Smart Grid Research at NREL

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Ben Kroposki, PhD, PE
Director, Energy Systems Integration
National Renewable Energy Laboratory
What is the Smart Grid?

The Smart Grid is the electricity production and delivery system along with consumption integrated with communications and information technology.

The Smart Grid is an automated, widely distributed energy delivery network characterized by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from power plants to customer preferences to individual appliances.

Source: NIST/EPRI Architecture Task Group
Smart Grid R&D at NREL

• Development of Smart Grid Interoperability Standards (IEEE 2030) and Interconnection Standards (IEEE 1547)

• Integration of High Penetration of Renewables and Distributed Generation (Modeling, Simulation, Testing, and Analysis)

• Advanced Distribution System Operations (Microgrids and Intentional Islands)

• Control, Testing and Evaluation of dispatchable generation, loads and energy storage (V2G, GridAgents, and Energy Storage Testing)

• Development of Conformance Test Protocol for Smart Grid Technologies (Interoperability and Operations)

• Analysis of Smart Grid Projects [www.smartgrid.gov]
Energy Systems Integration – The Concept

ESI has a broader vision: Highly integrated, flexible, and efficient systems that enable utilization of clean energy sources while maintaining reliability at an affordable cost.
Residential and Commercial Scale

- **Demonstrate “end-to-end” microgrid capability**
  - Smart power optimization with responsive loads
  - Onsite small wind, PV
  - Electrical and thermal storage
  - EV charging
  - H₂ production
  - Visualization & analytics
  - Demonstrate interoperability and energy reliability

- **Multiple lines allow users to “plug and play”**
NREL is working with the California Energy Commission and several industry partners to develop a standardized, highly integrated, modularized power electronic interconnection technologies that will come as close as possible to “plug-and-play” for distributed energy resource (DER) platforms.

The goal is to develop power electronics technology that improves and accelerates the use of DER systems.

Reduce costs for DER and interconnections by developing standardized, high production volume, power electronic modules.
V2G Testing and Applications

NREL conducts testing EV and PHEVs for Vehicle-to-Grid (V2G) application

Developing Standard test protocol for V2G
Replication at Scale: Systems

• **NREL-PNNL Smart-Grid Integration Project**
  o Connect devices in ESIF and HIL with GridLab-D modeling and signals

• **Interoperability & Smart Building Controllers**
  o Testing and evaluating of home and commercial building controllers

• **Smart Appliance Suites**
  o Testing and evaluation of smart appliances for demand response and grid services
Smart Grid Simulation at Scale

• NZEB for Grid Services
  o RSF and other NREL campus data is being collected and could be used to identify opportunities to reduce total energy use and/or reduce peak load and provide grid services with Xcel Energy

NZEB significantly changes demand profile
Campus, Community, and City Scale

Technologies
1. Photovoltaics
2. Fleets and mass transit
3. Plug-in hybrid electric vehicles
4. District heating and cooling
5. Combined heat and power
6. Electricity distribution
NREL Campus - Energy DataBUS

Energy DataBus  http://www.nrel.gov/analysis/databus/

Open Source solution to collect, store, clean, aggregate data from energy systems

Connect to meter drivers (BACnet, Modbus, etc)

Push and pull into to app layer

Become a Databus partner: http://en.openei.org/wiki/NREL_Energy_DataBus/Partners
NREL Campus Energy - Apps

Energy DataBUS – Data Collection and Analytics

Campus Energy Dashboard

Engaging Occupants with Building Agent

Campus Energy Control and Optimization
Replication at Scale: Microgrid & Area

- Rooftop PV & Wind
- Energy Storage Lab
  - Residential, Community & Grid Battery Storage, Flywheels & Thermal
- Smart Power Lab
  - Buildings & Loads
- Energy Systems Integration Lab
  - Electric Vehicles
- Outdoor Test Area
- Power Systems Integration Lab
  - PV Simulator
- Outdoor Test Area
- Power Transformers
Microgrid Projects

- Development of IEEE 1547.4 – Microgrid Standard
- Portland General Electric (PGE)
- Sacramento Municipal Utility District (SMUD)
- Santa Rita Jail Microgrid
- SPIDERS – DoD high reliability microgrids
- Other US DoD Bases – microgrids for high reliability
Regional, National, Continental Scale

**Technologies**
1. Solar energy
2. Wind energy
3. Geothermal energy
4. Hydroelectric power
5. Nuclear energy
6. Fossil-fuel energy
7. Electricity transmission
NREL is working with SMUD on visualizing impact of DG deployments
Energy Systems Integration – The Facility

Addressing the challenges of large-scale integration of clean energy technologies into the energy systems infrastructure

http://www.nrel.gov/eis/facilities_esif.html

“This new facility will allow for an even stronger partnership with manufacturers, utilities and researchers to help integrate more clean, renewable energy into a smarter, more reliable and more resilient power grid.”

- Energy Secretary Ernest Moniz

U.S. DEPARTMENT OF ENERGY

- NREL’s largest R&D facility (182,500 ft²/20,000 m²)
- Space for ~200 NREL staff and research partners
- Petascale HPC and Data Center supports all research at NREL
- Labs focus on R&D of integrated energy systems
  - Electricity
  - Fuels
  - Transportation
  - Buildings & Campus
- Integrated electrical, thermal, fuel, and data infrastructure
ESIF’s Unique Advanced Capabilities

- Multiple parallel AC and DC experimental busses (MW power level) with grid simulation
- 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
- “Hardware-in-the-loop” simulation capability to test grid scenarios with high penetration of renewables
ESIF Office Area

- Integrated Energy Efficiency into Design and Operations
- High use of daylight
- Natural use of ventilation through operable windows
- Uses about 25% national average for energy in office space
- Installed Enmetric plug load control system
- Collecting circuit level load information in office area
ESIF - High Performance Computing

This computer-generated simulation shows the turbulent nature of wind turbine wakes. The simulation helped uncover potential differences in output between downstream 'waked' turbines and upstream turbines.

