PS-1 Reducing Grid Integration Risks and Demonstrating Smart Inverter Technologies Through Advanced, Full-Scale Power Testing

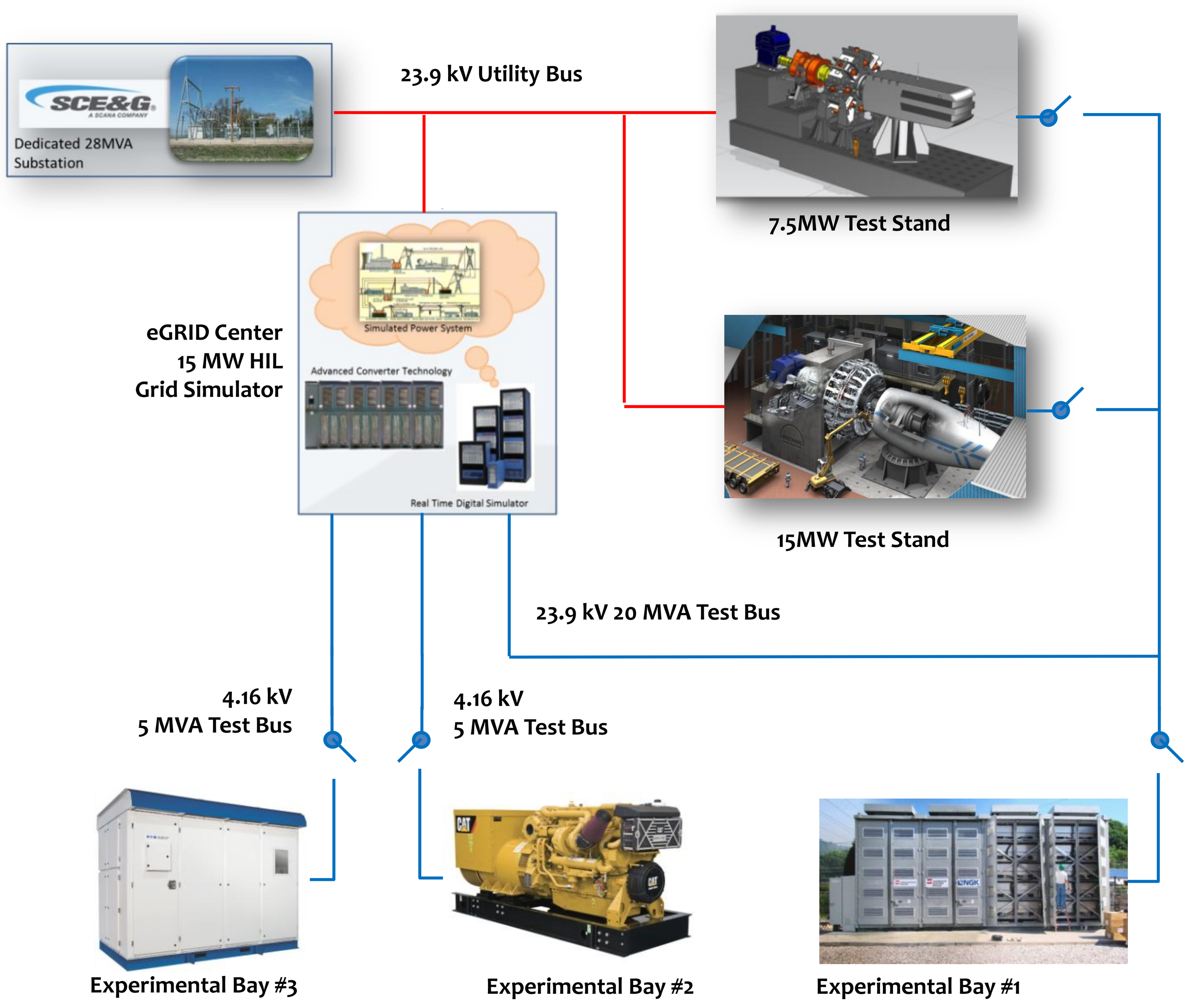
The Duke Energy eGRID Center

In 2009, Clemson University was awarded a competitive grant to build a facility to mechanically test the next generation of wind turbine nacelles. The testing capabilities of the facility were to mimic the mechanical stresses rotating turbine blades induce on wind turbine nacelles up to 15MW. In addition to mechanical testing, a separate grant was issued to provide electrical testing capabilities; this became the Duke Energy Electrical Grid Research Innovation and Development (eGRID) Center. Both the mechanical and electrical facilities are housed in the South Carolina Electric and Gas Energy Innovation Center located in North Charleston, South Carolina.

