Microgrids (RONM).



Formulation and Methodology

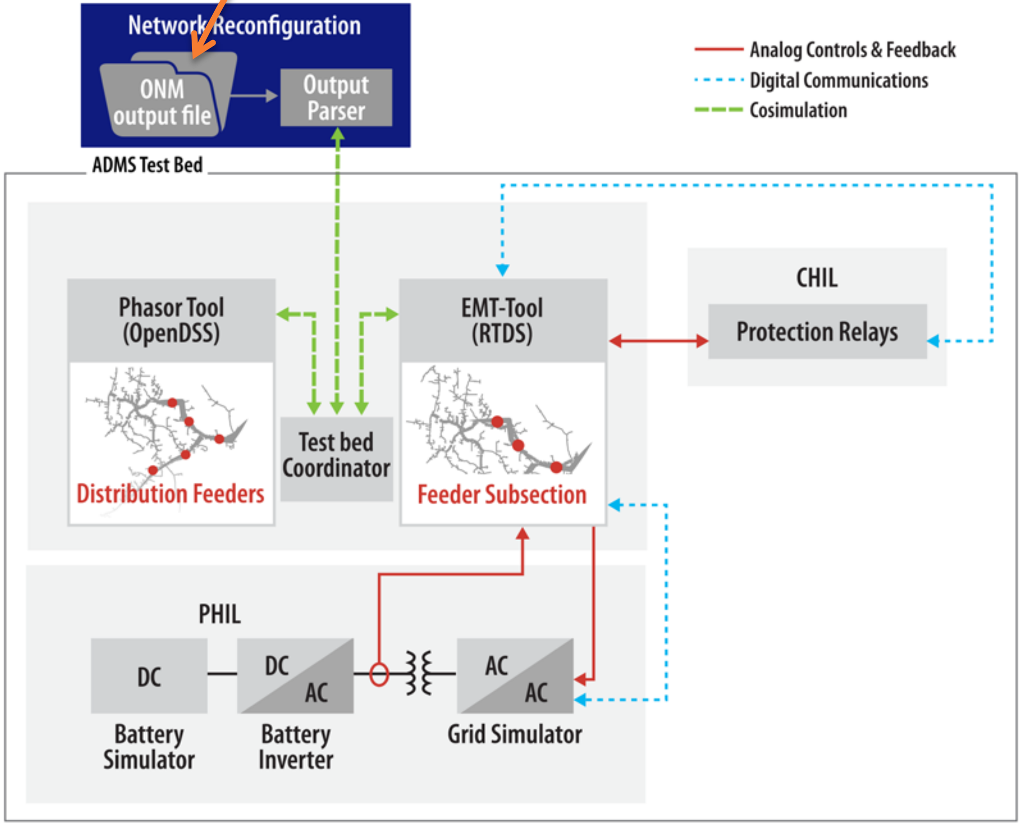


RONM Laboratory Evaluation

Timeline

Device	Time	Action	Load Before	Load After
l2	1	Switching	50	0
s701a	3	Load Shed	20	10
s713c	7	Load Pickup	10	20
799r	10	Battery Control	50	60
705	15	Generator Control	50	40

- Evaluate RONM solutions for reconfiguration and restoration of distribution systems after extreme events.
- Validate on a HIL evaluation platform, NREL’s advanced distribution management system (ADMS) test bed.
- Use distribution system models adapted from utility partners.
- Demonstrate that the solutions do not violate key physical and engineering constraints:
    - E.g., cold-load pickup.



