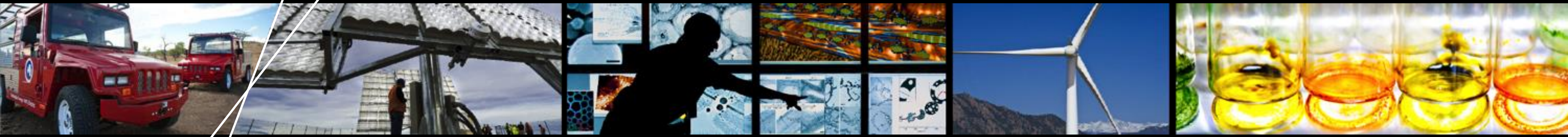
Experience in Microgrid Testing at NREL



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Assumptions/Definitions

- **Microgrid –** A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or "island" mode.
- **Microgrid Controller -** High level supervisory controller communicating to microgrid DER, meters, local loads and possibly grid system operator to manage and optimize microgrid on seconds to minutes time scale.
- **System Stability Functions** – Low level fast controls to regulate islanded voltage and frequency, control disconnection and reconnection to grid, and possibly implement load shedding.
- **IID (Island Interconnect Device) –** Electric device that connects or disconnects the microgrid at the PCC from the larger grid.
- **Live Transition/Dead Transition –** Whether the microgrid can transition from grid connected to islanded without interruption to load power.
- **Droop (CERTS) vs. Isochronous (constant voltage/frequency) –** Two different microgrid control options determining how voltage and frequency are regulated in islanded mode.

