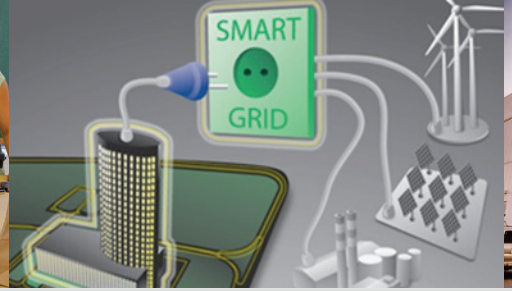




Model and System Validation with15 MVA HIL Grid Emulator at Clemson University

Johan Enslin
Ramtin Hadidi; Jesse Leonard; Curtiss Fox
SCE&G Energy Innovation Center (EIC)
www.clemsonenergy.com

Driving workforce development, innovation and economic development for power and energy

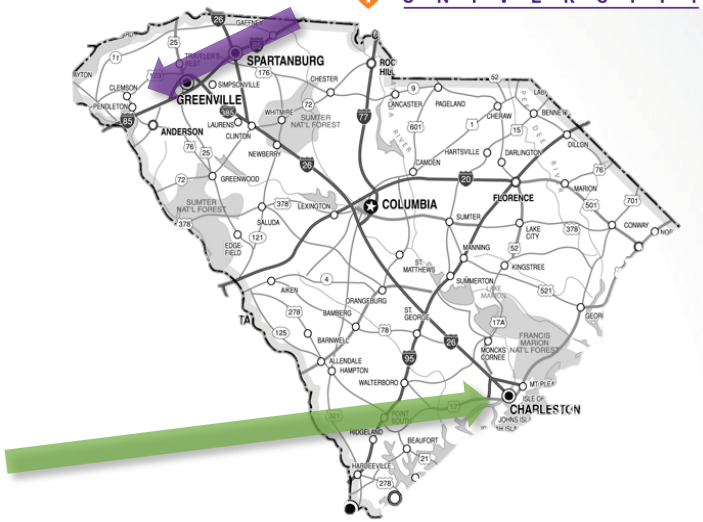
CLEMSON UNIVERSITY

Zucker Family Graduate Education Center (ZFGEC)
SCE&G Energy Innovation Center (EIC)
Clemson University Restoration Institute (CURI)

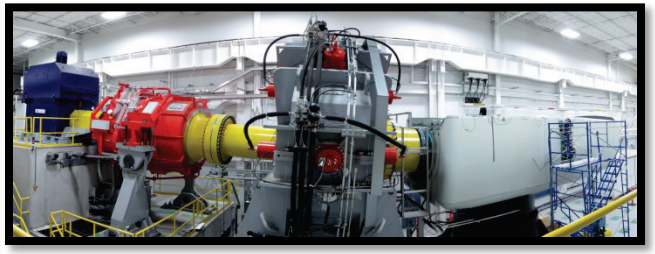
Overview

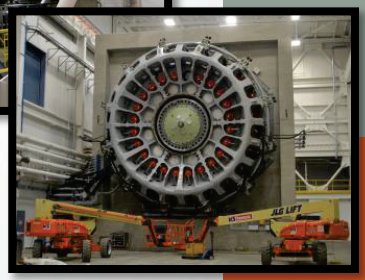
- Clemson in Charleston: SCE&G Energy Innovation Center
- Duke Energy eGRID 20 MVA grid emulator
- Validation of Power Amplifier Units
- PV Inverter Testing and Model Validation
- BESS Testing and Model Validation
- Control Hardware-in-the-Loop Testing
- PV Synchronous Generator

The SCE&G Energy Innovation Center

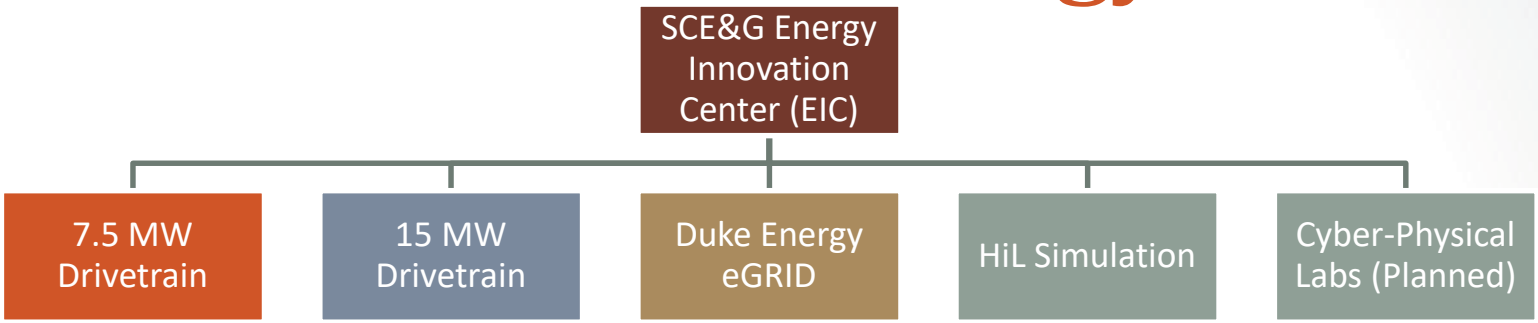


- Clemson University Restoration Institute
  - SCE&G Energy Innovation Center
    - Duke Energy eGRID Center
      - 15 MW HIL Grid Simulator
    - Wind Turbine Drivetrain Testing Facility
      - 7.5 MW Test Bench
      - 15 MW Test Bench



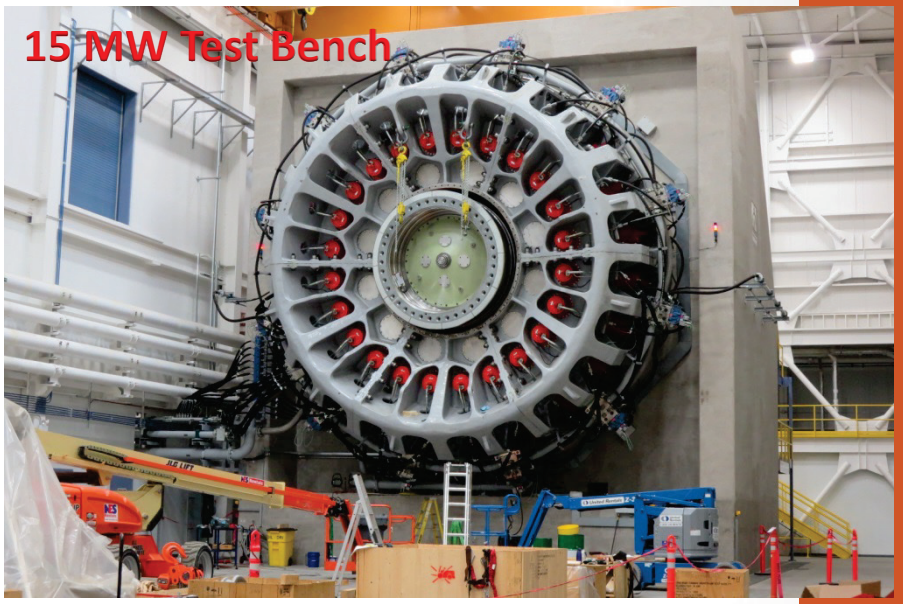


CURI Power and Energy Labs



- SCE&G Energy Innovation Center
  - Wind Turbine Drivetrain Test Facilities (7.5 MW & 15 MW)
    - Accelerated mechanical and electrical testing in controlled environment.
  - Duke Energy Electrical Grid Research Innovation & Development Center
    - eGRID – 15 MW Dynamic grid emulation (steady-state, dynamic, and faults).
  - HiL Simulation facility with electrical / mechanical testbeds
- Power related Cyber-Physical Security labs (Planned)
- Currently 15+ Research Scientists, Engineers and Technicians
- Currently hiring 12 multi-disciplinary power-related faculty
- Planned 30 research, technical and administrative staff
- Planned 200 students as working professionals and full-time