The initial vision for the facility has been guided and refined through detailed collaboration with an industrial and technical advisory board and the strong involvement of the founding partners.

Transforming the electrical grid into a more robust and efficient network requires:

- New technologies that will have to play a role in system stability and security
- Extensive testing of hardware and software systems to meet safety and quality assurance requirements through '***fully integrated***' system testing.



The eGRID Center is collocated with both a 7.5 MW and 15 MW wind turbine dynamometer at the SCE&G Energy Innovation Center

Advanced, Full-Scale System Testing and Demonstration

- Several advanced testing facilities are coming online to meet these needs
- The overall objective of all of these testing facilities is to ensure to continued reliable operation of the power grid while incorporating new technologies
- The eGRID Center is designed to incorporate standards testing with Power Hardware-In-the-Loop testing (PHIL)
- The eGRID Center will be fully operation Q4-2014

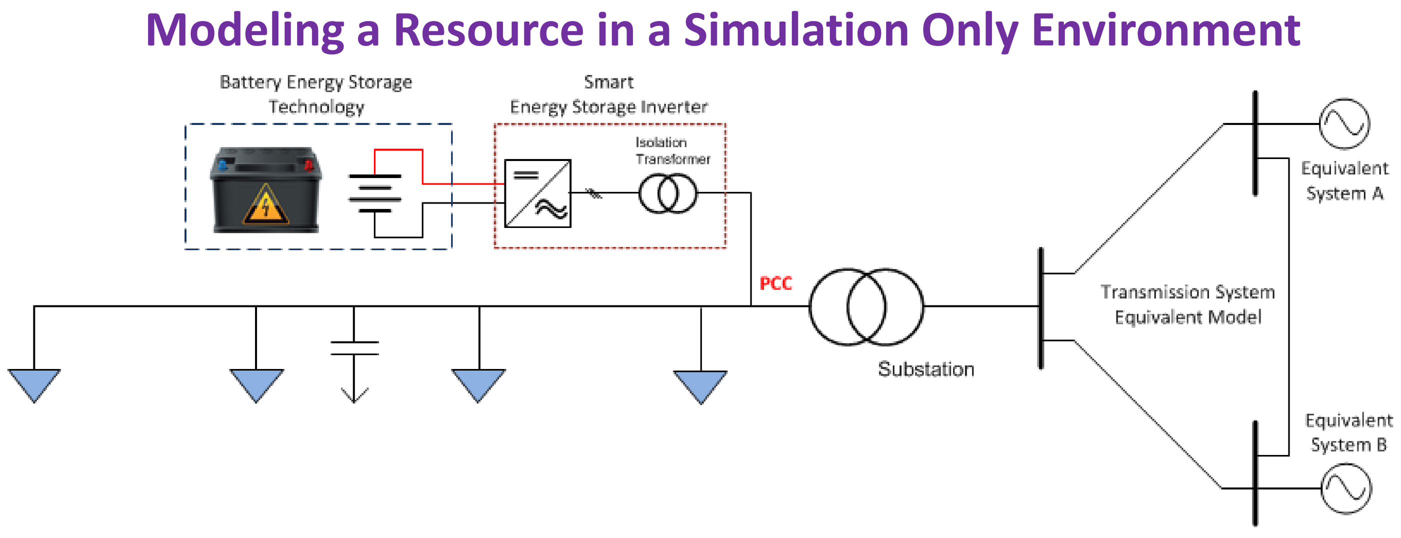
Possible Grid Integration Evaluations at Advanced Testing Facilities

