Microgrids: A Utility's Friend or Foe?

Analysis, Testing and Conformance: Establishing Microgrids As A Utility's Friend

Tom Basso (Senior Engineer Thomas.Basso@NREL.gov)

(Acknowledgments: S. Chakraborty, J. Giraldez, W. Kramer, B. Kroposki, B. Lundstrom, G. Martin, and M. Shirazi

National Renewable Energy Laboratory

Energy Systems Integration **http://www.nrel.gov/eis/facilities_esif.html**

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Abstract. Microgrids, especially with increasing penetration of distributed energy resources (DER) including renewable energy systems, are providing unheralded challenges to legacy utility distribution systems as well as for the modern smart grid. The challenges include: effective grid integration; managing two-way power and communications; enabling interoperable operations of all grid-connected devices and sub-systems including legacy systems; and, accounting for state of the art microgrid devices, energy storage systems, smart loads, and, adaptive protection and operating devices. Beyond individual component advances, these challenges must be met by system-level revised and new analyses, systems engineering design and operations improvements, system testing, and, by establishment and use of best practices for evaluation and conformance assessment for not only components such as power electronics, but also for the integrated microgrid system as a whole, with approaches including hardware in the loop as well as devices under test and algorithms under test approaches.

Elucidation and validation of the technical features and claims promised by microgrids establish where and how microgrids are proven as friend. Microgrid evaluations include modeling and simulation, performance characterization and testing, and, component integration and operations validation, including microgrid responses to abnormal conditions. Technology advancements, analysis, testing, and, conformance to standards and best practices pave the way to turn microgrids as foe to microgrids as friend.

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Power Electronics Advancing Microgrids

Modeling

- Switch-level modeling and simulation
- Averaged and discrete-time analysis
- Expertise in various PE software - Simulink, PLECS, PSIM, PSCAD
- Systems-level model development

Controls and Optimization

- Implement PE controller in various firmware platforms – µController, DSP, FPGA
- Advanced control functionalities
- System-level control algorithms, e.g., hybrid power systems

Hardware Development

- Design of low-cost, reliable modular power electronics building blocks and advanced controller hardware
- Design and construction of various PE converters – PV inverter, battery charger, microgrid converter

Testing and Analysis

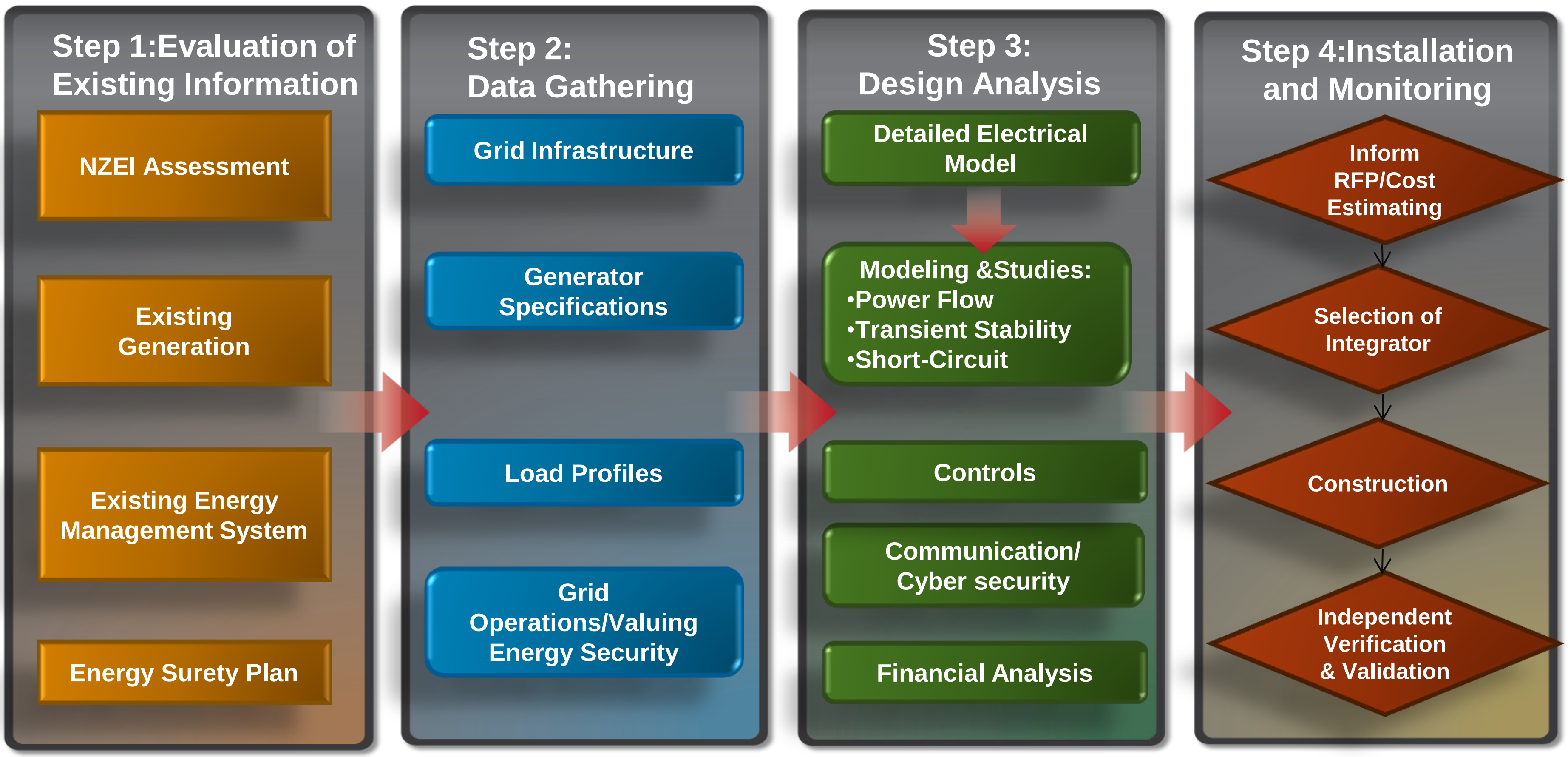
- Testing of power quality, pre-standards grid-compliance, efficiency, smart grid control and communications verification -- PV inverters, battery chargers, energy storage, microgrid systems, electric and hybrid vehicles