Microgrid Experience At NREL

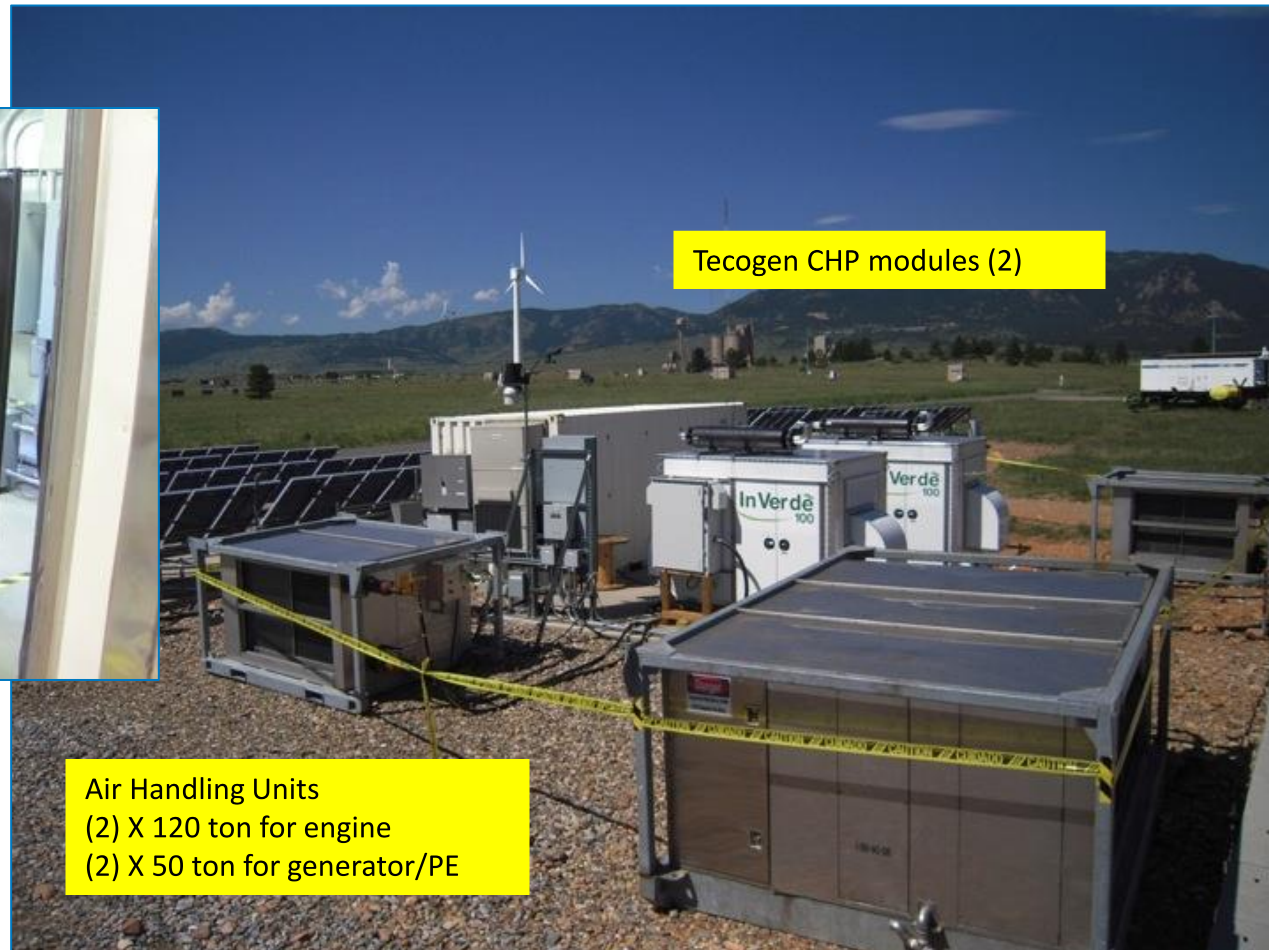
- **SMUD ~200kW (2011)**
  - Solid state microgrid switch (IID)
  - TecoGen inverter-coupled natural gas co-generation
  - CERTS droop-based system with live transitions from and to grid-connected
- **PGE ~250kW (2012)**
  - Implements live transition to and from grid-connected mode (Eaton battery inverter is grid-forming unit)
  - Integrated diesel generator control
  - Relay coordination of IID open/close
- **CUBE ~60kW (2008 - ongoing)**
  - Implements live transfer between AC grid-forming units (diesel generators and inverter)
  - Integrates DC-coupled battery energy storage and PV inputs
  - Advanced dispatch strategy to maximize load power reliability and reduce diesel fuel use
- **CSIRO ~200kW (2014)**
  - Integration of diesel generator, PV inverter and controllable load
  - Microgrid controller under test for optimization functions
  - Did not test grid-connected operation
- **ERIGO ~300kW (2014 - ongoing)**
  - Battery energy storage system - 3 chemistries each with inverter – 400kWh
  - Live re-synchronization
  - Live transfer to island mode is currently under test
- **RAYTHEON ~500kW (2014)**
  - 750kW battery inverter functions as grid-forming unit in islanded mode (208 Vac 3-phase)
  - High penetration PV inverters (up to 100 % tested)
  - Microgrid controller manages PV curtail and dead transition from and to grid-connected mode

SMUD Microgrid

Test Performed:

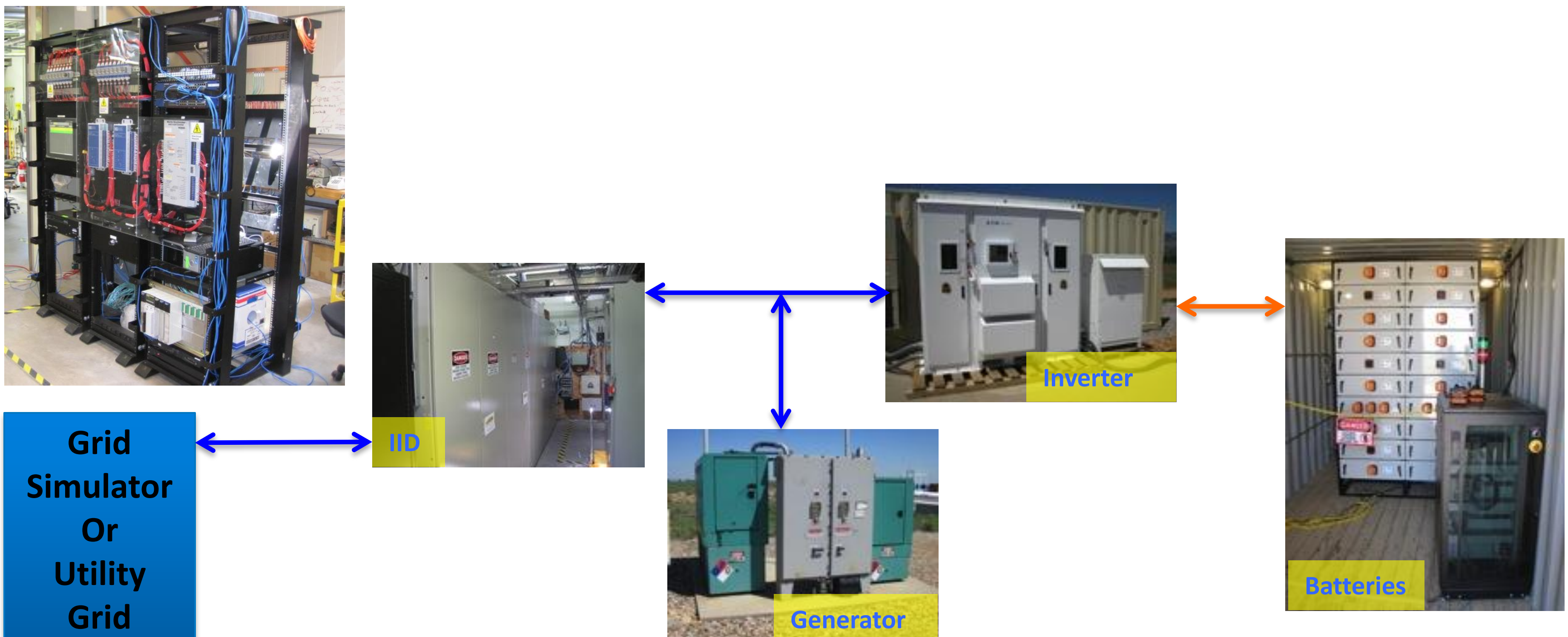
1) Droop characterization
2) Synchronization inrush
3) IEEE 1547 abnormal V, f interconnection response

Thomas and Betts Smart Switch
1200 A solid state switch
Passive droop-based synchronization

