eGRID Introduction and Status

2nd International Workshop
September 17th, 2014

Driving economic growth, innovation, and workforce development for South Carolina
The SCE&G Energy Innovation Center

- Clemson University Restoration Institute
- SCE&G Energy Innovation Center
  - Duke Energy eGRID Center
  - Wind Turbine Drivetrain Testing Facility
    - 15 MW HIL Grid Simulator
    - 7.5 MW Test Bench
    - 15 MW Test Bench
The EGRID Center Team Members

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Project Co-PI
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Transforming the electrical grid into an energy efficient network requires:

- new technologies that must play a significant role in power system stability.
- the ability to replicate a complex dynamic system like the electrical grid for testing purposes.
- extensive testing of hardware and software to meet safety and quality assurance requirements through ‘fully integrated’ system testing.
- parallel model verification and validation of physical hardware to ensure higher reliability and stability once deployed on the electrical grid.

**Advanced Testing Lowers the Risks and Costs of New Technology Introduction into the Market**

- Development
- Demonstration
- Verification

- Total Costs
- Time to Market
- Deployment Risks
How the EGRID center fits into the technology development cycle

- Design and Development
  - Simulations
  - Functional Testing
  - Controls Algorithms

- Independent Certifications
  - Equipment Safety
  - Basic Functionality

- Demonstration Projects
  - Complete Systems
  - Controls Verification

- Commercial Deployment
  - Operations Training
  - Technician Training

- Prototype Testing
  - Standards Testing (UL, IEC, IEEE)

- Hardware-in-the-Loop Testing

- Academics and Education
eGRID Founding Partners

DUKE ENERGY
SRNL
SCANA
Santee Cooper
UL
Underwriters Laboratories
TECO Westinghouse

eGRID Market Applications

Large Solar PV Converters
Micro-Grid Applications
EV Charging Stations
Utility Scale Energy Storage

Wind Energy
Traditional Distributed Generation (Diesel, NG. etc.)
Smart Grid Technologies
Aerospace
SCE&G Energy Innovation Center

- Graduate Education Center
- 500 kW Solar Array (Future)
- 23.9 kV Utility Bus
- 20 MVA HIL Grid Simulator
- 4.16 kV 5 MVA Test Bus
- 23.9 kV 20 MVA Test Bus
- 7.5 MW Test Stand
- 15 MW Test Stand

Up to three independent grid integration tests can run simultaneously in each of the three experimental bay’s.
SCE&G EIC Electrical Single Line

Main Facility Electrical Bus (23.9 kV)

15 MW Test Bench

15 MW Test Bench Recirculation Bus

Harmonic Filter

Full Nacelle Under Test

GS

T2

7.5 MW Test Bench

7.5 MW Test Bench Recirculation Bus

Harmonic Filter

Full Nacelle Under Test

GS

T2

20 MVA HIL Grid Simulator

Simulated Grid Experimental Bus

Variable 23.9 kV (50/60 Hz)

15 MW Test Bench

Harmonic Filter

Building Power

Hydraulic System

20 MVA HIL

Grid Simulator

M1

M2

LAI

15 MW Test Bench Recirculation Bus

Reactive Divider Network

Floor Disconnect
The 20 MVA HIL Grid Simulator

Three Independent Test Bays

<table>
<thead>
<tr>
<th>Overall Electrical Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Test Bay</strong></td>
</tr>
<tr>
<td>Nominal Voltage</td>
</tr>
<tr>
<td>Nominal Power</td>
</tr>
<tr>
<td>Frequency Range</td>
</tr>
<tr>
<td>Sequence Capabilities</td>
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<tr>
<td>Overvoltage capabilities</td>
</tr>
<tr>
<td>Fault Simulation</td>
</tr>
<tr>
<td>Hardware In the Loop</td>
</tr>
<tr>
<td><strong>Small Test Bay 1</strong></td>
</tr>
<tr>
<td>Nominal Voltage</td>
</tr>
<tr>
<td>Nominal Power</td>
</tr>
<tr>
<td>Frequency Range</td>
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</tr>
<tr>
<td>Fault Simulation</td>
</tr>
<tr>
<td>Hardware In the Loop</td>
</tr>
<tr>
<td><strong>Small Test Bay 2</strong></td>
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<tr>
<td>Nominal Voltage</td>
</tr>
<tr>
<td>Nominal Power</td>
</tr>
<tr>
<td>Frequency Range</td>
</tr>
<tr>
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</tr>
<tr>
<td>Overvoltage capabilities</td>
</tr>
<tr>
<td>Fault Simulation</td>
</tr>
<tr>
<td>Hardware In the Loop</td>
</tr>
</tbody>
</table>
The 15 MW HIL Grid Simulator

