eGRID Introduction and Status

3rd International Workshop

November 5th, 2015

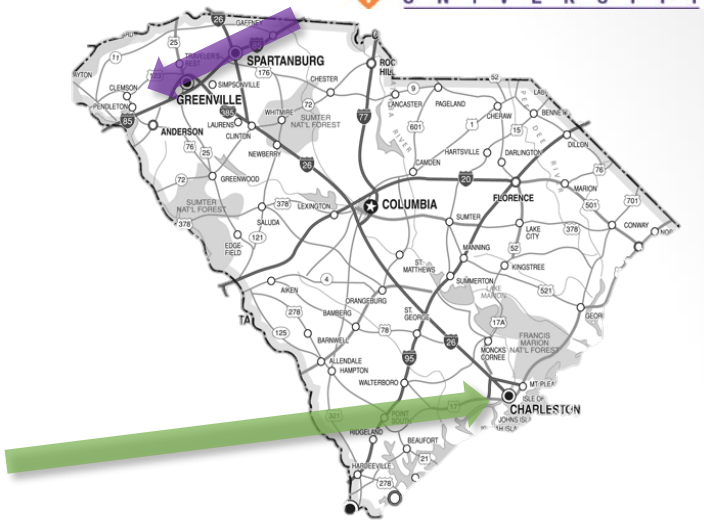
CLEMSON UNIVERSITY
RESTORATION INSTITUTE

Driving economic growth, innovation, and workforce development for South Carolina

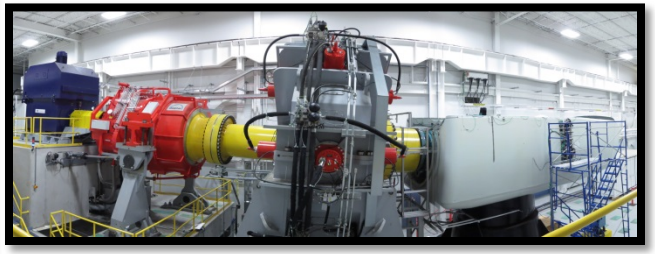
Outline

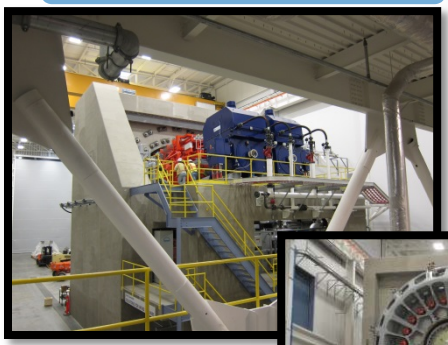
- Laboratory Introduction
- Test Equipment Update
- Solar Inverter Testing
- Battery Energy Storage Testing
- Wind Turbine Testing

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





Duke Energy eGRID Team

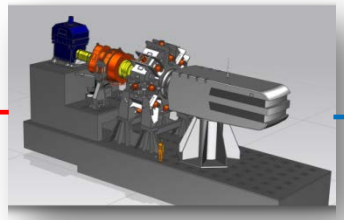
Curtiss Fox, PhD	Director of Operations
Randy Collins, PhD, PE	Project Co-PI
Thomas Salem, PhD, PE	Research Professor
Ramtin Hadidi, PhD	Research Assistant Professor
Jesse Leonard, PhD	Research Assistant Professor
Mark McKinney, PhD	Visiting Research Scientist (The Citadel)
Benjamin Gislason	Research Engineer
Eric Boessneck	Research Engineer
Mark Milcetich	Electrical Technician

<u>Graduate Students:</u>
4 PhD, 2 MS

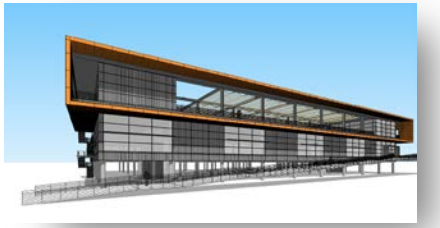
<u>2015 Summer Interns:</u>
3 undergraduates, 1 high school

SCE&G Energy Innovation Center

23.9 kV Utility Bus

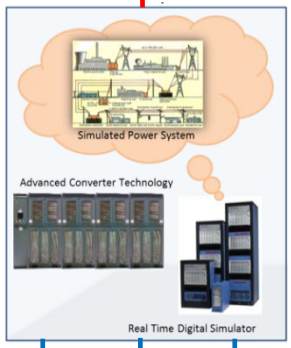


7.5MW Test Stand



Graduate Education Center
500 kW Solar Array (Future)

20 MVA HIL
Grid Simulator
eGrid Center



15MW Test Stand

4.16 kV 5 MVA Test Bus

23.9 kV 20 MVA Test Bus

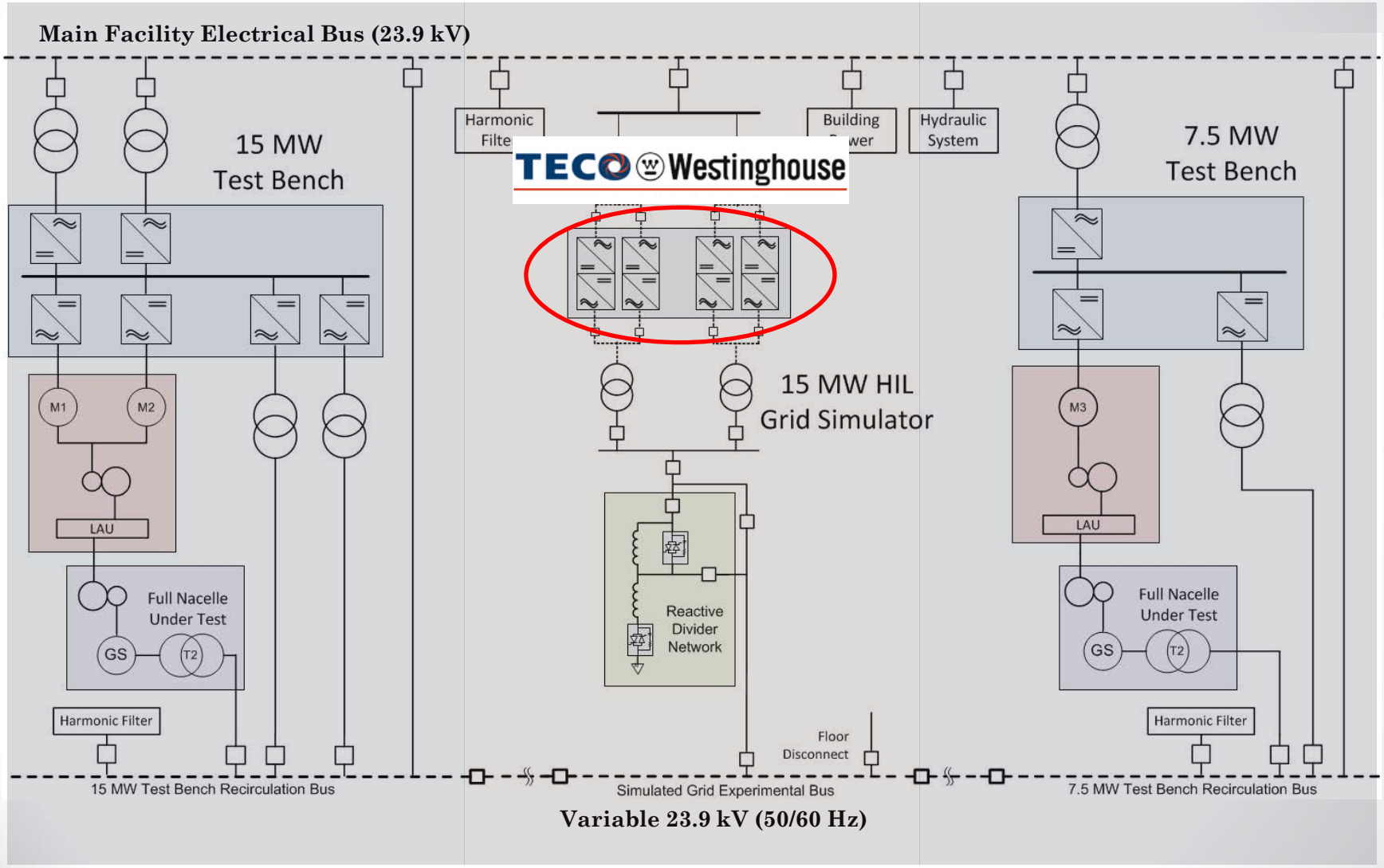
Up to three independent grid integration tests can run simultaneously in each of the three experimental bay's

