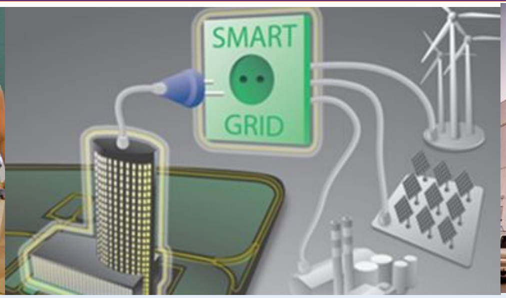





Digital Twin Validation for Distributed Resource Converters and Assets

Dr. Johan H Enslin, FIEEE, FSAIEE, PrEng
Executive Director, Energy Systems Program
Duke Energy Endowed Chair in Smart Grid Technology

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

Zucker Family Graduate Education Center (ZFGEC)
Energy Innovation Center (EIC)

CLEMSON
CHARLESTON

Overview

- Building a Digital Grid on Legacy Infrastructure
- Digital Twin – Analytics and Operations
- Clemson in Charleston: Dominion (SCE&G) Energy Innovation Center
- PV Inverter Testing and Model Validation
- BESS Testing and Model Validation
- Digital Twin Implementation – Operating Wind Turbine Drive Trains
- Wind Turbine Validation - Low Voltage Ride-Through
- Conclusions

Building a Digital Grid on Legacy Grid

Figure 13: Link between digital modernization strategy initiatives

Key Findings of Survey Report:

- 91% of respondents embracing digital technology for future success of their utilities.
- 23% of utilities reached a level of digital maturity where they are making capital expenditure decisions based on predictive analytics.
- In the next 3 years, 76% of utilities expect to be able to align digital strategy with regulatory policy and fill key digital roles.

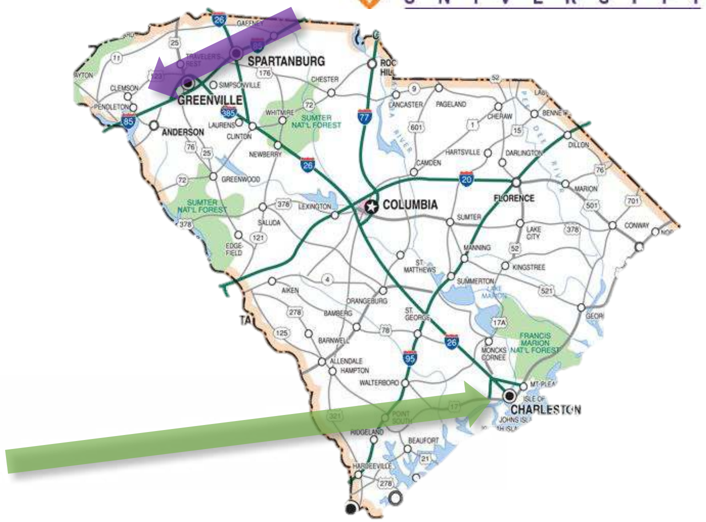
"Building the 21st Century Digital Grid", Zpryme, 2019

Digital Twin - Analytics and Operations

CLEMSON CHARLESTON

- **Definition of Digital Twin**: *"A digital representation of the way the various network elements and participants behave and interact, enabling an infinite range of "what-if?" scenarios to be tested out."*
- **The Result**: More accurate forward visibility, awareness and better real-time decisions and operations.
- **Recommendations**:
  - Don't reinvent the wheel. Reuse existing trusted models, but validate them continuously.
  - Don't be limited by immediate needs. The more components and interrelationships, the closer digital representation of the physical asset.
  - Update and develop new standards for DER and System Operations
  - Leverage existing platforms that allow to update or replace models and test new technologies.
  - Implement good Cyber – Physical Security in Operation Technology
  - Use Digital Twins to make distributed assets visible to system operators

Dominion (SCE&G) Energy Innovation Center



Clemson University Restoration Institute

SCE&G Energy Innovation Center

Duke Energy eGRID Center

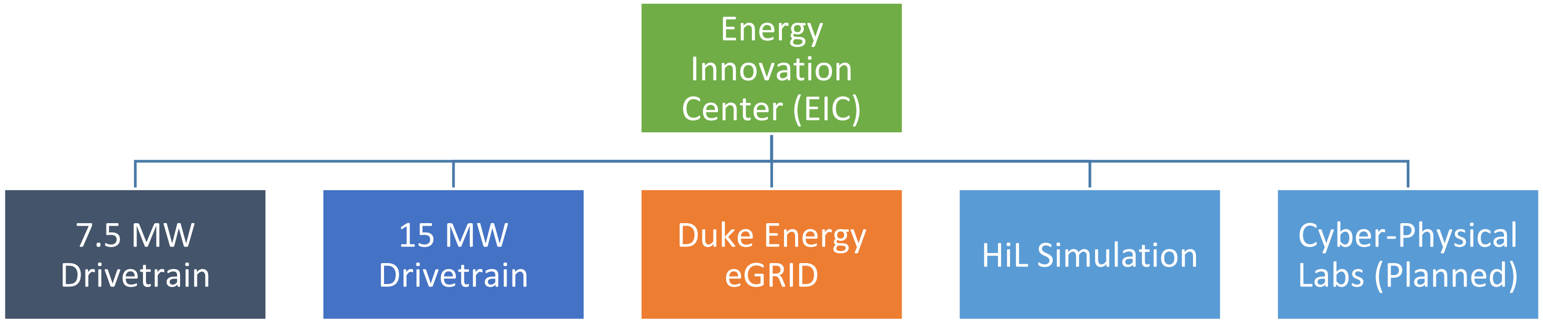
Wind Turbine Drivetrain Testing Facility