Step Up and Step Down Transformers

Medium Voltage Switchgear and Test Floor

Four TWMC Versabridge Power Amplifiers

Reactive Divider Network Room
Grid Integration Evaluations

Steady State and Envelope Evaluations
- Power Set Points
- Voltage and Frequency Variations
- Controls Evaluation

Power Quality Evaluations
- Voltage Flicker
- Harmonic Evaluations
- Anti-Islanding (Software)

Ancillary Services
- Frequency Response
- Active Volt-VAR Control
- Active Frequency Regulation

Grid Fault Ride-Through Testing
- Low Voltage Ride-Through (LVRT)
- Unsymmetrical Fault Ride-Through
- High Voltage Ride-Through (HVRT)

Open Loop Testing
- Recreation of field events with captured waveform data

Hardware-In-the-Loop Testing
- Simulated dynamic behavior and interaction between grid and the device under test
Hardware-in-the-Loop Testing

15 MVA Series Connected H-Bridge Power Amplifiers

Commanded Voltage Reference

Loop timing and latency are critical

Real Voltages associated with BUS #N

National Instruments Interface Controller

Voltage and Current Set Point Commands

Voltage and Current Information

BUS #N

Device Under Test

“I’m connected at Bus #N”
Energy Storage Integration

Model of a Physical System
Energy Storage Integration
Adding Distributed Control
Hardware and Communications

Model of a Physical System

- Battery Energy Storage Technology
- Smart Energy Storage Inverter
- Isolation Transformer
- PCC
- Transmission System Equivalent Model
- Transmission and SCADA IEDs
- Equivalent System A
- Equivalent System B
- Feeder Circuit IEDs

Simulated Grid at EGRID

- Battery Energy Storage Technology
- Smart Energy Storage Inverter
- Isolation Transformer
- PCC
- TWMC Power Amplifier Cabinet 2
- Real or Simulated IED Control and Response
- Grid Simulator

Substation
TECO Westinghouse Motor Company: Power Amplifier Units

### TWMC Power Amplifier

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Power</td>
<td>20 MVA (15 MW @ 0.8 PF)</td>
</tr>
<tr>
<td>Rated Power</td>
<td>15 MVA (12 MW @ 0.8 PF)</td>
</tr>
<tr>
<td>Cabinet Power Split</td>
<td>4 x 3.75 MVA or 2 x 7.5 MVA</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>0 - 4160 V</td>
</tr>
<tr>
<td>Overvoltage</td>
<td>133 % Rated Output Voltage</td>
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<tr>
<td>Multilevel Operation</td>
<td>7 - Levels (9 - Levels Overvoltage)</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>3 - 66 Hz</td>
</tr>
<tr>
<td>Overload Capability</td>
<td>110% for 60 s (10 min duty cycle)</td>
</tr>
</tbody>
</table>

Individual power cube with three phase input and single phase output

4 Power Slices per Amplifier Section

8 Parallel Amplifiers arranged into 4 Cabinets
TECO Westinghouse Motor Company: Power Amplifier Units

- Phase Shifted Carrier PWM
  - High degree of harmonic cancelation due to multilevel architecture
  - Increased reference sampling fidelity
- Sampling fidelity is further increased by using asymmetrical sampling of each individual carrier

Simulations and FAT testing show excellent results with 2 kHz switching frequencies

First noise mode is at 16 kHz (Fs x 2 x Carriers), 8 times the switching frequency

Reference resolution also at 12 kHz using asymmetrical sampling
Power Amplifier Units Commissioning Data

PAU Cube output switching frequency parameter set to 2 kHz
Fault-Ride Through (FRT) Requirements

Reactive Divider Network Method
- ABB Factory Testing (2009)
- FGH Test Systems Field Testing (2006)

Voltage Source Converter Method
- GE Power Conversion (Fr. Converteam)
- Vestas V164 Test Bench (2013)
- NAREC 15 MW Test Bench (Hybrid?) (2014?)
- ABB Test Systems
  - NWTC at NREL (4Q-2013)

A Hybrid Method
- Clemson University (4Q-2014)
Why a Hybrid Method?

