NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Borrego Springs Community Microgrid

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International Microgrids Symposium

High-Penetration Microgrid: SDG&E Borrego Springs

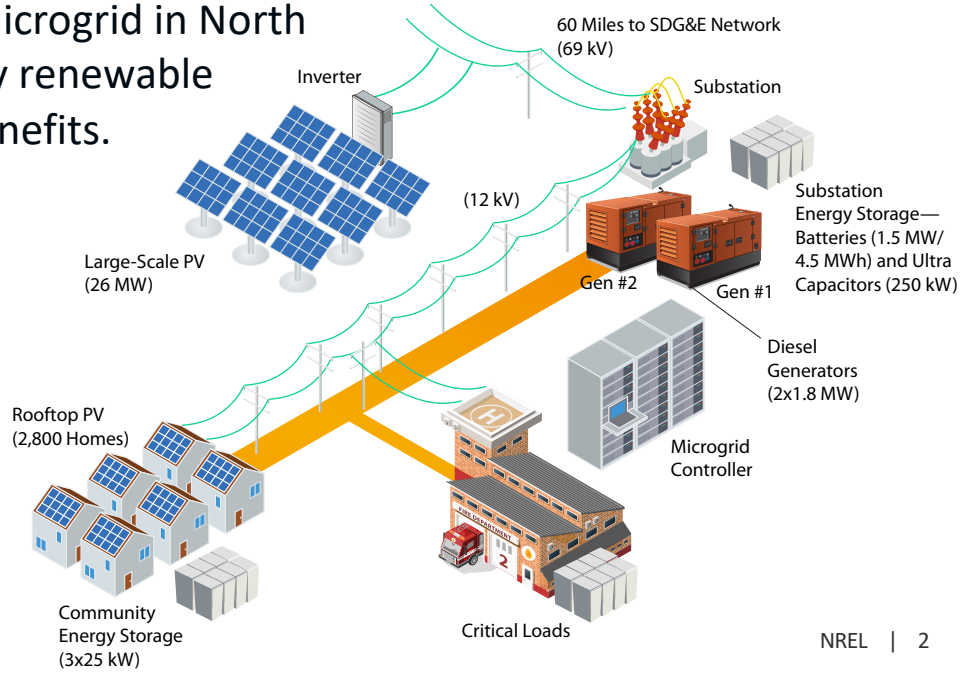
Goal: Demonstrate the viability of a microgrid to manage high amounts (up to 100%) of renewable, intermittent energy resources to meet community load that can be replicated by others while leveraging (post-project) off-the-shelf software

Impact: Successful implementation of the largest microgrid in North America will prove that a community-scale, highly renewable microgrid can be implemented with economic benefits.

Funded by:
California Energy Commission

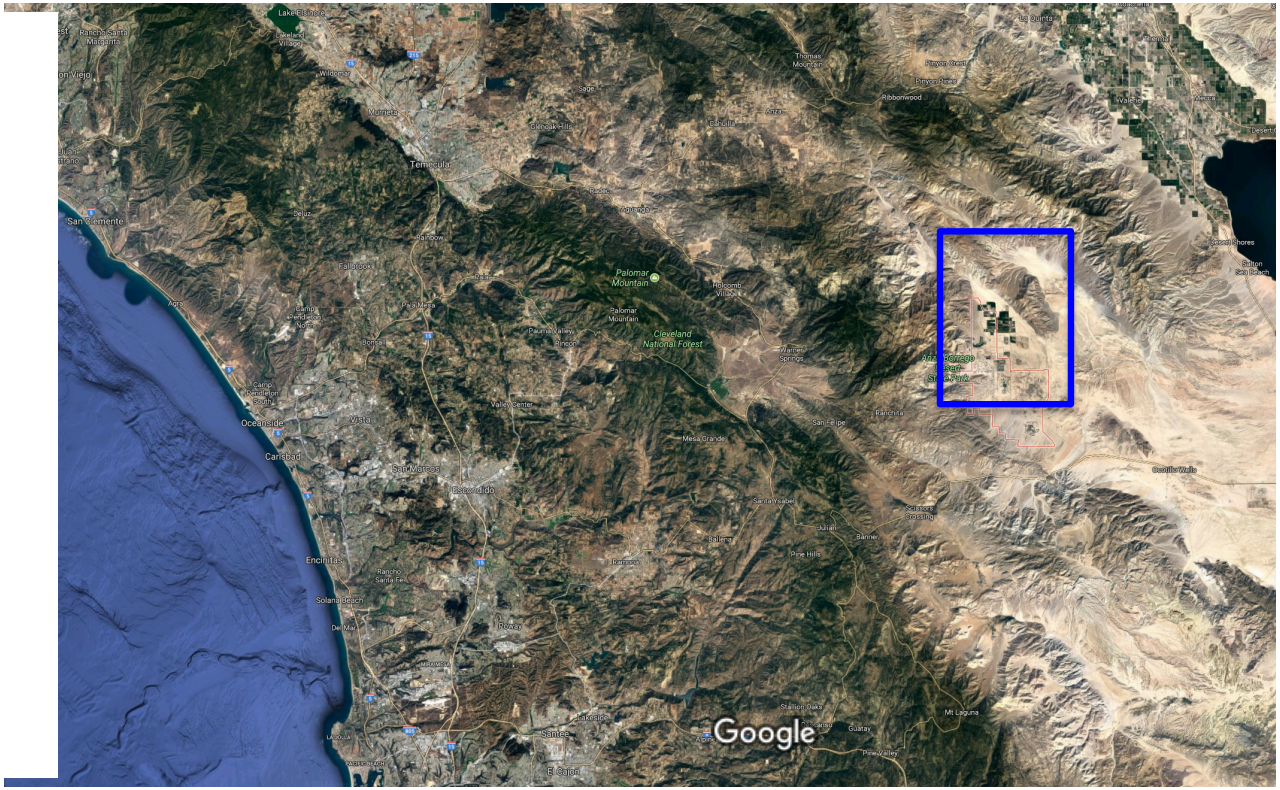
Led by:
SDG&E

Partners:
NREL, Spirae, UCSD, OSIsoft, SMA, NRG



Brief Visual Tour of Borrego Springs

- Progressive-minded community
- High concentration of customer-owned solar generation
- Potential for reliability enhancements
- Opportunity to balance supply and demand to be more self-sufficient
- Extendable to service territory