15 MW HIL Grid Simulator

7.5 MW Test Bench

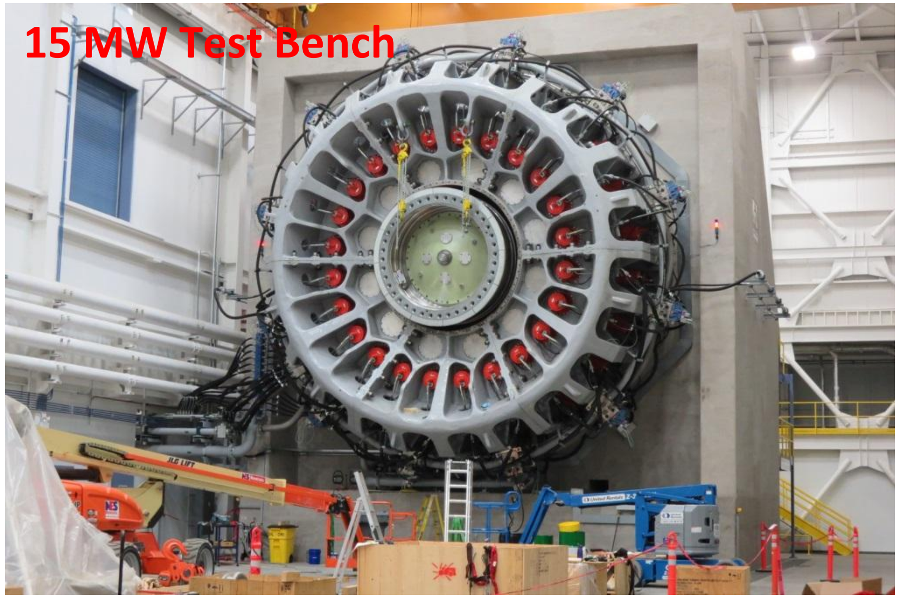
15 MW Test Bench

Graduate Education Program and Power Labs



- Dominion (SCE&G) Energy Innovation Center (EIC)
  - 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 3 Faculty, 12 planned in power program (ECE; CS; ME)
- Currently 30+ Research Scientists, Engineers and Technicians
- Currently 50+ Students, planned 200 as professionals and full-time

7.5 MW and 15 MW Test Benches



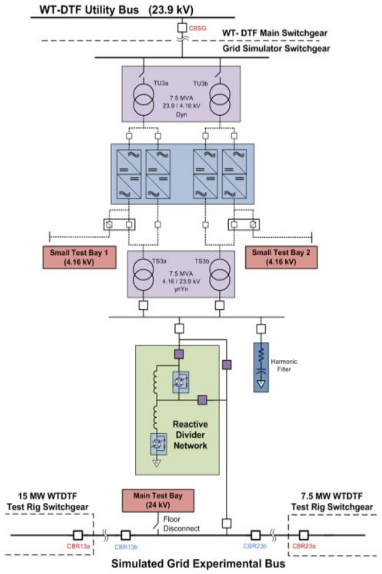
7.5 MW Test Bench Performance Specifications

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

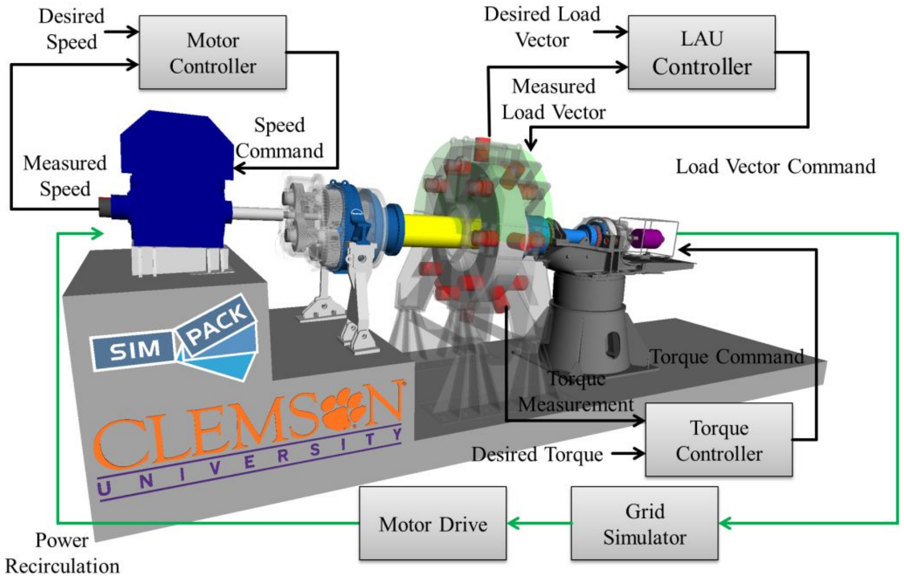
15 MW Test Bench Performance Specifications	
Test Power	15,000 kW
Maximum Torque	16,000 kNm
Maximum Speed	17 rpm
Inclination	6 °
Static Axial Force	± 4,000 kN
Static Radial Force	± 8,000 kN
Static Bending Moment	± 50,000 kNm