3D Simulation model of Polymeric organic nitrooxide radical (PTMA) film for battery applications

- High performance computing provides a multi-faceted basis for simulating future integrated energy innovations that would otherwise be too expensive, too lengthy, too dangerous, or otherwise impossible to study by direct experimentation.

- HPC also has integrated energy control and waste heat capture

<table>
<thead>
<tr>
<th>HPC Demand Controller: 12.5% Limit of Previous Month's Peak</th>
</tr>
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<tbody>
<tr>
<td>Power (kW)</td>
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<tr>
<td>------------------</td>
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<tr>
<td>Peak Load reduction</td>
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<tr>
<td>Time of Day</td>
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ESIF - Energy System Simulated Operations

A Flight Simulator for Energy System Operators
“connecting integration studies to operations”

Operations techniques development for:
• High renewables and energy efficiency penetrations
• New systems configurations and contingency response
• High storage / DR penetrations
• Resource forecast integration

Transmission

Distribution

Campus Energy Dashboard
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)
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

Simulation and Visualization at ESIF

Visualization Interface

HIL I/O Interface

Replicated into Larger Simulation

Simulation loop closed with actual hardware

Solar Simulator

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

Load Banks

Grid Simulator

Utility Substation

Subdevelopment with PV at end of circuit

Simulation and Visualization at ESIF

Visualization Interface

HIL I/O Interface

Replicated into Larger Simulation

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Solar Simulator

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

Load Banks

Grid Simulator
• Interaction between homes
• Different appliances, technologies, communications
• Impacts on distribution transformer
• Community-scale DR transients
ESIF Laboratories

**Electrical Systems Laboratories**
1. Power Systems Integration
2. Smart Power
3. Energy Storage
4. Electrical Characterization
5. Energy Systems Integration

**Thermal Systems Laboratories**
6. Thermal Storage Process and Components
7. Thermal Storage Materials
8. Optical Characterization

**Fuel Systems Laboratories**
9. Energy Systems Fabrication
10. Manufacturing
11. Materials Characterization
12. Electrochemical Characterization
13. Energy Systems Sensor
14. Fuel Cell Development & Test
15. Energy Systems High Pressure Test

**High Performance Computing, Data Analysis, and Visualization**
16. ESIF Control Room
17. Energy Integration Visualization
18. Secure Data Center
19. High Performance Computing Data Center
20. Insight Center Visualization
21. Insight Center Collaboration
ESIF – Control Room

In the ESIF Control Room, researchers can see the electrical bus, close switches, and checkout grid simulators. The Supervisory Control and Data Acquisition (SCADA) system in the ESIF monitors and controls research facility-based processes and gathers and disseminates real-time data for collaboration and visualization.

Lab Functions

- The data from experiments throughout the facility is streamed to secure servers in the control room
- The SCADA supports a large visualization screen in the ESIF control room allowing researchers and partners to watch the experiment in real-time

Major Lab Equipment

- SCADA
- State-of-the-Art Visualization Screen
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 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
- Several 250kW DC power supplies
- 100 ton research chiller
- 750MBH research boiler
- Connections to REDB
ESIF – Smart Power Lab

Research in the Smart Power Laboratory focuses on the development and integration of smart technologies, including distributed and renewable energy resources 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.

Lab Functions
- Test lab 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
- Small grid simulators
- Opal RT and RTDS Hardware-in-the-Loop Systems
- Connections to REDB
ESIF – Energy Storage Lab

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
- REDB Connections
- Research Chiller & Boiler
- PV Simulator
ESIF – Energy Systems Integration Lab

The Energy Systems Integration Laboratory provides a flexible, renewable-ready platform for research, development, and testing of state-of-the-art hydrogen based and other energy storage systems.

Lab Functions
- Assessment of the technical readiness, performance characterization, and research to help industry move these systems towards optimal renewable-based production and efficient utilization of hydrogen
- Testing of electrolyzers, fuel cells, compression equipment, delivery systems

Major Lab Equipment
- Gas Chromatograph
- Ion Chromatograph
- PEM electrolyzer
- Alkaline electrolyzer
- Fuel cell
- H2 high pressure compressor
- Two high pressure testing bays fully rated for testing systems to 15,000 psig
ESIF – Electrical Characterization Lab

The Electrical Characterization Laboratory supports detailed electrical characterization of components and systems. This laboratory allows researchers to test the ability of equipment to withstand high voltage surges and high current faults, including equipment using standard and advanced fuels such as hydrogen.

Lab Function
• Provides a safe environment for conducting high voltage surge testing and high current short circuit tests on equipment

Major Lab Equipment
• Surge generator system for simulating lightning strikes and other high voltage, high current events
• Separate ventilation system
• Video links to main test area
• Class 1; Division 2 approved
ESIF – Outdoor Test Areas

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

**ESIL Major Lab Equipment**
- H₂ storage vessels
- H₂ IC engine testing
- H₂ Vehicle fueling station

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

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

Ben Kroposki
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http://www.nrel.gov/esi