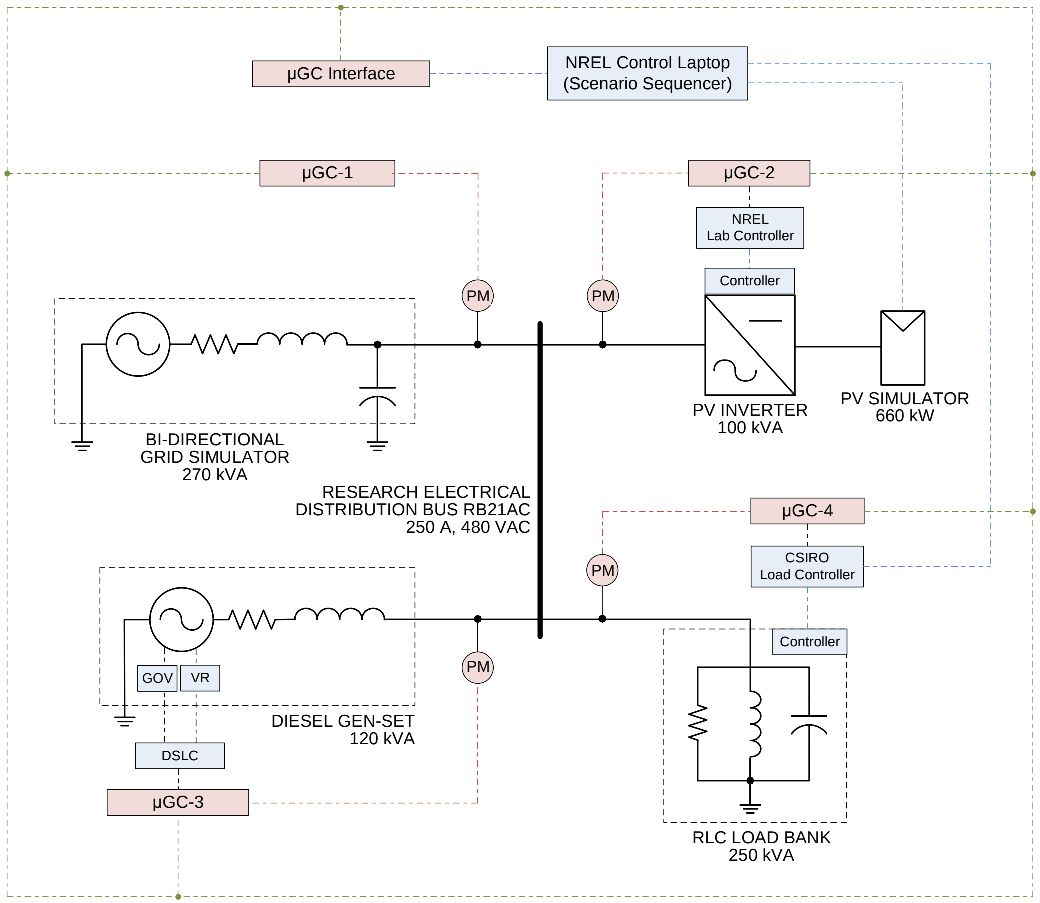


PGE Microgrid

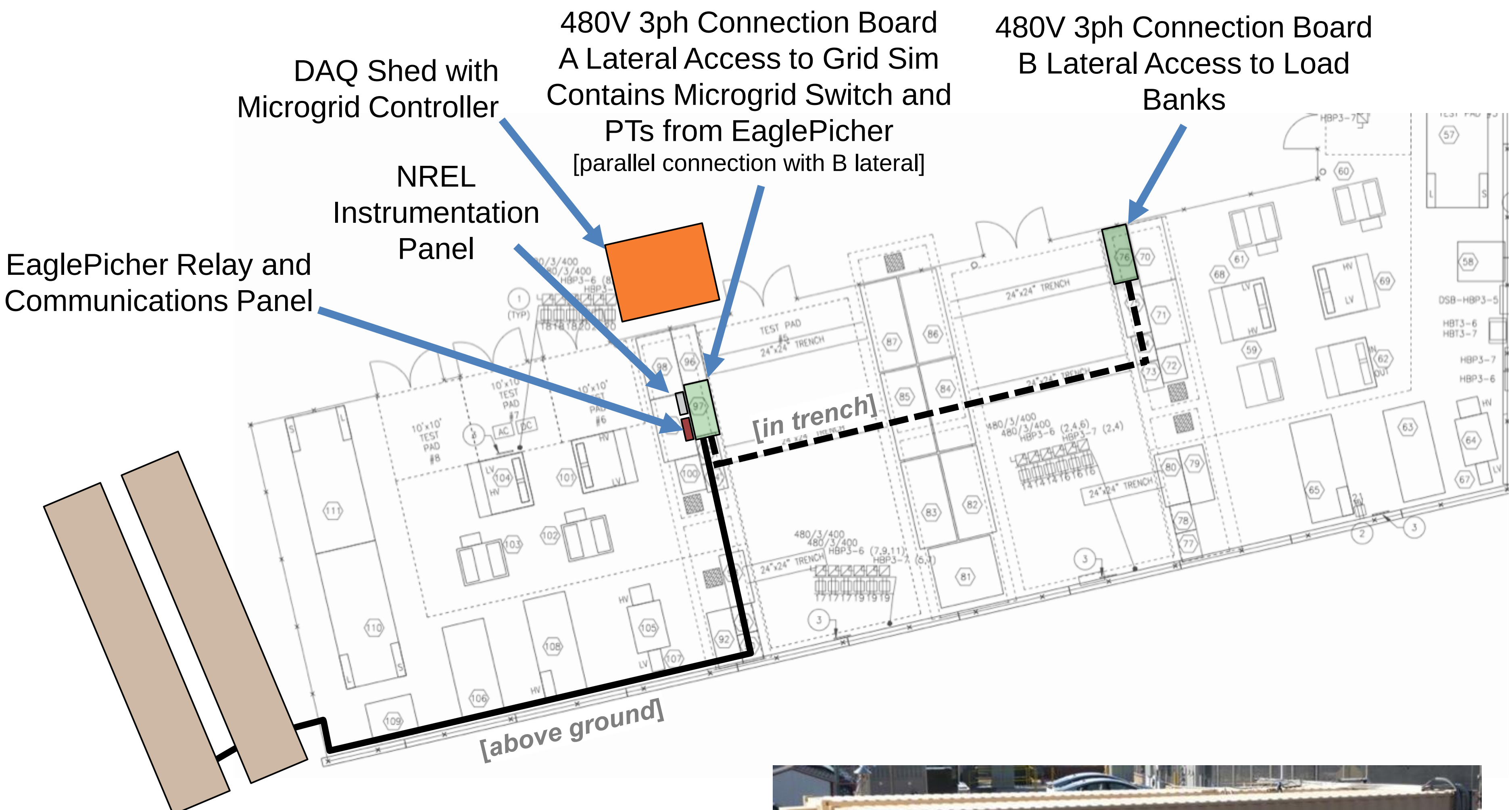
- 250kW/80kWh Lithium Ion battery
- 4-quadrant inverter, 250kW
- Diesel genset controlled by DSLC
- Custom communications and user interface control rack
- NREL built fault injection apparatus



