eGRID Introduction and Status

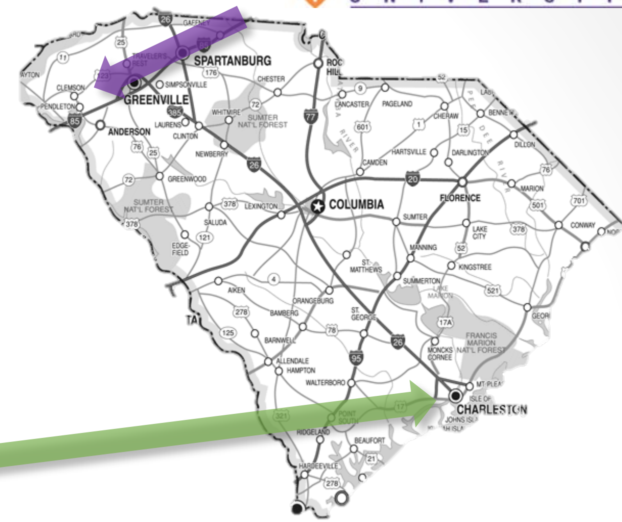
2nd International Workshop

September 17th, 2014

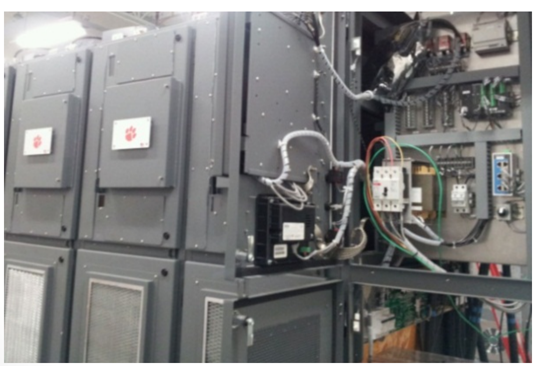
CLEMSON UNIVERSITY
RESTORATION INSTITUTE

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
      - 15 MW HIL Grid Simulator
    - Wind Turbine Drivetrain Testing Facility
      - 7.5 MW Test Bench
      - 15 MW Test Bench



The EGRID Center Team Members

J. Curtiss Fox, PhD	Director of Operations
Randy Collins, PhD, PE	Project Co-PI
Thomas Salem, PhD, PE	Research Scientist
Mark McKinney, PhD	Visiting Research Scientist
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Lindsey Stephens	MSEE
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<u>Undergraduate Students:</u>

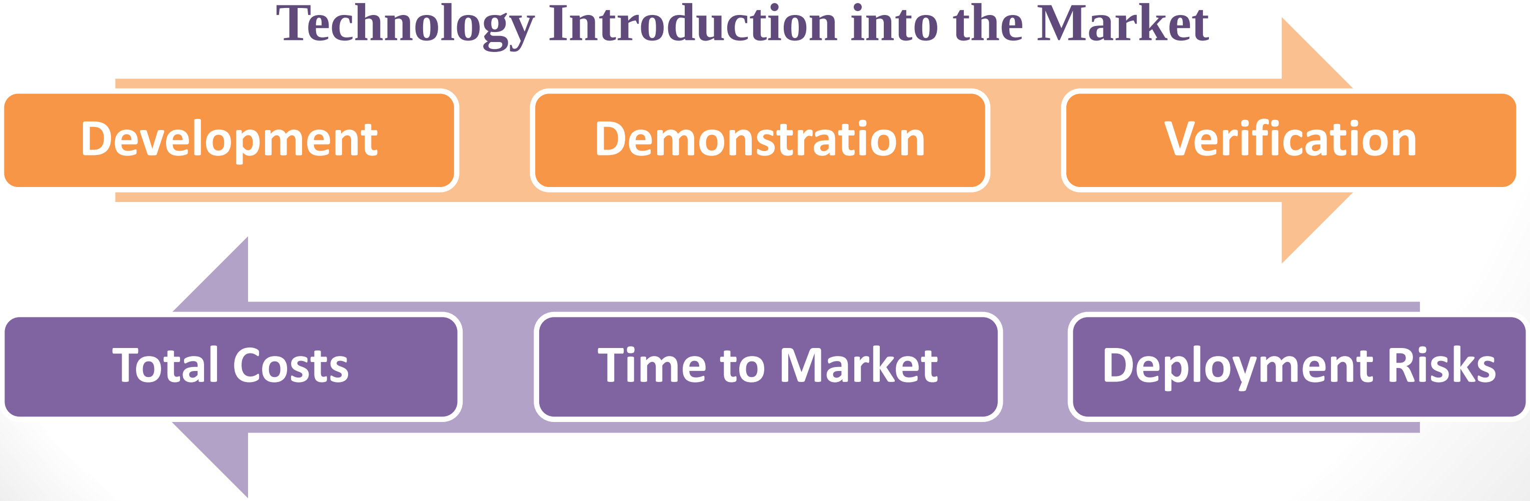
Diana Agrest	Clemson University
Tyler Vasas	The Citadel

The SCE&G Energy Innovation Center

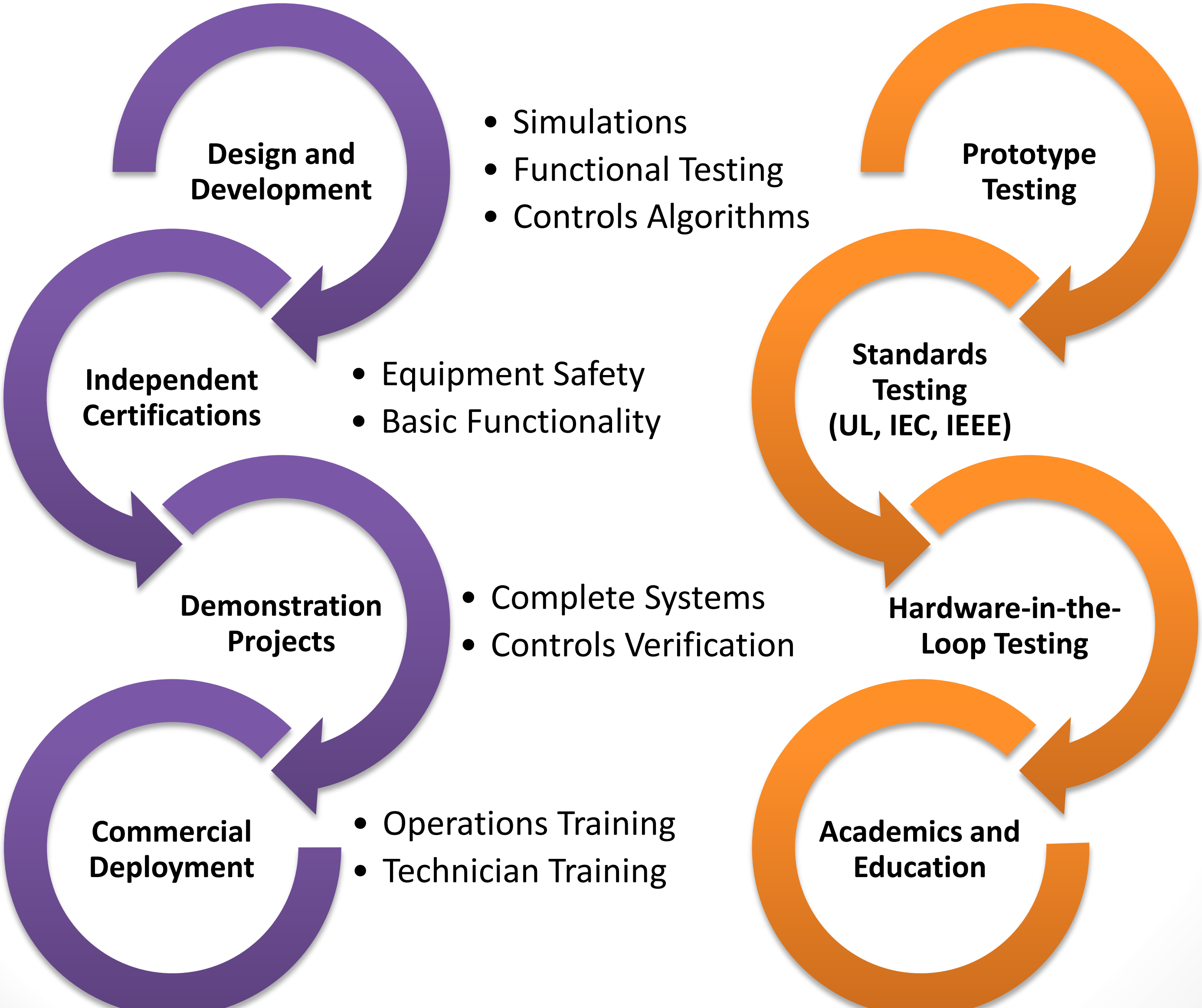
Transforming the electrical grid into an energy efficient network requires:

- 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



How the EGRID center fits into the technology development cycle



eGRID Founding Partners

DUKE ENERGY®

SRNL™

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

SCANA® Power For Living

Santee Cooper

UL® Underwriters Laboratories

TECO Westinghouse

eGRID Market Applications

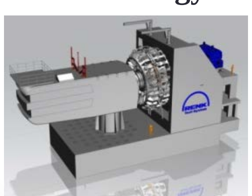
Large Solar PV Converters

Micro-Grid Applications

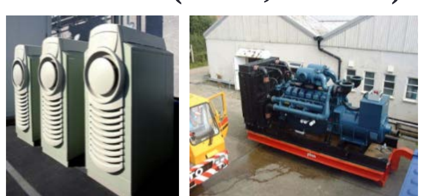
EV Charging Stations

Utility Scale Energy Storage

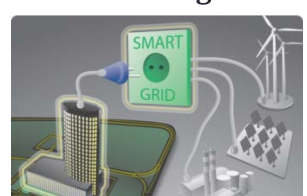
Wind Energy



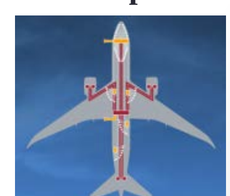
Traditional Distributed Generation (Diesel, NG. etc.)