Experimental Bay #3

Experimental Bay #2

Experimental Bay #1

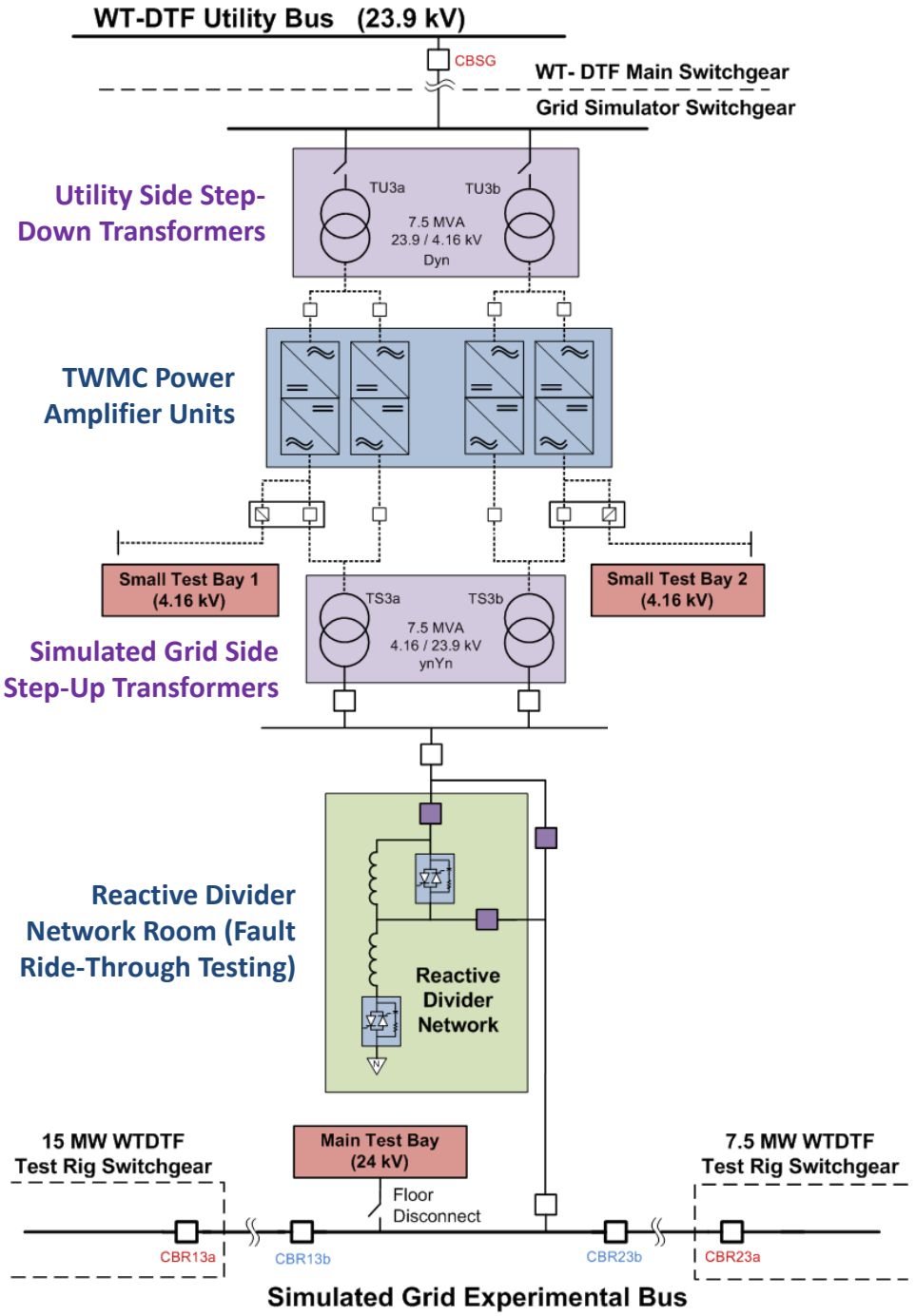
SCE&G EIC Electrical Single Line



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

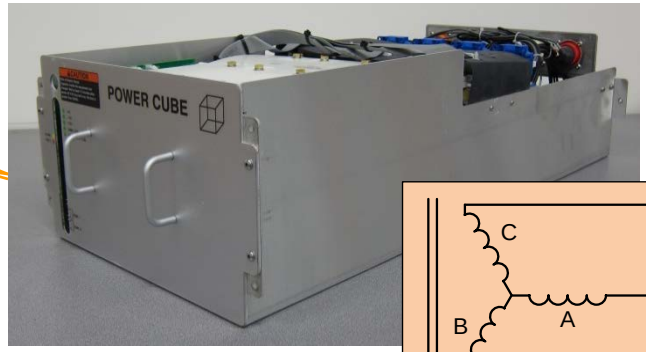


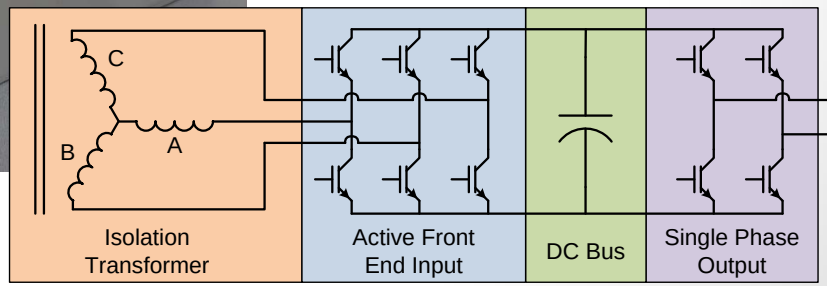
TWMC Power Amplifier Units

4 Power Amplifier Units (PAUs)

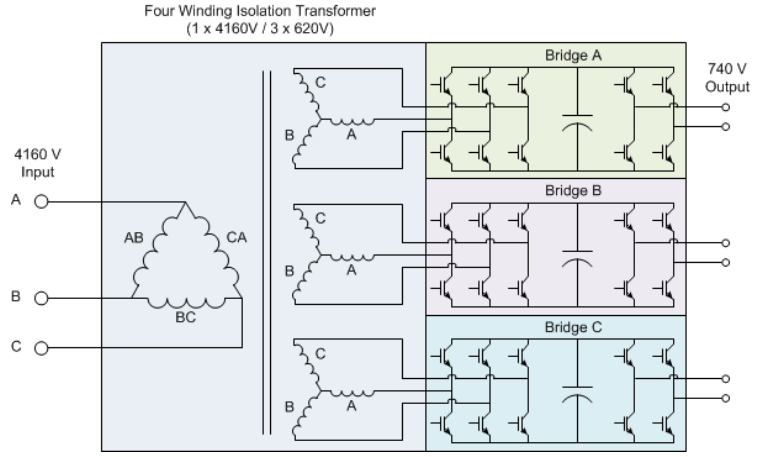
8 Slices Per PAU

3 Cubes Per Slice