7.5 MW and 15 MW Test Benches

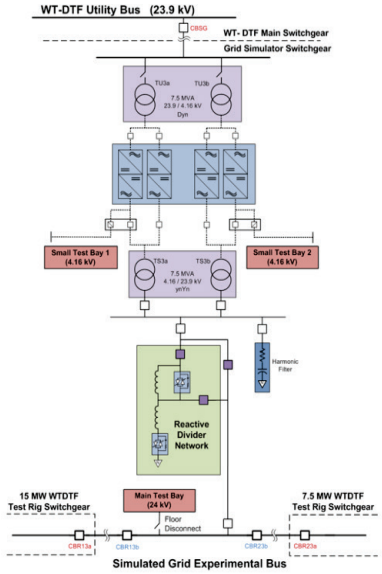


7.5 MW Test Bench Performance Specifications	
Test Power	7,500 kW
Maximum Torque	6,500 kNm
Maximum Speed	20 rpm
Inclination	4 ° to 6 °
Static Axial Force	± 2,000 kN
Static Radial Force	± 2,000 kN
Static Bending Moment	± 10,000 kNm

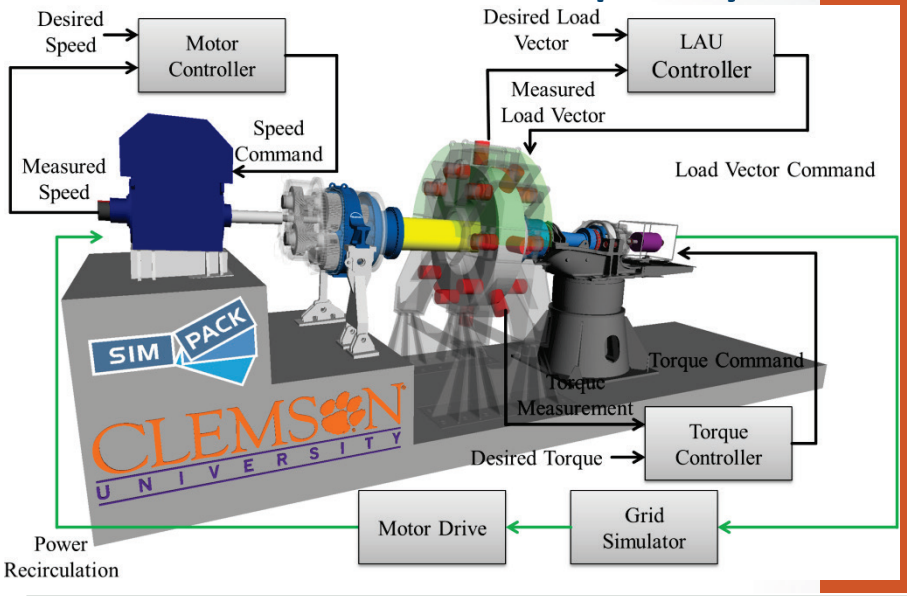
15 MW Test Bench Performance Specifications	
Test Power	15,000 kW
Maximum Torque	16,000 kNm
Maximum Speed	17 rpm
Inclination	6 °
Static Axial Force	± 4,000 kN
Static Radial Force	± 8,000 kN
Static Bending Moment	± 50,000 kNm

15 MW Power HiL Facility

15 MW HIL Grid Simulator



Virtual Test Bench Test Capability

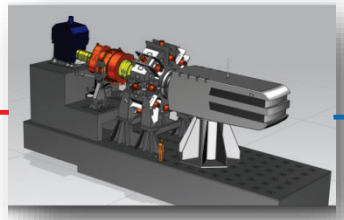


15 MW HIL Grid Simulator Performance Specifications	
Test Power	15 MVA
Frequency range	45…65 Hz to 400 Hz
Sequence capability	3 and 4 wire
High Voltage Ride Through HVRT	100…145%
Low Voltage Ride Through LVRT	100…0%
Unsymmetrical LVRT	yes
Power quality PQ evaluation	yes

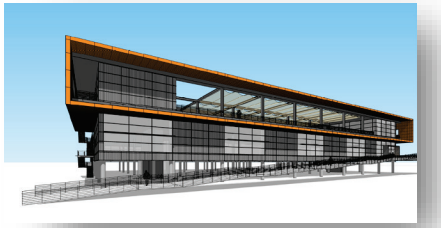
Virtual Test Bench Simulator Performance Specifications	
Virtual testing and validation	yes
Multi-domain modeling	yes
Test protocol verification and optimization	yes
Flexible model configuration	yes
Uncertainty in analyses	reduced
Operator training	yes
Students involvement	high

SCE&G Energy Innovation Center

23.9 kV Utility Bus

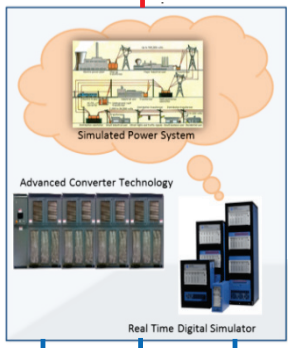


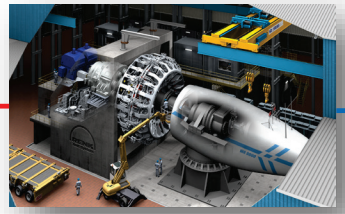
7.5MW Test Stand



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

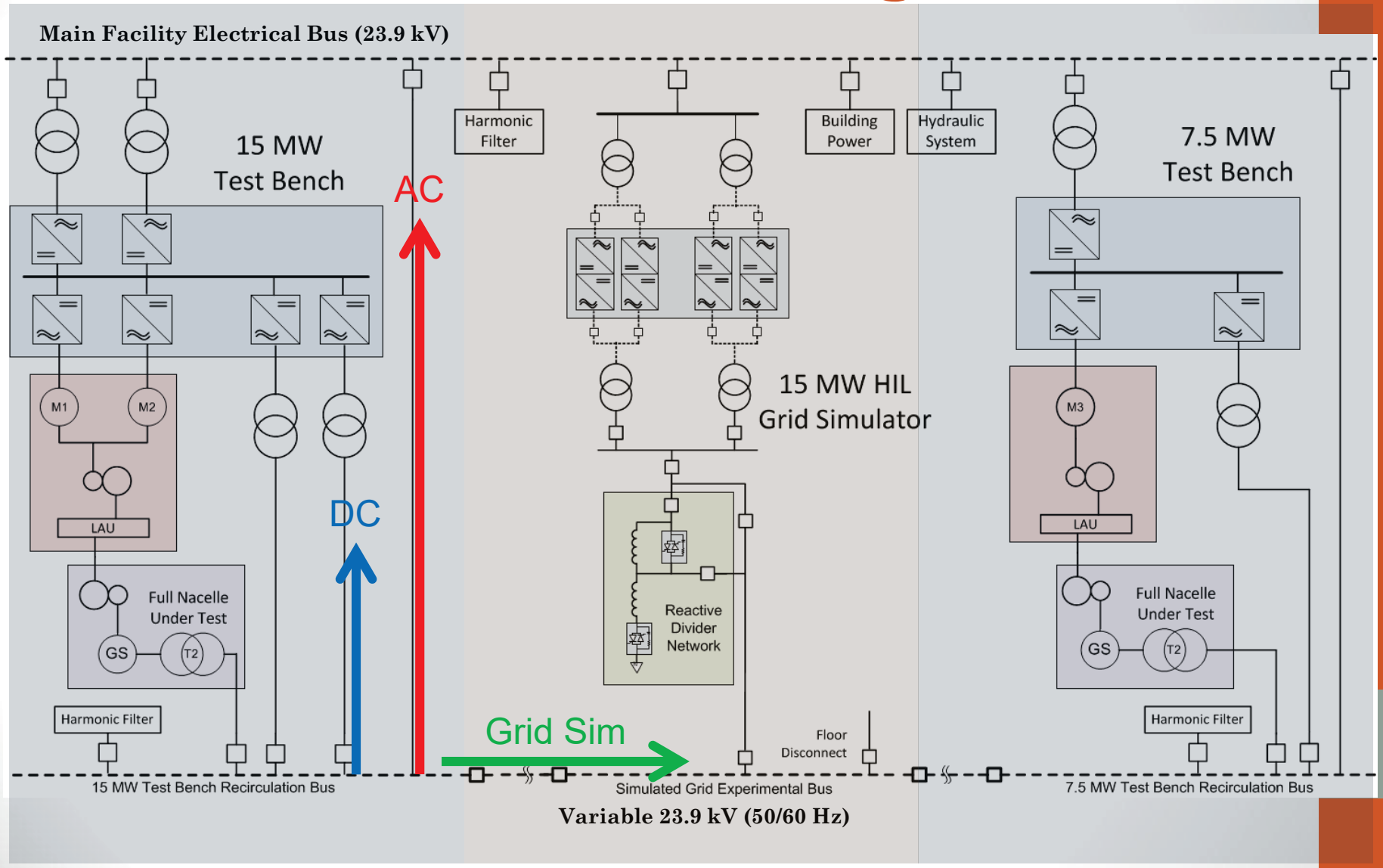
Up to three independent grid integration tests can run simultaneously in each of the three experimental bay's