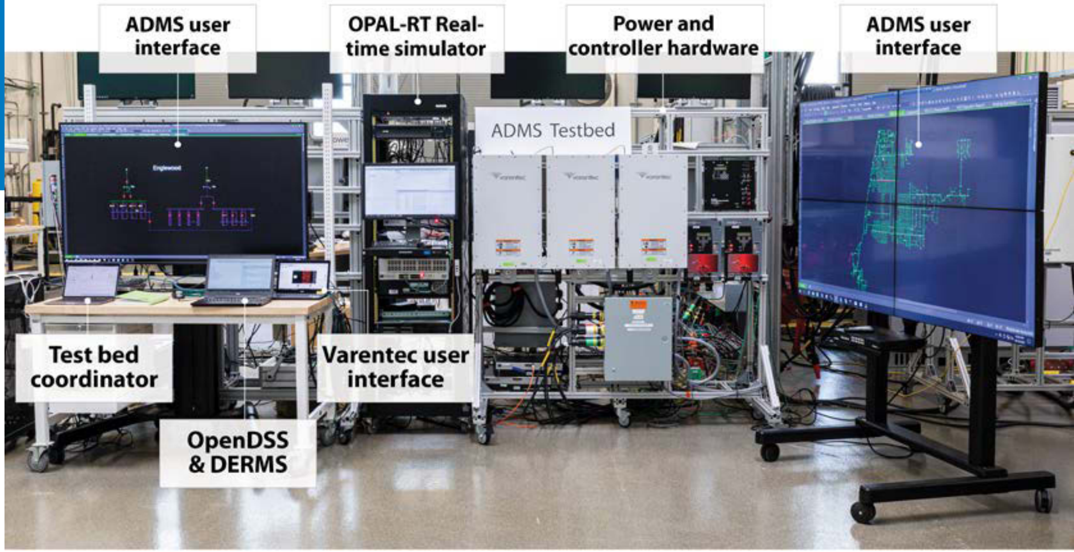
ADMS Test Bed

Expected outcomes: Increased industry confidence in ADMS technology through:

- Laboratory demonstration of applications for specific use cases
- Analysis and potential application to other utilities.

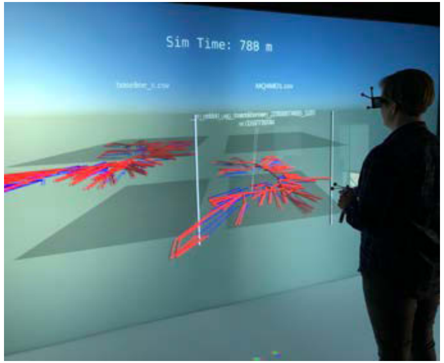
Progress:

- ADMS test bed capabilities developed:
  - Multi-timescale cosimulation using HELICS (OpenDSS/Opal-RT/RTDS)
  - Hardware integration
  - Communications interfaces
  - Data collection and visualization.