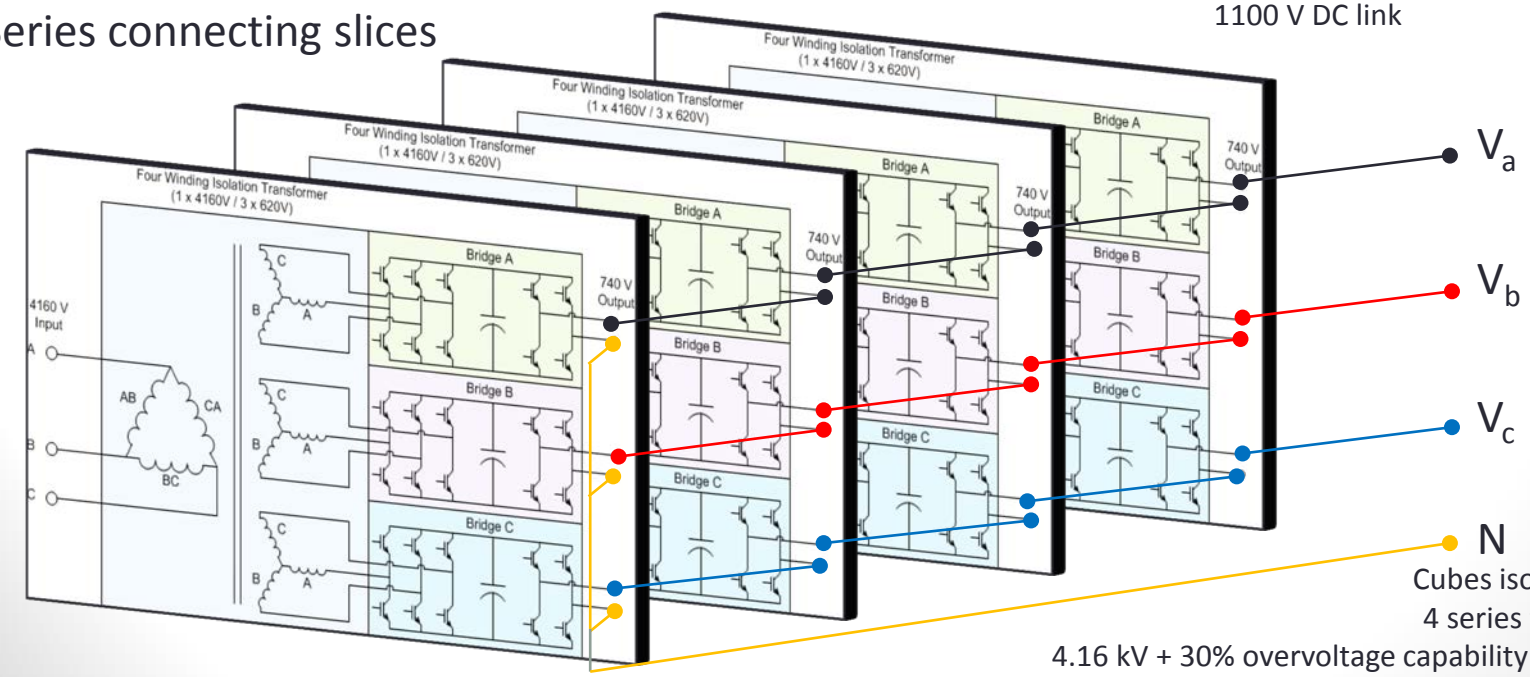


TWMC Power Amplifier Units



1100 V DC link

Series connecting slices

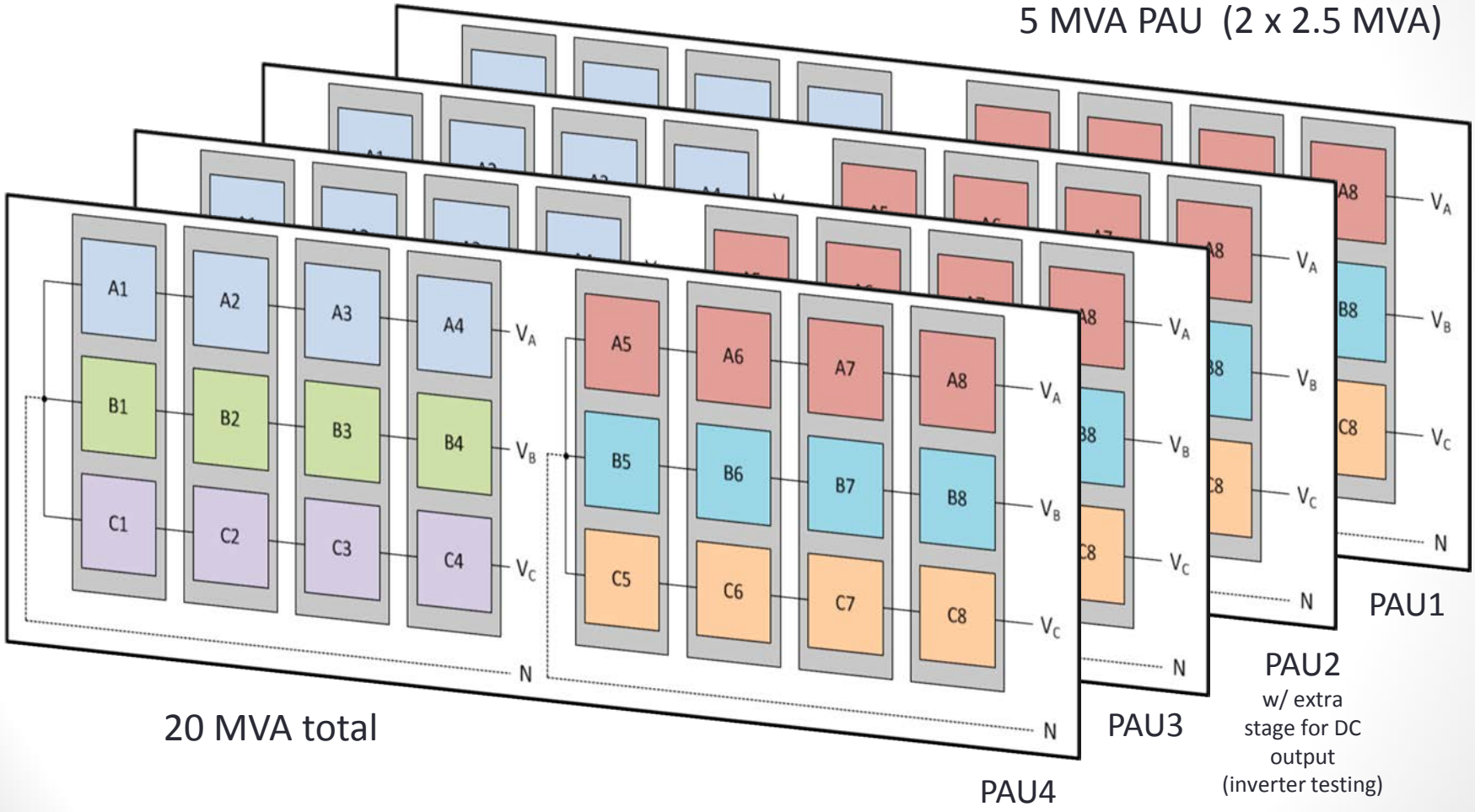


Cubes isolated to 15 kV

4 series for 3100 V L-N

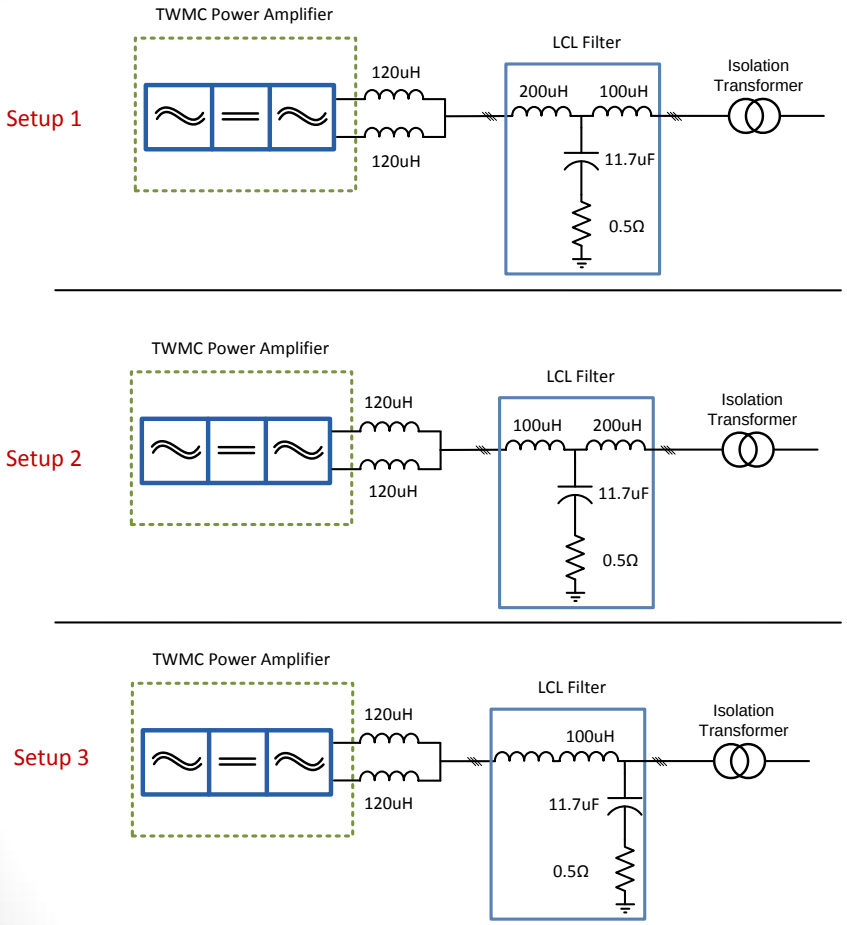
4.16 kV + 30% overvoltage capability (non- clipped)

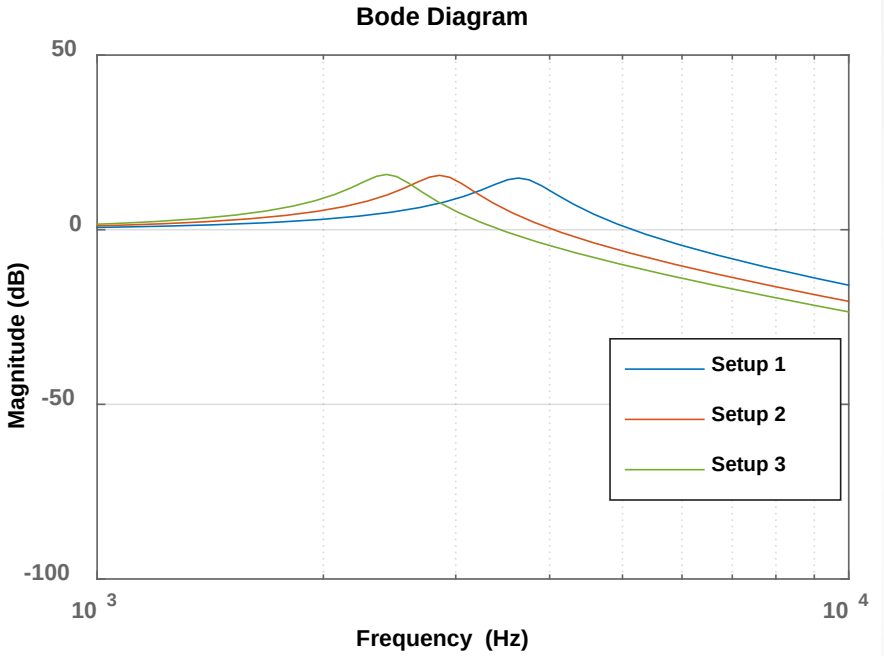
TWMC Power Amplifier Units



Repurposing one PAU for DC leaves others to perform AC grid emulation.