Experimental Bay #3

Experimental Bay #2

Experimental Bay #1

SCE&G EIC Electrical Single Line

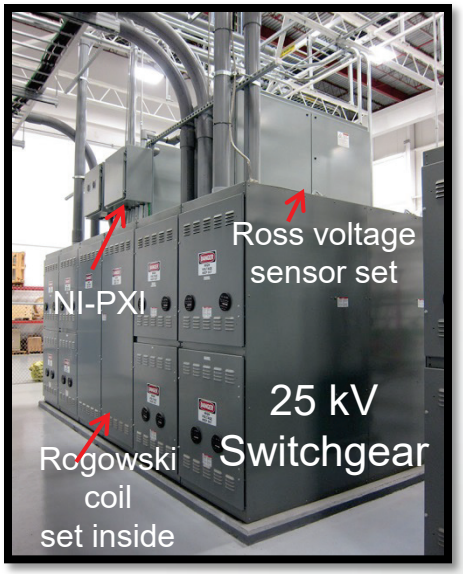


PHIL Configuration



RTDS
PB5 PB5 PB5 PB5
PB5 PB5 PB5 PB5
ML 605 GTFPGA Board
LPC FMC
POF Transceivers
POF Transceivers
NI-PXI Interface Controller
NI-7966 FlexRIO FPGA
NI-6683 IEEE1588
NI-PXI eGRID Controller
POF Transceivers
TWMC Controller
Power Stage Components
25 kVSwitchgear
Device Under Test
Rogowski coil set
Ross voltage divider set
POF Transceivers
NI-PXI High Speed RIO
NI-7842 FPGA
NI-6683 IEEE1588
*Located on top of 25 kV switchgear