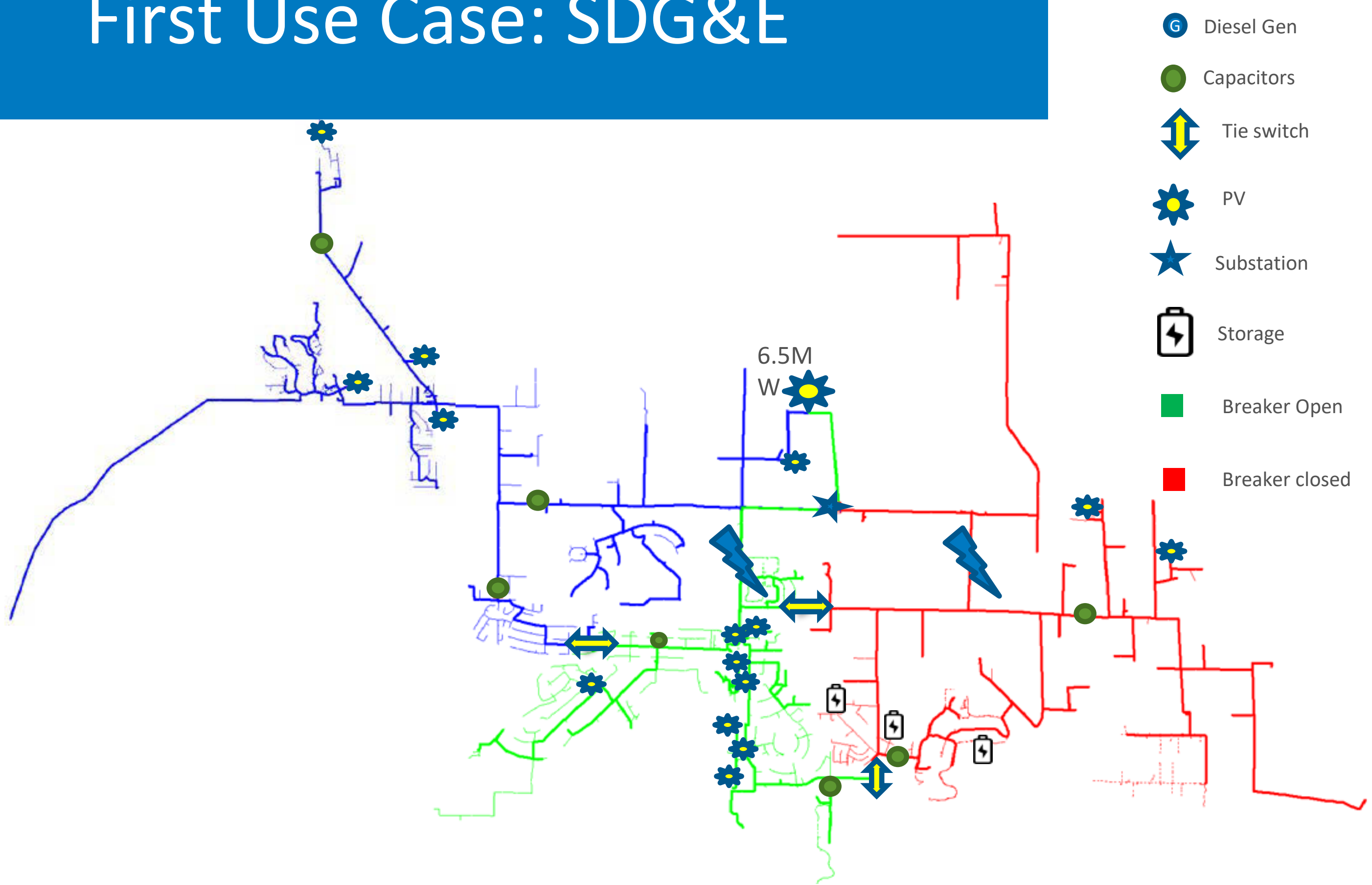
Photos by NREL

2D real-time visualization

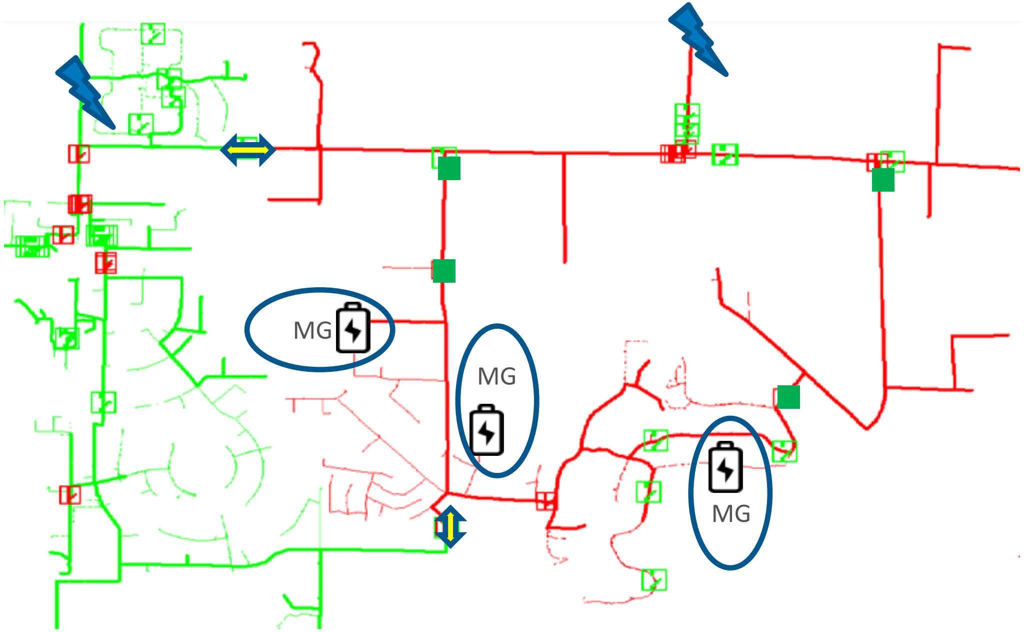


3D visualization

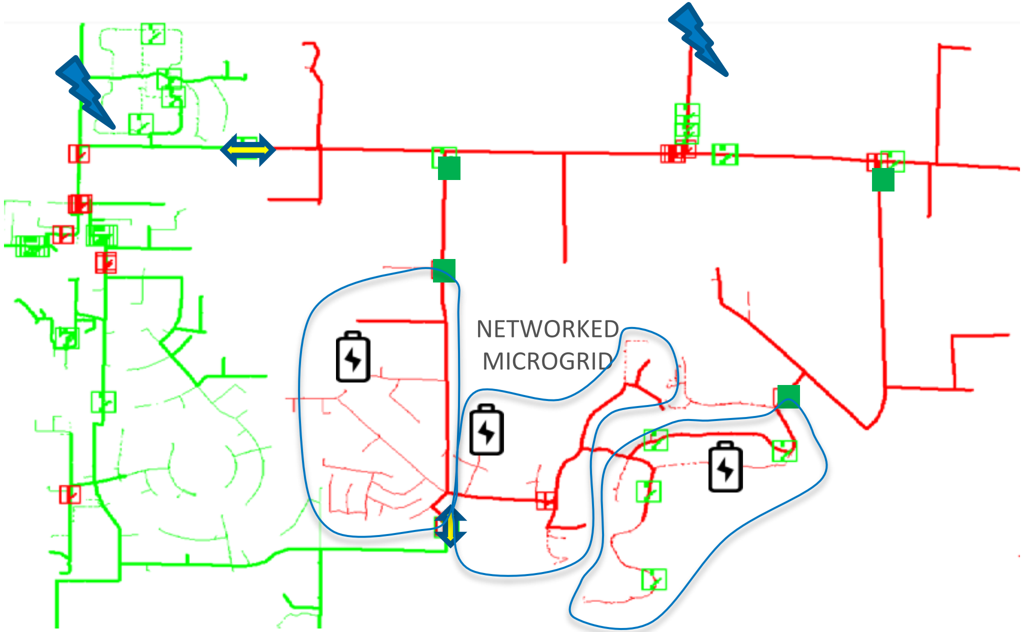
First Use Case: SDG&E



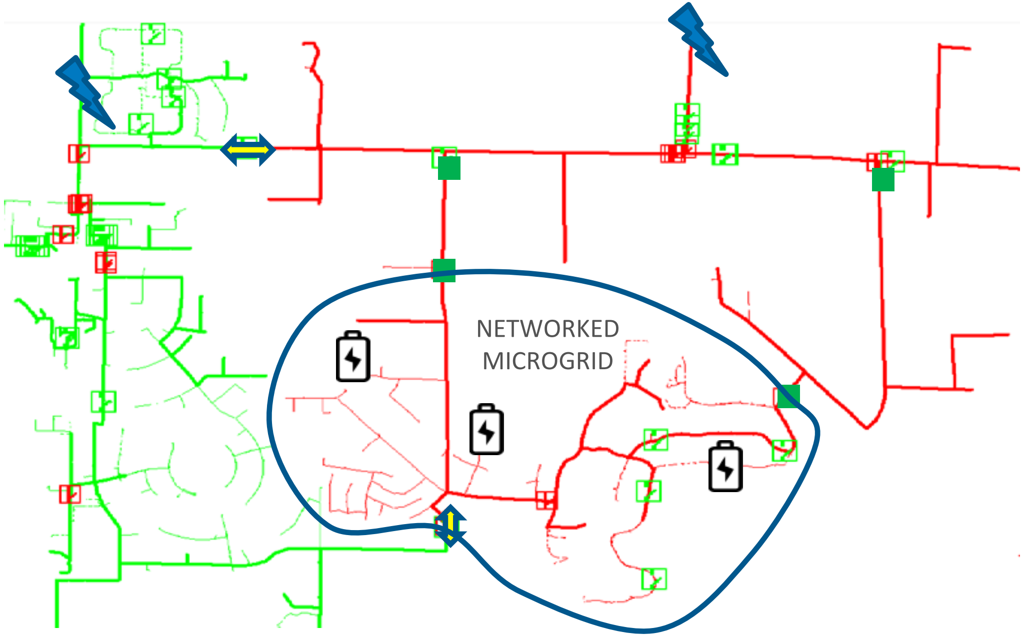
Individual Microgrid Formation