Reconfigurable PAU Filter

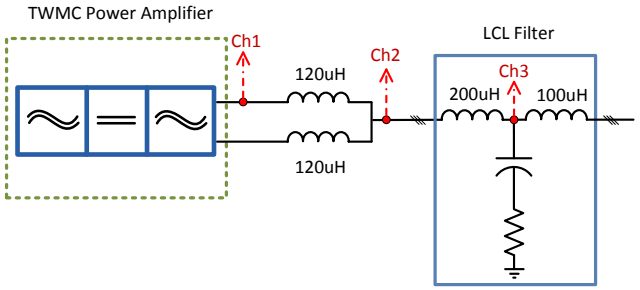


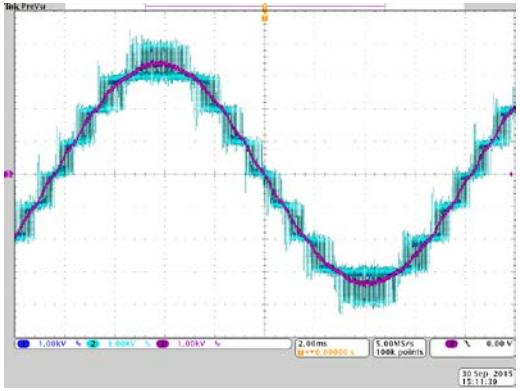


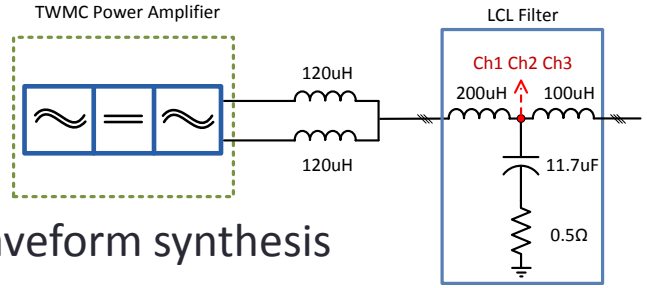
Zero-sequence carried through to DUT

- Wye filter
- (3)Single-phase step-up transformers

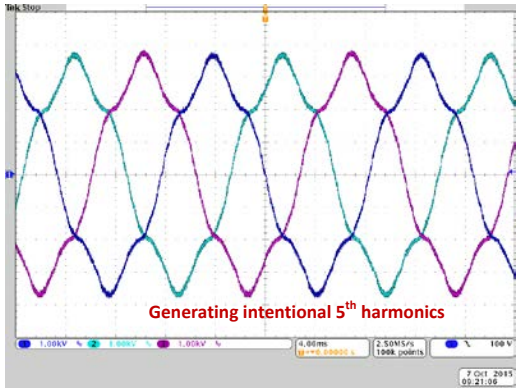
PAU Filter Scope Captures

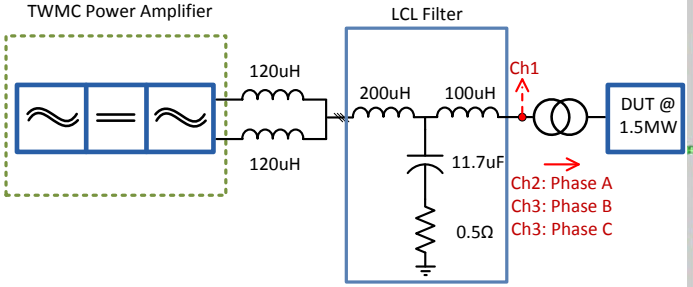


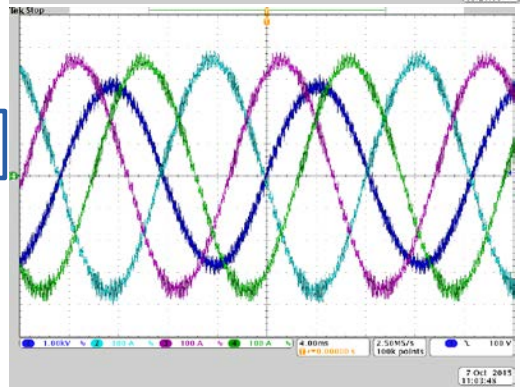




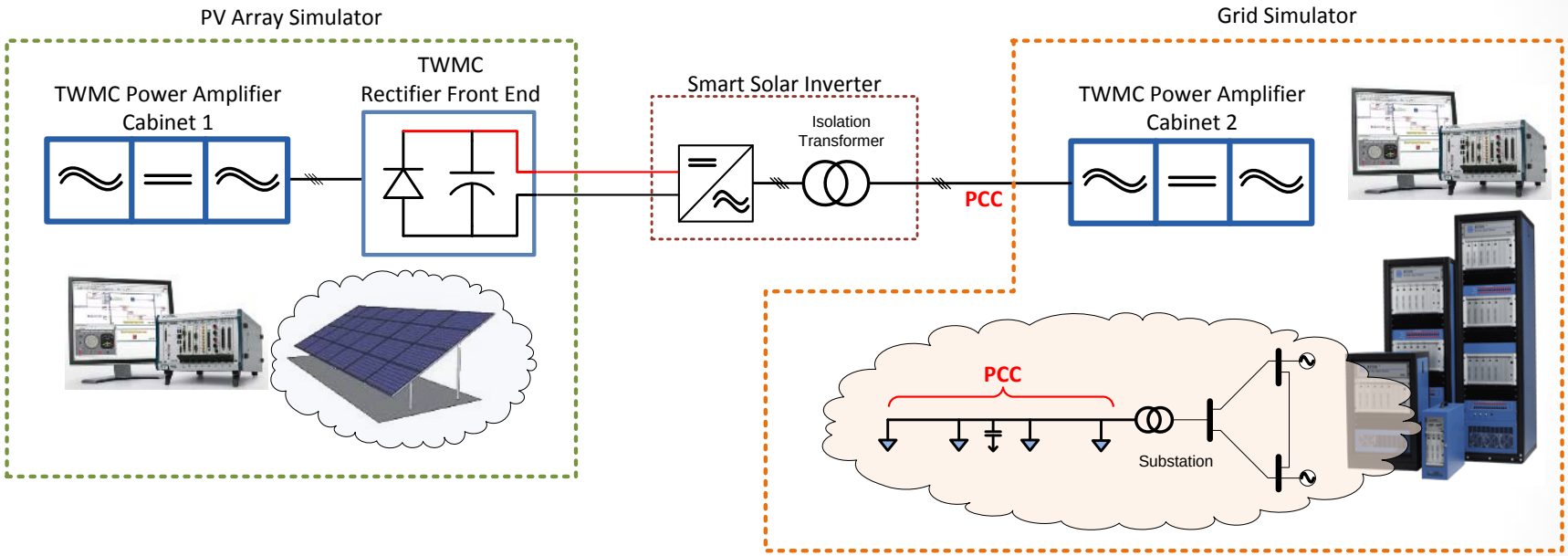
Waveform synthesis





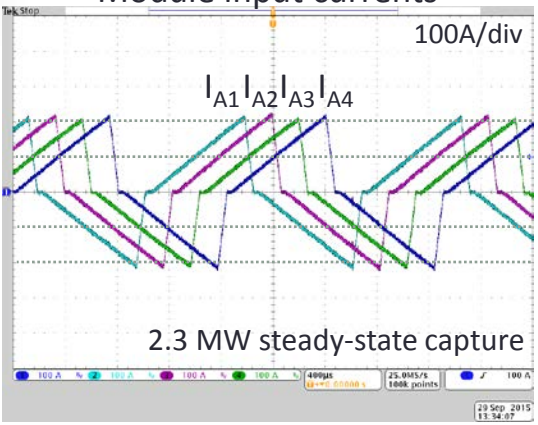


PAU Retrofit for 2.5 MW DC Supply

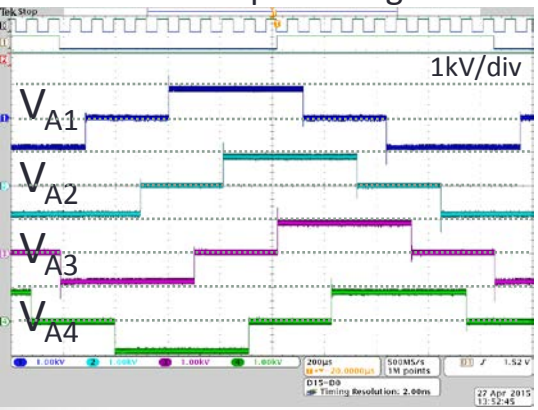


DC Supply Output Stage

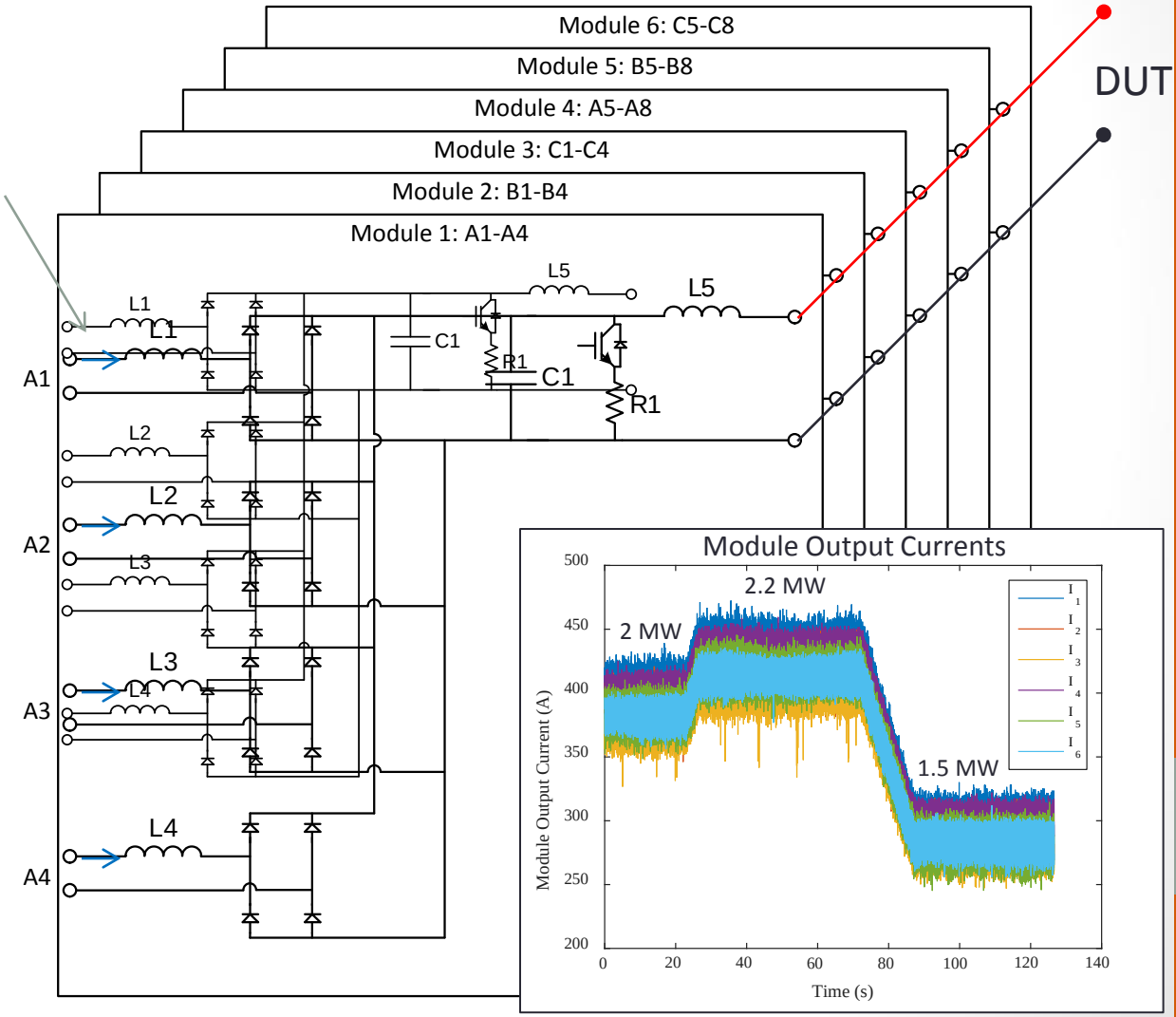
Module input currents



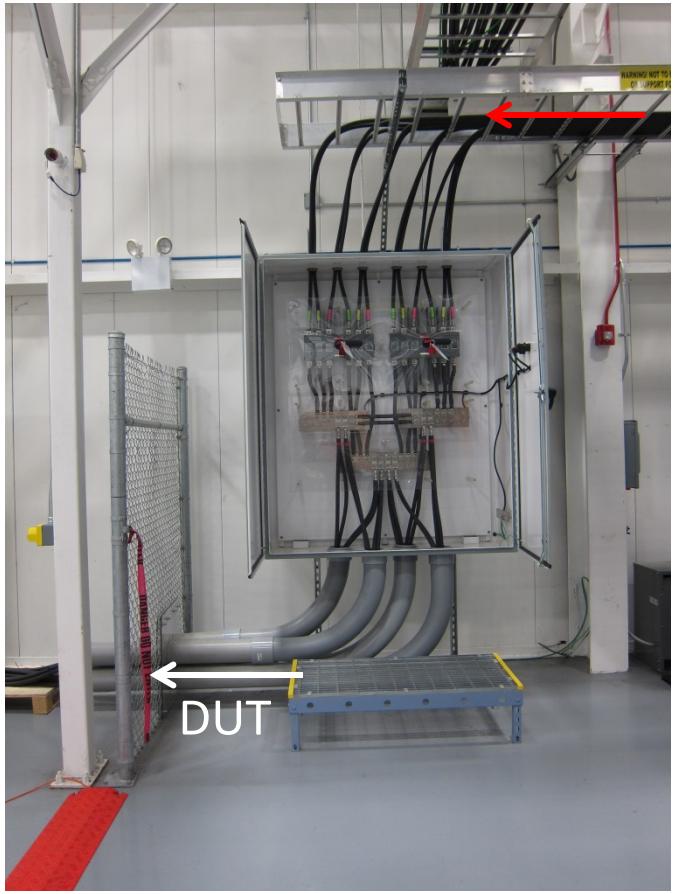
Module input voltages



Interleaved PWM from phase-shifted PAU carriers



DC Supply Output Stage



DC output interconnection enclosure parallels 6 cabinets

DC lock-out switches

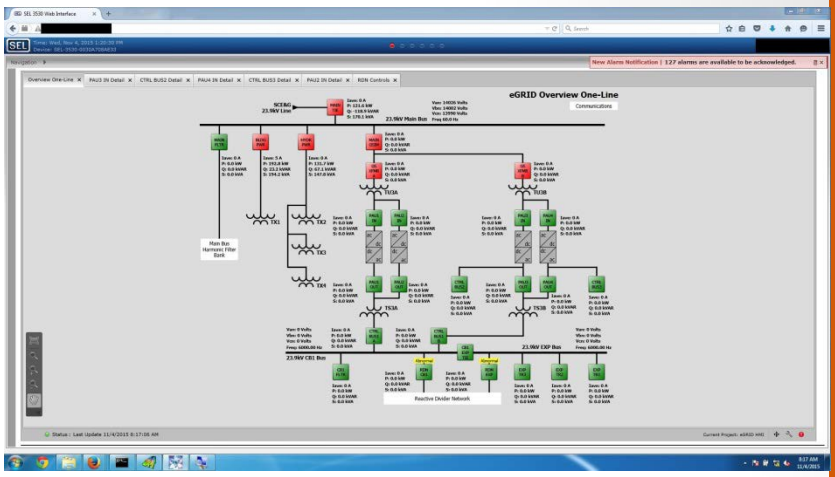
DC modules

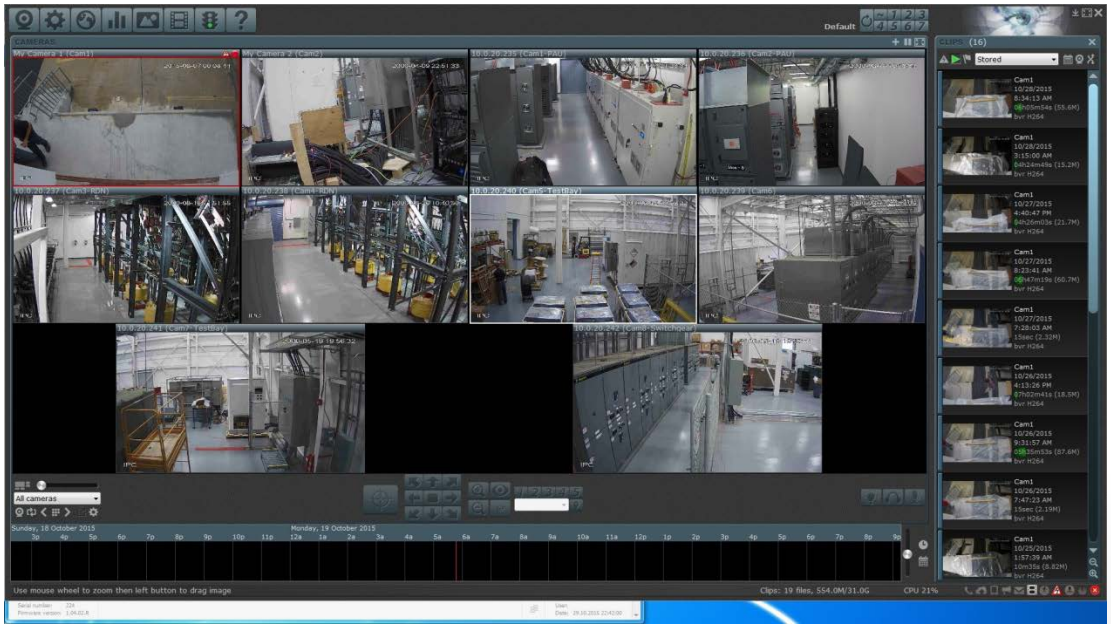
Operations


DANGER
AUTHORIZED PERSONNEL
ONLY
DANGER
HIGH VOLTAGE
KEEP OUT
EQUIPMENT HAS
MULTIPLE POWER
SOURCES

Operations