Data Room

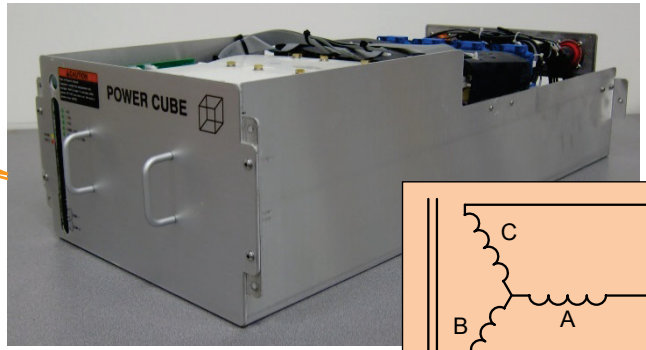


High Bay

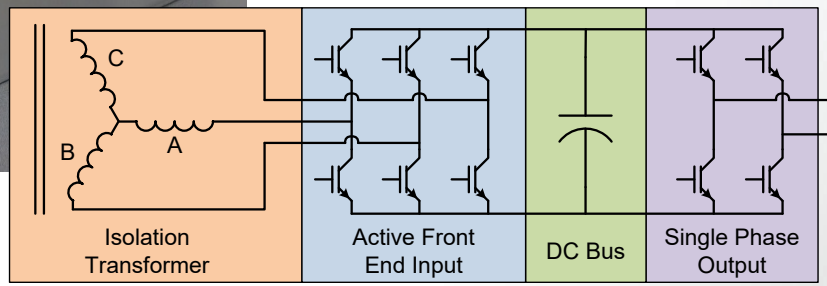
Power Amplifier Units

4 Power Amplifier Units (PAUs)

8 Slices Per PAU

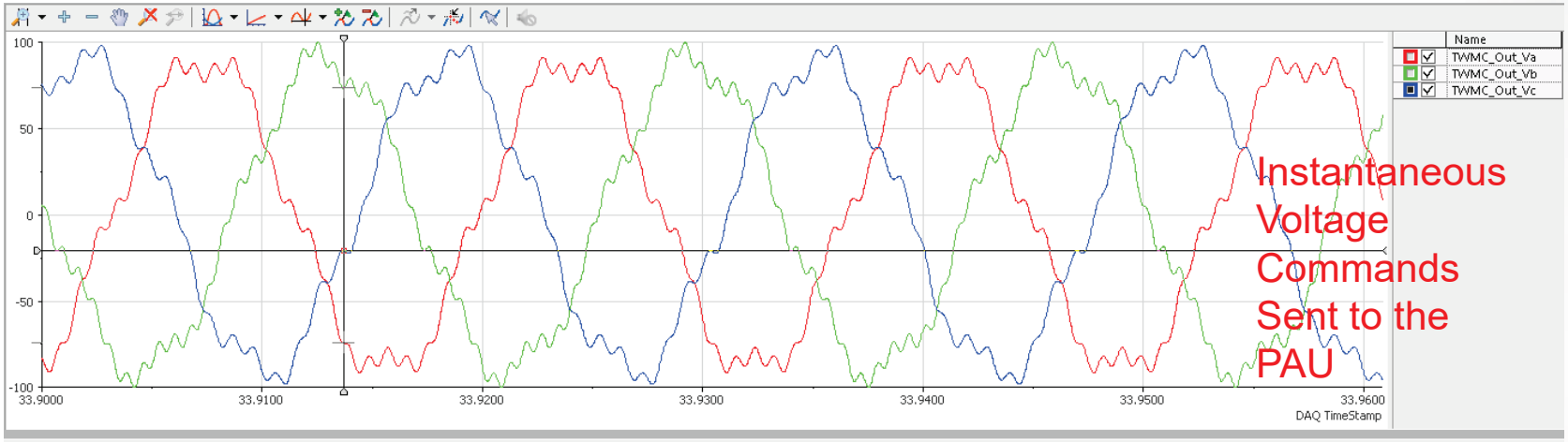


3 Cubes Per Slice

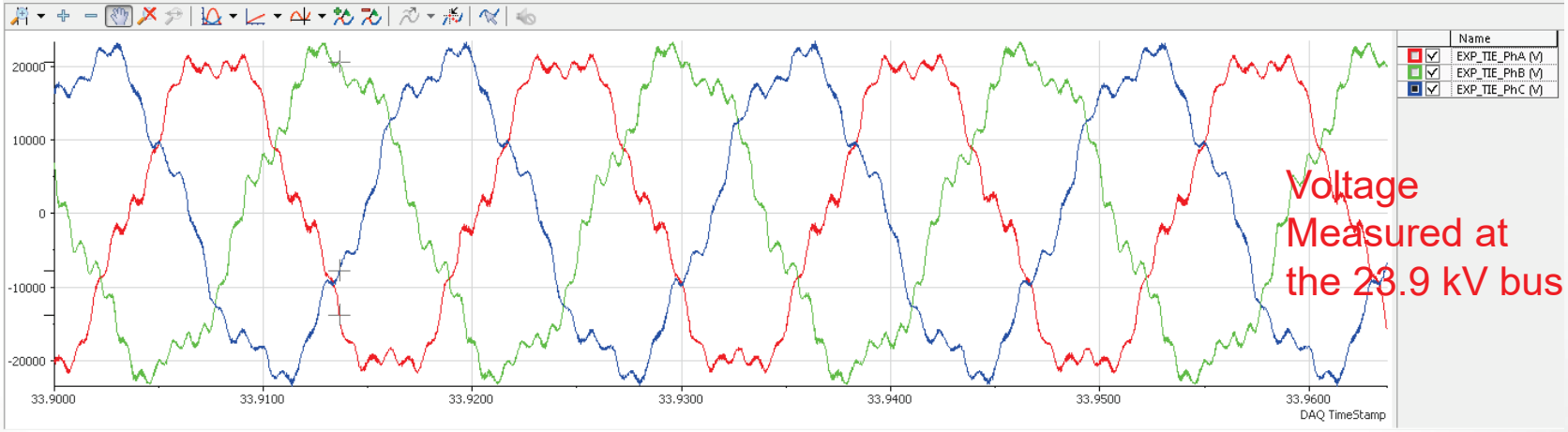


Open Circuit Harmonic Generation

Phase A: 5% 19th, 10% 5th Phase B: 5% 23rd, 10% 5th Phase C: 5% 17th, 10% 5th



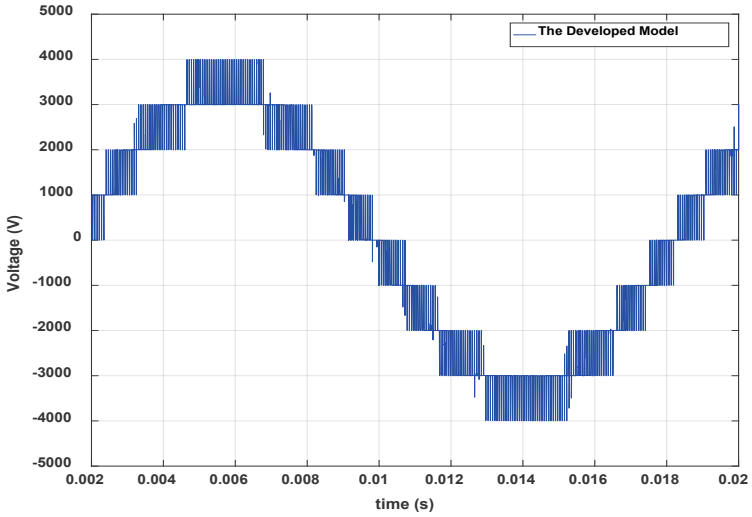
Instantaneous Voltage Commands Sent to the PAU



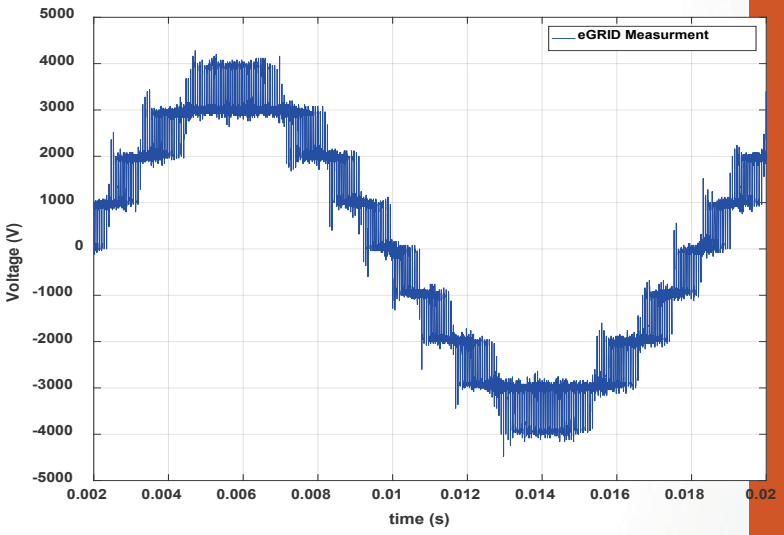
Voltage Measured at the 23.9 kV bus

PAU Model Validation

- The test is designed to validate a full PAU model.
- Single PAU output voltage validation to the rated voltage of 4160V.