NREL Approach to Microgrid Design

Continuously Optimized Reliable Energy^{TM} (CORE^{TM}) Microgrids

- Differentiating Characteristics:
  - Integrates into 24/7 operations
  - Can optimize on economics or surety
  - Focuses on fuel diversity
  - Expands/contracts to provide energy for all load coverage spheres
  - Phased approach can allow for gradual addition of components over time
    - Load prioritization and migration with added generation

CORE™ Microgrid Design Process



- Detailed electrical model and financial analysis are fundamental to project implementation

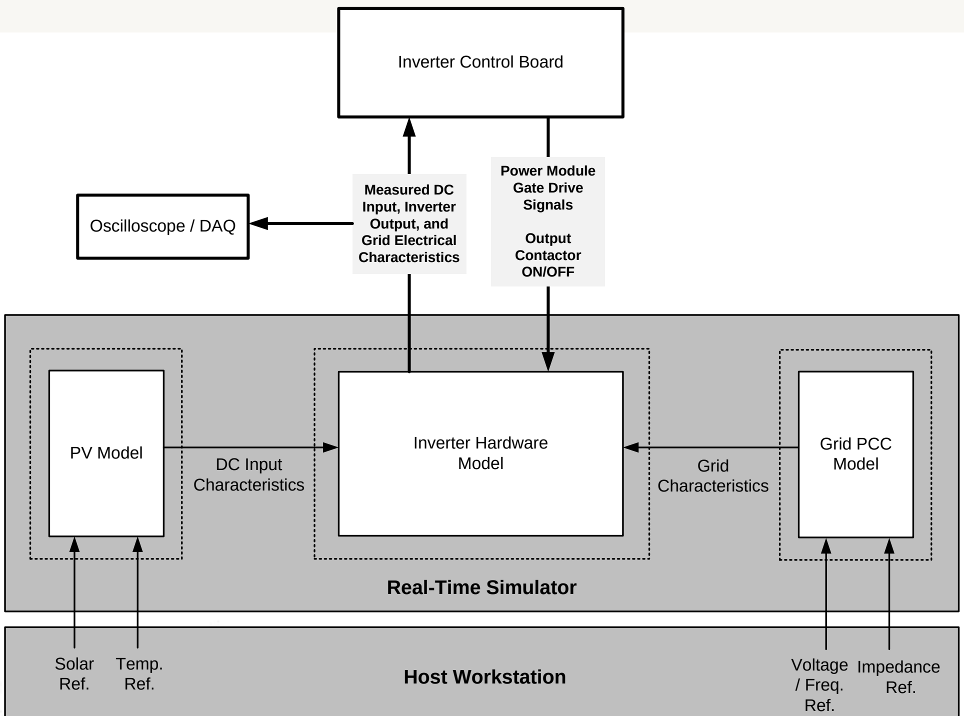
Modeling Overview

- **Modeling is needed because Microgrids present unique design challenges**
  - Self regulation for voltage and frequency
  - Advanced controls and protection schemes
  - Fossil fuel and alternative energy generation resources
  - Need to analyze start up sequence
- **What do you Model:**
  - Electrical distribution system, generation equipment, loads, and control system response
- **Use the model to simulate operating scenarios and predict performance**
  - Microgrid start up, feeder loss, faults, different generation options
- **Modeling conclusions can be used to inform**
  - Generation type/sizes, supervisory controls, operating procedures

