NREL Energy Systems Integration Facility (ESIF)

Ben Kroposki, PhD, PE, FIEEE
Director – Power Systems Engineering Center
Energy Systems Integration Facility (ESIF)
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http://www.nrel.gov/esif

Unique Capabilities

- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation and loads
- Flexible interconnection points for electricity, thermal, and fuels
- Medium voltage (15kV) microgrid test bed
- Virtual utility operations center and visualization rooms
- Smart grid testing lab for advanced communications and control
- Interconnectivity to external field sites for data feeds and model validation
- Petascale HPC and data mgmt system in showcase energy efficient data center
- MW-scale Power hardware-in-the-loop (PHIL) simulation capability to test grid scenarios with high penetrations of clean energy technologies

Shortening the time between innovation and practice
Research in the Systems Performance Lab (SPL) focuses on the development and integration of smart, connected technologies, including distributed and renewable energy resources, energy efficiency, and smart energy management. The 5,300-ft² laboratory is designed to be highly flexible and configurable to enable a range of smart power activities—from developing advanced inverters and power converters to testing residential- and commercial-scale meters and control technologies, to integrated home/building devices and systems.

## Lab Functions

- Residential scale distributed resources, smart appliances, and HVAC evaluations
- Interoperability and communications testing
- Individual test labs for development and testing of the power electronics components and circuits used in renewable energy integration
- Instrument development area for basic electronics work

## Major Lab Equipment

- AC power supplies
- 45kW and 15kW grid simulators
- Opal RT and RTDS Hardware-in-the-Loop Systems
- Connections to larger electrical bus
- 3 Smart home appliances (refrigerators, water heaters, dish washers, lights, etc.)
- 2 environmental chambers to test small HVAC systems
ESIF – System Performance Lab

PV

EV, EVSEs, & battery storage

Distribution Transformers

Thermal Energy Storage

Major Appliances

Environmental Chambers for realistic HVAC loading

Hot Water use under simulated occupancy
As part of the Grid Modernization Laboratory Consortium (GMLC) – PNNL, NREL, ORNL, LBNL, Sandia, INL, LLNL are working to:

- Enable distributed energy resource (DER) devices with proven ability to provide the flexibility required for operating a clean and reliable power grid at reasonable cost.
- Defining a test protocol to characterize the ability of DER to respond to grid signals
- Define a standard set of grid services that DER can provide
- Develop “drive cycles” that describe the capabilities
Current Project: Home Energy Management Systems

Capabilities

- Smart Home Hardware-in-the-loop – includes appliances, HVAC, PV, EV, Batteries
- Centralized optimization (within home/buildings) based on Model Predictive Controls
- Simulation of aggregated homes with distribution systems – including market signals

How can ESIF help ARPA-e GENSETS?

Generators for Small Electrical and Thermal Systems (GENSETS)

ESIF – Integrated Electrical/Thermal HIL Capabilities

SIMULATION

FEEDER MODEL

MICROGRID MODEL
REAL-TIME SIMULATOR

HARDWARE

MAIN BUS

GRID SIM

CONTROLLED LOAD

BATTERY

PV SIM

WATER HEATER

HEAT PUMP

CHP GENERATOR

THERMAL STORE

V*I

Grid

Gas

Water

Generator

Electricity

Heat


grid

Electricity

Heat

Technologies to enable widespread deployment of CHP systems for residential & commercial sectors

NATIONAL RENEWABLE ENERGY LABORATORY

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ESIF Research Infrastructure

- **Research Electrical Distribution Bus** – REDB (AC 3ph, 600V, 1200A and DC +/-500V, 1200A)
- **Thermal Distribution Bus**
- **Fuel Distribution Bus**
- **Supervisory Control and Data Acquisition (SCADA)**

![Research Electrical Distribution Busway for Laboratory Access]

1MW Grid Simulator

- 250A DC
- 1600A DC
- 250A AC
- 1600A AC

Direct Current Research Electrical Equipment Room

Alternating Current Research Electrical Equipment Room

House Power

![Diagram of 1MW Grid Simulator]
Large-Scale Grid, PV, and Load Simulators

1MW Grid Simulator

1.5MW PV Array Simulator

1MW RLC Load Bank
Additional Equipment

- PV Simulators
  - 100 kW Ametek TerraSAS
- DC Supplies
  - 250 kW AeroVironment AV-900
- Load Banks
  - 100 kW R-L (portable)
  - 100 kW R (portable)
- Small grid simulators
  - 45 kW Ametek MX45
  - 15 kW Elgar
- Diesel generators
  - 125kVA and 80 kVA Onan/Cummins
  - 300kVA Caterpillar
- Hydrogen Systems
  - Electrolyzers: 50kW, 10kW
  - Storage tanks
  - Fuel cells
- Real-Time Digital Simulators
  - Opal-RT (3 racks)
  - RTDS (1 rack)
Hardware-in-the-Loop: Connecting Experiments to Simulations

Simulation validated with real field data

Actual hardware at ESIF

Simulation and Visualization at ESIF

Replicated into Larger Simulation

Simulation loop closed with actual hardware

Utility Substation

Subdevelopment with PV at end of circuit

Load Banks

Grid Simulator

Solar Simulator

Device Under Test (e.g. inverter, energy storage, EV, load, etc.)