CSIRO Microgrid

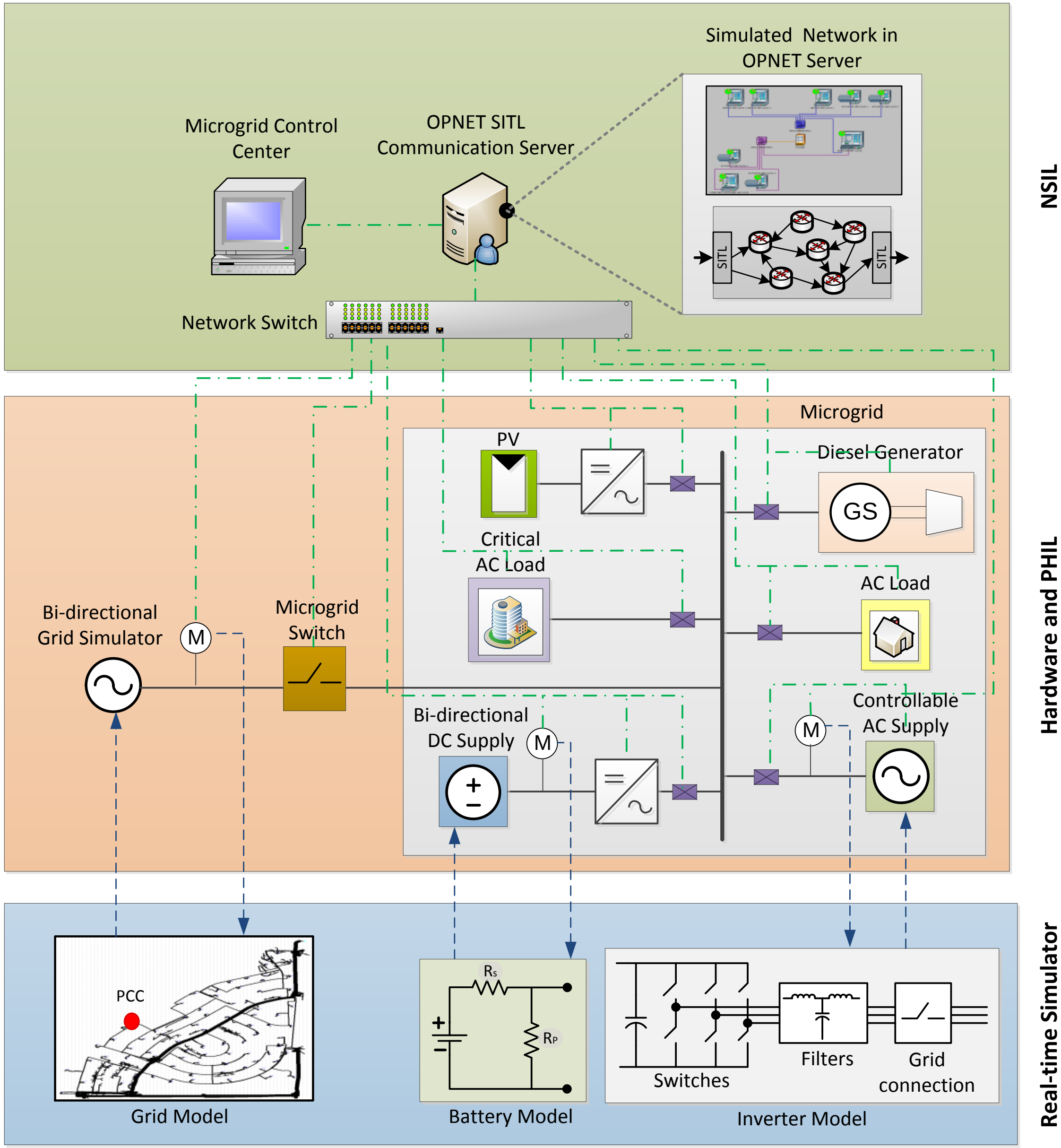


ERIGO / Eagle Picher Microgrid



Advanced Microgrid Testing

- Develop a cyber-physical test platform for microgrid
- Includes communications simulation
- A comprehensive research, development and test platform for microgrid and smart grid



Lessons Learned from Microgrid Testing

Stability and Power Quality

- Power quality/stability/interactions between equipment on DC or AC system (e.g. high penetration of PV). May need to revisit input and output impedances of equipment if oscillations are encountered in any condition.
- Method/location for neutral/ground bonding, as well as galvanic isolation.

Controls and Signaling Performance

- Clearly define important local functions of equipment versus microgrid controller functions such as control of IID; local functions versus connect or disconnect requests
- Control signal command/response speed. Actual responses to controller commands may be delayed by more than just network latency.

Communications/Microgrid Management

- Determination of required metering (PMU, relays, PQ meters)
- How to “simulate” forecasting or predictive features in the lab

Lessons Learned from Microgrid Testing

Testing Objectives and Approach

- If similar (not actual) devices are used what is the impact to testing and results
- Scope of test plan is important. Recognize that testing of only microgrid controller functions is nearly impossible. Low level stability, power quality, synchronization, etc. needs to sorted out before microgrid controller testing can commence.

Administrative

- Have appropriate designers/coders on-site or directly supporting for each critical component (main controller, battery inverter, PV inverter, etc.)
- Plan time for de-bugging communications interfaces and component controllers, as well as power quality and stability tuning.

Considerations for Microgrid Testing

Stability and Power Quality

- Interconnection standard deviations needed to keep system online (ride-through, abnormal voltage, etc.) what if some but not all microgrid resource trip off during an event – can they be reset immediately?
- Is the system stable in islanded mode, can mode transitions be made without microgrid DER tripping offline? Load rejection tests, fault tests, high penetration PV effects.

Controls and Signaling Performance

- Resiliency to unexpected upset/failure
- Ground fault detection on DC side may be impacted by switching or system connections on AC side.
- Will PHIL be used to simulate the larger EPS or a portion of the microgrid?

Communications/Microgrid Management

- What are the “designed for” network latencies and equipment response times

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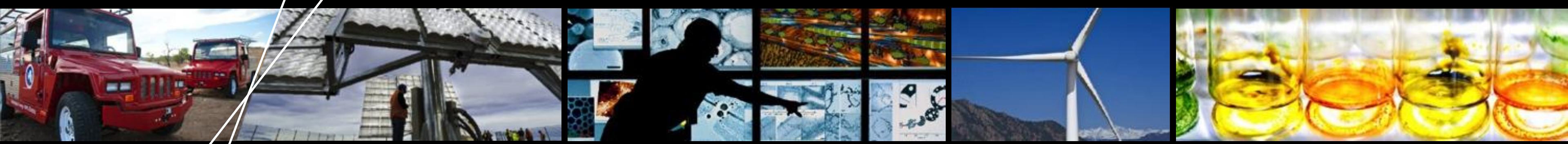

Thank you