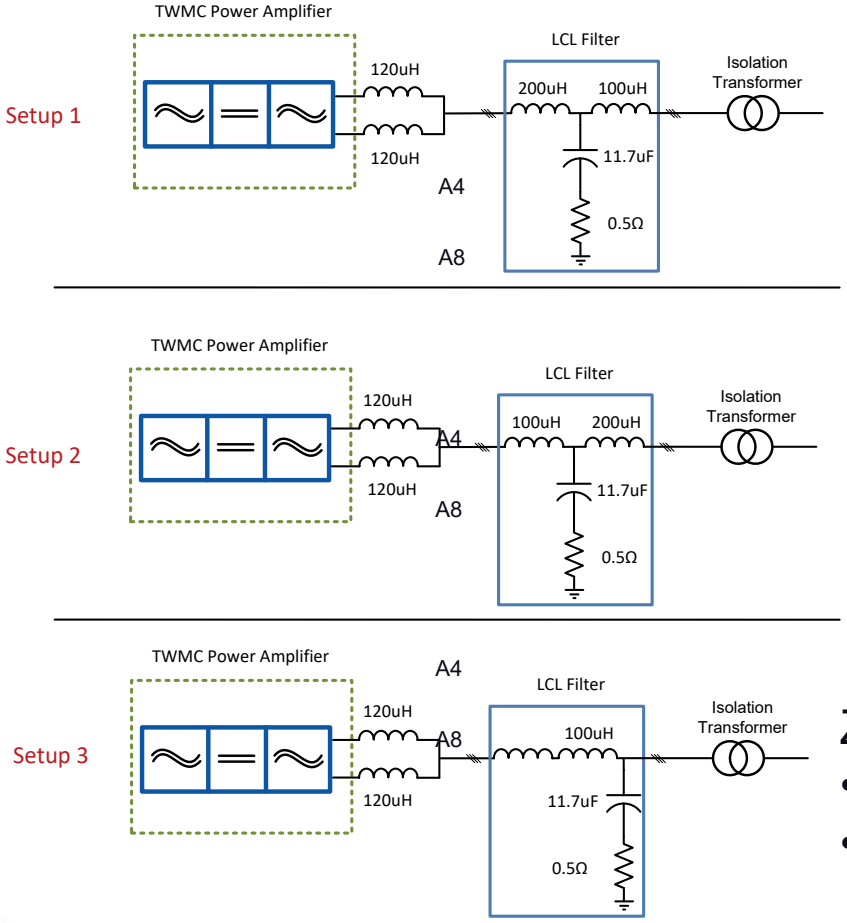


The developed model response

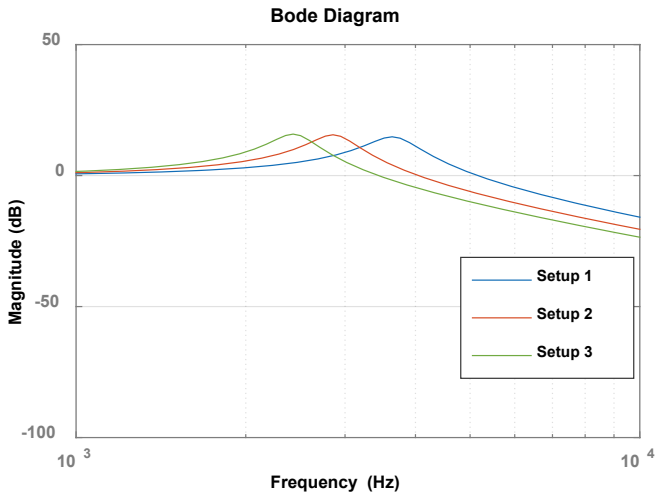


The data capture by eGRID data acquisition system

Reconfigurable PAU Filter



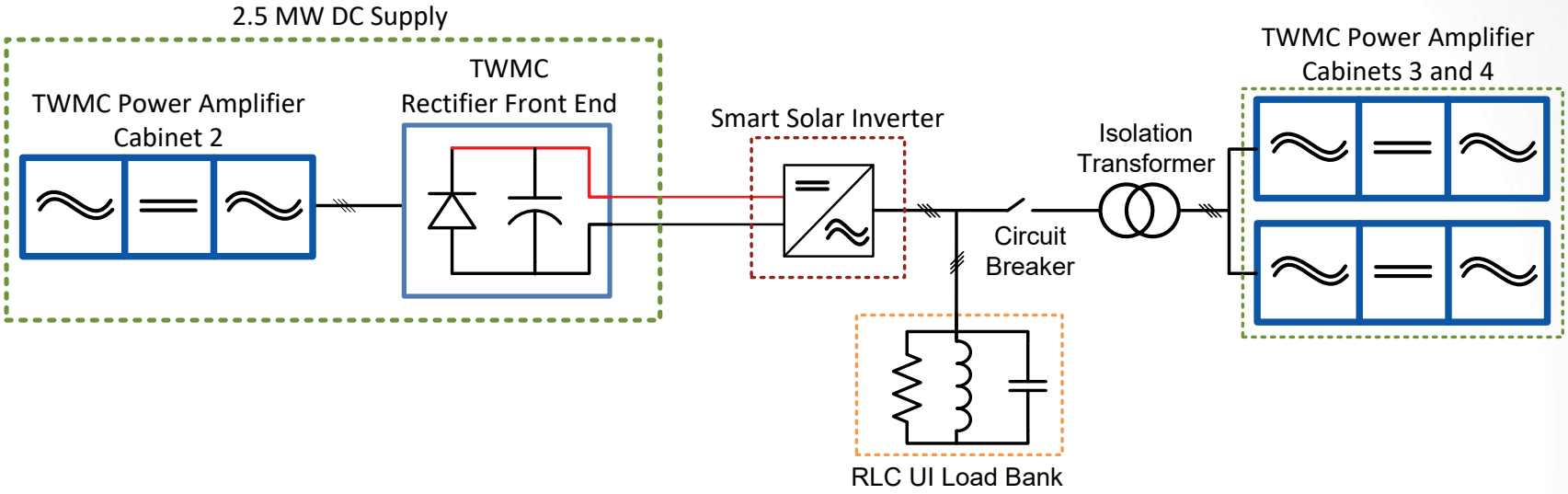
(Phase A components shown)



Zero-sequence carried through to DUT

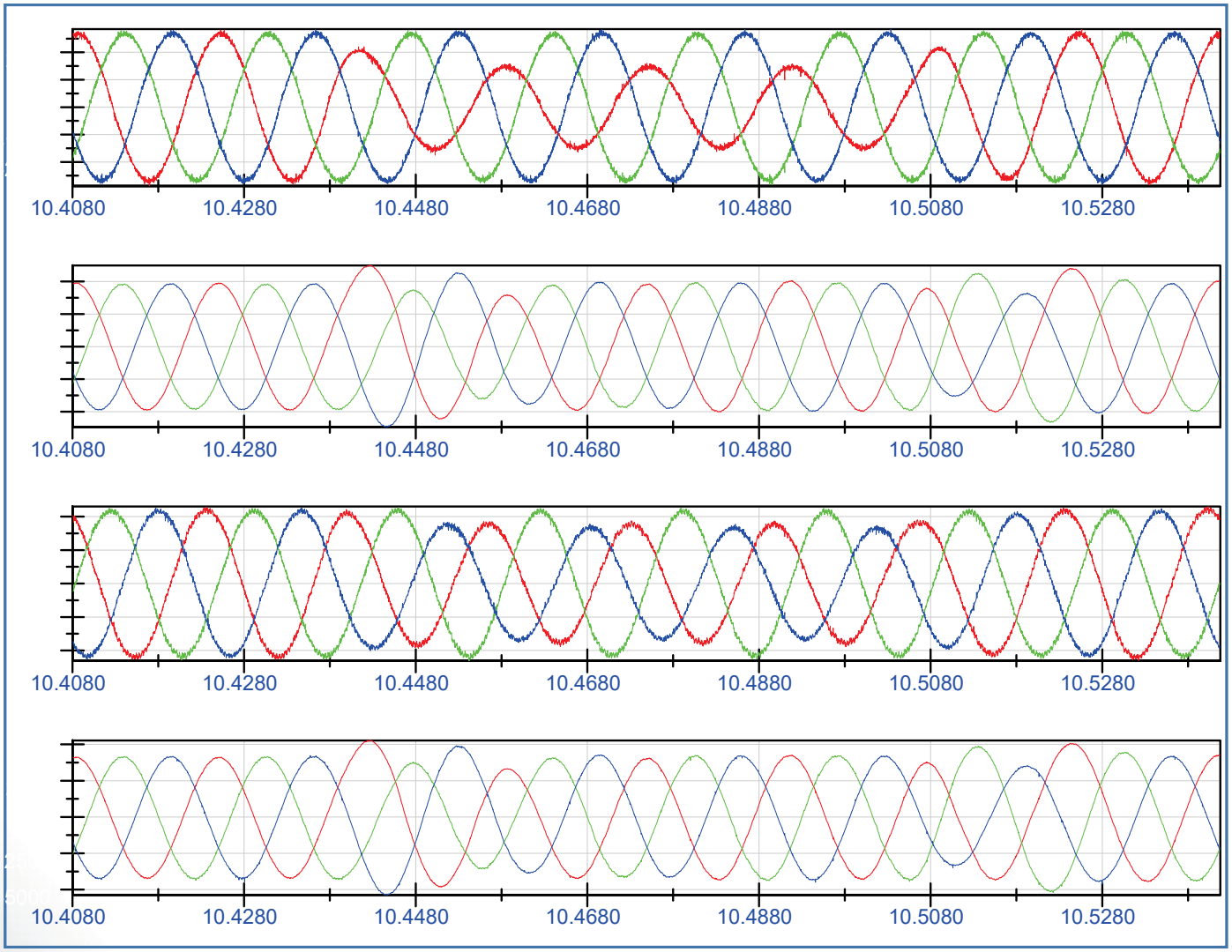
- Wye filter
- (3)Single-phase step-up transformers 4160/23.9 kV