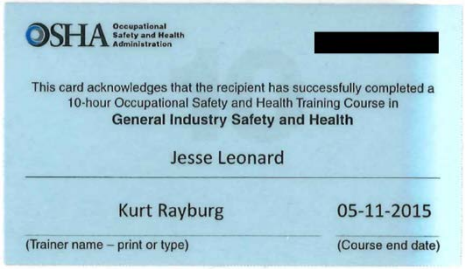
- Two way radio communication required in the test bay
- Multiple facility IP cameras
  - DUT visibility
  - Test equipment visibility
  - Switchgear visibility during actuation
- Remote switchgear control
  - Reduce arc flash hazard





Operations – Safety

- Full time site safety coordinator
- Implemented contractor safety program
- Employee Training Programs
  - OSHA 10-hour class
  - Personal Protective Equipment
  - Electrical Safety
  - Arc Flash Hazard Analysis (NFPA 70E)
  - Fall Protection
  - Fork lift and areal lift
  - First Aid, CPR, AED
  - Hazardous Waste
  - Spill Prevention and Cleanup


OSHA Occupational Safety and Health Administration

[redacted]

This card acknowledges that the recipient has successfully completed a 10-hour Occupational Safety and Health Training Course in
General Industry Safety and Health

Jesse Leonard

Kurt Rayburg — 05-11-2015

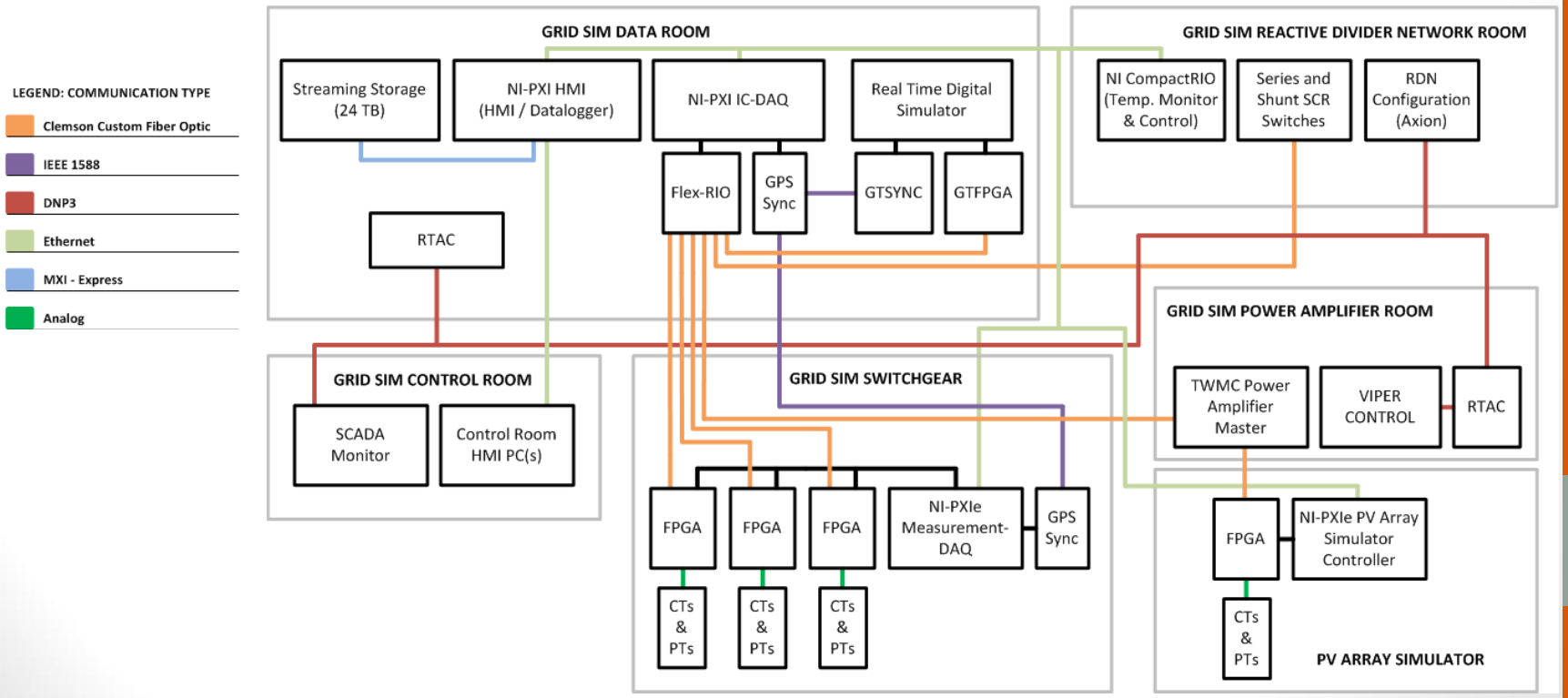
(Trainer name – print or type) — (Course end date)

eGRID SCADA System

- Detailed specifications developed through coordinated efforts between:

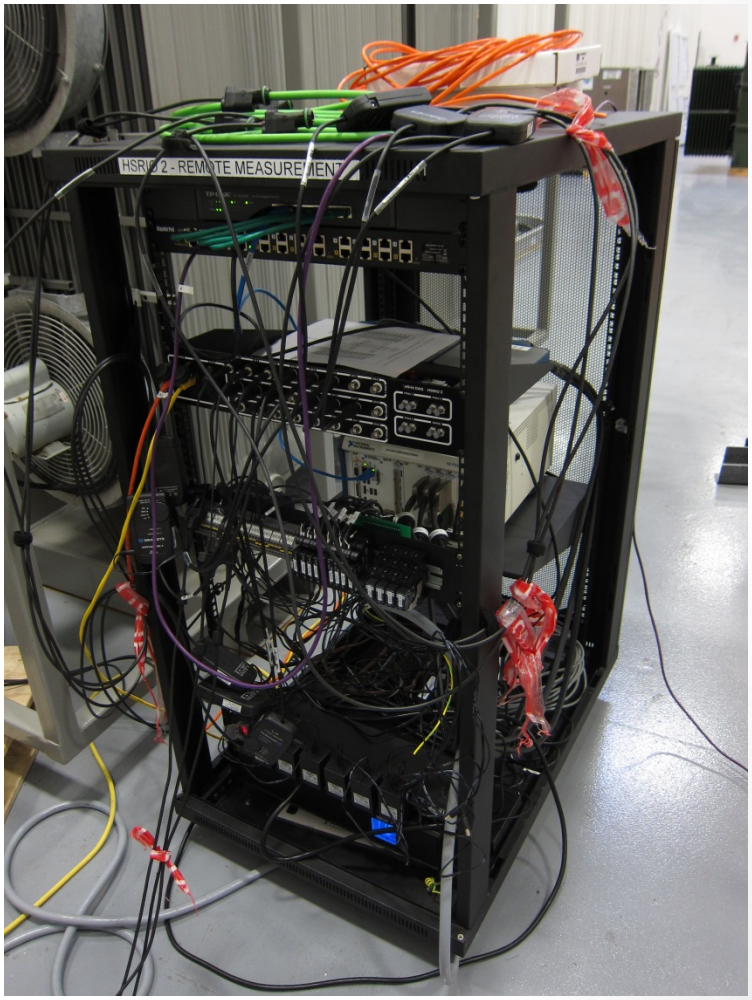
Savannah River National Laboratory | **Clemson University** | **National Instruments**

- 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



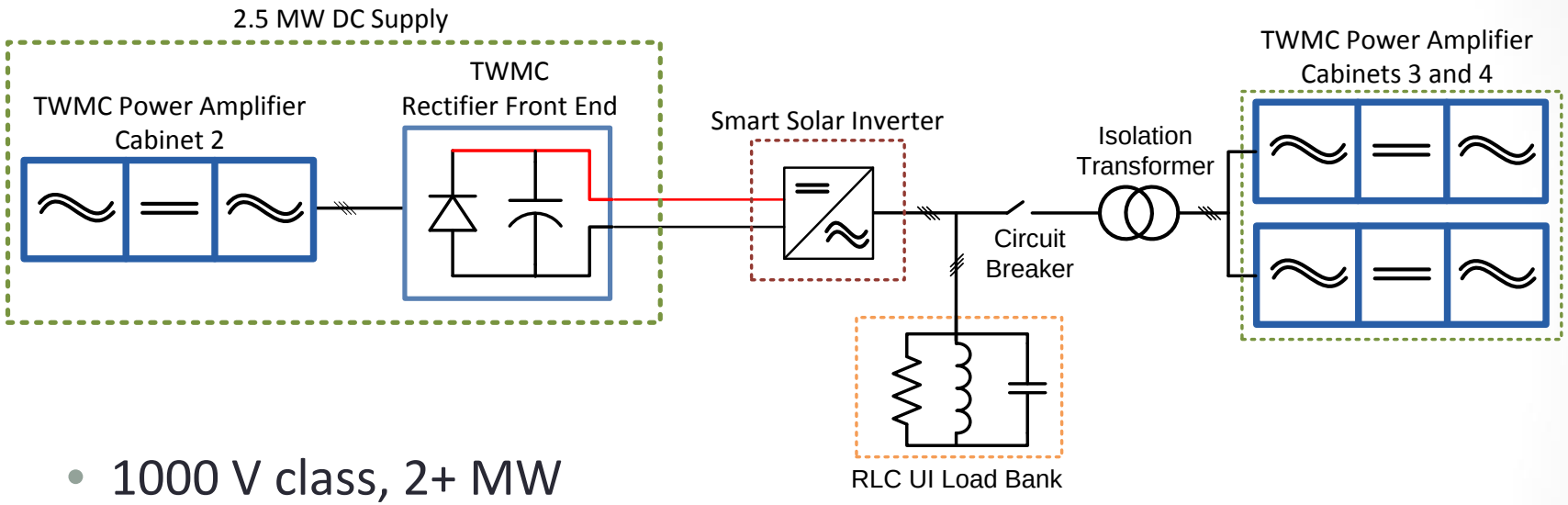
High-speed RIO 2 & 3 Remote I/O

- NI PXI w/ NI-7842r FPGA cards
  - ISO 17025 calibrated
- 24 analog inputs
- Time sync on IEEE 1588 network
- Control network extender
  - PoE for IP cameras
  - DUT communications
  - Web interfaced oscilloscope
  - Web interfaced power analyzer
- Buffered 24 Vdc, 120 Vac I/O
  - Breaker coil actuation
  - Breaker status feedback