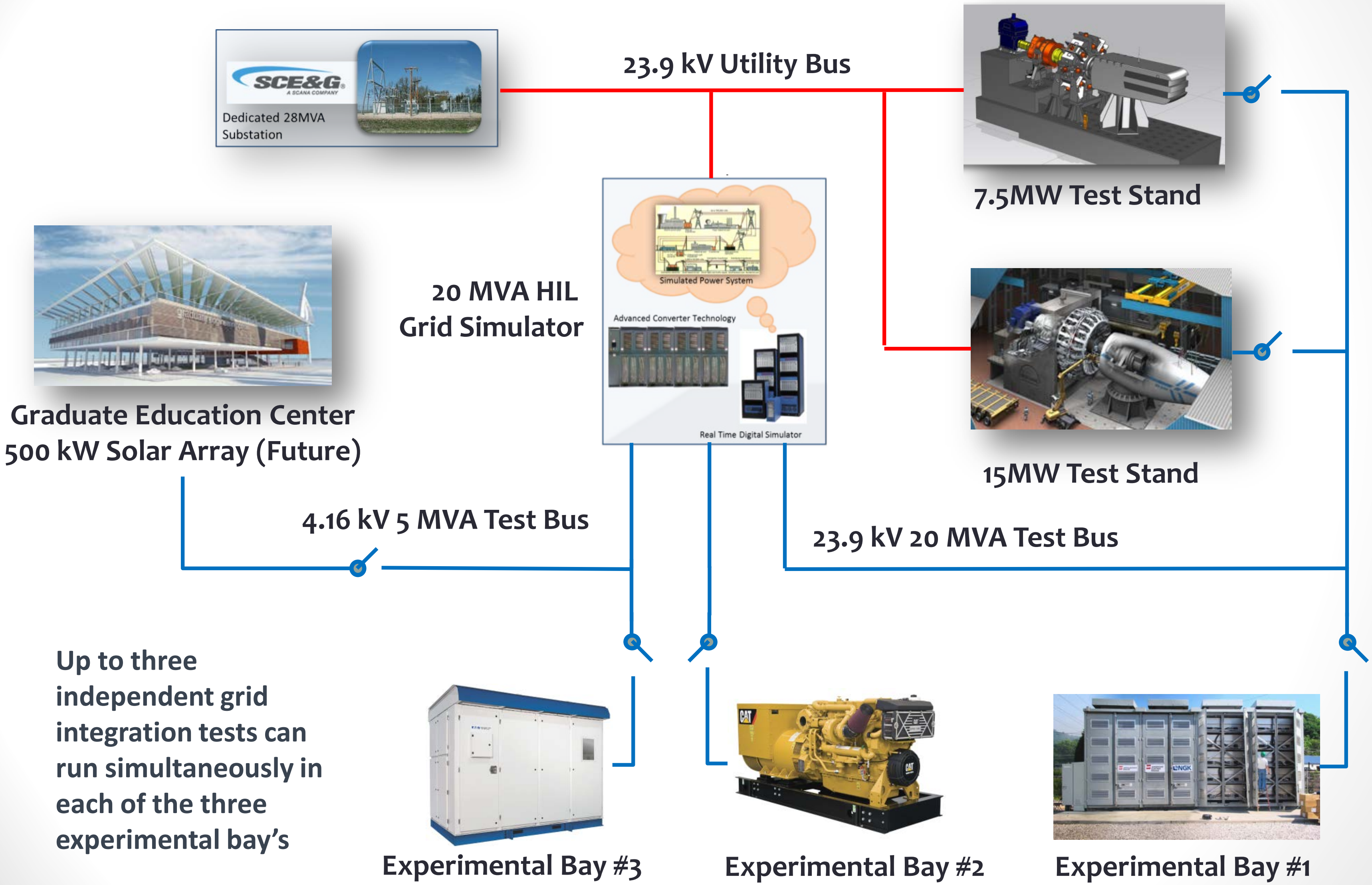
Smart Grid Technologies



Aerospace

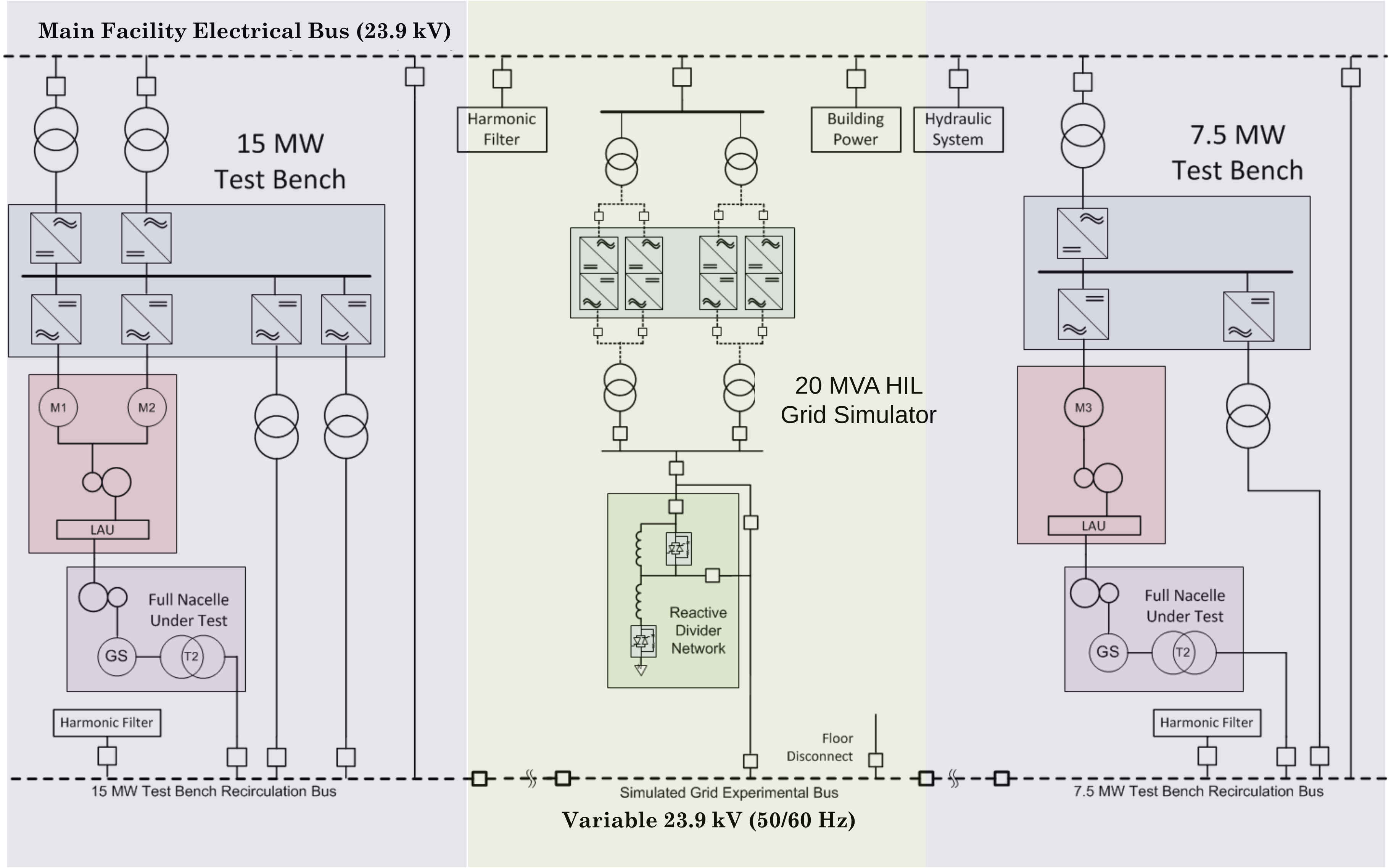


SCE&G Energy Innovation Center



Up to three independent grid integration tests can run simultaneously in each of the three experimental bay's