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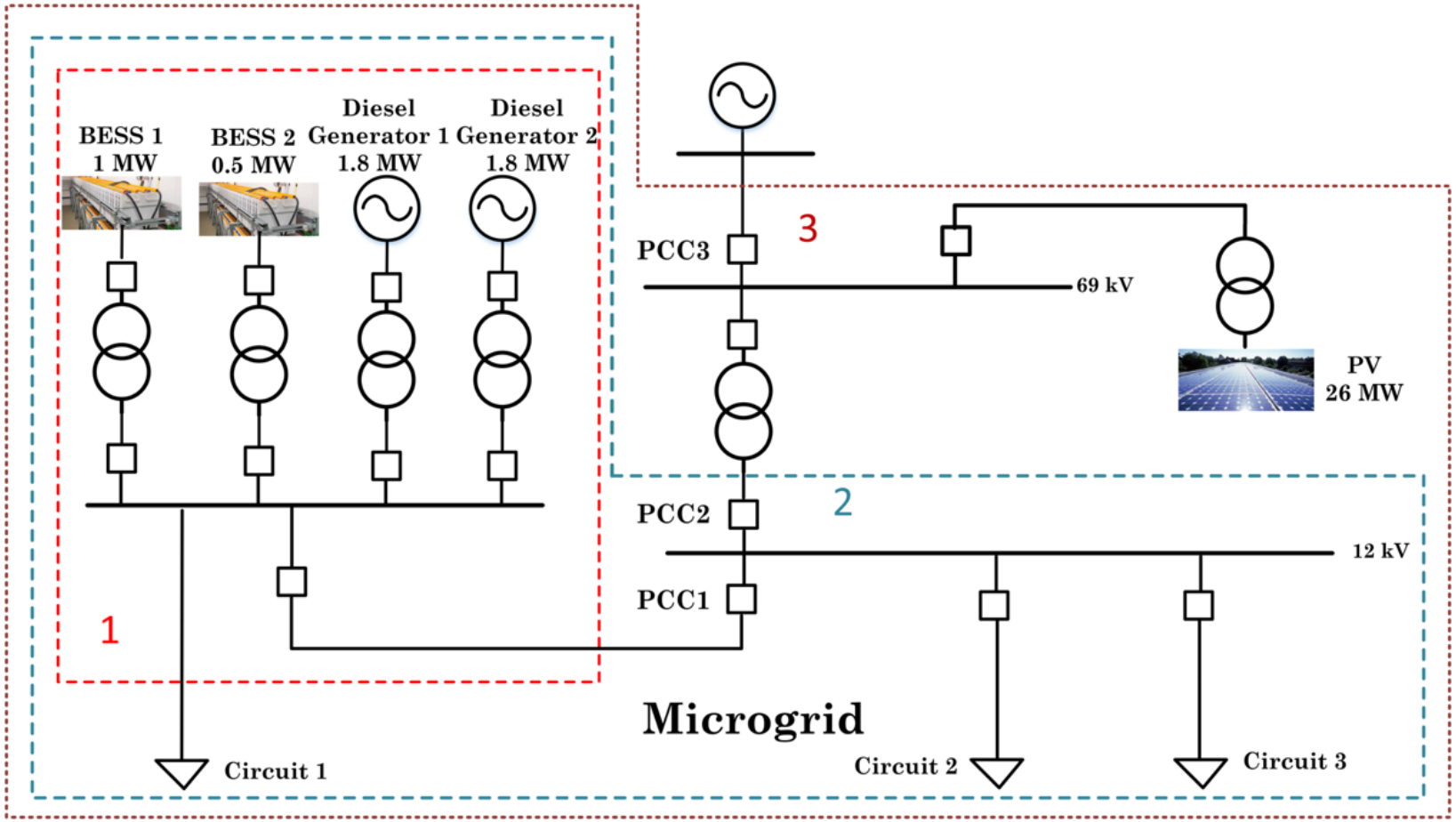
United States

Borrego Springs Microgrid



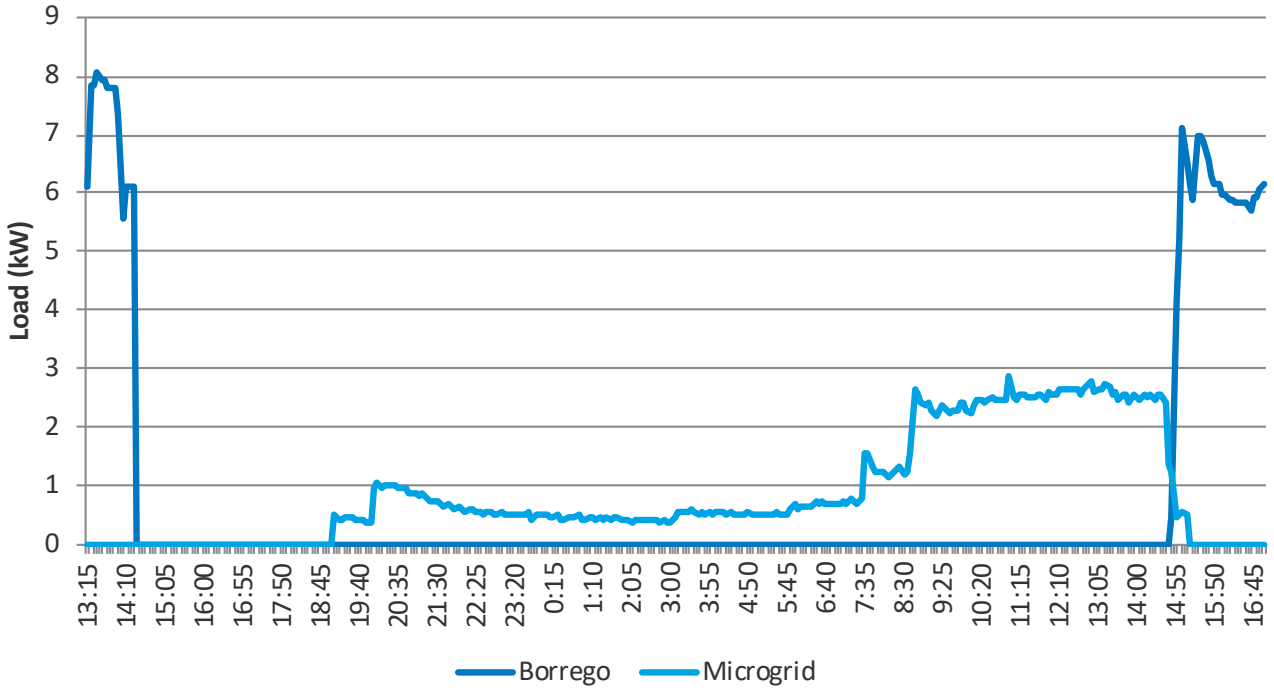

250-kW, 15-min ultracapacitor
Diesel generators
Control room
1000-kW, 3000-kWh battery
500-kW, 1500-kWh battery