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

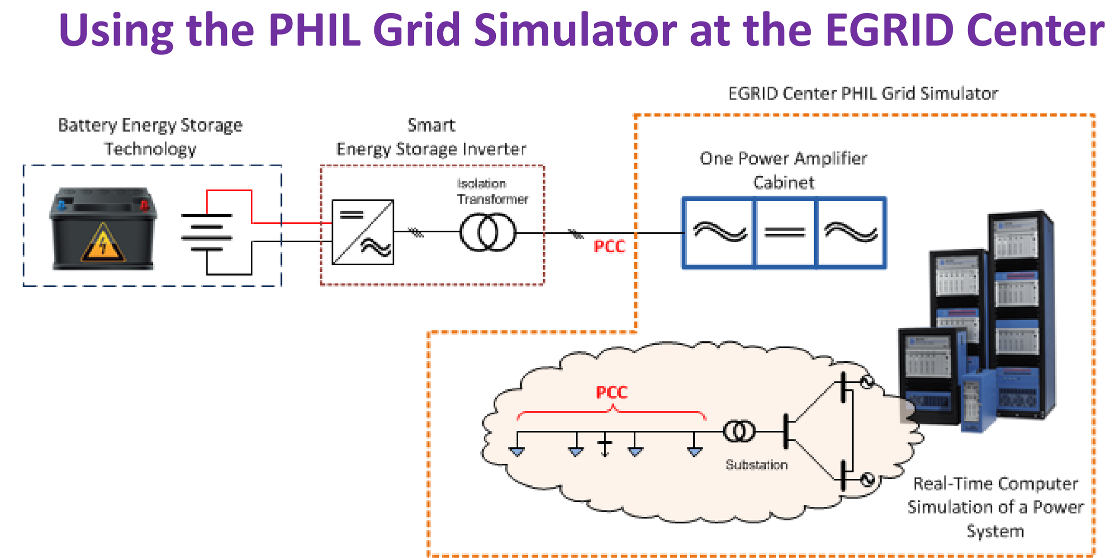
Power Hardware-In-the-Loop (PHIL) Testing

Power Hardware-In-the-Loop testing is where a physical device is coupled to a simulated power system through a large power amplifier. PHIL experiments are essentially a demonstration project on an arbitrary system. It is envisioned that PHIL can aid in developing resources and control systems to further aid in system stability. Specifically through parallel model verification and validation, where simulation models can be refined by evaluation of the real behavior of the physical devices.