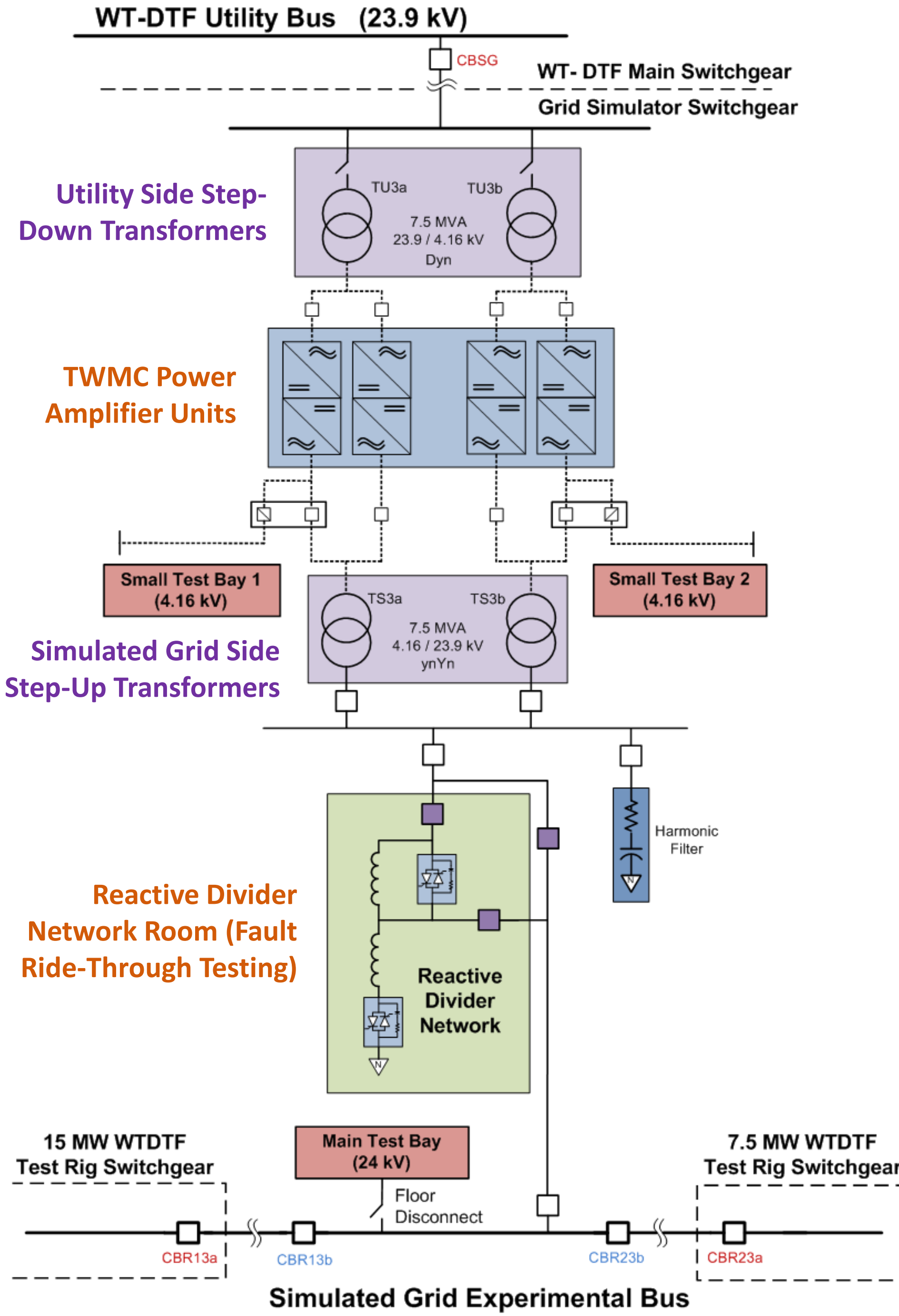
SCE&G EIC Electrical Single Line



The 20 MVA HIL Grid Simulator

Three Independent Test Bays

Overall Electrical Capabilities	
Main Test Bay	
Nominal Voltage	24 kV (50/60 Hz)
Nominal Power	20 MVA
Frequency Range	45 to 65 Hz
Sequence Capabilities	3 and 4 wire operation
Overvoltage capabilities	133% Continuous Overvoltage
Fault Simulation	Yes (includes Reactive Divider)
Hardware In the Loop	Yes
Small Test Bay 1	
Nominal Voltage	4160 V (50/60 Hz)
Nominal Power	5 MVA (4 MW @ 0.8 PF)
Frequency Range	0 to 800 Hz
Sequence Capabilities	3 and 4 wire operation
Overvoltage capabilities	133% Continuous Overvoltage
Fault Simulation	Limited to Converter Only
Hardware In the Loop	Yes
Small Test Bay 2	
Nominal Voltage	4160 V (50/60 Hz)
Nominal Power	5 MVA (4 MW @ 0.8 PF)
Frequency Range	0 to 800 Hz
Sequence Capabilities	3 and 4 wire operation
Overvoltage capabilities	133% Continuous Overvoltage
Fault Simulation	Limited to Converter Only
Hardware In the Loop	Yes



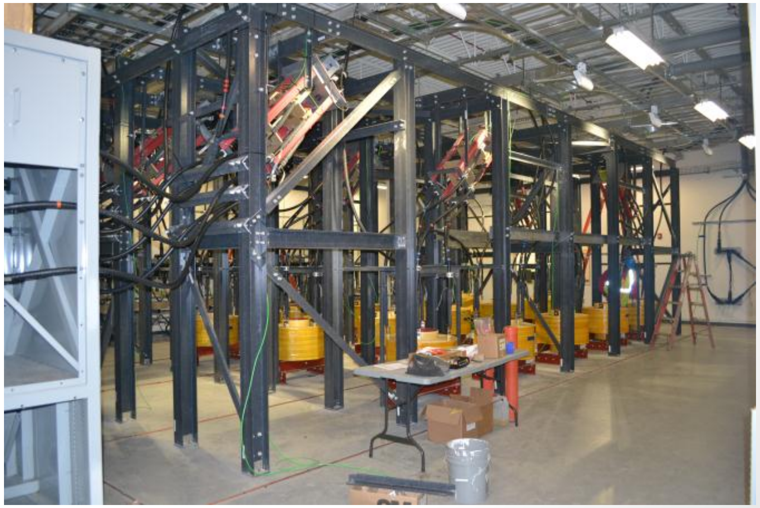
The 15 MW HIL Grid Simulator

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

Increasing level of difficulty

Hardware-in-the-Loop Testing

15 MVA Series Connected
H-Bridge Power Amplifiers

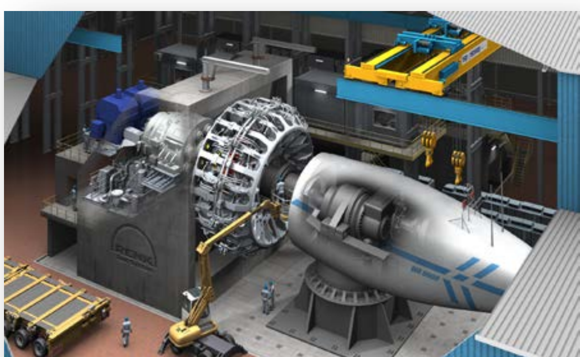
Commanded Voltage
Reference

National Instruments
Interface Controller

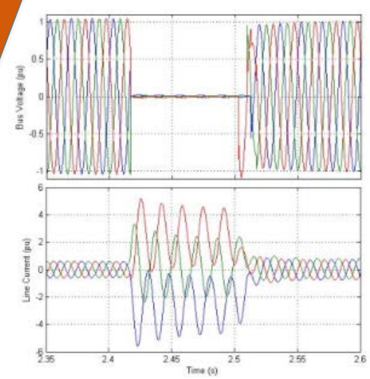
Voltage and Current
Set Point Commands

Loop timing
and latency
are critical

Real Voltages associated
with ***BUS #N***



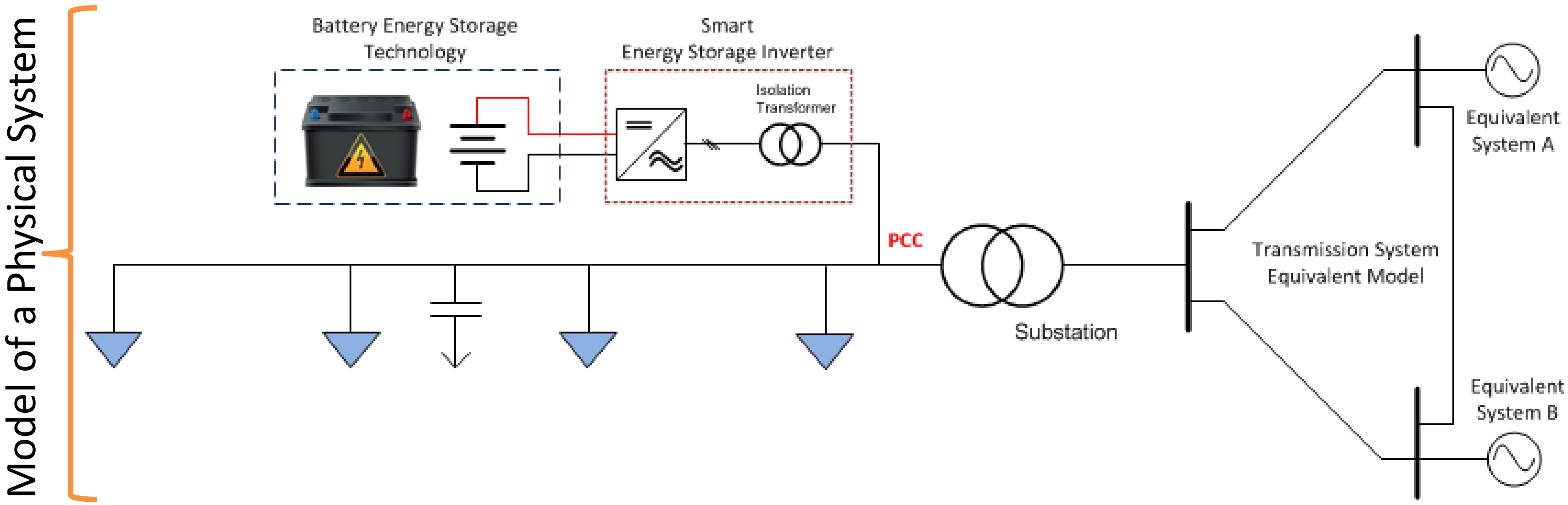
Device Under Test
*"I'm connected at **Bus #N**"*