15 MW Power HHL Facility

15 MW HIL Grid Simulator



Virtual Test Bench Test

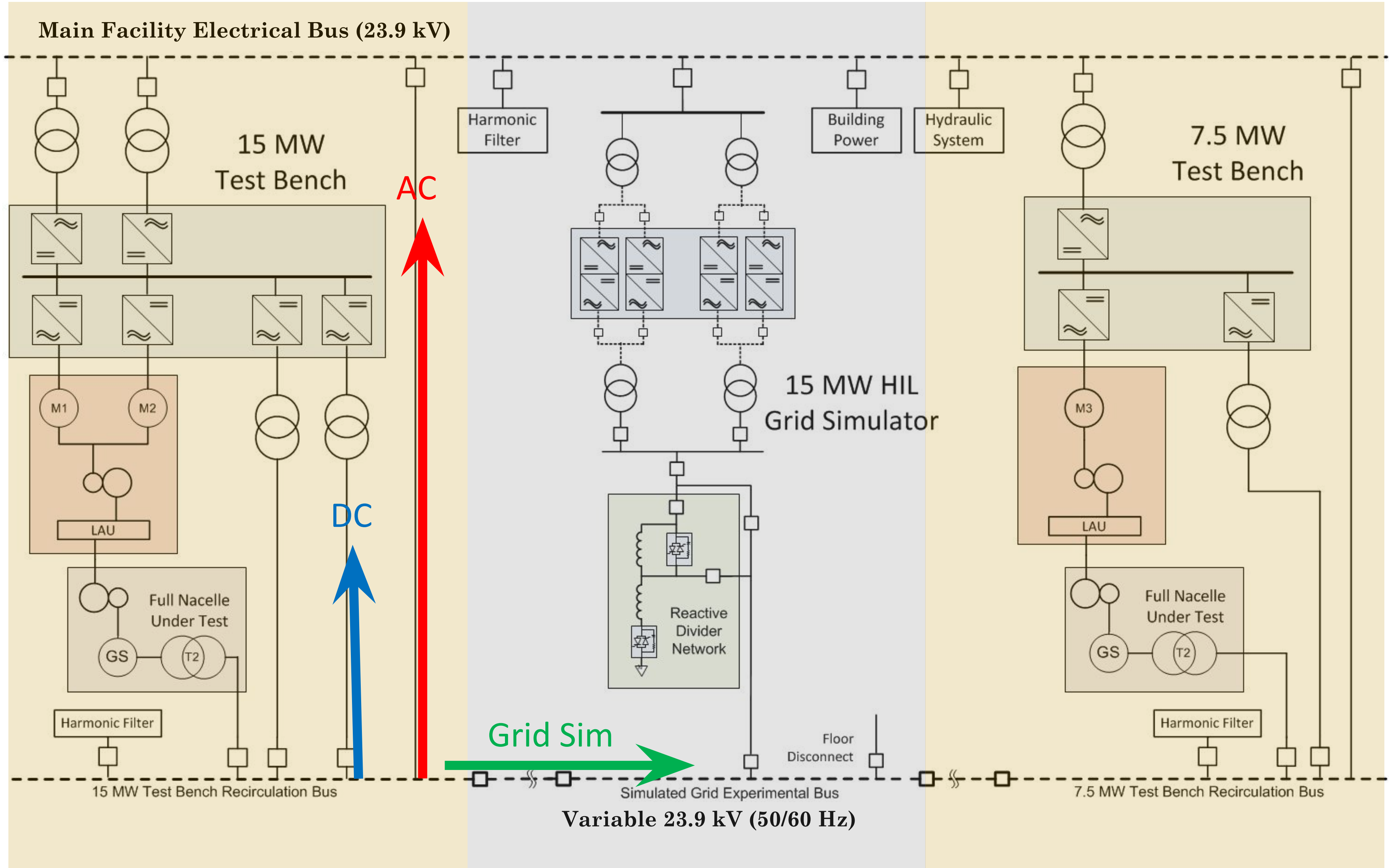


15 MW HIL Grid Simulator Performance Specifications

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 Digital Twin Simulator 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

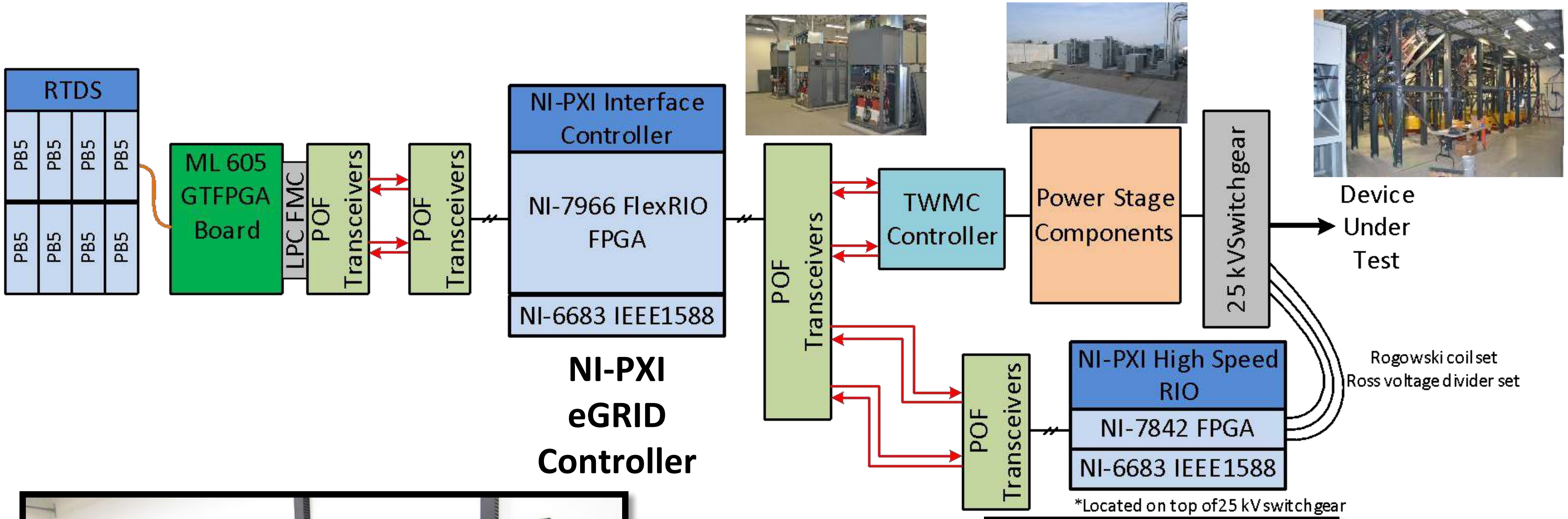
SCE&G EIC Electrical Single Line



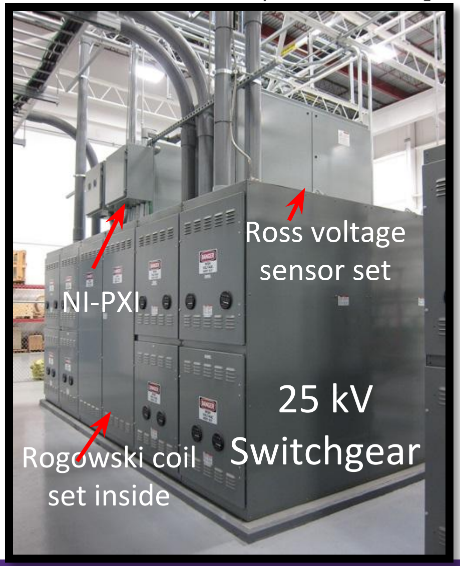
Control C-HIL Setup

- 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

Power P-HIL Configuration



Data Room



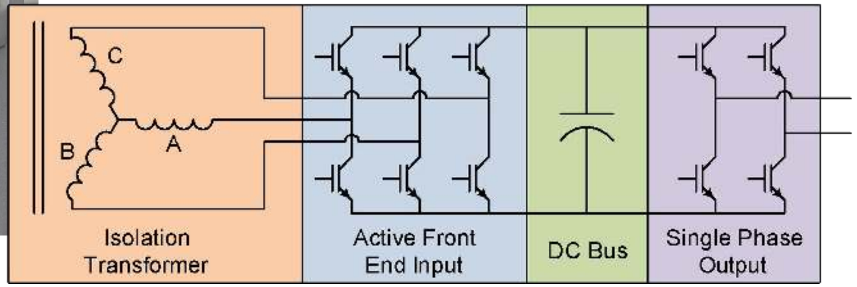
High Bay

Power Amplifier Units (PAU)