Modeling a Resource in a Simulation Only Environment



Using the PHIL Grid Simulator at the EGRID Center



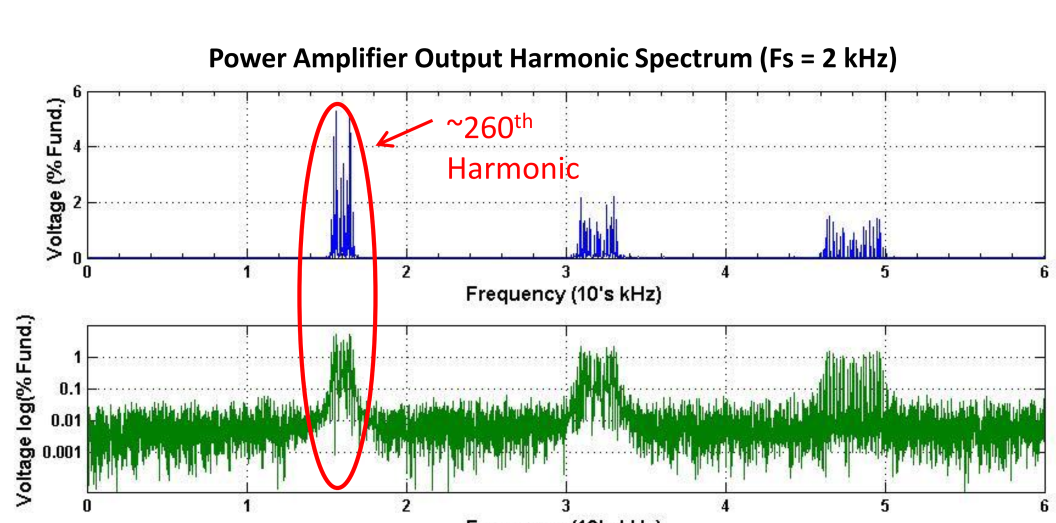
PHIL Power Amplifier Units

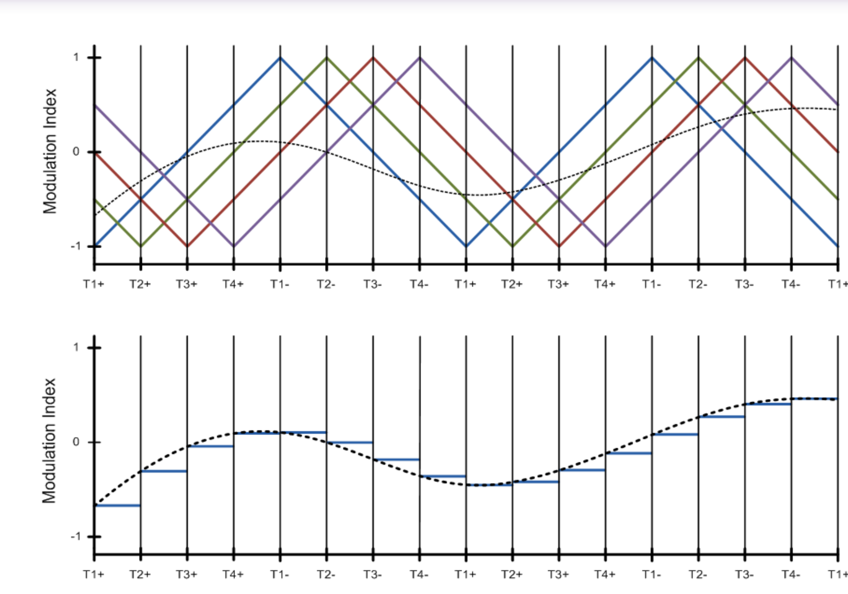
The Power Amplifier Units (PAU) installed at the eGRID Center feature a Series Connected H-Bridge (SCHB) modular multi-level inverter topology

- The multi-level inverter allows for a cleaner representation of the system voltages, reducing the filtering required and increasing the bandwidth
- The system consists of four PAUs that can be split apart for separate testing scenarios, including multiple buses on a single PHIL experiment
- The PAUs include a built in over-voltage capability to aid in PHIL experiments and to test for high voltage ride-through

Multi-level Phase Shifted Carrier Pulse Width Modulation

- High degree of harmonic cancelation due to multilevel architecture
- 12 kHz low-level direct reference sampling down to the comparators for the IGBTs





- Commissioning tests 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 (THD[0-200th] ≈ 0.34%)

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Charlotte, NC USA

The Duke Energy eGRID Center
Clemson University Restoration Institute
North Charleston, South Carolina, USA