Real-World Experience (Island 1)

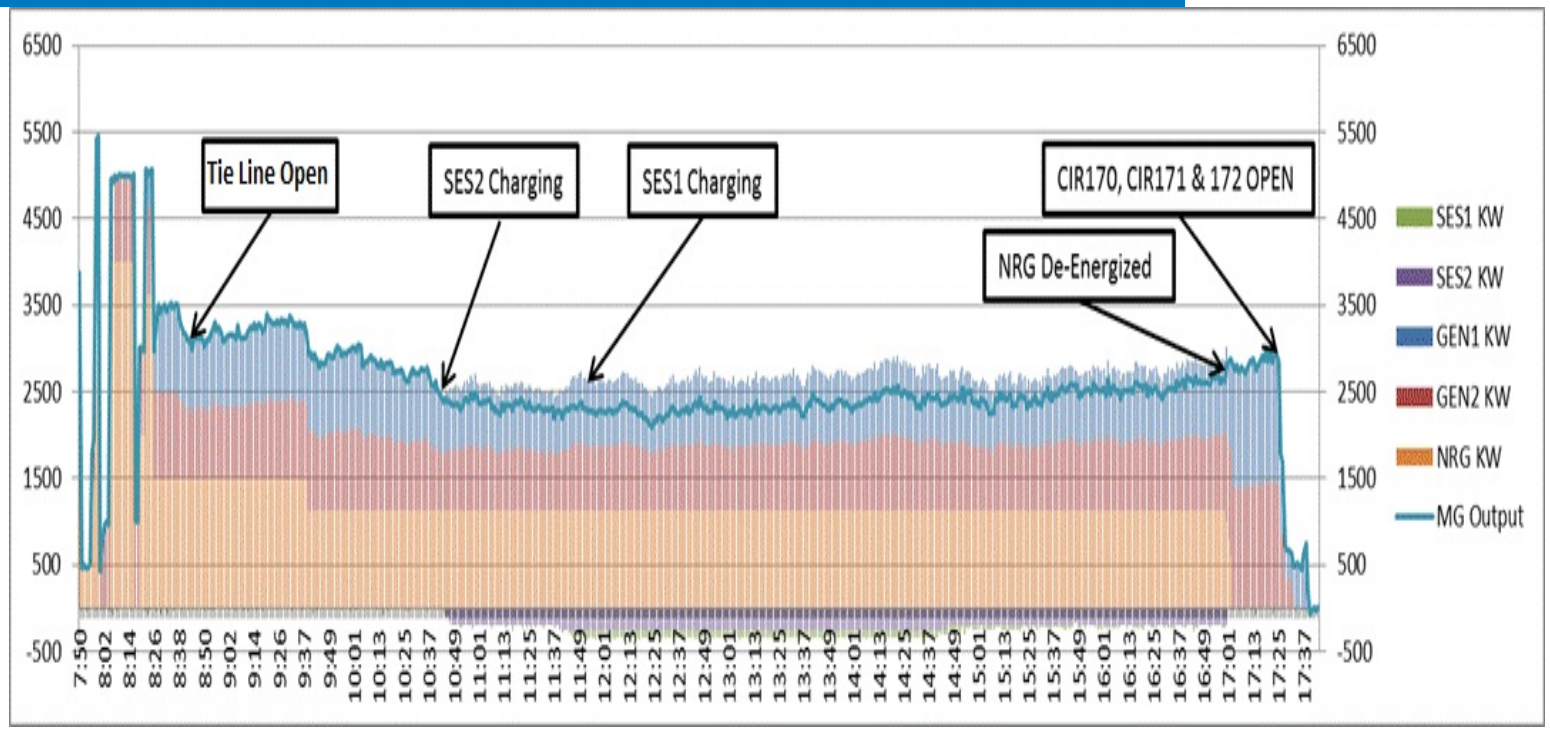
- 6/23/12 planned outage
  - Microgrid provided power to 2,128 customers for ~ 5.5 hours
- Q1 2013 conducted seven planned islanding events over 3 days
- 4/8/13 windstorm
  - Microgrid provided power to 1,225 customers for ~ 6 hours
- 8/25/13 flash flood
  - CES units islanded six customers for ~ 5.5 hours
- 9/6/13 intense thunderstorms
  - Microgrid provided power for up to 1,056 customers for > 20 hours

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.
- A total of 1,056 customers had power restored during the outage.



Real-World Experience (Island 3)



May 21, 2015, islanding event

Real-World Experience (Island 3)

May 21, 2015, islanding event

HIL Evaluation of Advanced Microgrid Controls

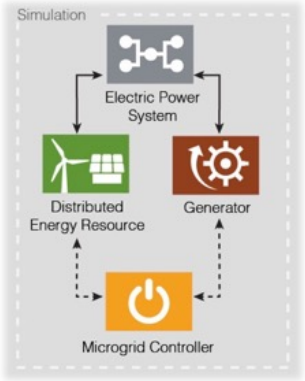
- Evaluation of an advanced microgrid controller
  - Spirae Wave microgrid controller
  - Similar to that deployed at Borrego Springs
  - Functional requirements (based on FOA 997):
    - Dispatch
    - Disconnection and reconnection
    - Steady-state frequency and voltage in islanded mode
    - Protection
- Evaluation of research-and-development (R&D) microgrid control functions
  - Advanced Control Technology (ACT)
  - Implemented by University of California San Diego (UCSD) and OSIsoft
  - Functions evaluated
    - Set point tracking and disturbance rejection