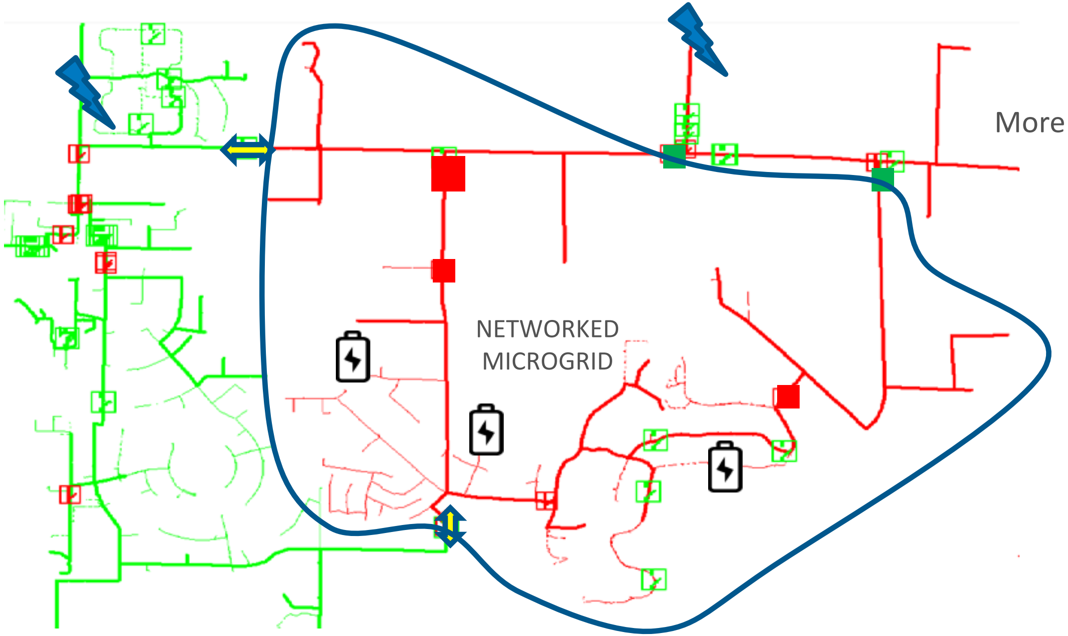
Networked Microgrids



Networked Microgrid



Extending Networked Microgrid



More switches closed

Summary

- Microgrid deployments continue to increase driven by resilience requirements.
- Increased penetration of inverter-based resources results in challenging low-inertia environments.
- Networking of microgrids hold promise but will require new tools.
- Laboratory evaluation can be used to simulate scenarios without risk to customers that can provide useful insight prior to field deployment.