2.2 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

L-N: 2000 kW, 0.55 Vpu, 67 ms



4160V bus
Van, Vbn, Vcn

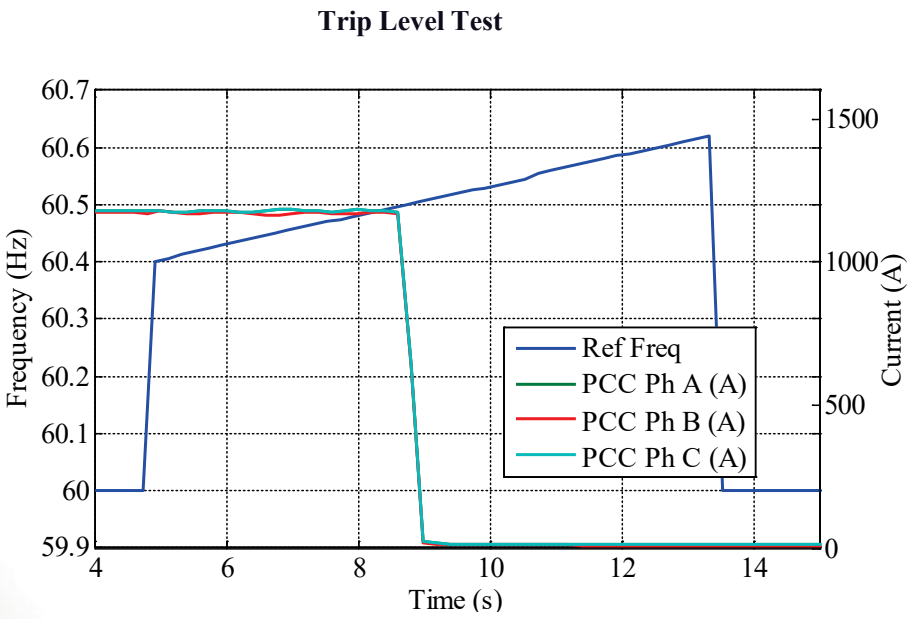
4160V bus
Ia, Ib, Ic

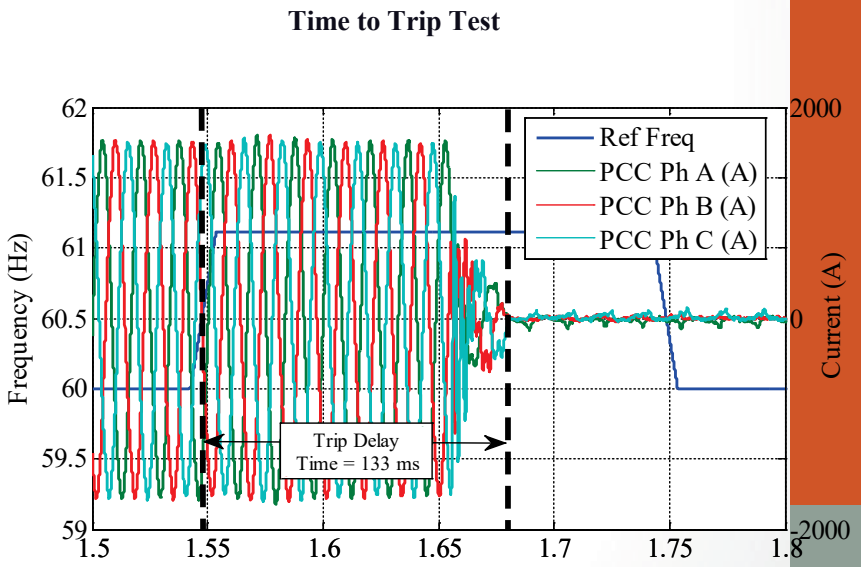
INV bus
Vab, Vbc, Vca

INV bus
Ia, Ib, Ic

Frequency Ride-Through Testing

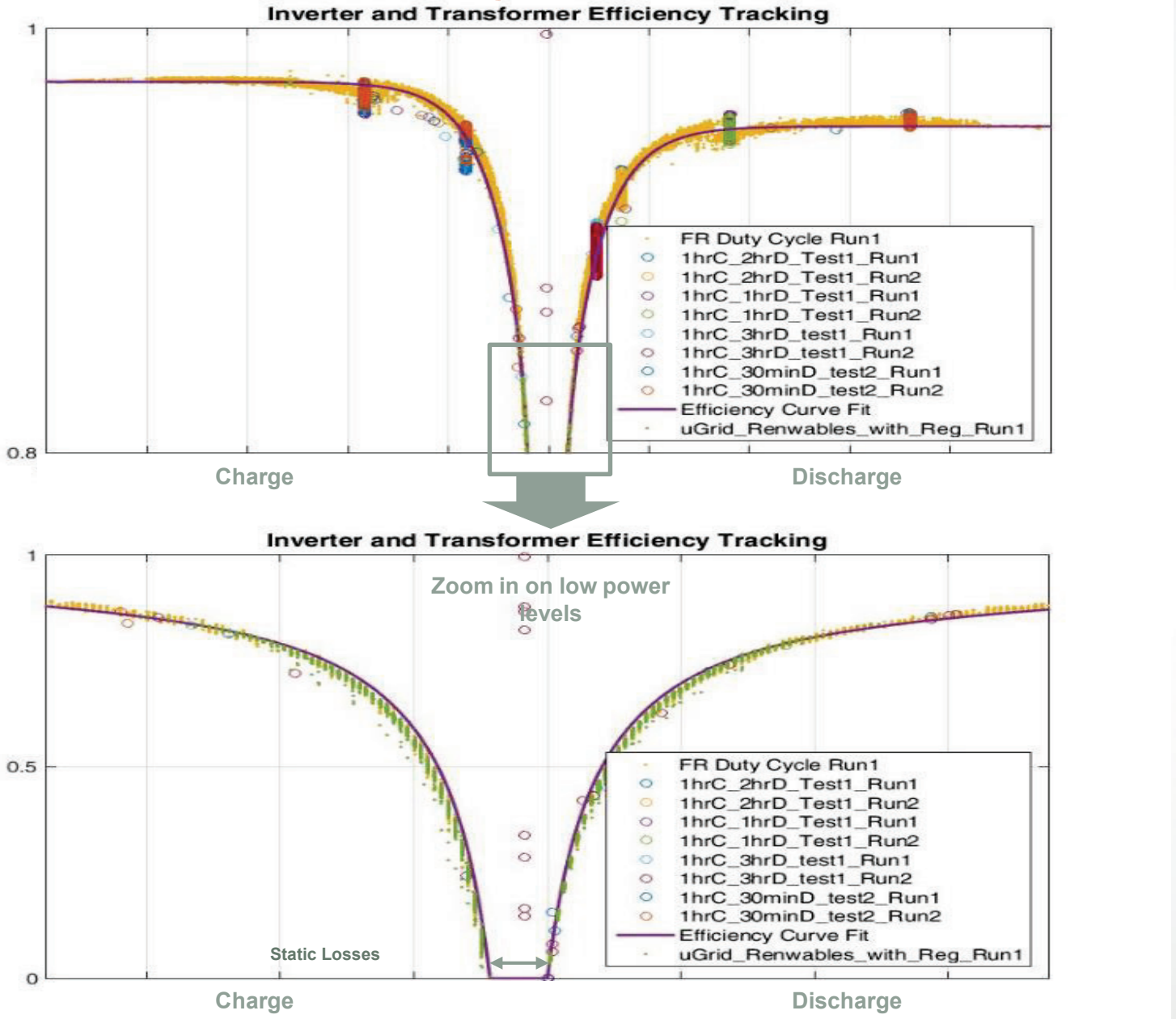
- Frequency ride-through testing is much easier than voltage ride-through