Microgrid Controller Evaluation Options

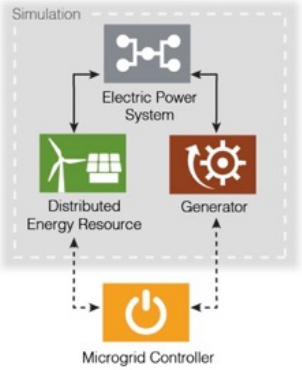
A) Pure simulation

Abstract or real-time

Need to integrate microgrid controller



A) Pure Simulation



B) CHIL

B) Controller hardware-in-the-loop (CHIL)

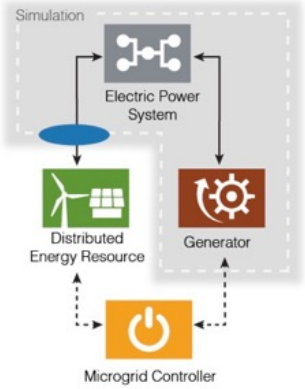
Interface real controller

Need to add communications interface

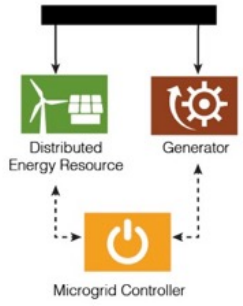
C) Controller and power HIL (PHIL)

Interface real controller and power assets, including internal proprietary controls

Power interface, more complex



C) CHIL & PHIL



D) Hardware only

D) Hardware only

Real controller and assets

Does not include power system model

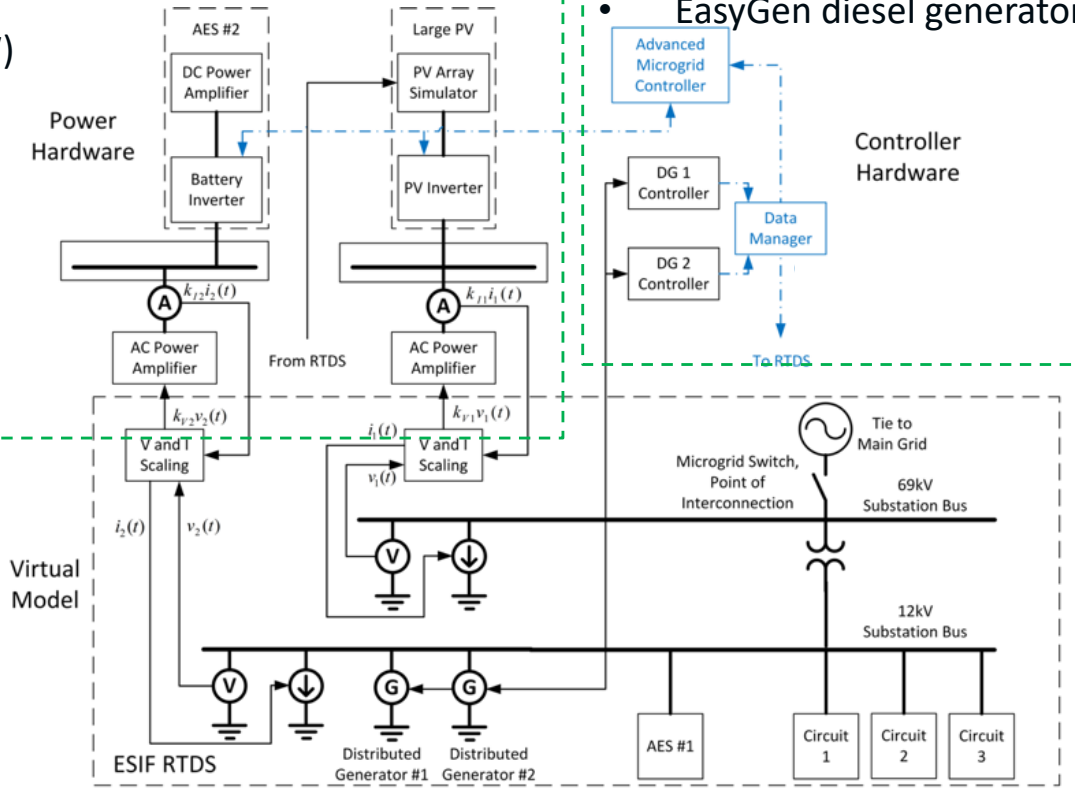
CHIL/PHIL Test Bed

PHIL:

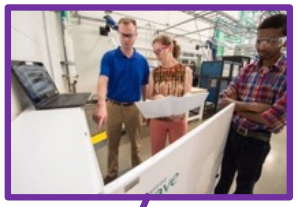
- Energy storage system inverter (representative Schneider 540 kW)
- Photovoltaic (PV) inverter (actual SMA 500 kW)

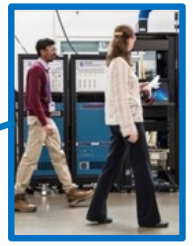
CHIL:

- Spirae Wave microgrid controller
- EasyGen diesel generator controllers



CHIL/PHIL Test Bed

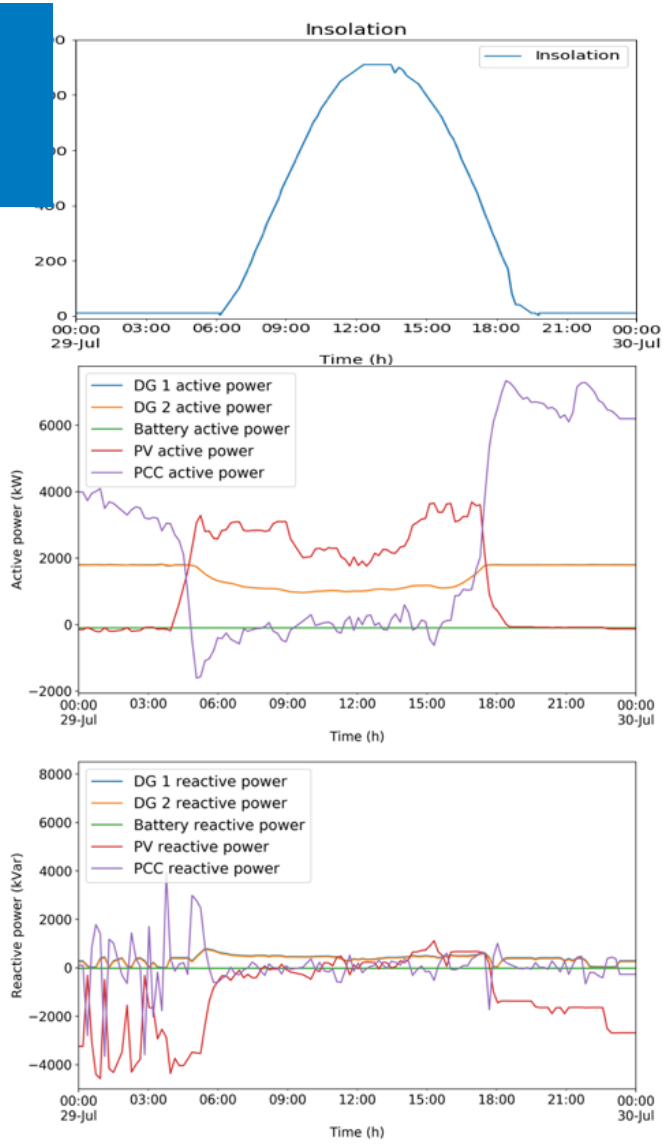




Dispatch—Grid-Connected

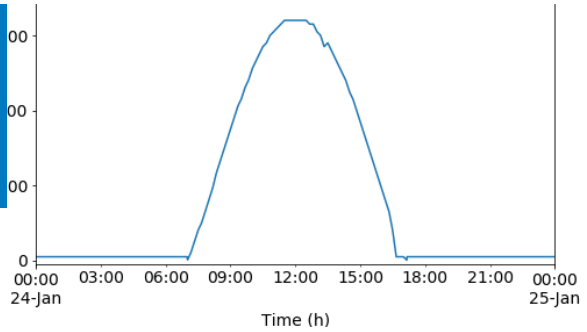
- Heavy-load day in summer
- Active and reactive power set points for point of common coupling (PCC) set to zero

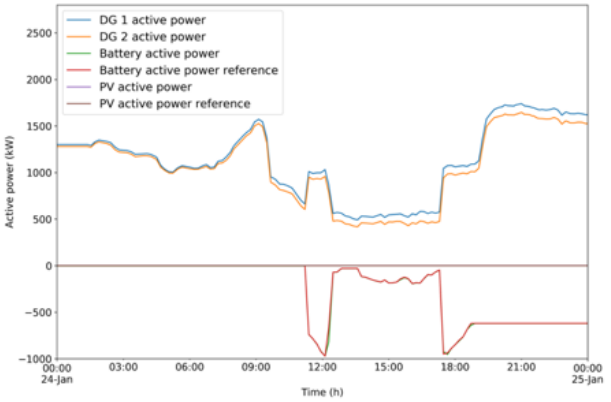
- Microgrid (MGC) can track set points when enough PV generation is available
- Diesel generators dispatched at about 60% during the day
  - To support transition to islanded mode
- NRG PV follows remaining load

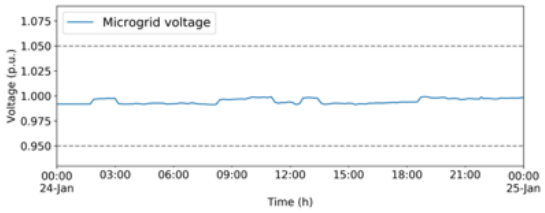


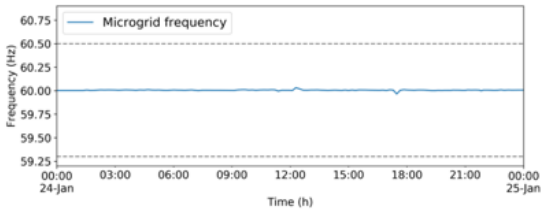
Real-World Experience (Island 3)

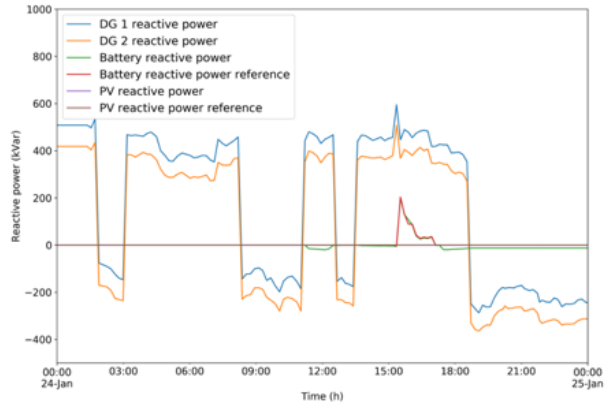
- Light load day in winter
  - Reduced by a factor of 1.7 to allow islanded operation
- Battery initial charge 70%
- Distributed generation operates in V/F master mode
- Distributed generation supports load
- PV is not dispatched: below minimum requirement for PV inverters
- Battery is dispatched to compensate for low power factor for the distributed generation
- Voltage and frequency meet steady-state requirements