Thank You

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NREL/PR-5D00-79638

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by Department of Energy, Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office, and Office of Electricity, Microgrids Program. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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Further Reading

- K. Prabakar et al. 2019. “Site-Specific Evaluation of Microgrid Controller Using Controller and Power-Hardware-in-the-Loop.” Presented at IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 2019, pp. 6463–6468, doi: 10.1109/IECON.2019.8927354.

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- A. Maitra et al. 2017. “Microgrid Controllers: Expanding Their Role and Evaluating Their Performance.” *IEEE Power and Energy Magazine* 15 (4) (July–August): 41–49, doi: 10.1109/MPE.2017.2690519.

- Katmale, Hilal, et al. 2018. “Borrego Springs: California’s First Renewable Energy Based Community Microgrid.” California Energy Commission, Publication Number: CEC-500-2019-013.

- Ainsworth, Nathan, Ali Hariri, Prabakar Kumaraguru, Annabelle Pratt, and Murali Baggu. 2016. “Modeling and Compensation Design for a Power Hardware-in-the-Loop Simulation of an AC Distribution System.” Presented at the North American Power Symposium (NAPS), Denver, Colorado, September 18–20, 2016.

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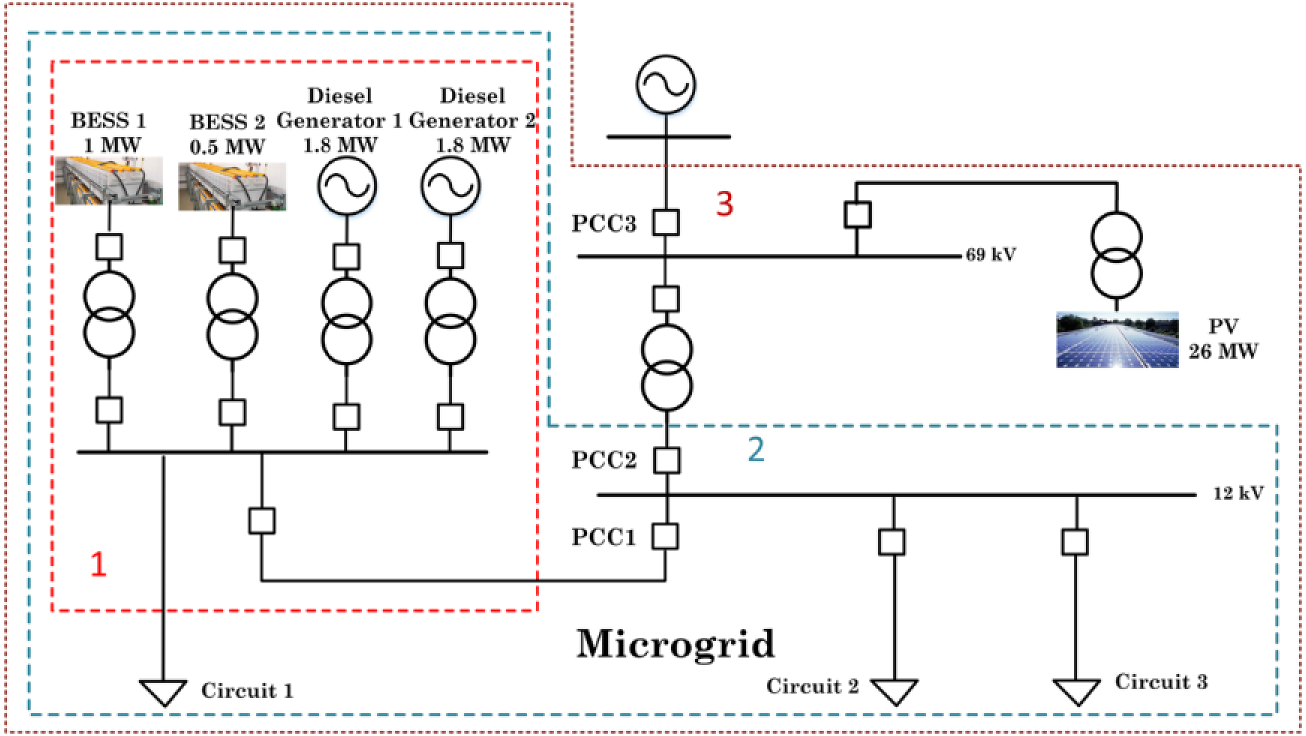
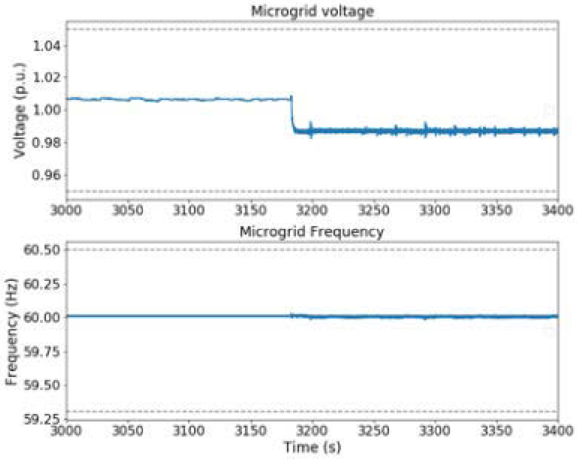
- Wang, Jing, John Fossum, Kumaraguru Prabakar, Annabelle Pratt, and Murali Baggu. 2018. “Development of Application Function Blocks for Power-Hardware-in-the-Loop Testing of Grid-Connected Inverters.” Presented at the 2018 IEEE 9th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), June 25–28, Charlotte, North Carolina.