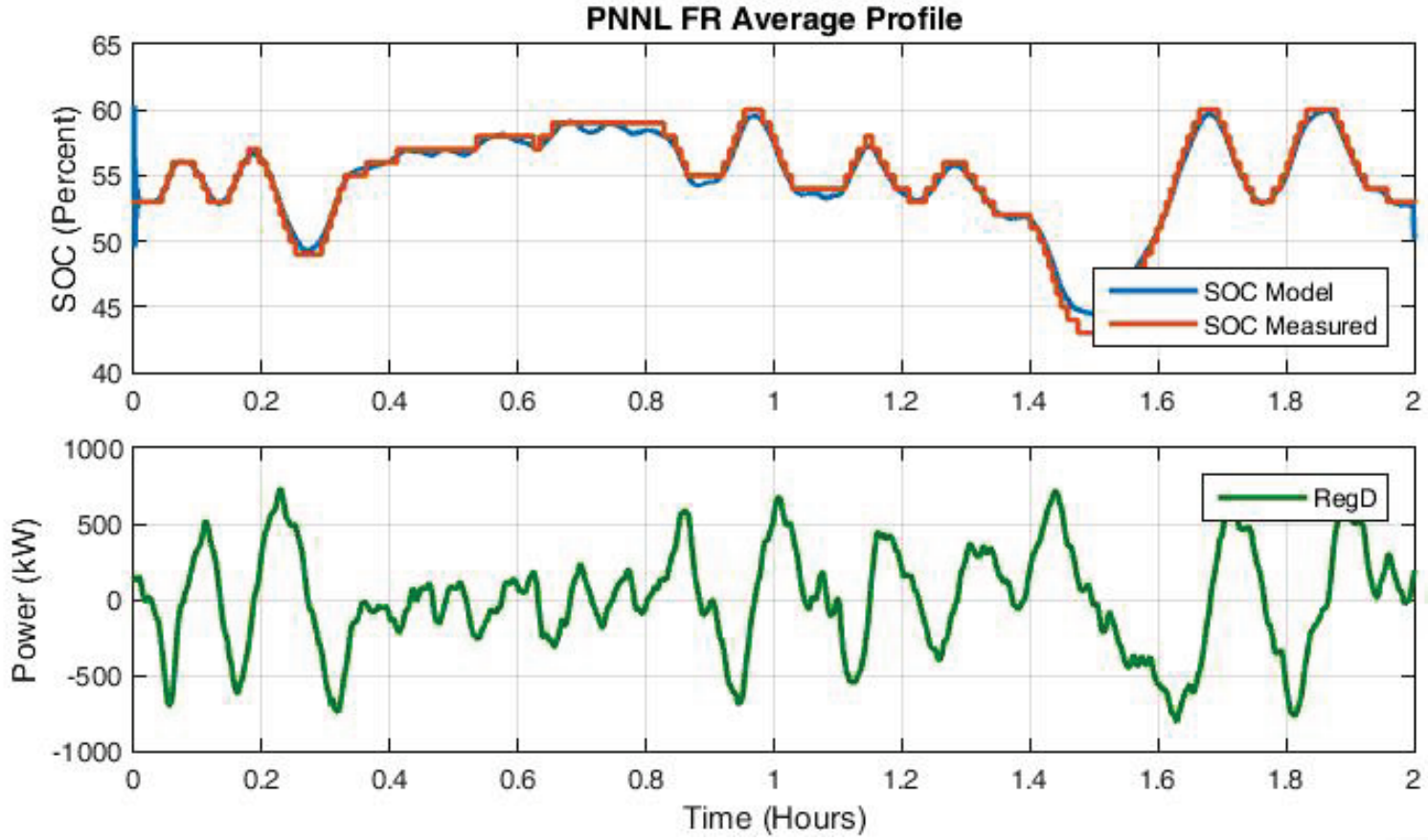


Battery Energy Storage System Testing

BESS Efficiency Curves



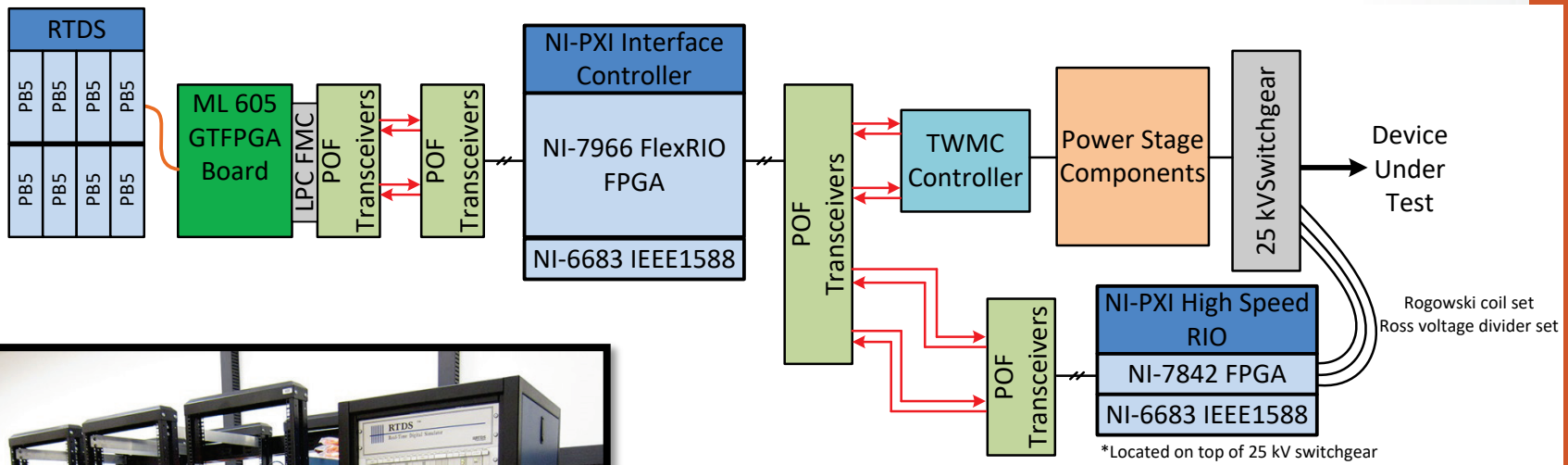
SOC Modeling and Validation



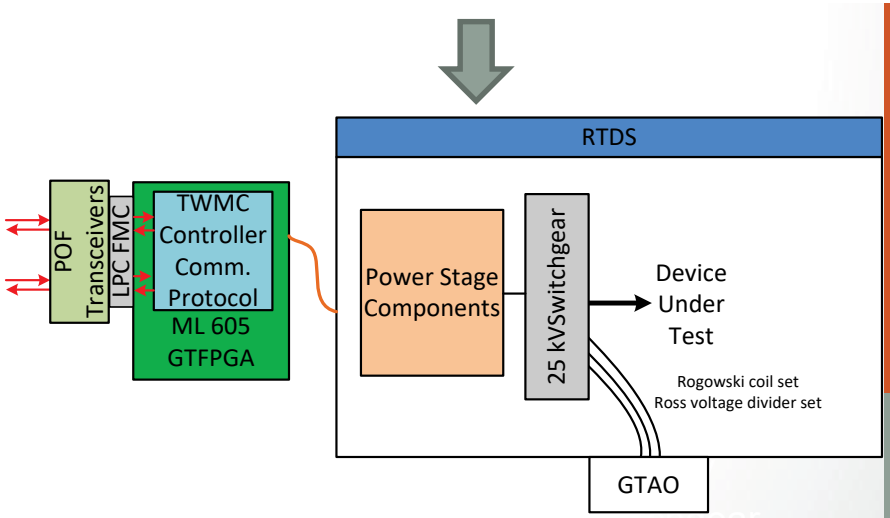
Distribution Automation CHIL Lab

- Baseline an IEC 61850 enabled substation
- SEL relays interface with RTDS
- RTDS simulate grid-tie inverters in real-time in a Controller-Hardware-In-the-Loop (CHIL) configuration

Controller Testing HIL (CHIL)