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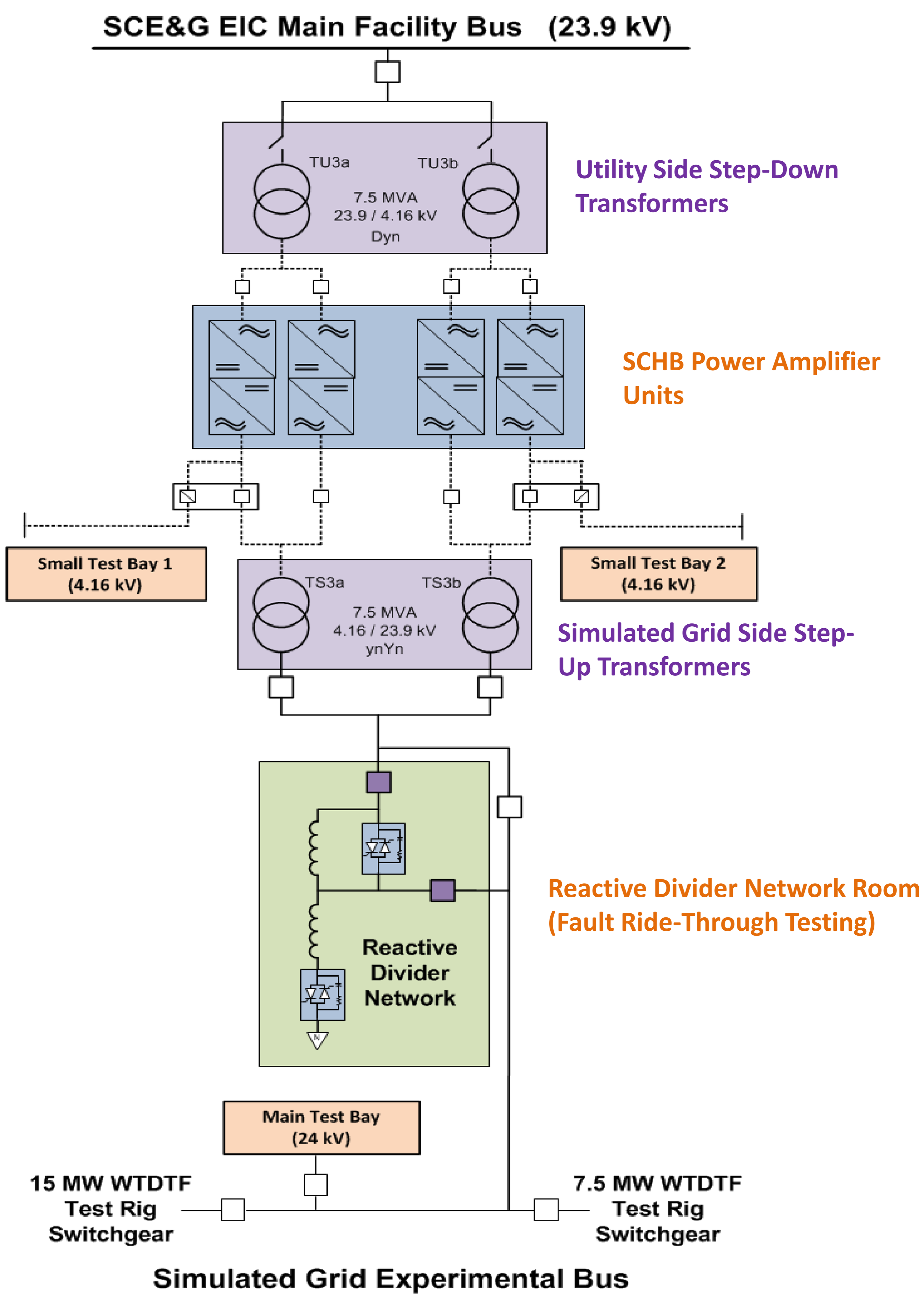
The 15 MW Hardware-In-the-Loop Grid Simulator System

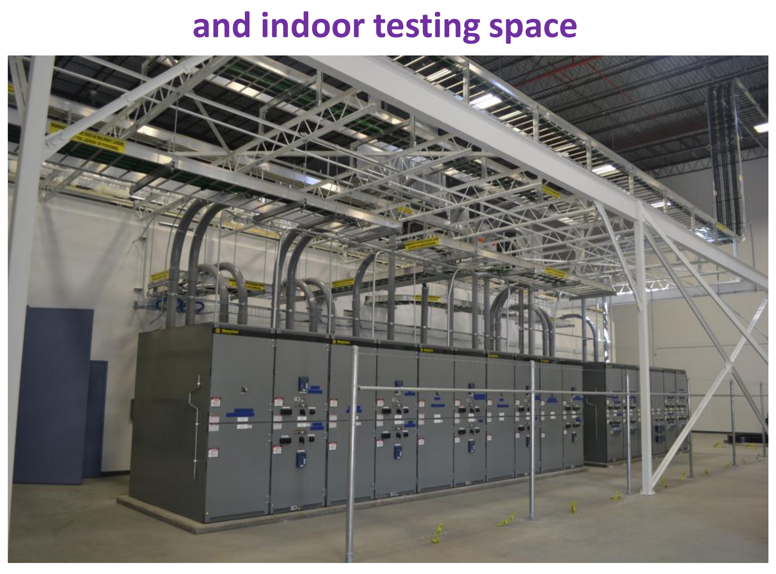
- The 15 MW Grid Simulator uniquely combines the topology of a power electronic converter connected with a reactive divider network
- This topology allows for more realistic fault conditions, such as transformer saturation and highly inductive fault impedances that replicate transmission lines
- The system is designed to mimic both a transmission or a distribution system by allowing for zero sequence components
- The system can be easily split into three independent test bays to facilitate multiple testing campaigns or more advanced testing scenarios
- The system has several unique features to ensure personnel and equipment safety while creating power system faults within a controlled environment
- The system is designed to produce arbitrary voltages at frequencies ranging from 45- 65 Hz with very low harmonic distortion