4 Power Amplifier Units (PAUs)

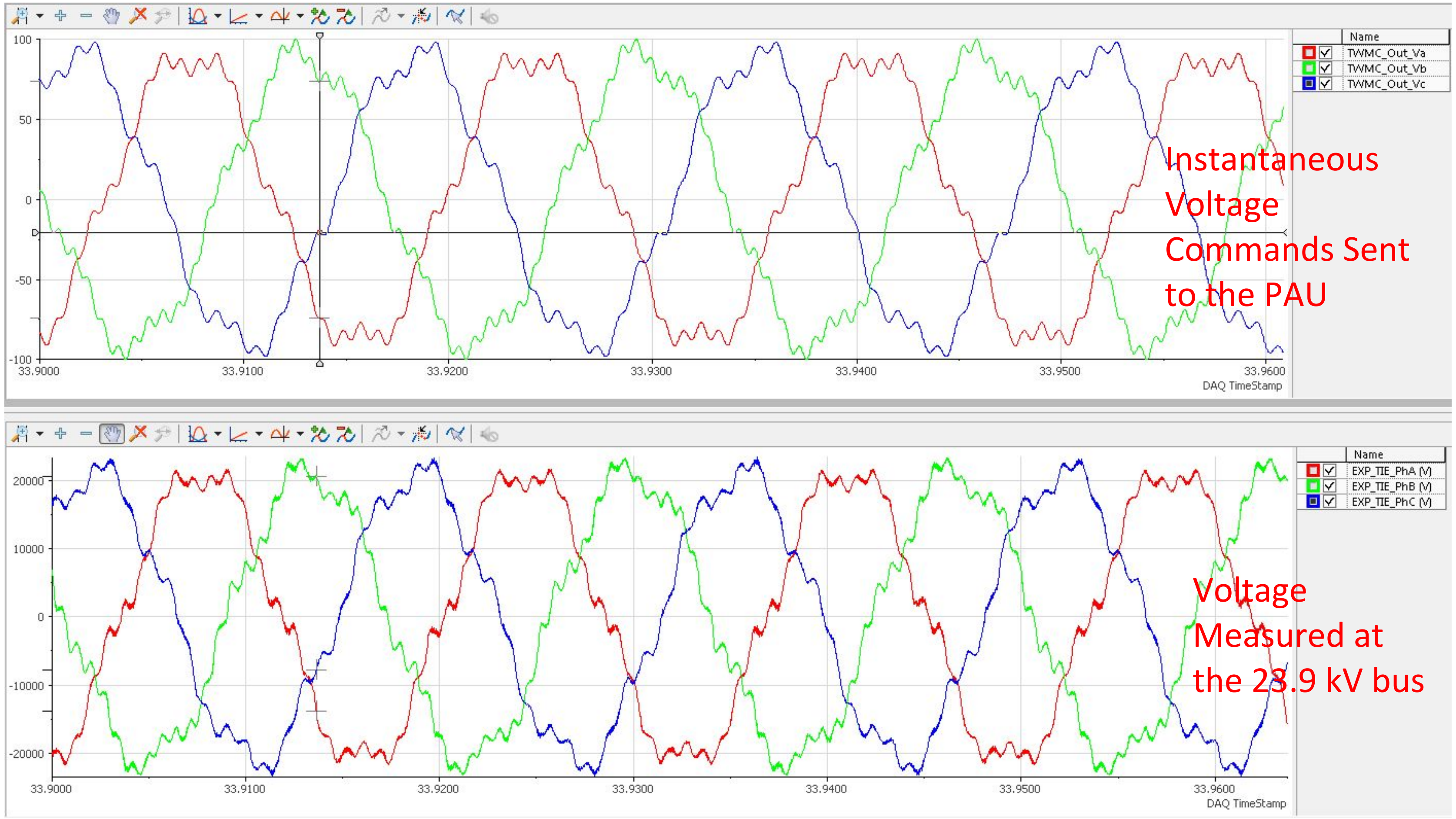
8 Slices Per PAU

3 Cubes Per Slice



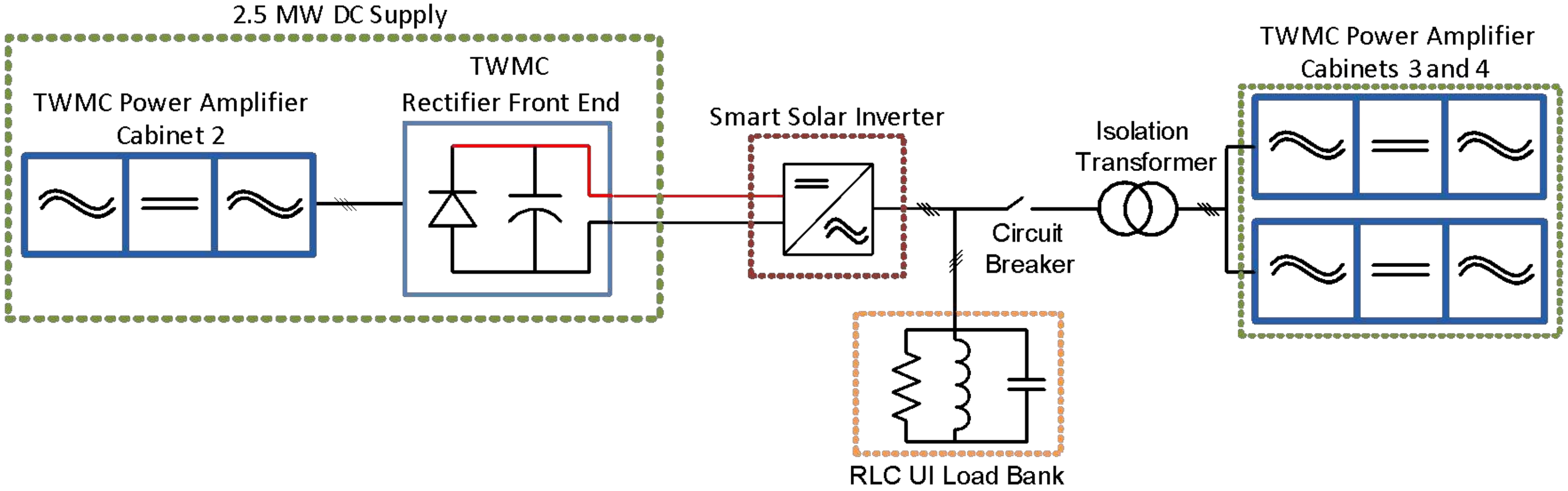
Open Circuit Harmonic Generation

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



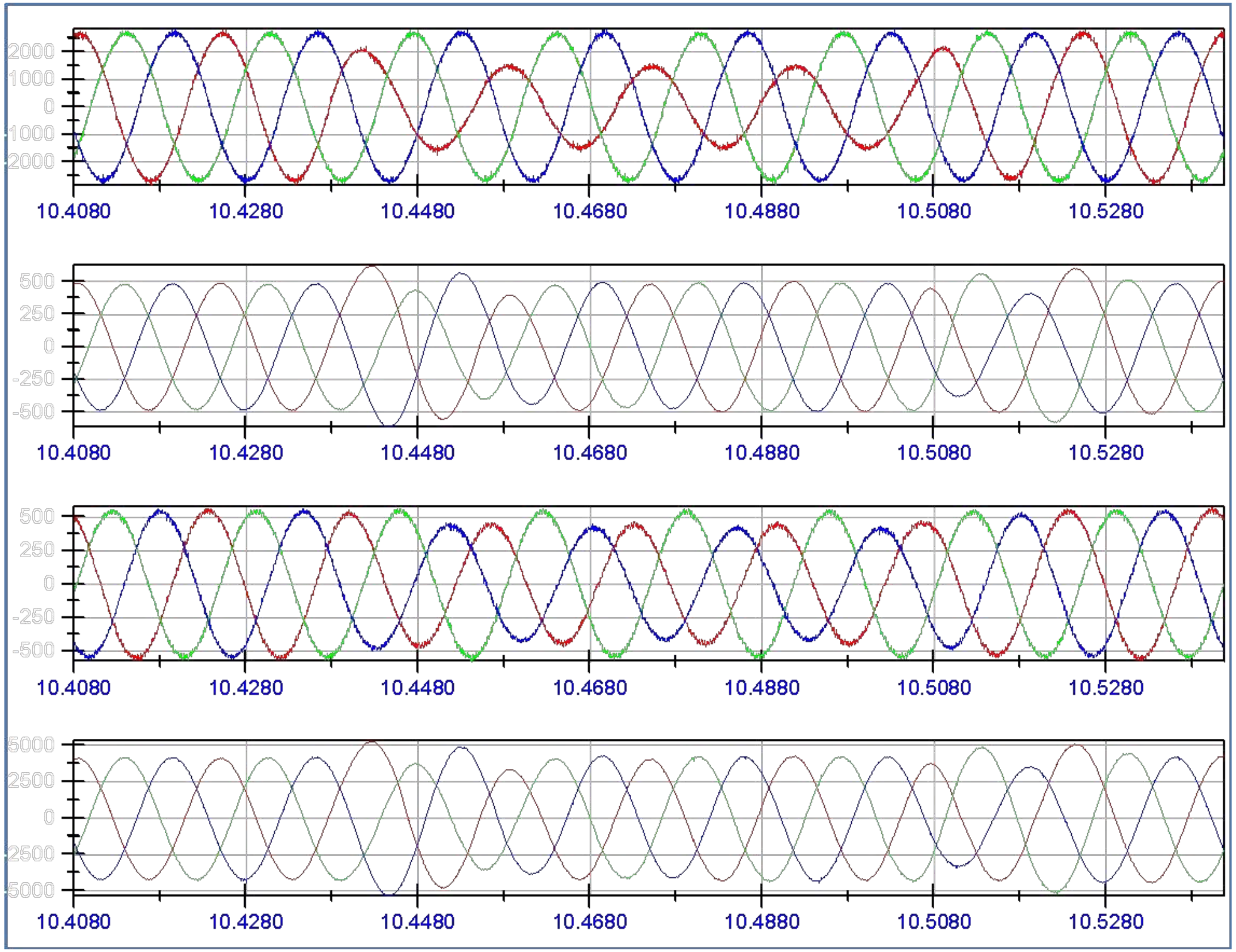
Leonard, J., Hadidi, R., Fox, C., "*Real-Time Modeling of Multi-level Megawatt Class Power Converters for Hardware-In-the-Loop Testing*," in *Proc.* International symposium on Smart Electric Distribution Systems and Technologies, Vienna, Austria, 2015.