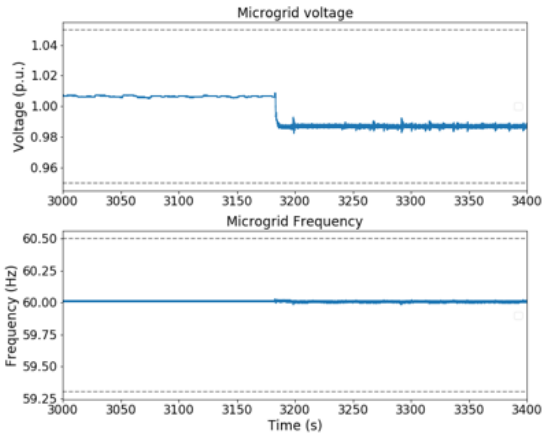


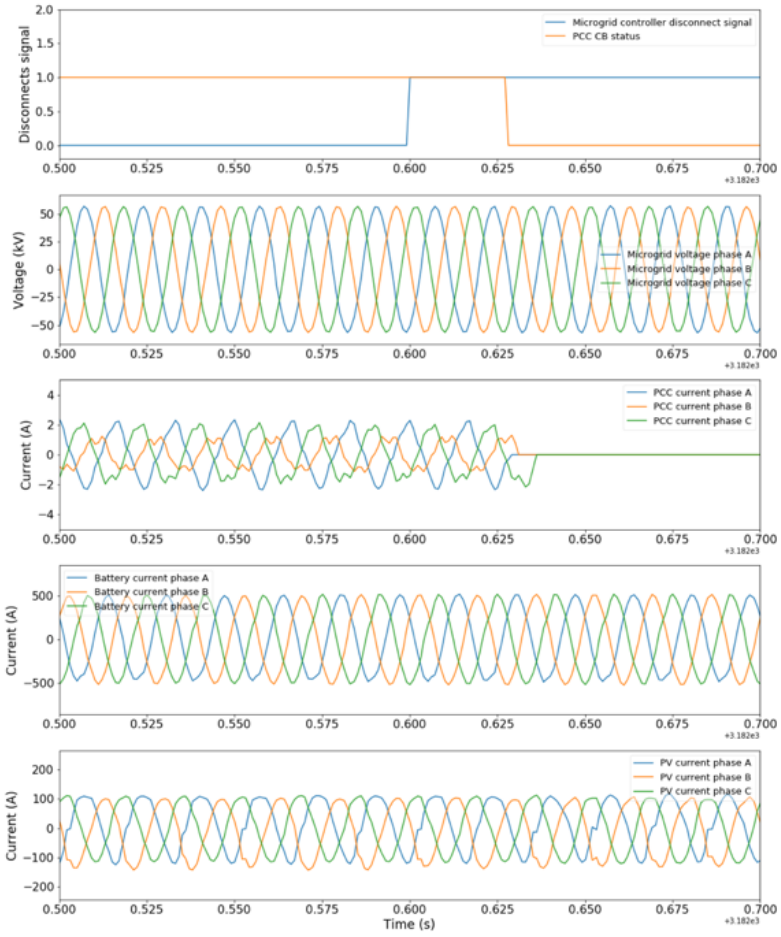




Planned Disconnection

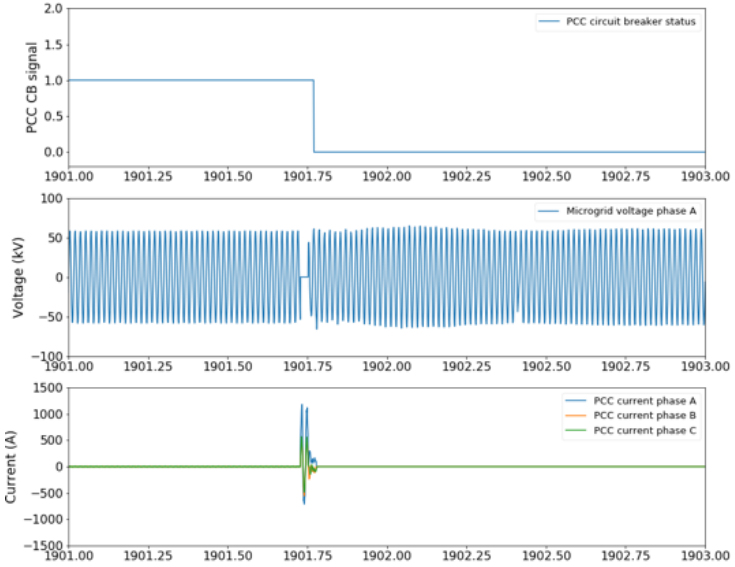
- Heavy-load condition
- MGC regulates power flow across PCC to near zero
- Smooth transition when microgrid switch is opened
- Voltage and frequency meet steady-state requirements