Real Voltage and
Current Measurements

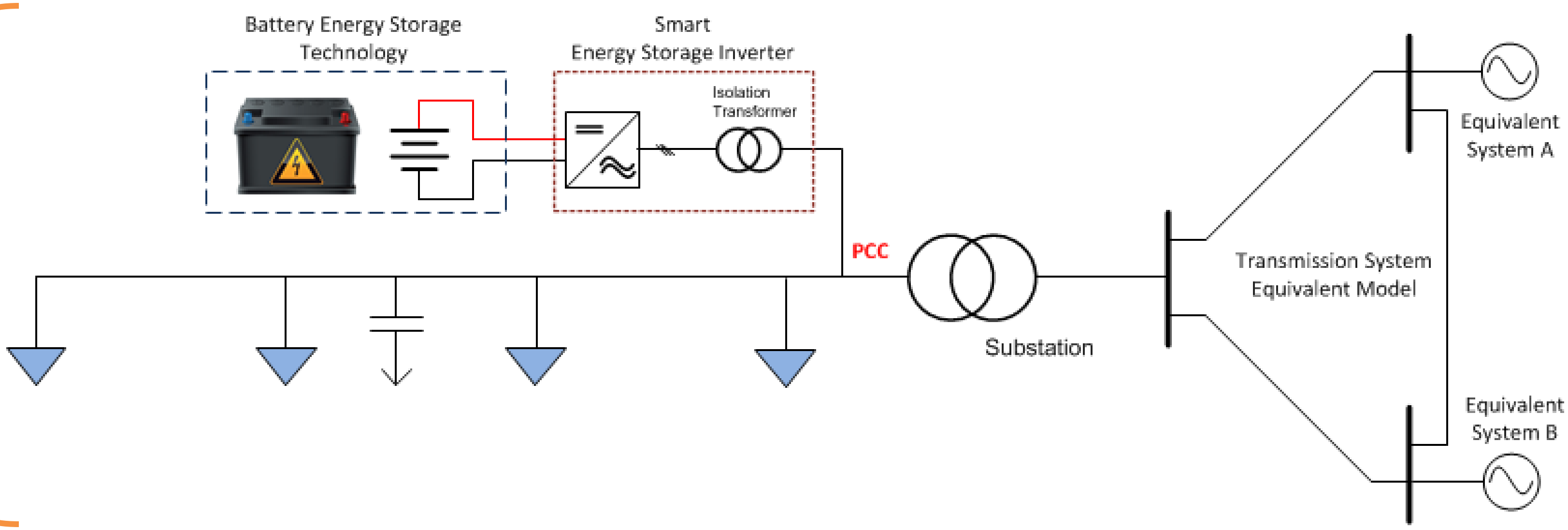
BUS #N
Voltage and Current
Information

Energy Storage Integration

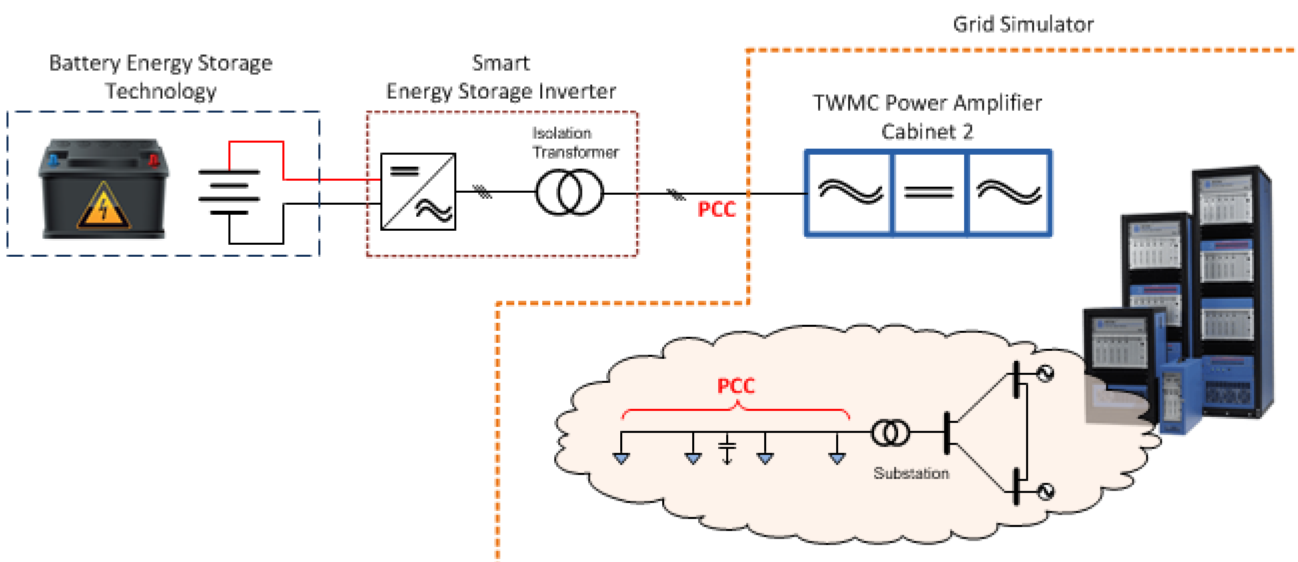


Energy Storage Integration

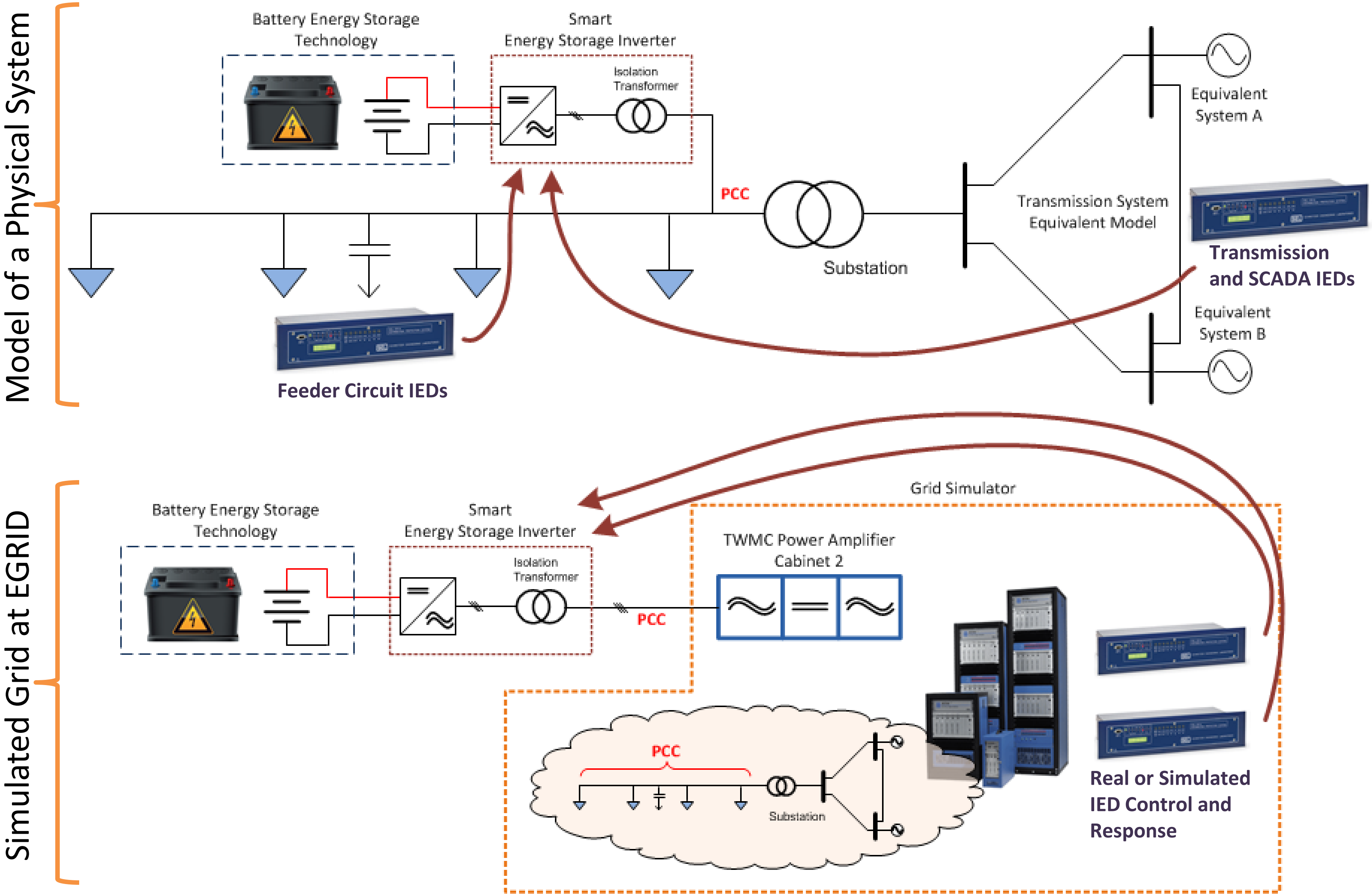
Model of a Physical System



Simulated Grid at EGRID

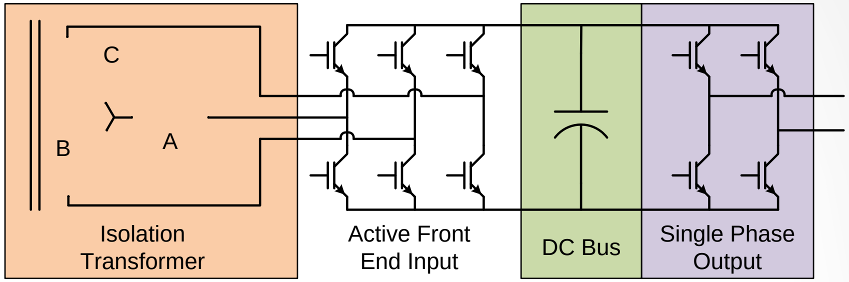


Adding Distributed Control Hardware and Communications

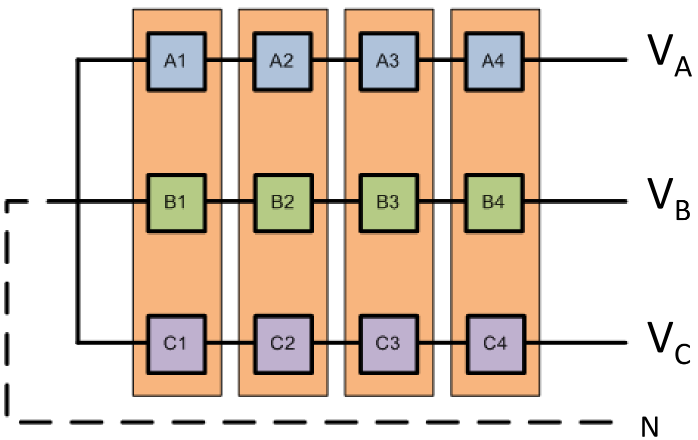


TECO Westinghouse Motor Company: Power Amplifier Units

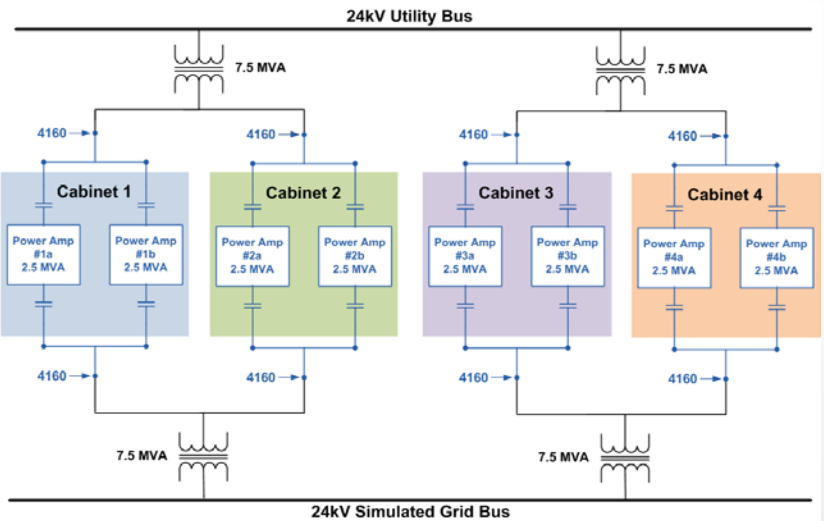
TWMC Power Amplifier	
Installed Power	20 MVA (15 MW @ 0.8 PF)
Rated Power	15 MVA (12 MW @ 0.8 PF)
Cabinet Power Split	4 x 3.75 MVA or 2 x 7.5 MVA
Rated Voltage	0 - 4160 V
Overvoltage	133 % Rated Output Voltage
Multilevel Operation	7 - Levels (9 - Levels Overvoltage)
Frequency Range	3 - 66 Hz
Overload Capability	110% for 60 s (10 min duty cycle)