Increased flexibility and accuracy of FRT evaluations

- Faulted at the point of common coupling (PCC)
- True zero voltage faults (ZVRT)
- Magnetic flux decoupling between transformers
- Real inductive loading for transient time constant analysis
- Power electronic switching for point-in-wave studies
- **Backwards compatible** with existing methods
The Hybrid Method: Operation Cycle

1. Open Series Bypass Switch
2. Close Shunt Fault Switch
3. Open Shunt Fault Switch
4. Close Series Bypass Switch

There are only three unique system states in the operation cycle.
Reactive Divider Network

- **Safety Considerations**
  - Access controlled room
  - Automatic grounding system when not in service
- **Voltage Isolation**
  - 35 kV insulation system
  - 2500 A (100 MVA) DUT fault duty
- **Performance and Flexibility**
  - Remote control of all elements allows for setup and operation without the need for room access
  - Individual phase operation allows for thousands of three phase impedance combinations

### Table of Fixed Reactance Combinations

<table>
<thead>
<tr>
<th>Fixed Switch Positions</th>
<th>Shunt Fixed (mH)</th>
<th>Series Fixed (mH)</th>
<th>Total Shunt (mH)</th>
<th>Total Series (mH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1-1-0</td>
<td>0</td>
<td>25</td>
<td>0-25</td>
<td>25-50</td>
</tr>
<tr>
<td>1-1-0-0</td>
<td>0</td>
<td>50</td>
<td>0-25</td>
<td>50-75</td>
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<tr>
<td>1-0-0-0</td>
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<td>75</td>
<td>0-25</td>
<td>75-100</td>
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<tr>
<td>0-1-1-1</td>
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<td>25-50</td>
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Reactive Divider Network Commissioning

Characteristics of the 60 kV $V_{DRM}$ SCR AC switches

Fiber optically coupled phase independent firing signals

Turn on times using FO triggering are near the rated turn on time of individual SCRs at just over 5 µs

Commissioning tests included:

Verification of each switch firing in situ with a VARIAC and ACR

Using one PAU and momentarily loading the PAU with the complete RDNuctive load
eGRID SCADA System

- Detailed specifications developed through coordinated efforts between:
  - Savannah River National Laboratory
  - Clemson University
  - National Instruments

- Significant amount of hardware and software shared with the WTDTF systems
- Provides a powerful and flexible platform for the development of custom control systems to meet the various grid integration evaluation scenarios

**Modified Architecture:**
Direct FPGA to FPGA communication, more deterministic for controls applications.
Next Up: TWMC Controlled DC Supply Front End

- Modify a single TWMC PAU cabinet to provide the DC supply without control changes
- Aimed at solar testing with Maximum Power Point Tracking and 2D PV field simulation
- Partial bi-directional power flow (dynamic braking resistors) allows for tight regulation
- A novel control system will be used on existing NI PXI/FPGA hardware to integrate with the SCADA system

### DC Supply Module Specifications

<table>
<thead>
<tr>
<th></th>
<th>1 Module</th>
<th>6 Modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Range</td>
<td>200 – 1000 V</td>
<td></td>
</tr>
<tr>
<td>Current Rating</td>
<td>420 A (1000 V)</td>
<td>2500 A (1000 V)</td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td>835 A</td>
<td>5000 A</td>
</tr>
<tr>
<td>Ripple Frequency</td>
<td>2400 – 4800 Hz</td>
<td></td>
</tr>
<tr>
<td>Reverse Power Flow</td>
<td>67 kW (1000 V)</td>
<td>400 kW (1000 V)</td>
</tr>
</tbody>
</table>
Thank You