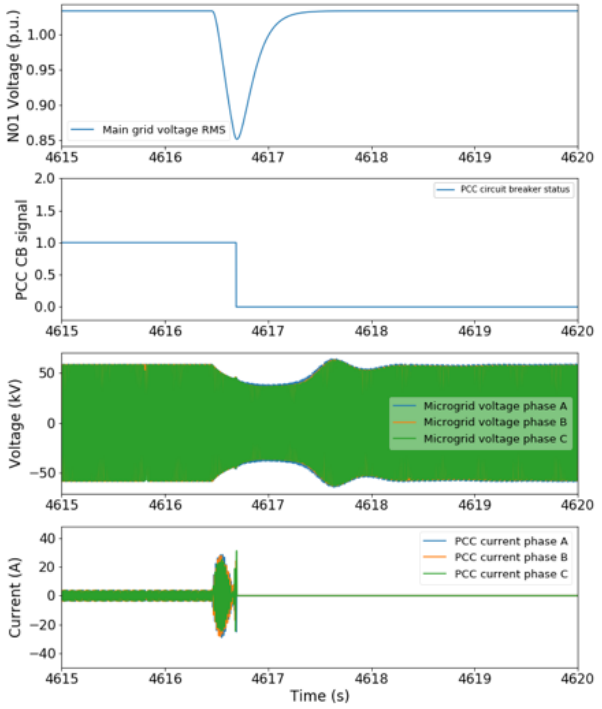




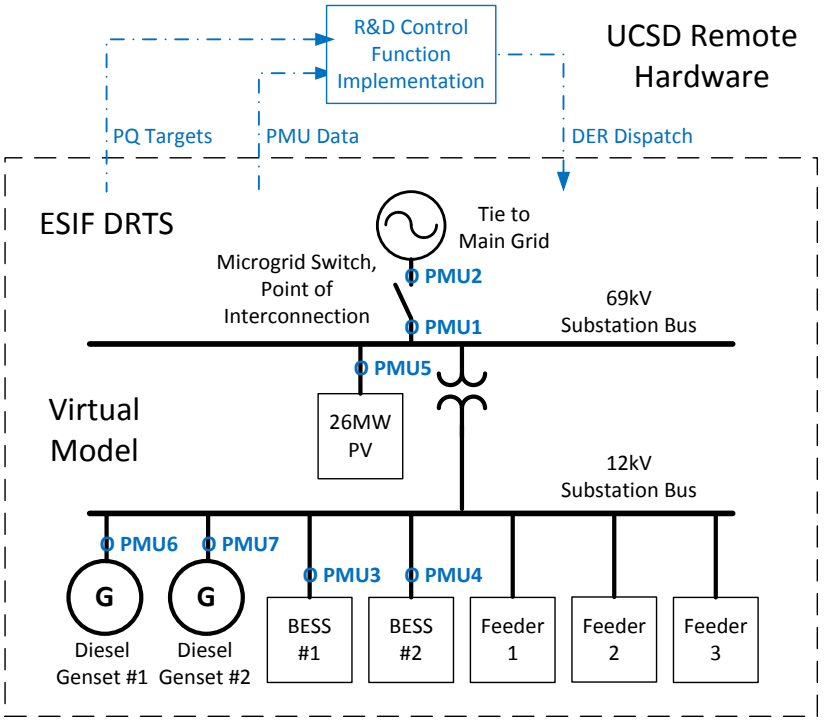
Unplanned Disconnection

- 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





Advanced R&D Control Function Evaluation



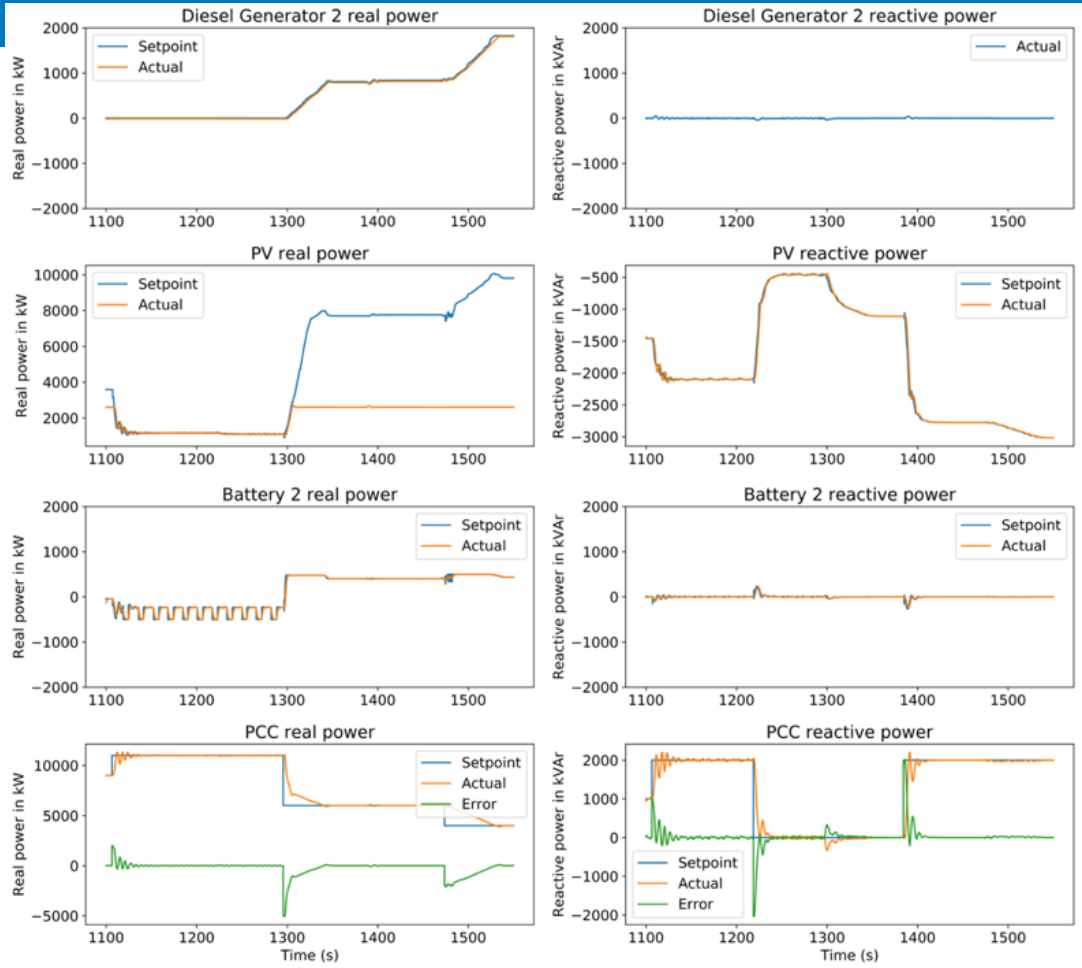
CHIL:

- UCSD Advanced Control Technology (ACT) implemented on SEL RTAC

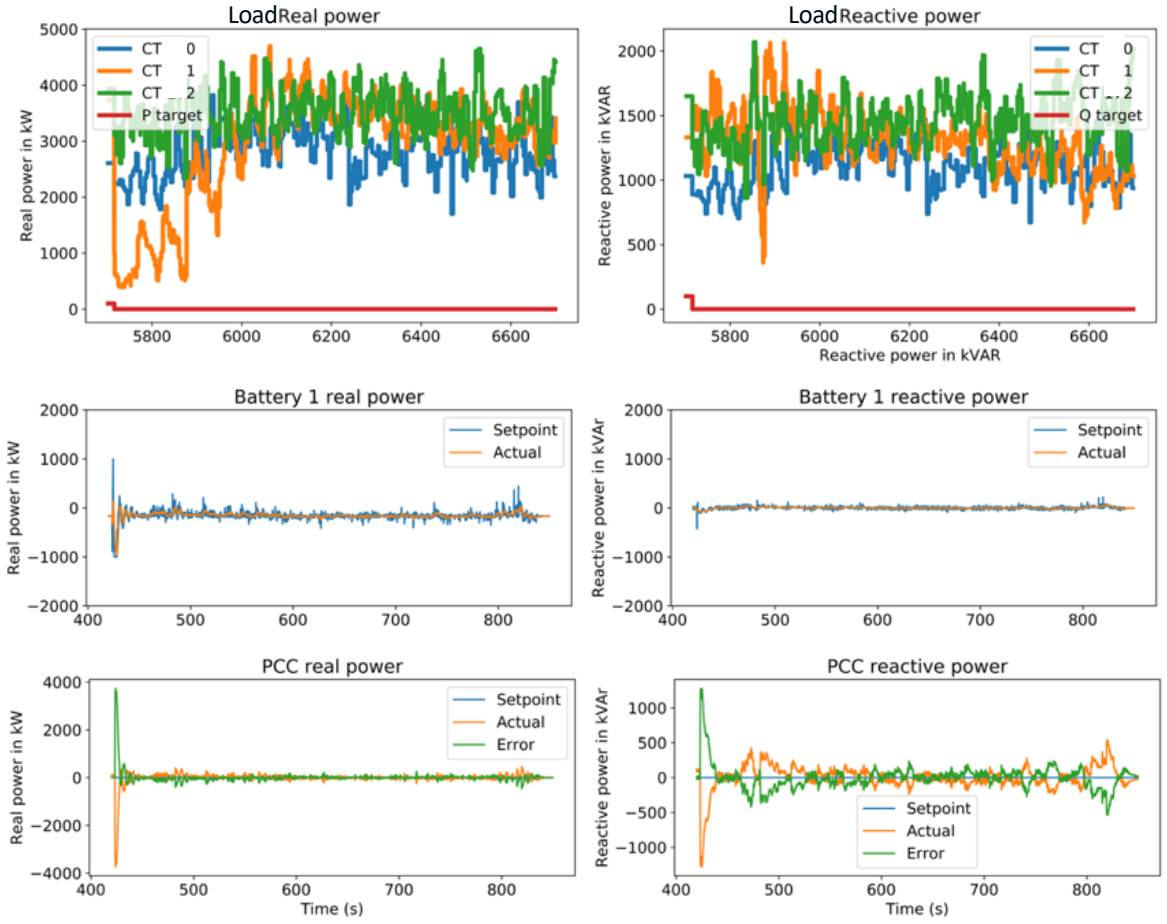
Remote HIL (RHIL):