Individual power cube with three phase input and single phase output



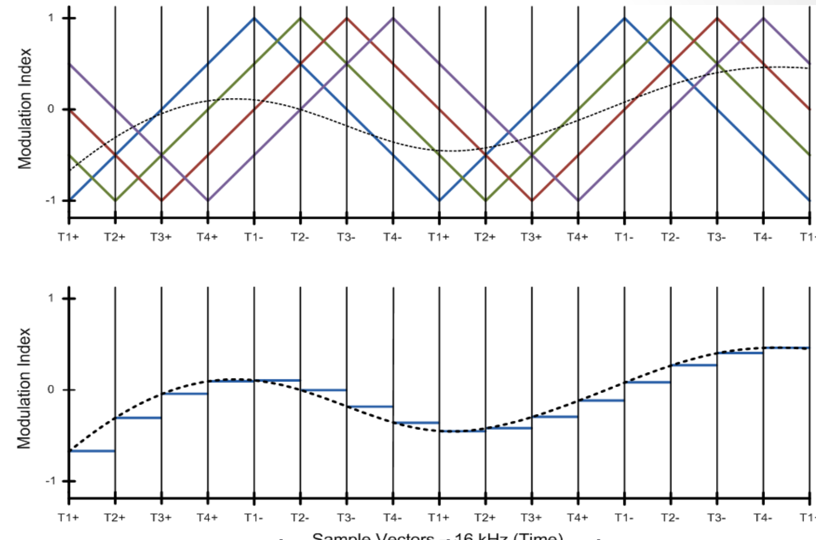
4 Power Slices per Amplifier Section



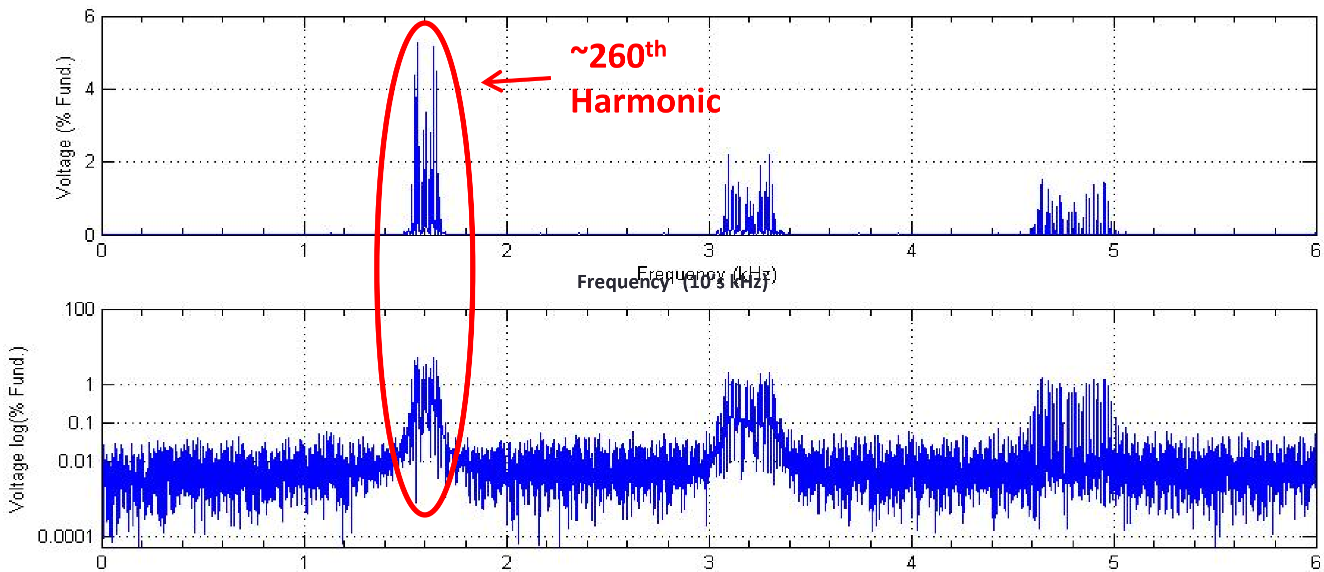
8 Parallel Amplifiers arranged into 4 Cabinets

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



Synchronous Sampling up to 12 kHz



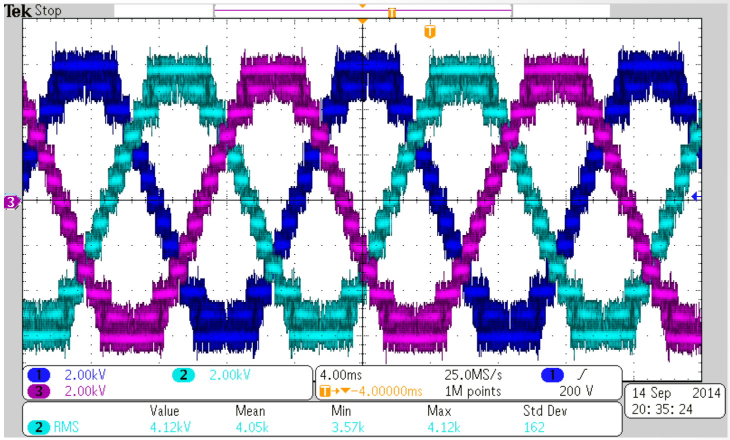
Simulations and FAT testing show excellent results with 2 kHz switching frequencies

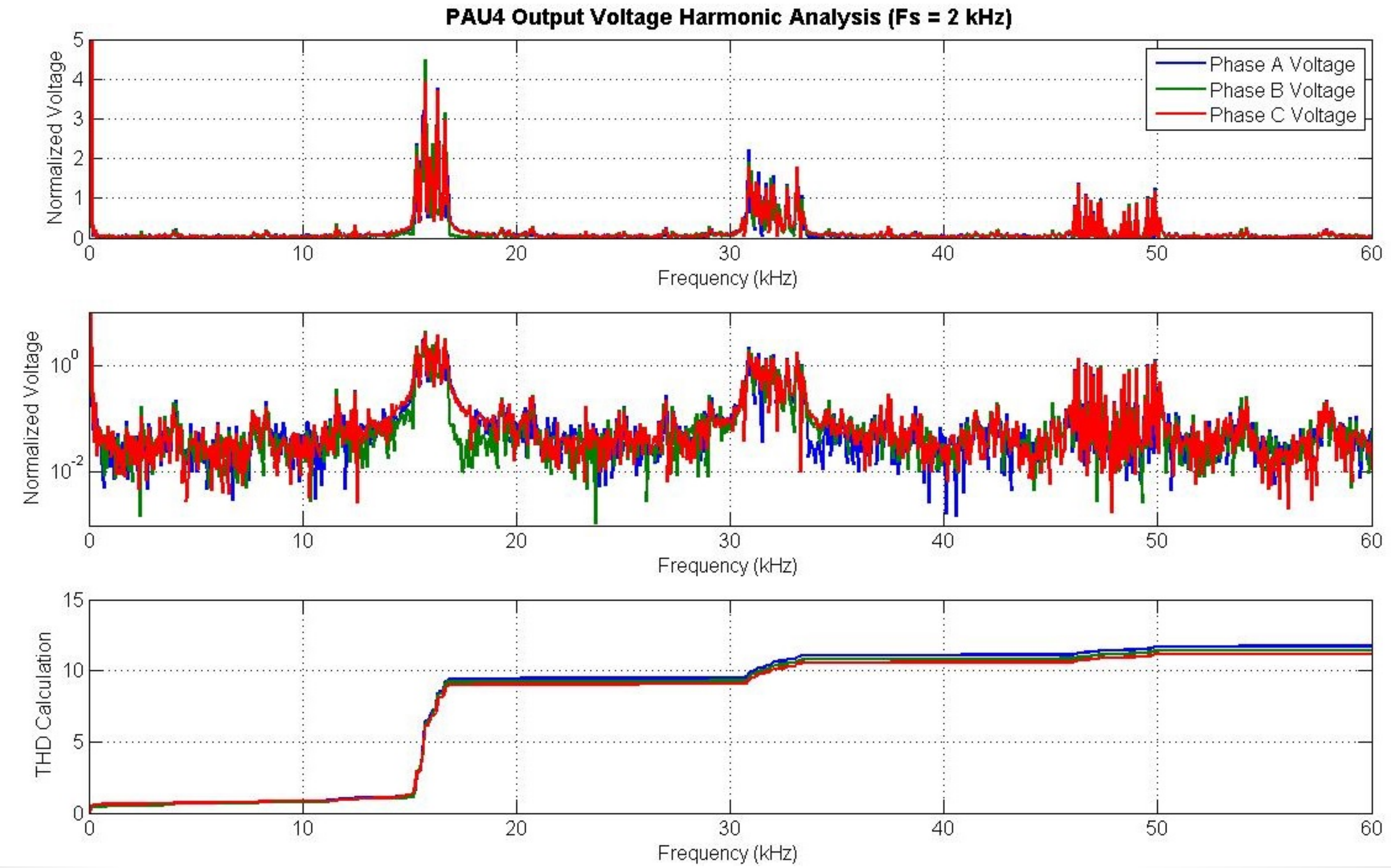
First noise mode is at 16 kHz (Fs x 2 x Carriers) , 8 times the switching frequency