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

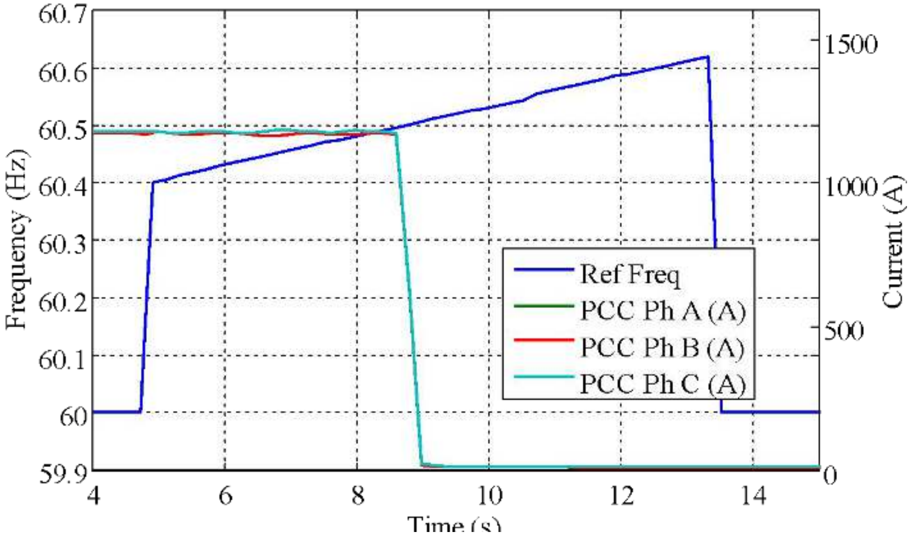
INV bus
Vab, Vbc, Vca

INV bus
Ia, Ib, Ic

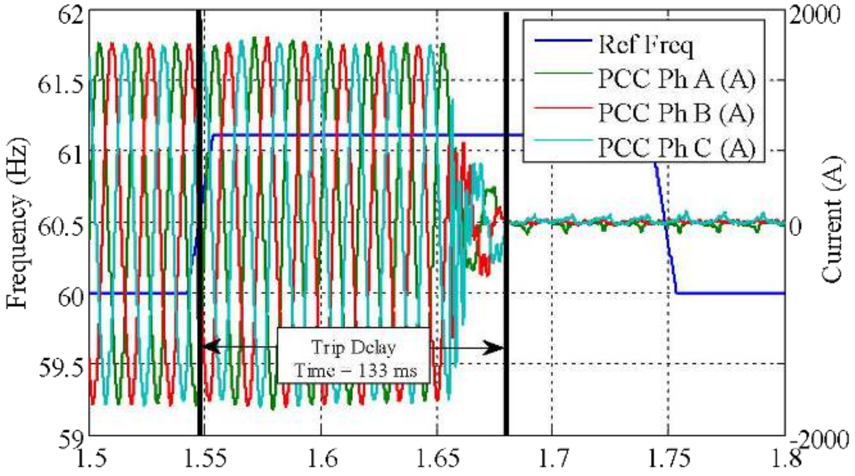
Frequency Ride-Through Testing

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

Trip Level Test