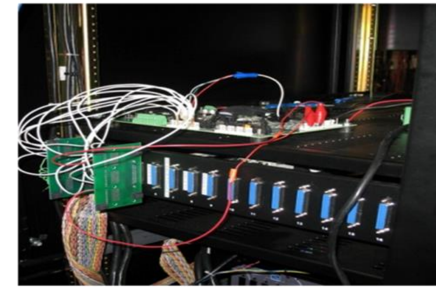
Evaluations using HIL, e.g., controllers, algorithms …

Controller HIL (CHIL)

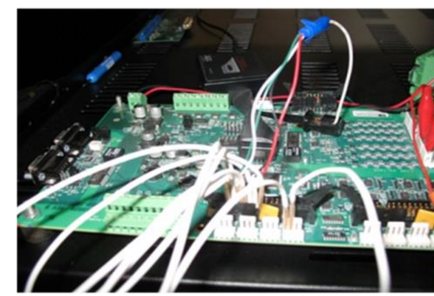
- **Use HIL system along with DSP or FPGA based real controller**
- **Controller board receives measurements from HIL model and sends switching pulses to inverter model**



(a) Front of HIL Simulator w/ I/O module



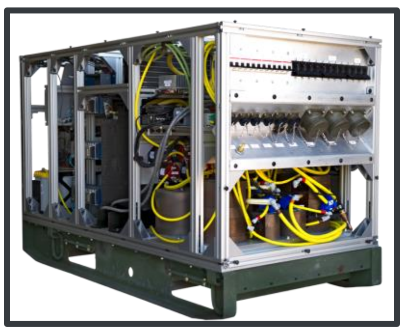
(b) Back of HIL simulator I/O module with connections to controller board



(c) Controller board with analog and digital signal connections

Development and Testing – Example Projects

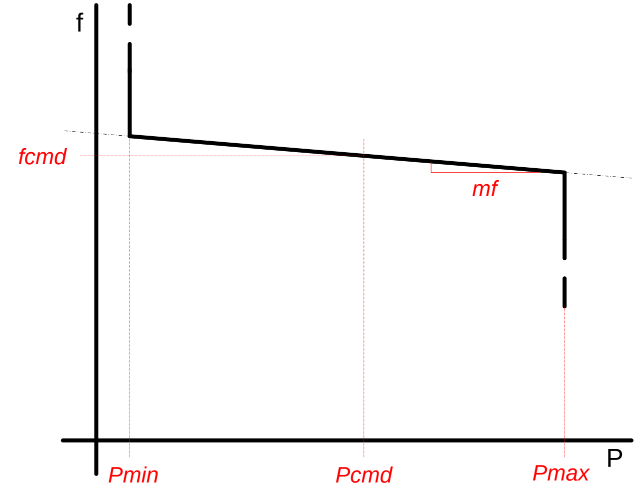
Scale → Mobile	Building / Campus	Distribution System
Rating → 60 kW	310 kW	5 MW
Army MEP CUBE	SMUD CERTS Microgrid Demo	PGE High Reliability Zone