- RSCAD network simulation at NREL connected to controller hardware at UCSD

Reference Tracking



Disturbance Mitigation



IEEE 2030.8

- NREL participated in working group for IEEE Std. 2030.8
- Standard for testing of microgrid controllers
- Approved as a new standard by the IEEE Standards Association Standards Board in June 2018

Summary

- Created CHIL/PHIL platform for microgrid controller derisking
- Developed compensation for stable and accurate simulation
- Developed remote HIL (RHIL) platform
- Evaluated Spirae's Wave microgrid controller
- Evaluated UCSD's advanced R&D control functions
- Developed test procedures

Further Reading

- 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." Paper presented at the North American Power Symposium (NAPS), Denver, Colorado, September 18–20, 2016.
- Maitra, Arindam, Annabelle Pratt, Tanguy Hubert, Dean Weng, Kumaraguru Prabakar, Rachna Handa, Murali Baggu, and Mark McGranaghan. 2017. "Microgrid Controllers: Expanding Their Role and Evaluating Their Performance." *IEEE Power and Energy Magazine* 15, no. 4 (July–August): 41–49.
- 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." Paper presented at the 2018 IEEE 9th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), June 25–28, Charlotte, North Carolina.

Thank You

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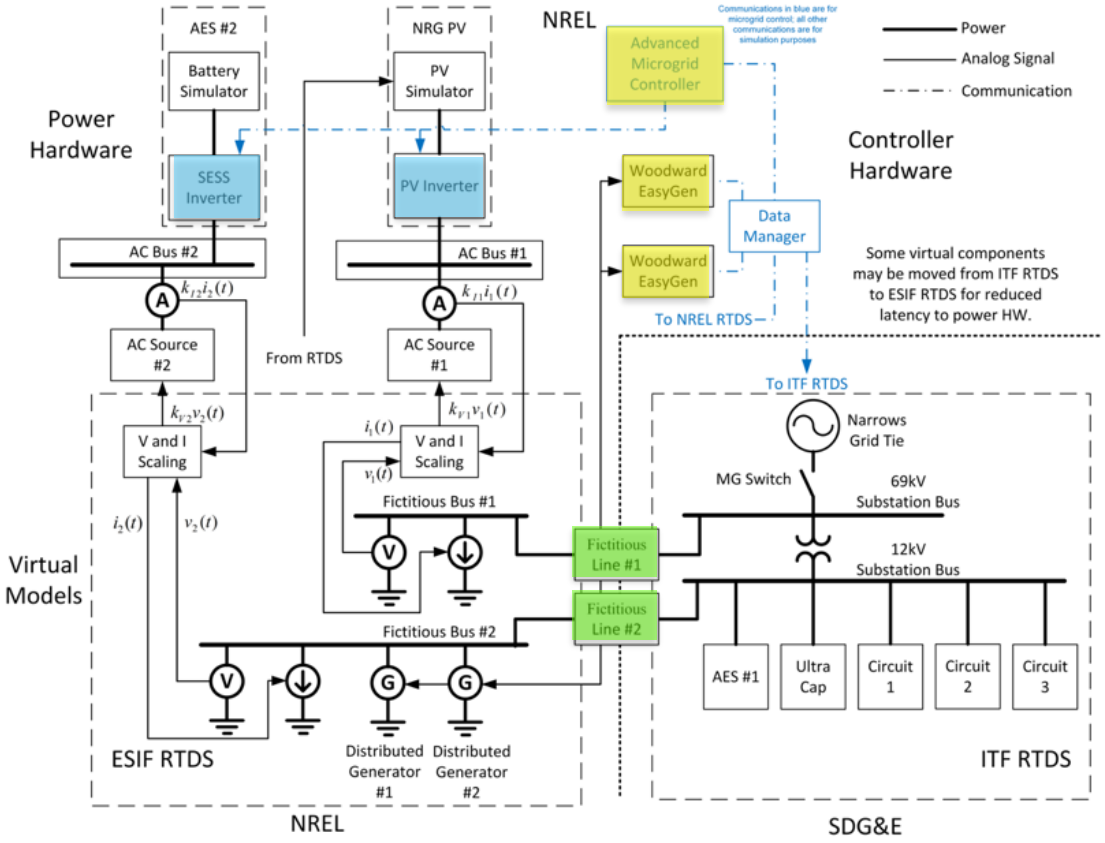
CHIL/PHIL/RHIL Test Bed



Remote HIL (RHIL):

- RSCAD network simulation at SDG&E's ITF connected to hardware at NREL's ESIF

Functional Testing Plan Overview

- Four use cases (A–D)
  - Each validates certain functional requirements (C1–C6)
  - Each consists of a set of test cases with specified initial conditions and test scenarios

	C1 Disconnect	C2 Reconnect	C3 Steady-state	C4 Protection	C5 Dispatch	C6 Resilience
Use Case A: Grid-connected					X	
Use Case B: Disconnect	X			X		
Use Case C: Islanded			X	X	X	X
Use Case D: Reconnect		X				