Outdoor Transformer Yard and Reinforced Concrete Testing Area

Power Amplifier Room with 4 separate amplifier cabinets

EGRID 5 kV and 25 kV Switchgear and indoor testing space



Reactive Divider Network Room for Fault Ride-Through Testing

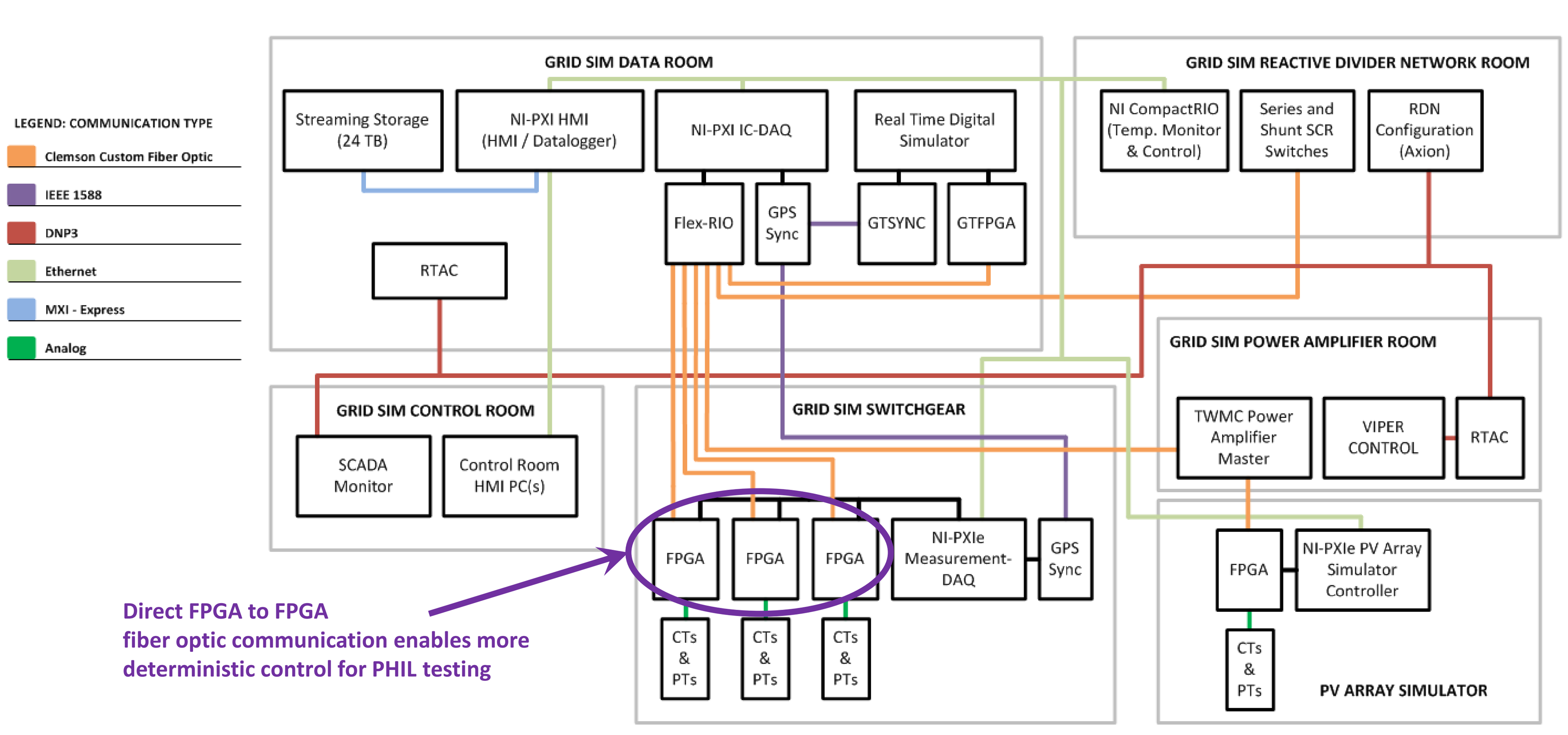
High Speed Control and Data Acquisition System to Support PHIL

To facilitate the accuracy and safety of PHIL experiments a high speed, highly deterministic control and data acquisition system has been designed.