Visualization Interface

HIL I/O Interface

1.5MW

1 MW

1 MW
ESIF – Power Systems Integration Lab

Research in the Power Systems Integration Laboratory focuses on the development and testing of large-scale distributed energy systems for grid-connected, standalone, and microgrid applications. The laboratory can accommodate large power system components, such as inverters for PV and wind systems, diesel and natural gas generators, battery packs, microgrid interconnection switchgear, and vehicles.

Lab Functions

- Main test lab for conducting MW-scale electrical system integration activities.
- Research explores a variety of operating configurations including: grid connected stand-alone, microgrids, and hybrid power systems.
- House infrastructure for DG research (AC and DC power supplies for REDB, chiller and boiler)

Major Lab Equipment

- 1 MW grid simulator
- 1.5MW PV Array Simulator
- 100kW PV Array Simulator
- Several 250kW DC power supplies
- 100 ton research chiller
- 750MBH research boiler
- Connections to Research Electrical, Thermal, Fuel Buses
Smart Inverter Testing (300W – 1MW)

500 kW PV Inverter with Volt-VAR and Freq-Watt Control

- Full Power Testing
- Both Utility and Grid Simulator Connections
- Regenerative Capability of Grid Simulator demonstrated (pushing power back to the utility)
- Inverter Advanced Functionality demonstrated
At the Energy Storage Laboratory, research focuses on the integration of energy storage systems (stationary and vehicle-mounted) and their interconnection with the utility grid. Includes batteries, ultra-capacitors, flywheels, compressed air, etc.

**Lab Functions**
- Testing energy storage components when integrated with renewable energy electrical systems:
  - Performance
  - Efficiency
  - Safety
  - Model validation
  - Long duration reliably

**Major Lab Equipment**
- DC Power Testing station 250 kW, up to 900 Vdc
- Grid Simulator connections
- REDB Connections
- Research Chiller & Boiler
- 600kW PV Simulator
- EV Chargers
Distribution Management Systems
• NREL is establishing a national, vendor-neutral Advanced Distribution Management System (ADMS) testbed to accelerate industry development and adoption of ADMS capabilities

• Enable utility partners, vendors, and researchers to evaluate existing and future ADMS use cases and integrate with HIL equipment
Microgrid Controller Optimization and Testing Platform

- **Flexible microgrid controllers**
  - to be deployed at sites with varying energy resource mixes and unique resilience requirements
  - to control facility, campus or community microgrids

- **Standardized functions and interfaces**
  - IEEE P2030.7
  - DOE FOA 997

- **Standardized test procedure**
  - IEEE P2030.8

- **Laboratory testing**
  - Options and example

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**KEY APPLICATIONS:**
Microgrid controller optimization and validation

NREL is recipient of two DOE OE Microgrid controller development FOA’s (with EPRI and GE) to validate the performance of new controllers at ESIF. NREL also built a NSIL test platform to include latency or communication loss similar to real world situations in Microgrid system simulation.
Securing Distribution Grid Management

Securing Distribution Grid Management Use Cases:
- Volt-VAR management
- Auto-Sectionalizing

- Distill the security requirements from the use cases for the logical layers in the various environments
- Built the distribution system test bed with a DMS, SCADA software, intelligent communication gateway, intelligent electronic devices and actual hardware in ESIF
ESIF – Outdoor Test Area

The outdoor test areas at the ESIF allow for testing either at 480 Volts or 13.2 kiloVolts

MV Major Lab Equipment
- 1MVA 13.2kV to 480 Y-Y transformers
- Connections to REDB, Utility
- Distribution transformers
- EV Chargers

LV Major Lab Equipment
- 80kW and 125kW Gensets
- 100kW, 250kW load banks
- Capstone Microturbine
- Connections to REDB

ESIL Major Lab Equipment
- \( \text{H}_2 \) storage vessels
- \( \text{H}_2 \) IC engine testing
- \( \text{H}_2 \) Vehicle fueling station
NWTC – Large-Scale Testing

- Total of 11 MW variable renewable generation currently at NWTC test site
- There are many small wind turbines (under 100 kW) installed as well
- 2.5MW and 5 MW dynamometers
- 7 MVA Controllable Grid Interface (CGI) for grid compliance testing
- Multi-MW energy storage testing capability under development
Controllable Grid Interface (CGI)

- Highly flexible and configurable system level multi-MW testing/demonstration platform
- Switchgear upgrade to connect field turbines and energy storage pads completed
- Possible to test grid connected generation
- Micro grids / EMS
- Combination of technologies / Advanced controls
Remote HIL Capability

IMPACT
First of a kind remote HIL experiments increase testing capability without large investments in physical equipment at multiple sites

For More Info: Contact Jim Cale
James.Cale @ nrel.gov
ESIF Annual Reports


http://www.nrel.gov/docs/fy16osti/65685.pdf
NREL ... Providing Solutions to Grid Integration Challenges

Thank You!

www.nrel.gov