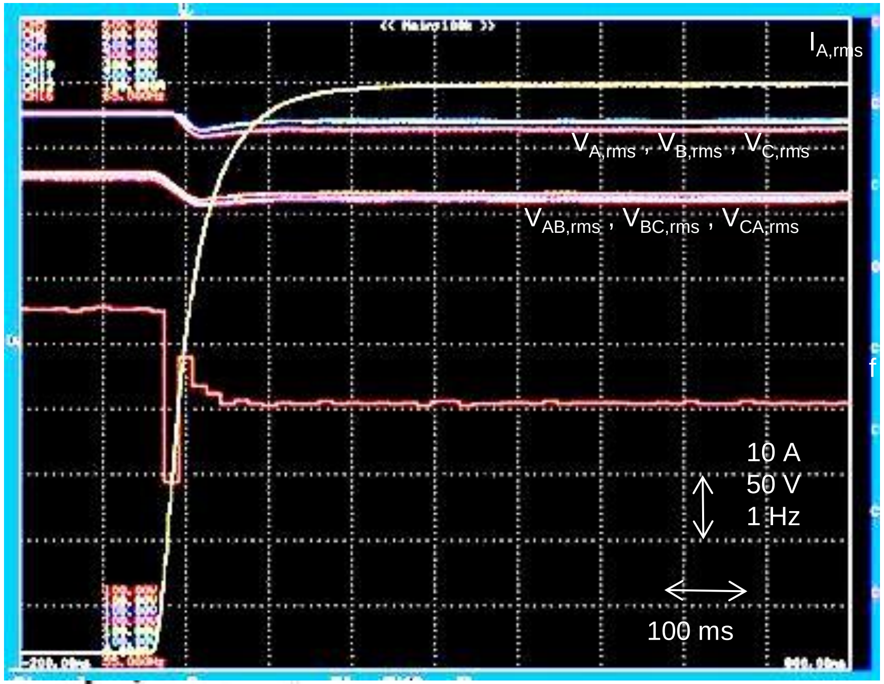
Microgrid Characterization Testing

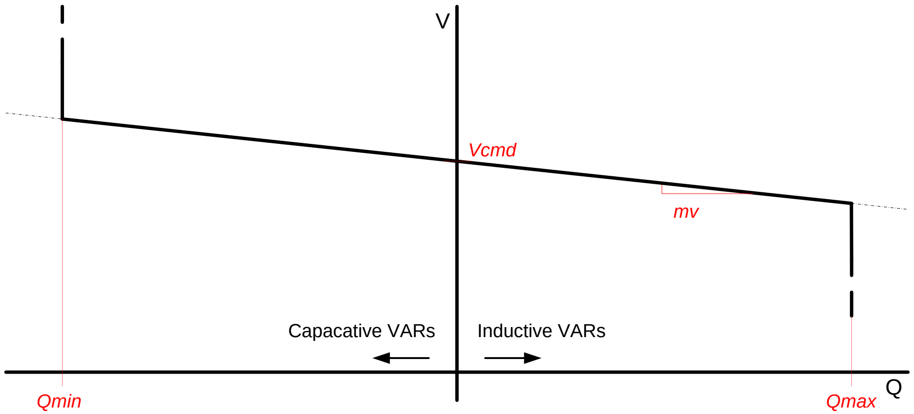
Based on IEEE Std 1547.4

- Droop curve characterization
- Load step response
- Load sharing
- Paralleling



Frequency vs. Real Power Droop





Voltage vs. Reactive Power Droop

Real Power Step Response

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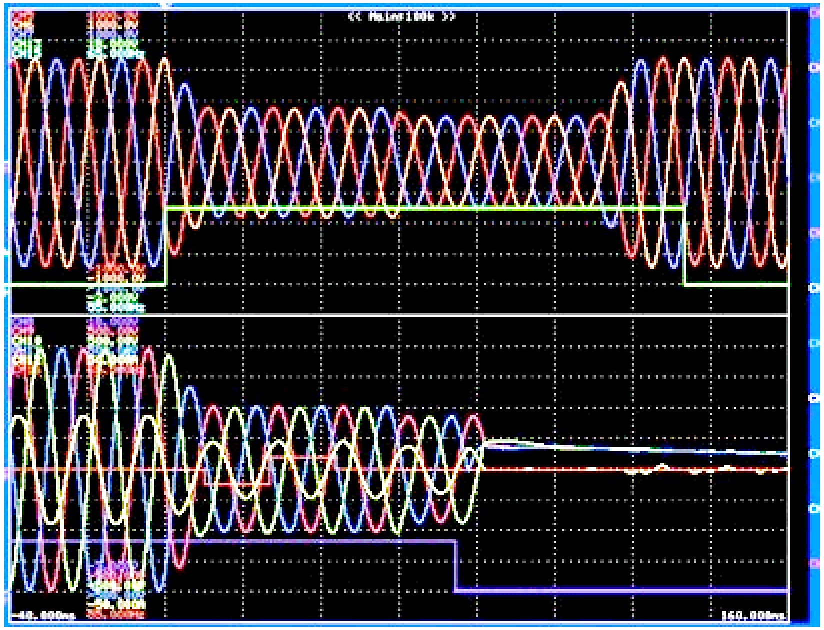
Interconnection System Tests (IEEE 1547.1)

- Temperature stability
- **Response to abnormal voltage conditions**
- **Response to abnormal frequency conditions**
- **Synchronization**
- Interconnection integrity
- **Limitation of DC injection for inverters without interconnection transformers**
- Unintentional islanding
- Reverse power (for unintentional islanding)
- Open phase
- **Reconnect following abnormal condition disconnect**
- Harmonics
- Flicker (no test)



Undervoltage Disconnect Time Test

Trip Level = 50% = 240 V_{rms} (l-l)
Time scale = 20 ms/div
Measured clearing time = 20.8 ms