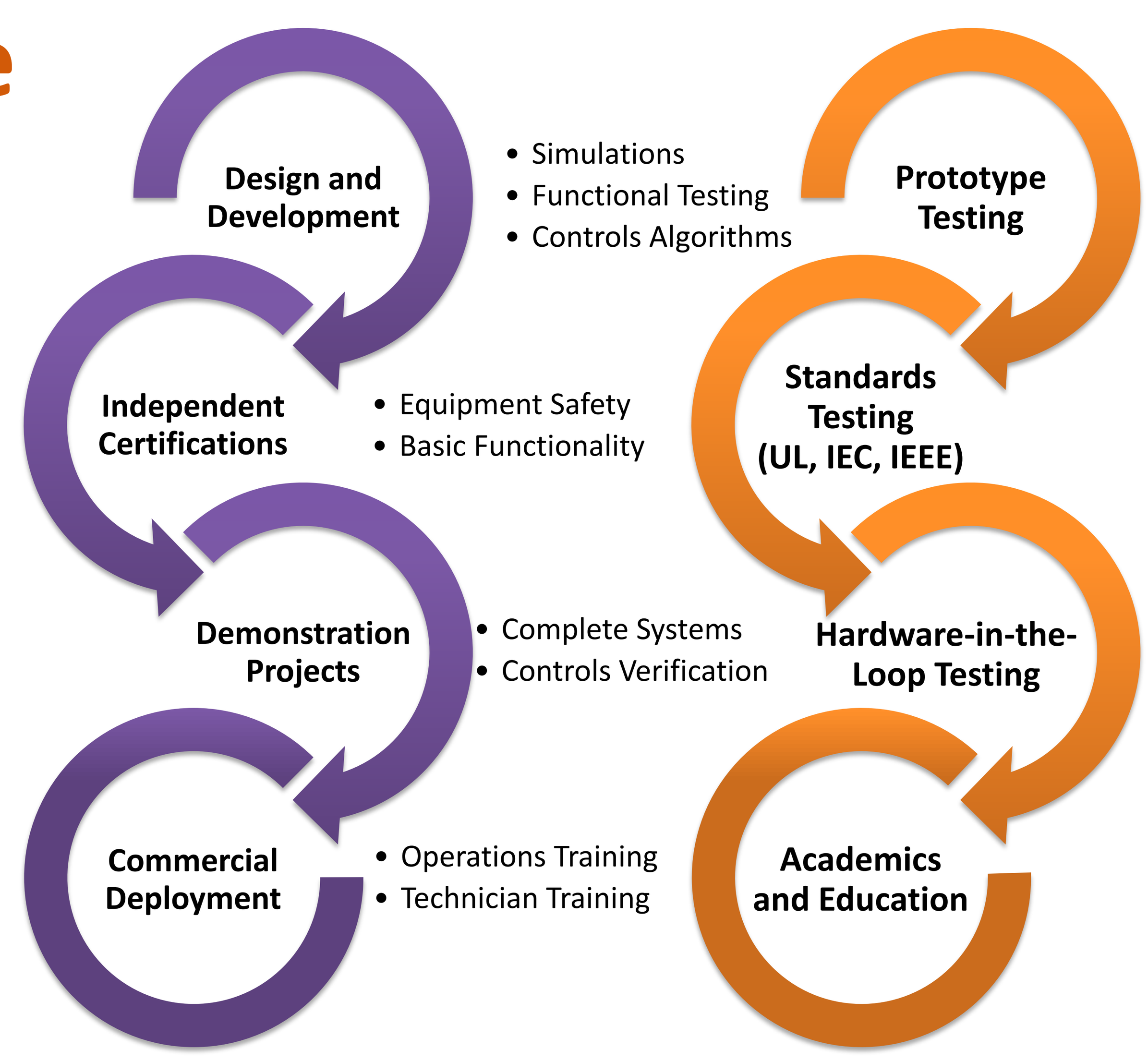
- The SCADA system has been developed in cooperation from:

Savannah River National Laboratory | Clemson University | National Instruments

- A supervisory interface controller processes all signals between the simulated and physical systems
- To achieve deterministic control the system utilizes FPGA's with a custom fiber optic network that supports low latency signal routing



Fitting into the development cycle



eGRID Center Founding Partners

DUKE ENERGY | SRNL | U.S. Department of Energy Energy Efficiency and Renewable Energy

SCANA | Santee Cooper | Underwriters Laboratories

TECO Westinghouse

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