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)

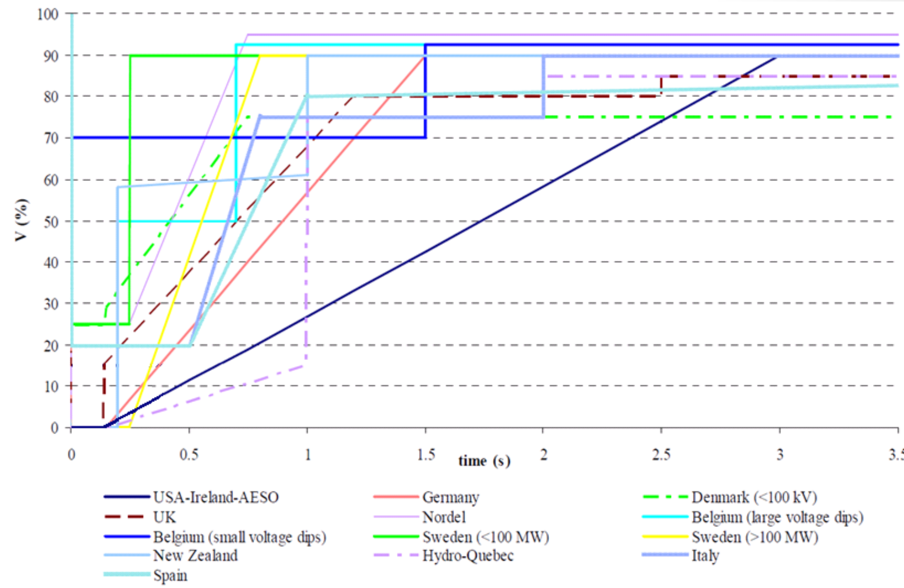
Voltage Source Converter Method

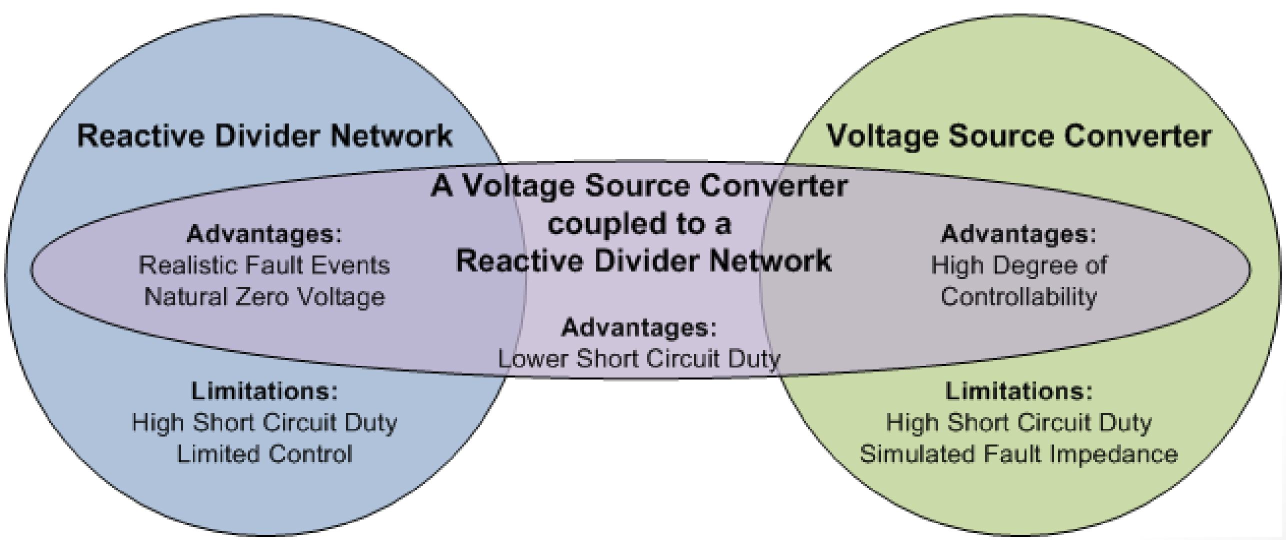
- **GE Power Conversion** (Fr. Converteam)
  - Vestas V164 Test Bench (2013)
  - NAREC 15 MW Test Bench (**Hybrid?**) (2014?)
- **ABB Test Systems**
  - NWTC at NREL (4Q-2013)

A Hybrid Method

- Clemson University (4Q-2014)

World Wide FRT Withstand Curves

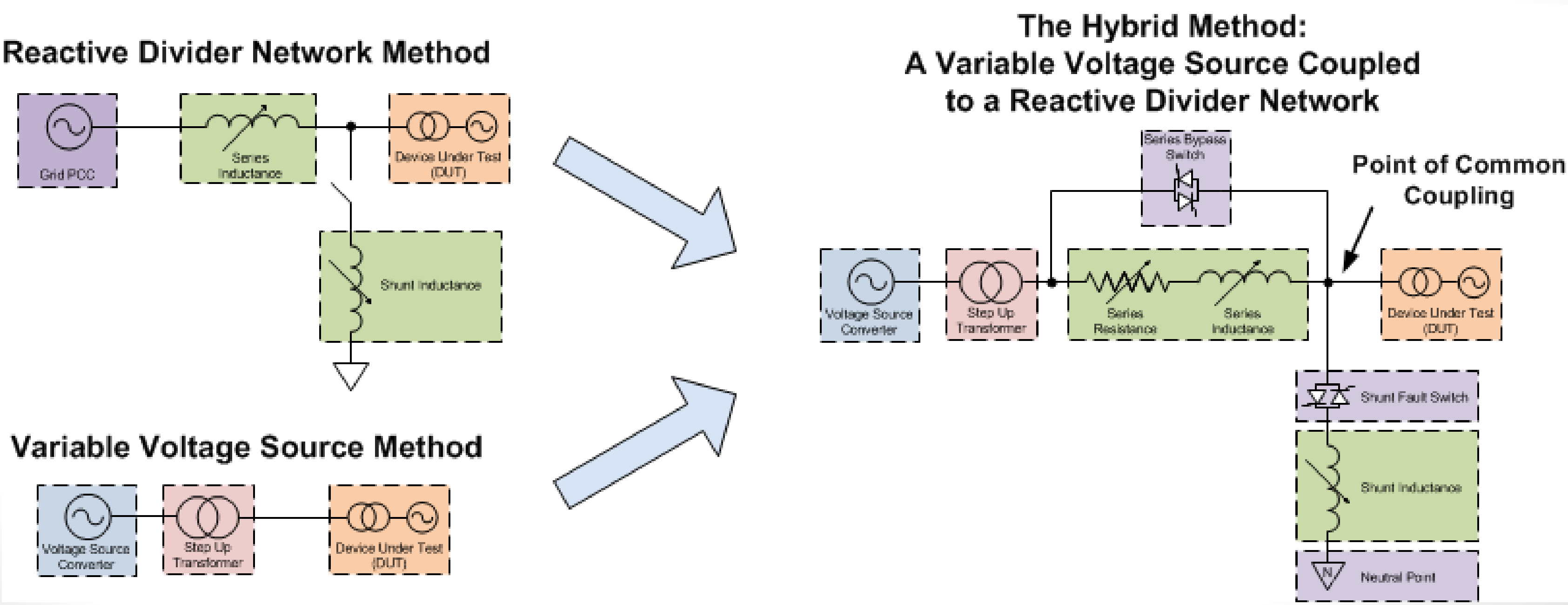




Why a Hybrid Method?

Increased flexibility and accuracy of FRT evaluations

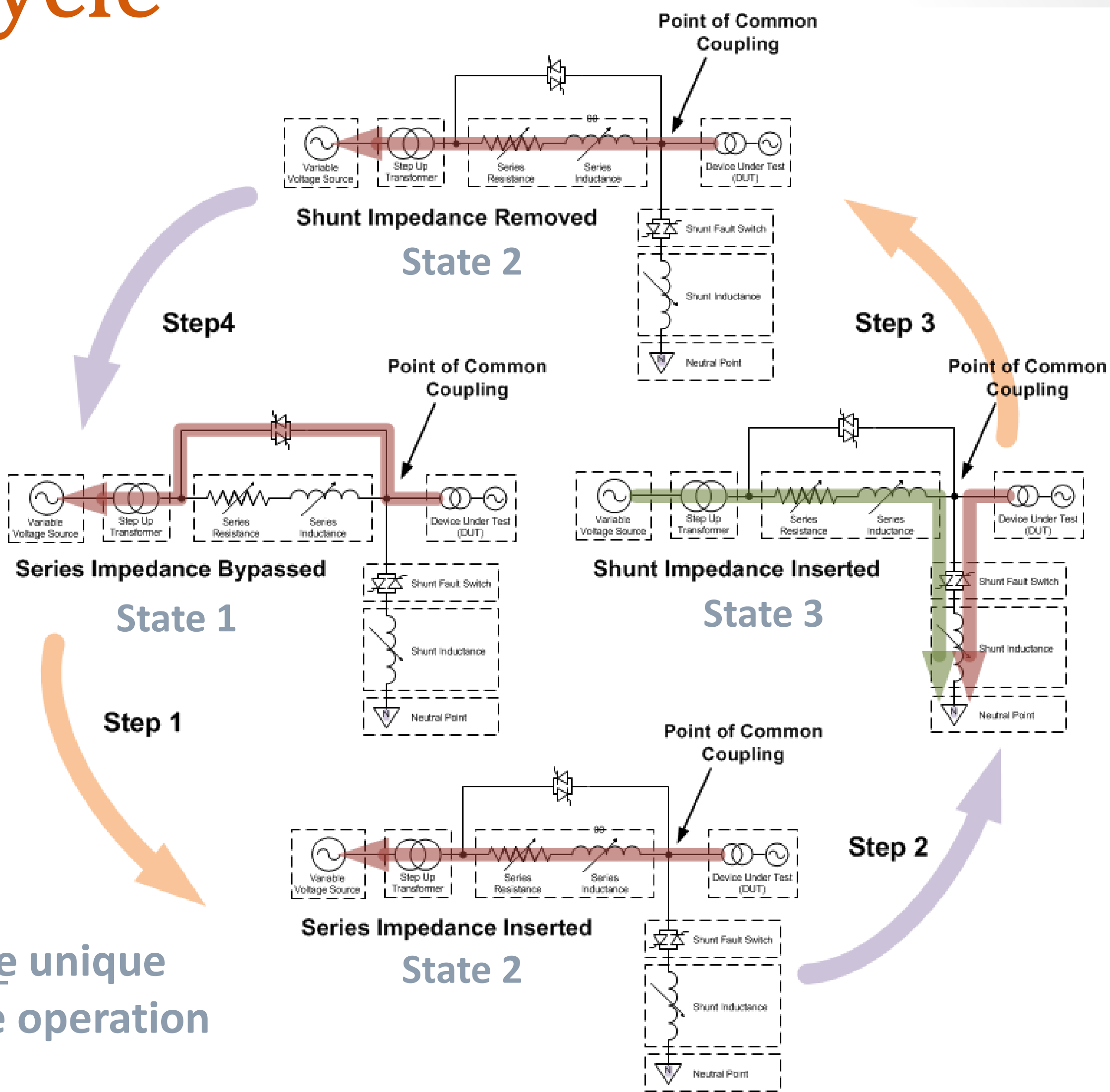
- Faulted at the point of common coupling (PCC)
- True zero voltage faults (ZVRT)
- Magnetic flux decoupling between transformers
- Real inductive loading for transient time constant analysis
- Power electronic switching for point-in-wave studies
- **<u>Backwards compatible</u>** with existing methods