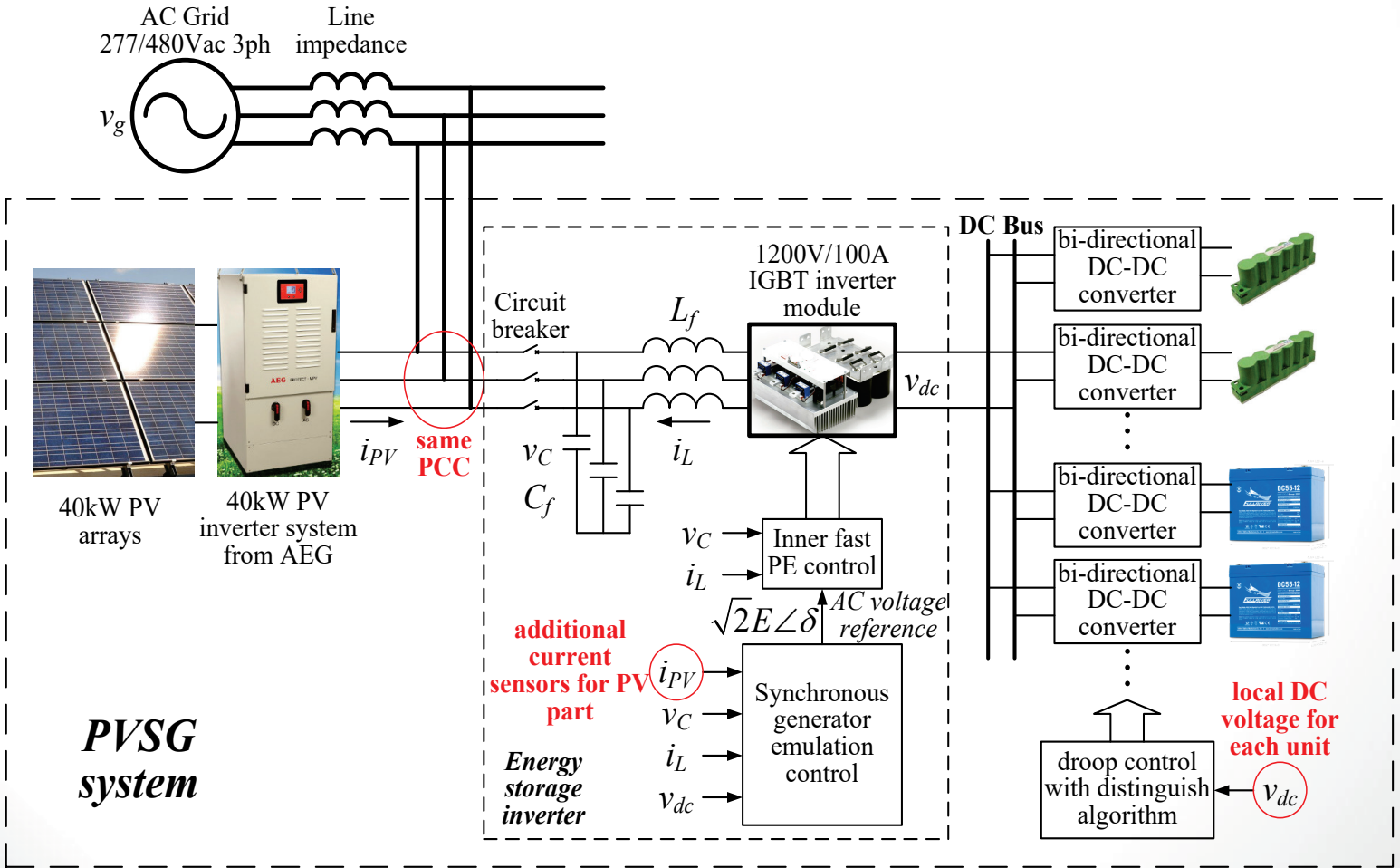
Data Room



Leonard, J., Hadidi, R., Fox, C., "*Real-Time Modeling of Multi-level Megawatt Class Power Converters for Hardware-In-the-Loop Testing*," in *Proc.* International symposium on Smart Electric Distribution Systems and Technologies, Vienna, Austria, 2015.

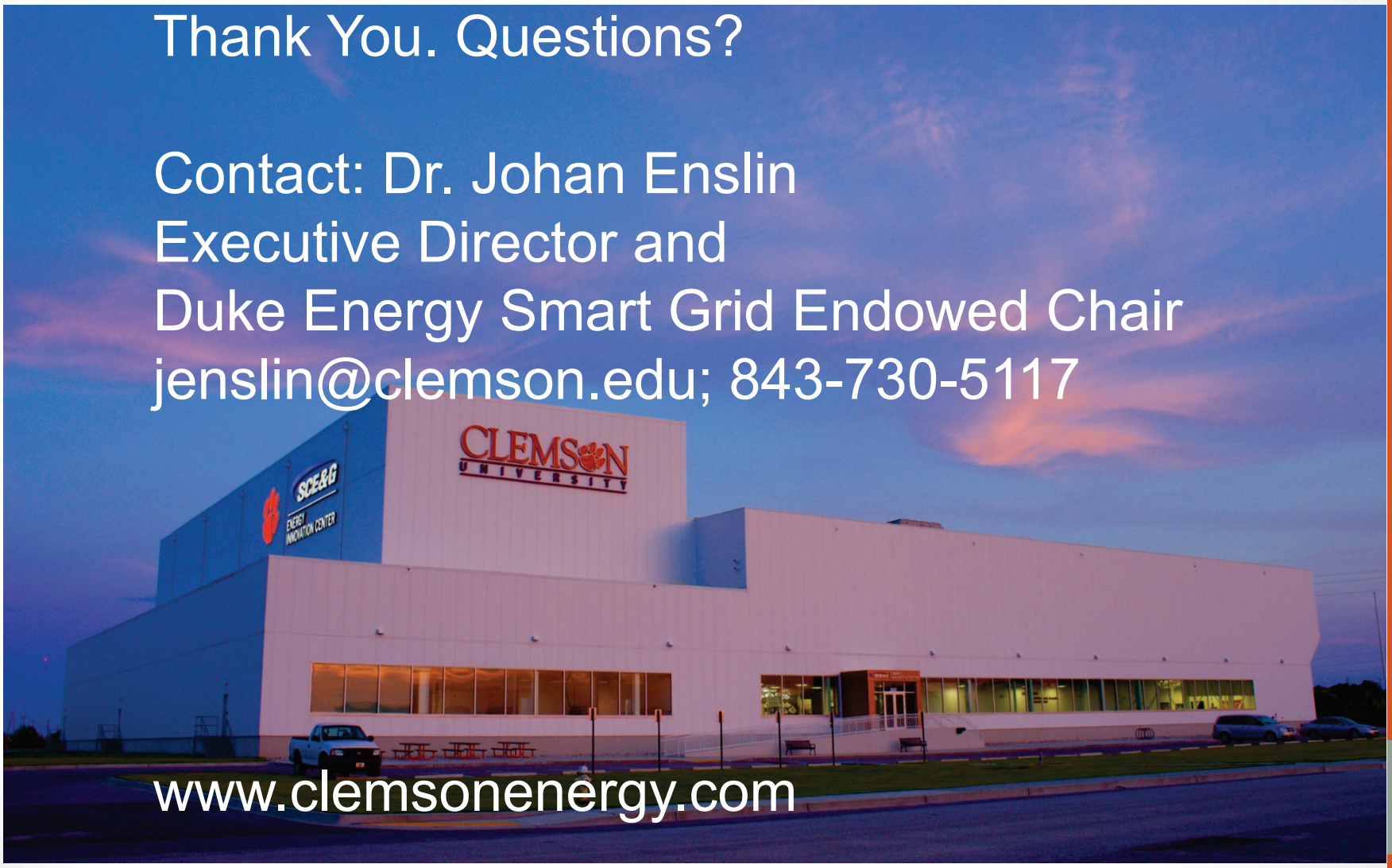
Photovoltaic Synchronous Generator

- Development a 40 kW hybrid energy storage system (HESS) that works in parallel with commercial PV inverters.
- Demonstrate virtual inertia, primary and secondary frequency response.



Thank You. Questions?

Contact: Dr. Johan Enslin
Executive Director and
Duke Energy Smart Grid Endowed Chair
jenslin@clemson.edu; 843-730-5117



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