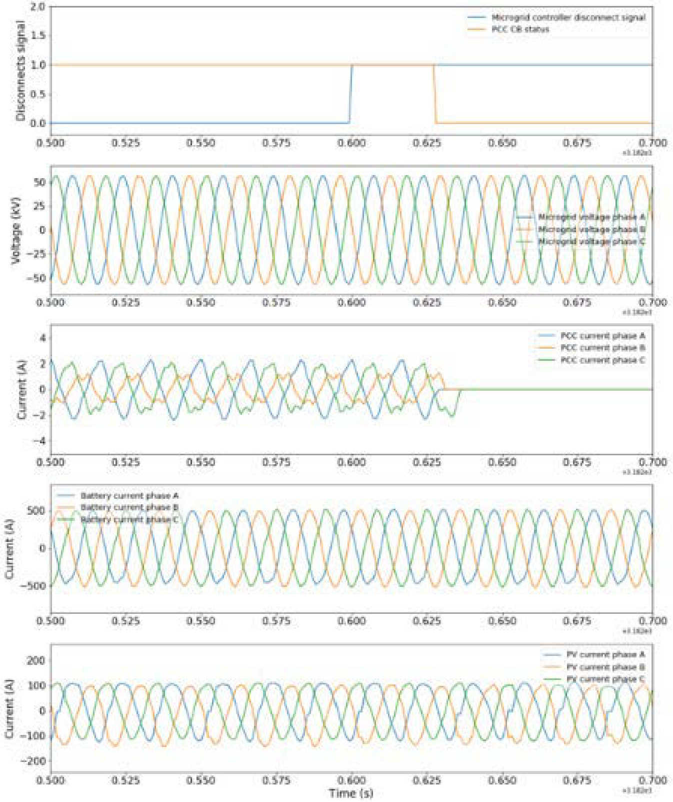
Microgrid Setup



CEC Project Results: Planned Disconnection

- Heavy-load condition
- MGC regulates power flow across PCC to near zero
- Smooth transition when microgrid switch is opened
- Voltage and frequency meet steady-state requirements





CEC Project Results: Unplanned Disconnection

- Simulated (CHIL only) over- and undervoltage and frequency conditions and faults
- MGC does not respond but relies on protection equipment
- MGC redispatches after disconnection if microgrid survives or manages black starts.