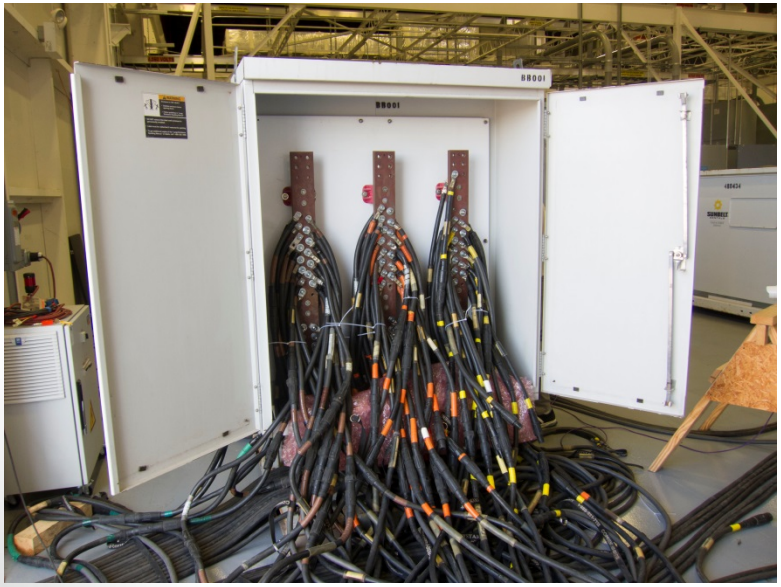
24 Channel NI PXI Data Acquisition Cart

2+ MW Solar Inverter Testing

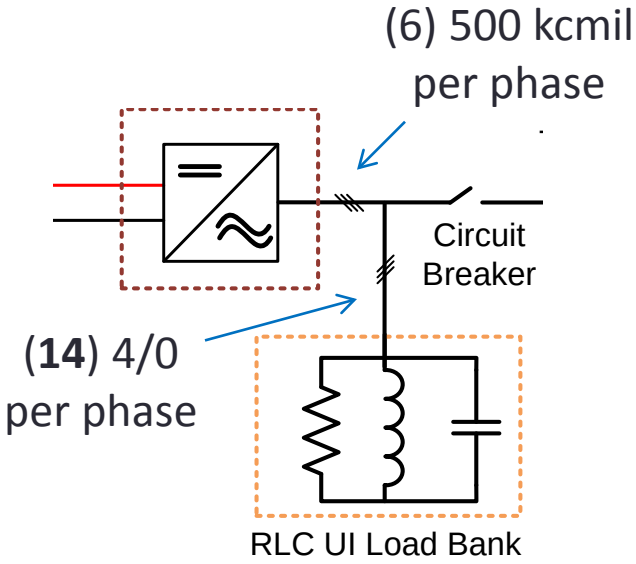


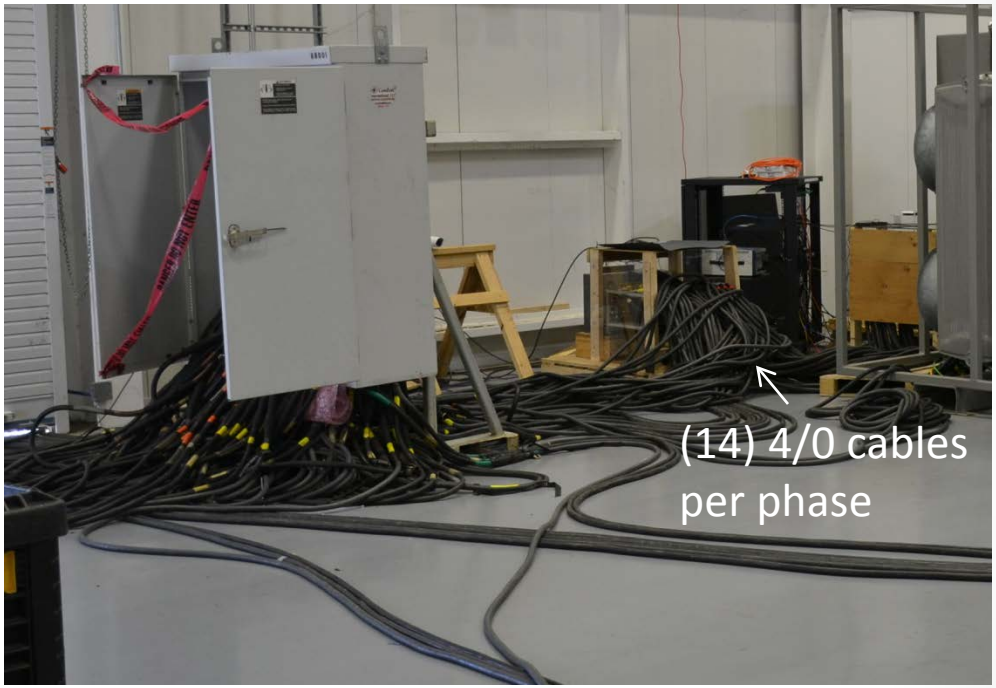
- 1000 V class, 2+ MW
- 385V delta w/ MVT to 4160 test bus
- UL 1741/IEEE 1547 @ 60Hz
- IEC 62116 @ 50 Hz
- Frequency ride-through
- Voltage ride-through

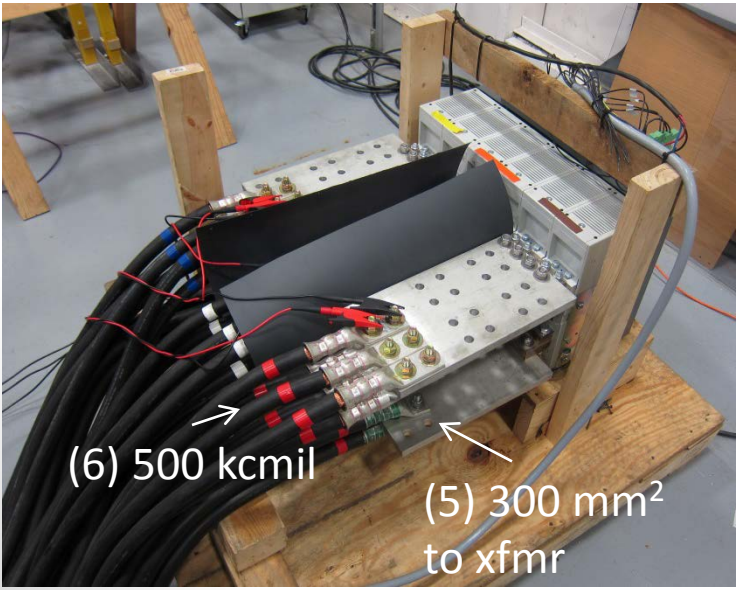
2.5 MW R, 2.5 MVAR L, 2.5 MVAR C



3300 A Three-way Breaker Connection

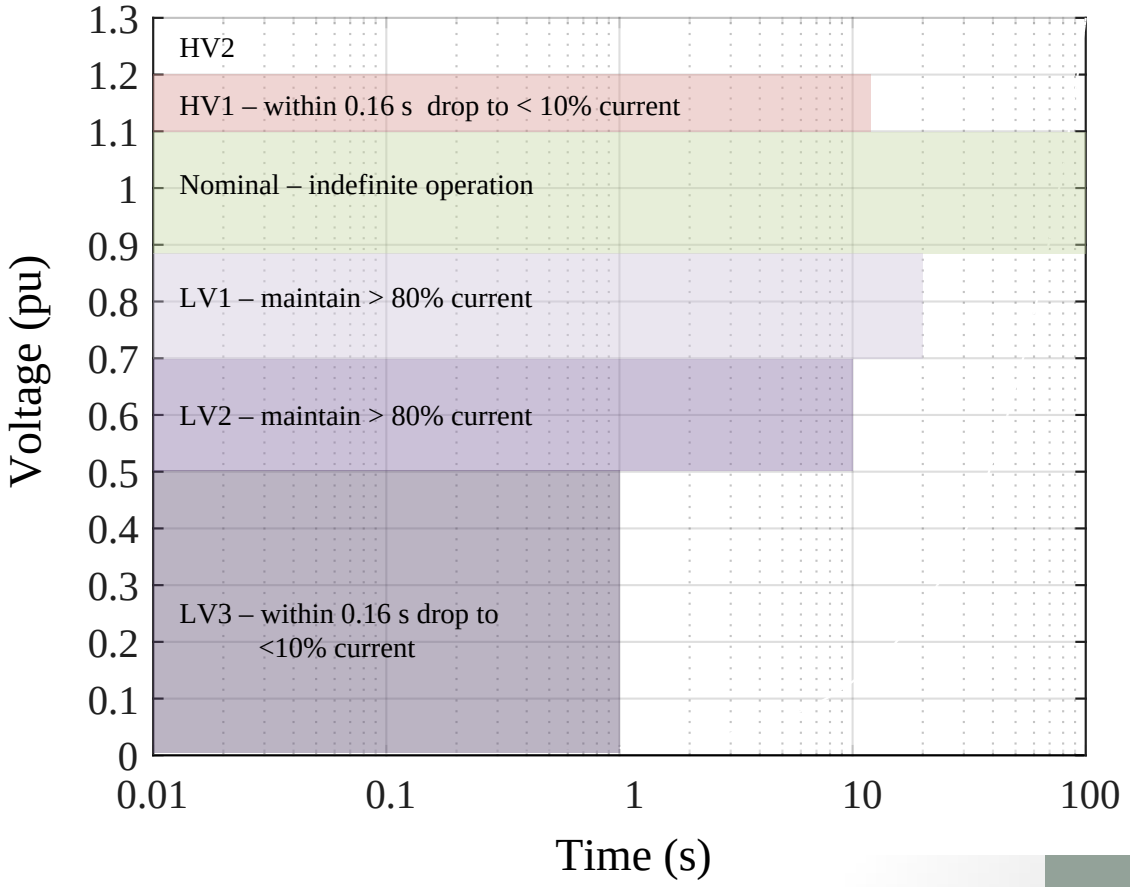






California Rule 21 Experience

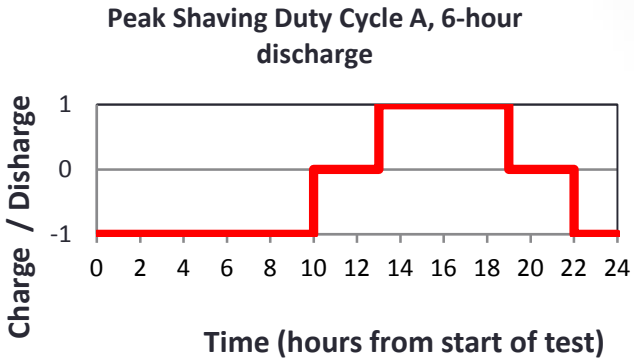
- $HV1^{+}$ → NN^{-} → LV1
  - Ramp of 120 ms allowed
- $LV1^{-}$ → NN^{+} → HV1?
  - Ramp of 200 ms allowed
- $LV2^{-}$ → NN^{+} → HV1?
  - Ramp of 100 ms allowed
- $LV3^{-}$ → NN^{+} → HV1?
  - Must ramp in 1 cycle in both directions

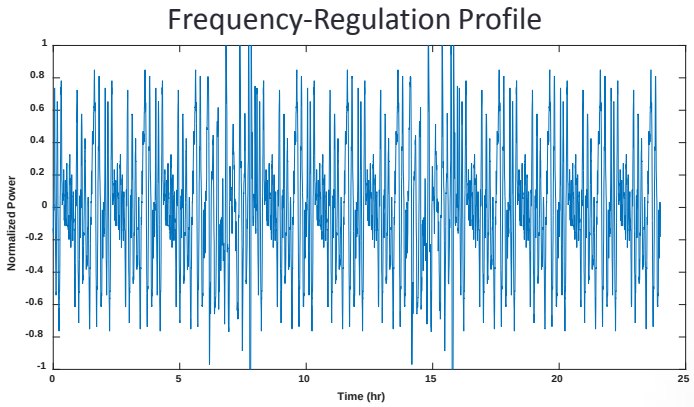


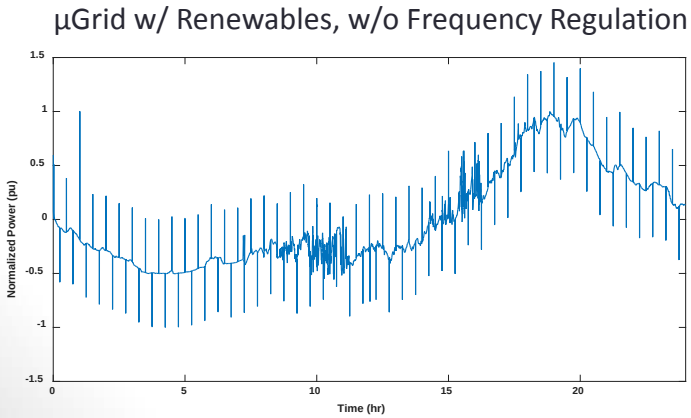
Battery Energy Storage Testing

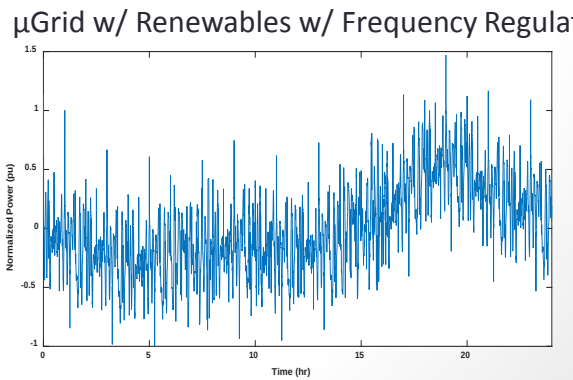
BESS Test Plan

- Voltage ride-through
- Frequency ride-through
- Ramp rate control
- Frequency/watt, Volt/var
- DOE Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems
- Other system specific tests