The Hybrid Method: Operation Cycle

The Operation Cycle

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



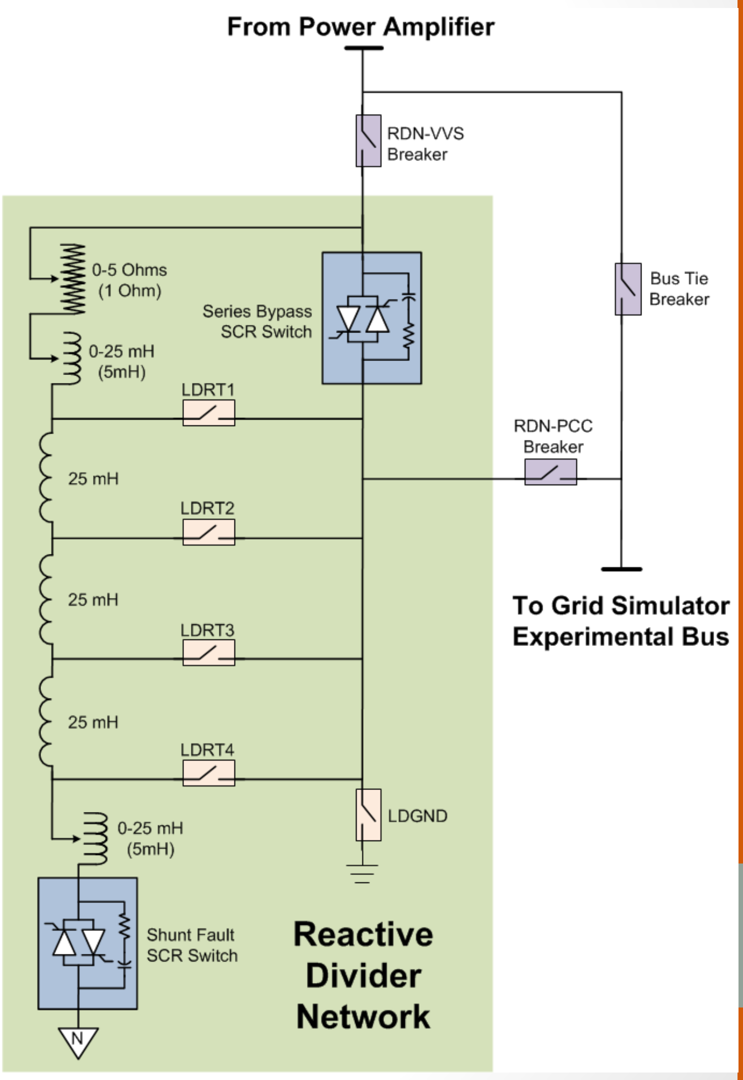
There are only three unique system states in the operation cycle.

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

Fixed Switch Positions	Shunt Fixed (mH)	Series Fixed (mH)	Total Shunt (mH)	Total Series (mH)
1-1-1-0	0	25	0-25	25-50
1-1-0-0	0	50	0-25	50-75
1-0-0-0	0	75	0-25	75-100
0-1-1-1	25	0	25-50	0-25
0-1-1-0	25	25	25-50	25-50
0-1-0-0	25	50	25-50	50-75
0-0-1-1	50	0	50-75	0-25
0-0-1-0	50	25	50-75	25-50
0-0-0-1	75	0	75-100	0-25



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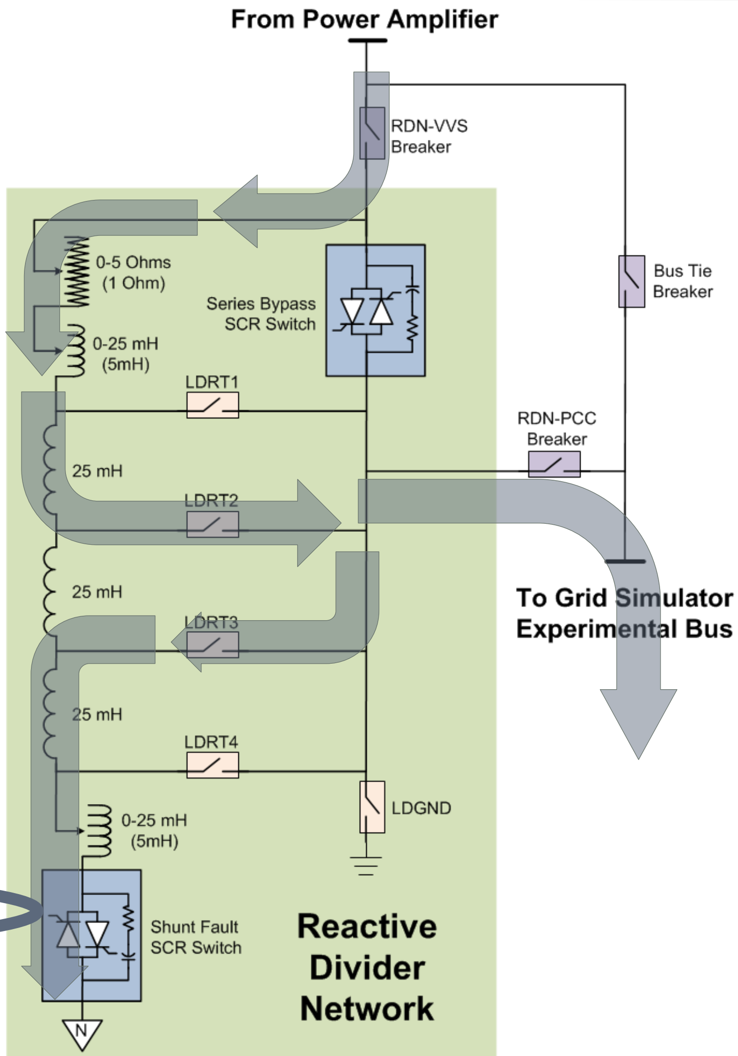
1-1-0-0	0	50	0-25	50-75
1-0-0-0	0	75	0-25	75-100
0-1-1-1	25	0	25-50	0-25
0-1-1-0	25	25	25-50	25-50
0-1-0-0	25	50	25-50	50-75
0-0-1-1	50	0	50-75	0-25
0-0-1-0	50	25	50-75	25-50
0-0-0-1	75	0	75-100	0-25