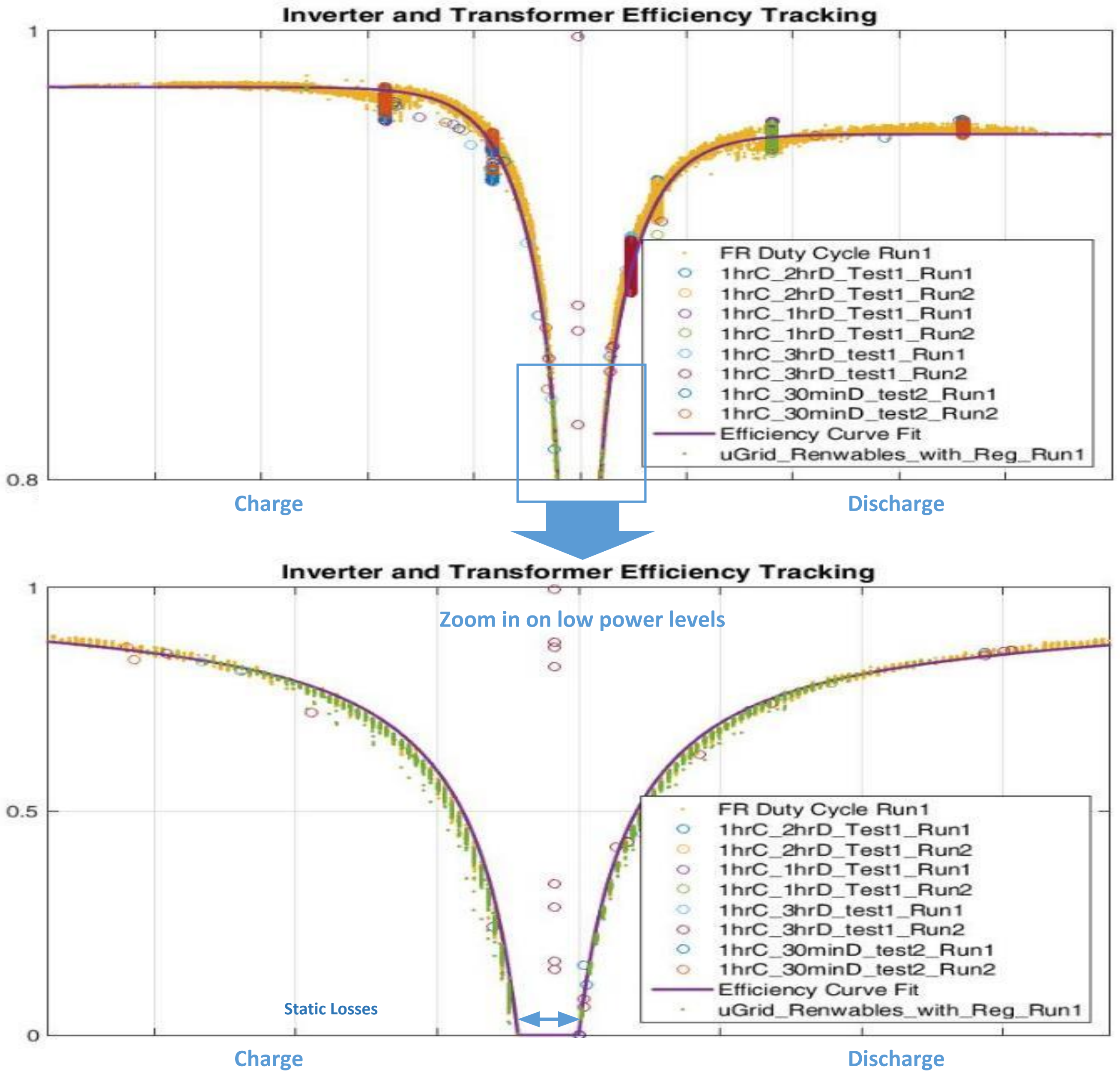


Time to Trip Test

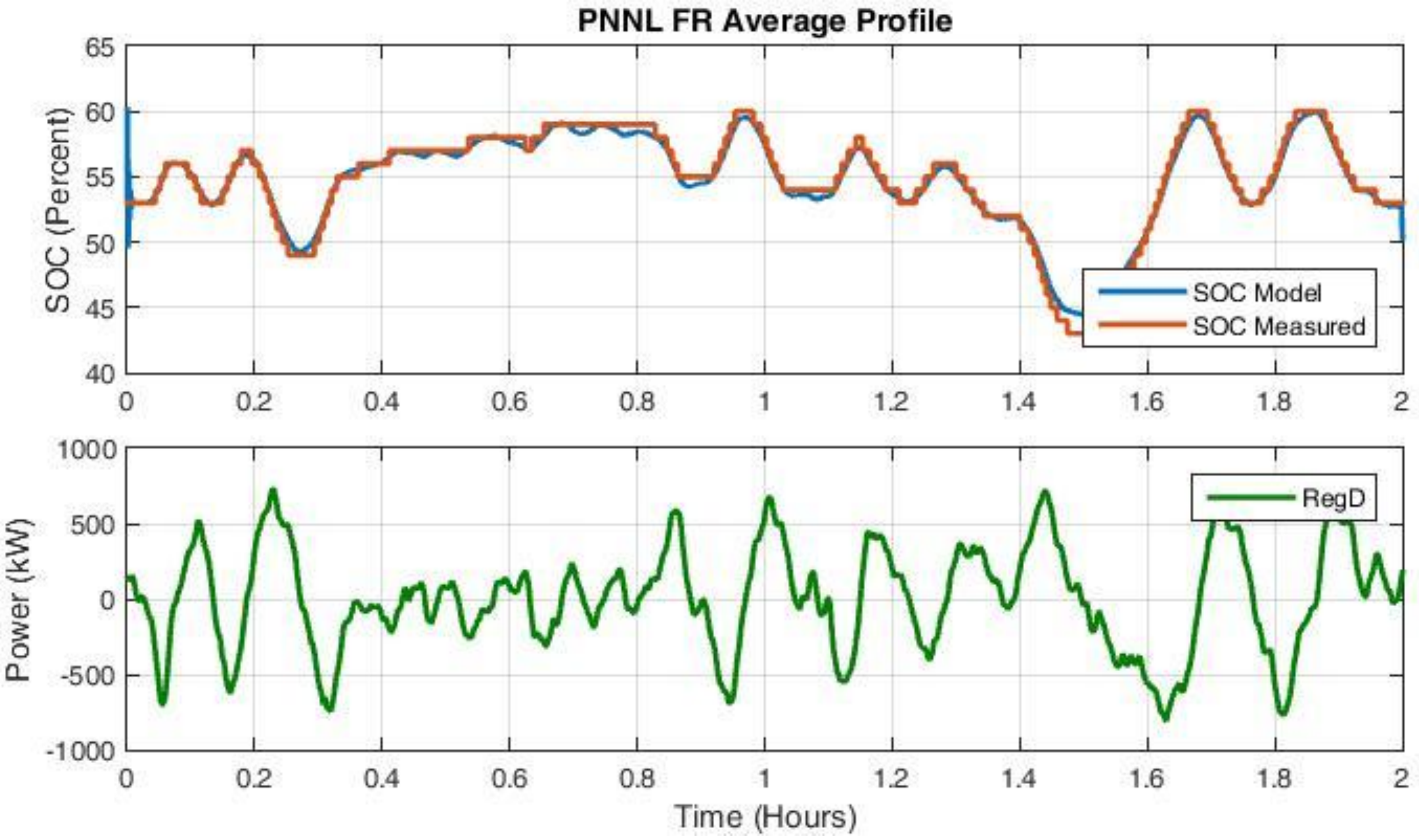


Battery Energy Storage System Testing

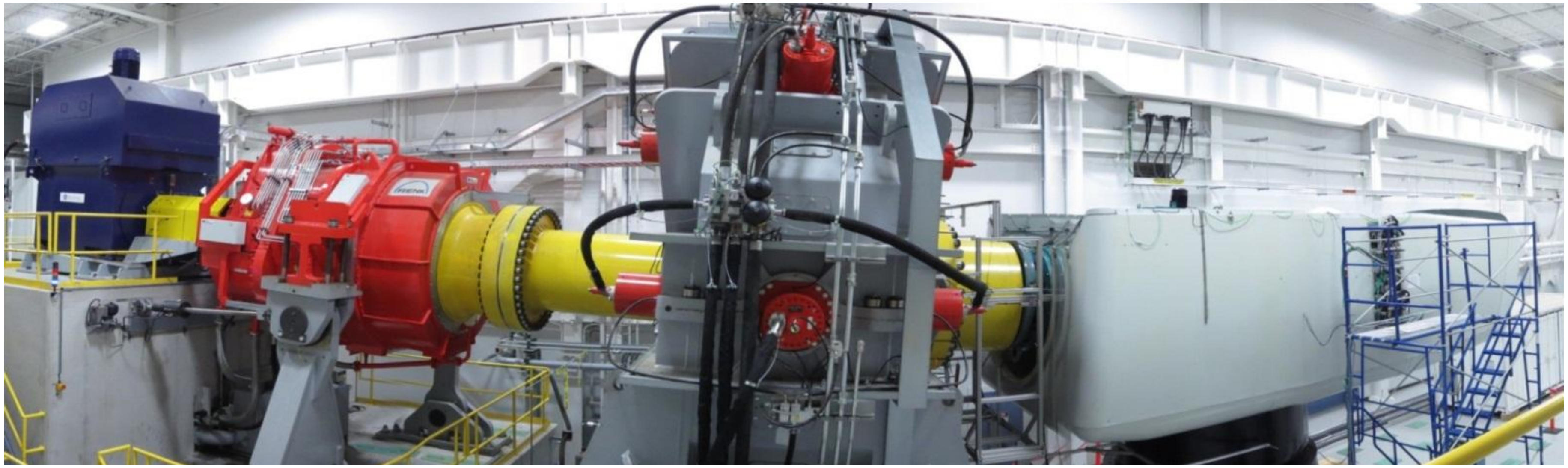
BESS Efficiency Curves

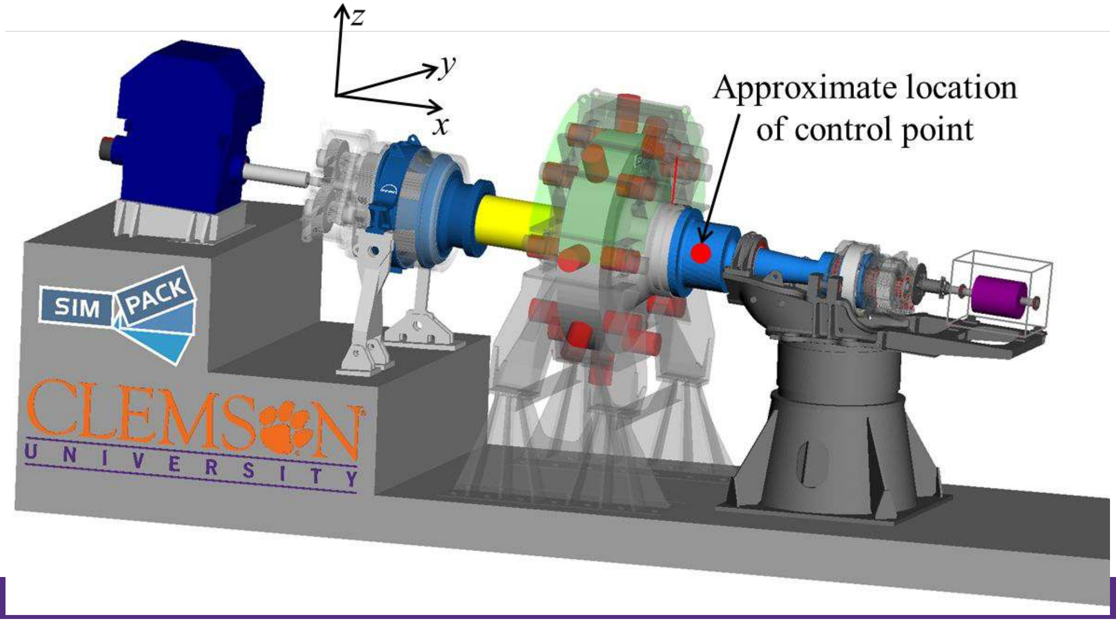


SOC Modeling and Validation



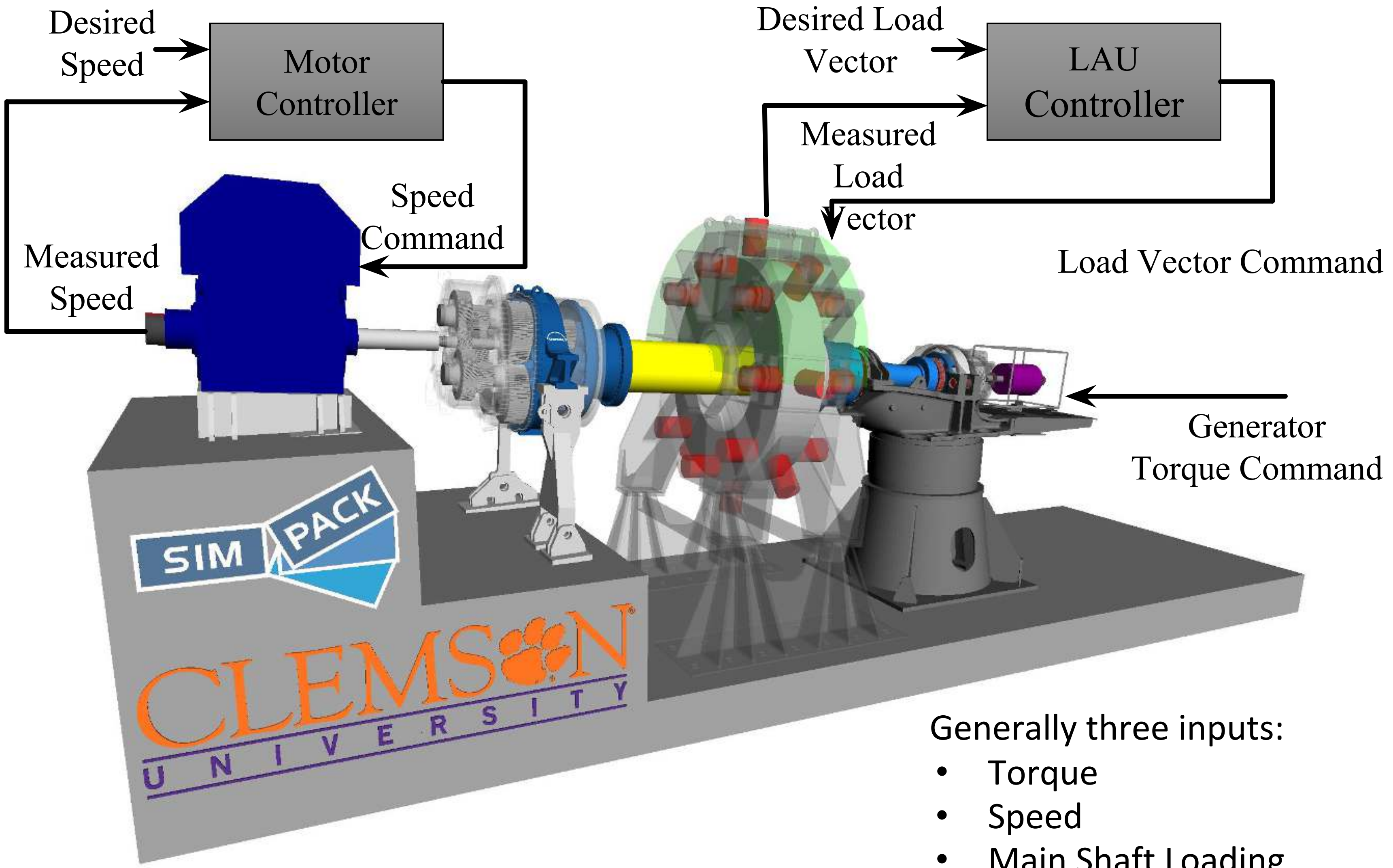