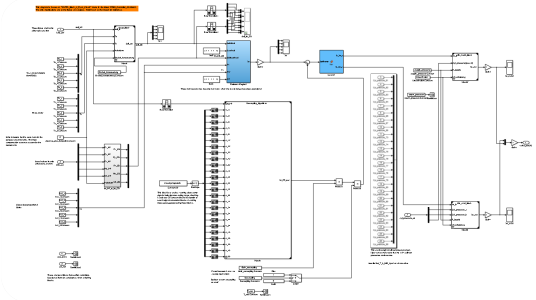


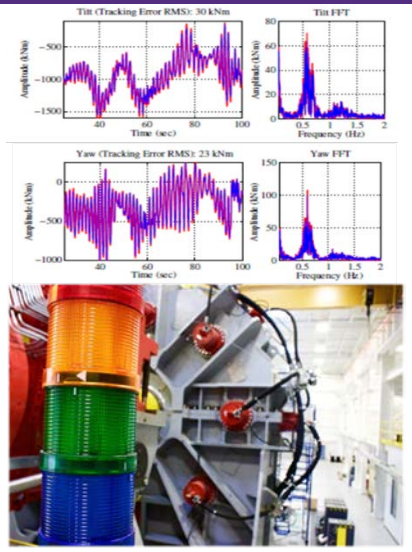


Simulation and Analysis Projects

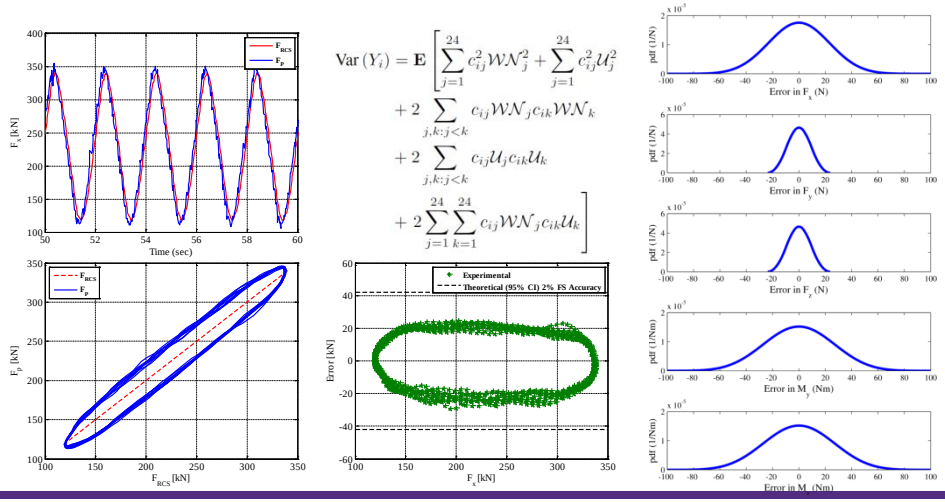
CLEMSON UNIVERSITY
ENERGY INNOVATION CENTER

Re-design LAU Controller for improved Test Bench dynamic performance.

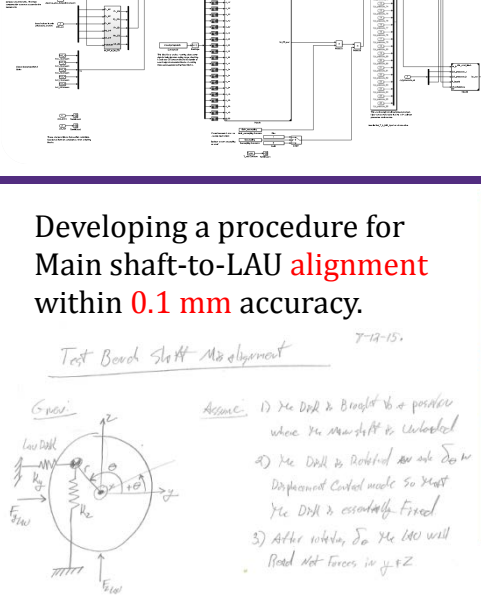


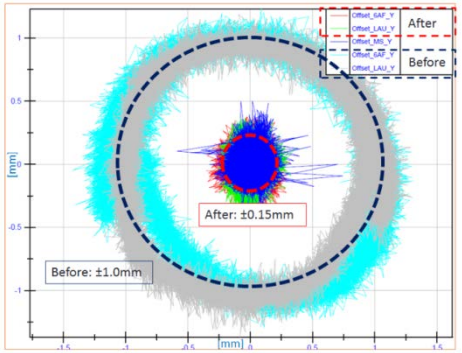


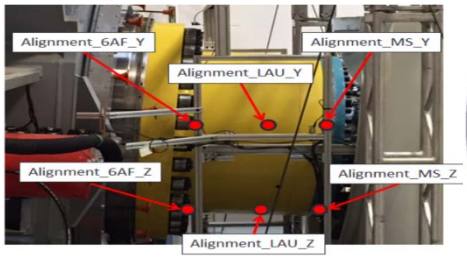
Accuracy evaluation and Uncertainty Analysis of LAU performance

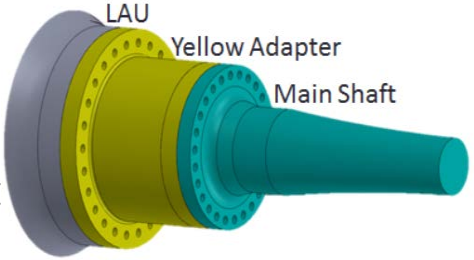


Developing a procedure for Main shaft-to-LAU alignment within 0.1 mm accuracy.

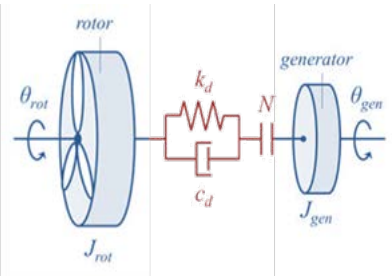


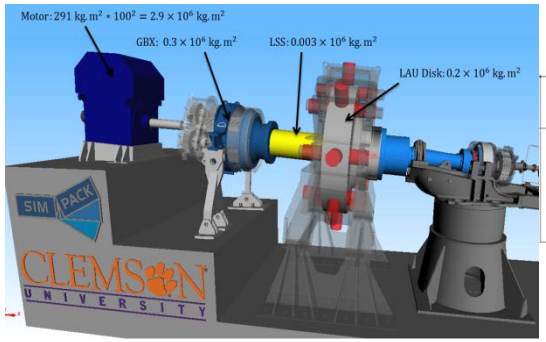


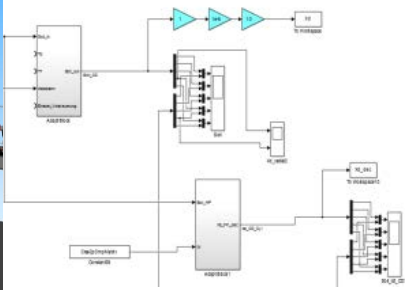




Rotor Inertia Compensation through Motor drive controller (on-going).







Recent Drivetrain Testing Activity

CLEMSON UNIVERSITY
ENERGY INNOVATION CENTER

- 7.5 MW rig has been in regular operation since commissioning
- 15 MW rig is scheduled to be commissioned in November 2015

2014

Commissioning 7.5 MW: October 2014

Test Campaign 1: Completed November 2014

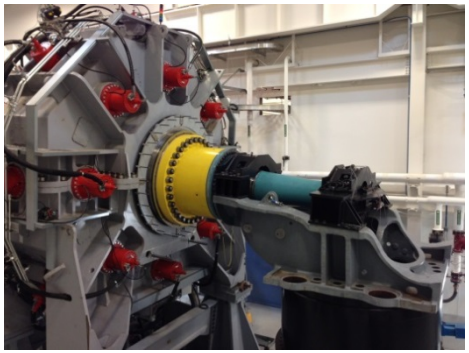
Test Campaign 2: Completed December 2014

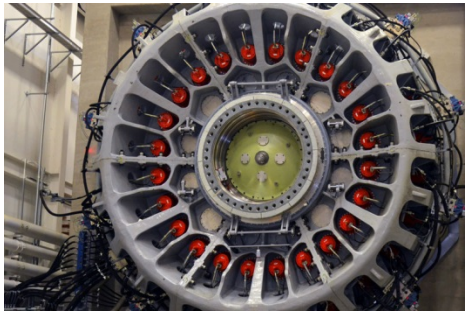
2015

Internal Test Campaign: February 2015

Test Campaign 3: Completed November 2015

Commissioning 15 MW: November 2015





Thank you