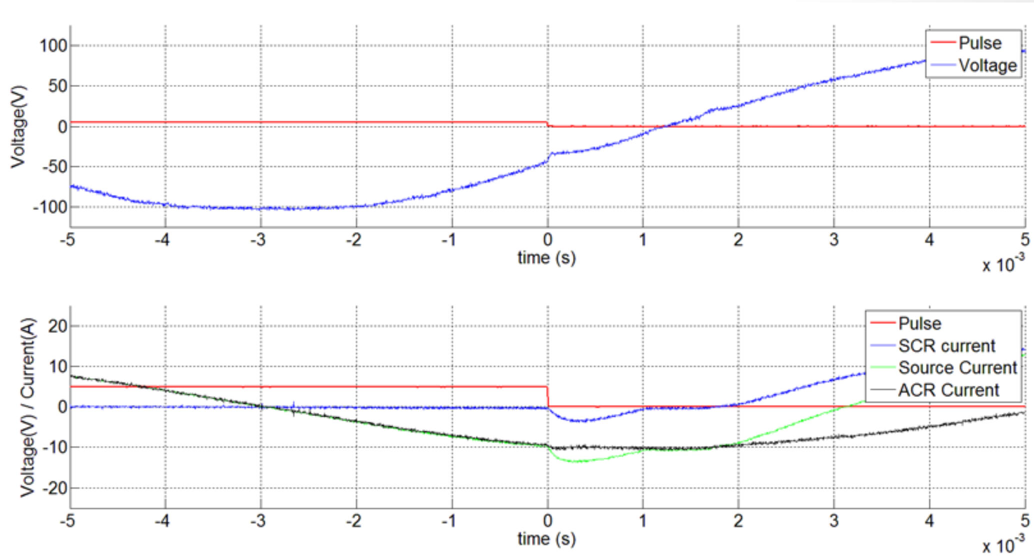


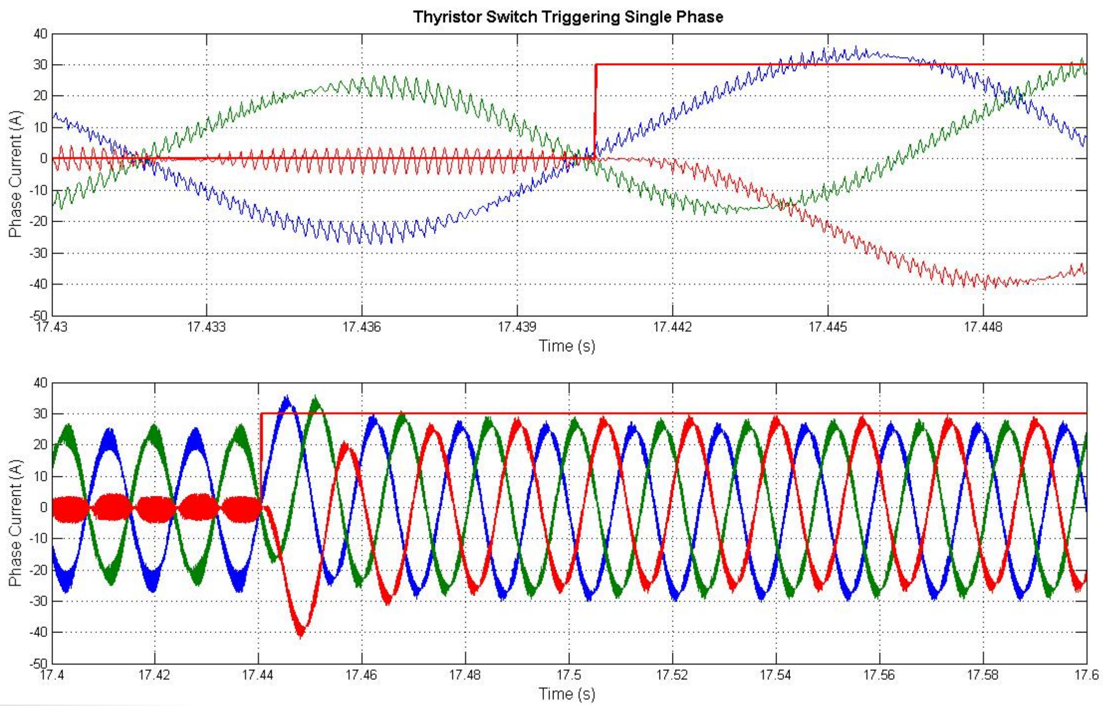
Reactive Divider Network Commissioning

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





ımissioning tests included:

ification of each switch
ıg in situ with a VARIAC and
ʀ

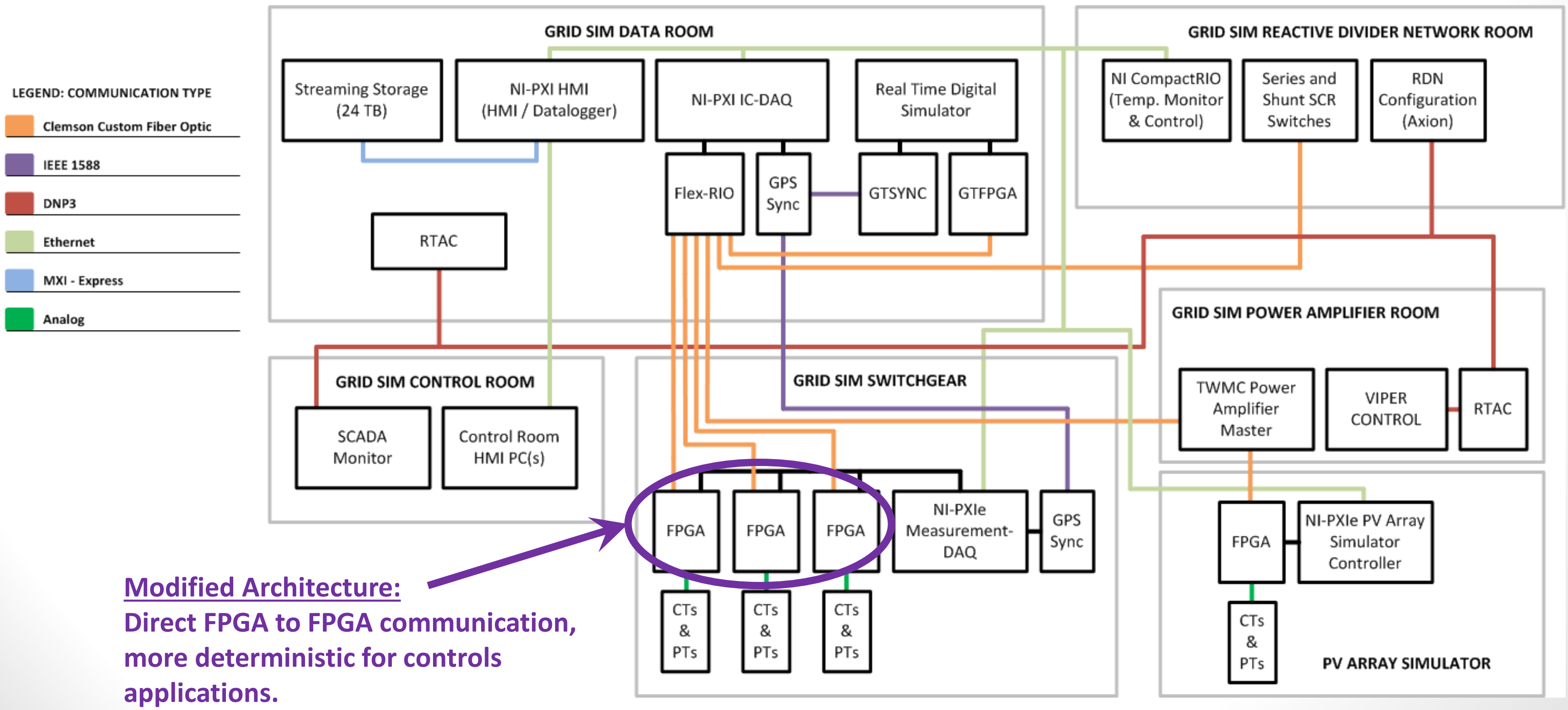
ıg one PAU and
mentarily loading the PAU
ı the complete RDN
ıctive load

eGRID SCADA System

- Detailed specifications developed through coordinated efforts between:

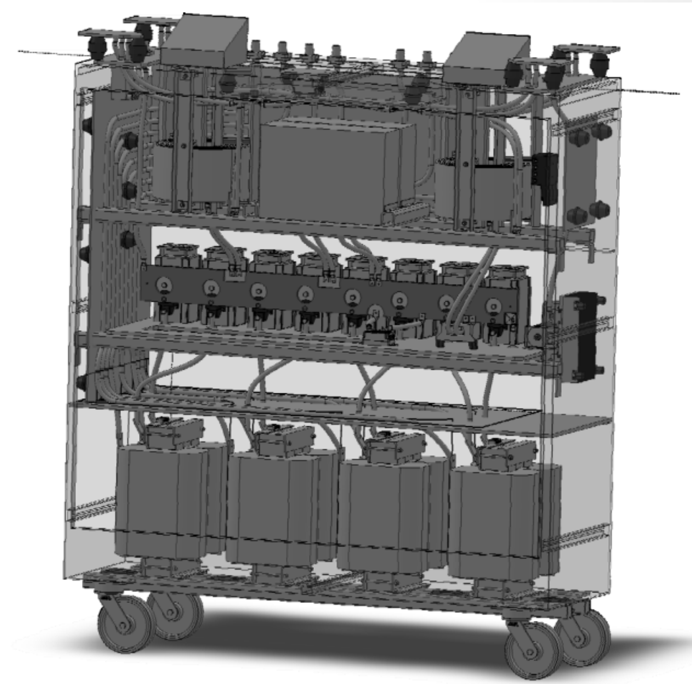
Savannah River National Laboratory | **Clemson University** | **National Instruments**

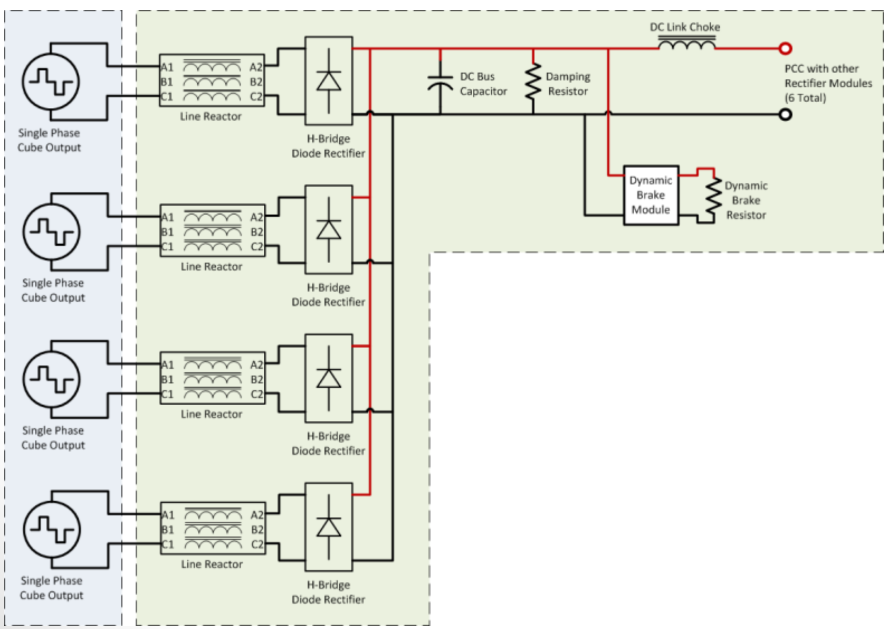
- Significant amount of hardware and software shared with the WTDTF systems
- Provides a powerful and flexible platform for the development of custom control systems to meet the various grid integration evaluation scenarios



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		
	1 Module	6 Modules
Voltage Range	200 – 1000 V	
Current Rating	420 A (1000 V)	2500 A (1000 V)
Short Circuit Current	835 A	5000 A
Ripple Frequency	2400 – 4800 Hz	
Reverse Power Flow	67 kW (1000 V)	400 kW (1000 V)

Thank You