Wind Turbine Test-bed Digital Twin





- Torque and speed are controlled on opposite ends of the drive train
- Hydraulic actuators push on disk to create forces and moments at hub point

Digital Twin Drive Train Model Topology

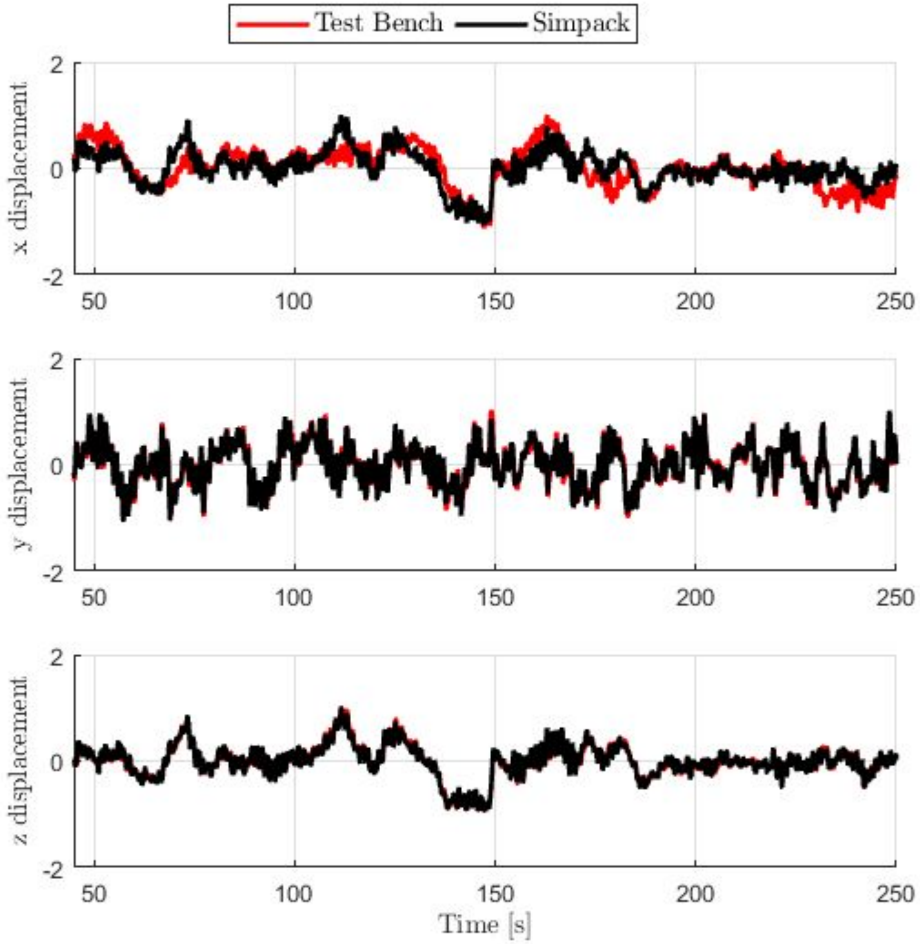


Generally three inputs:

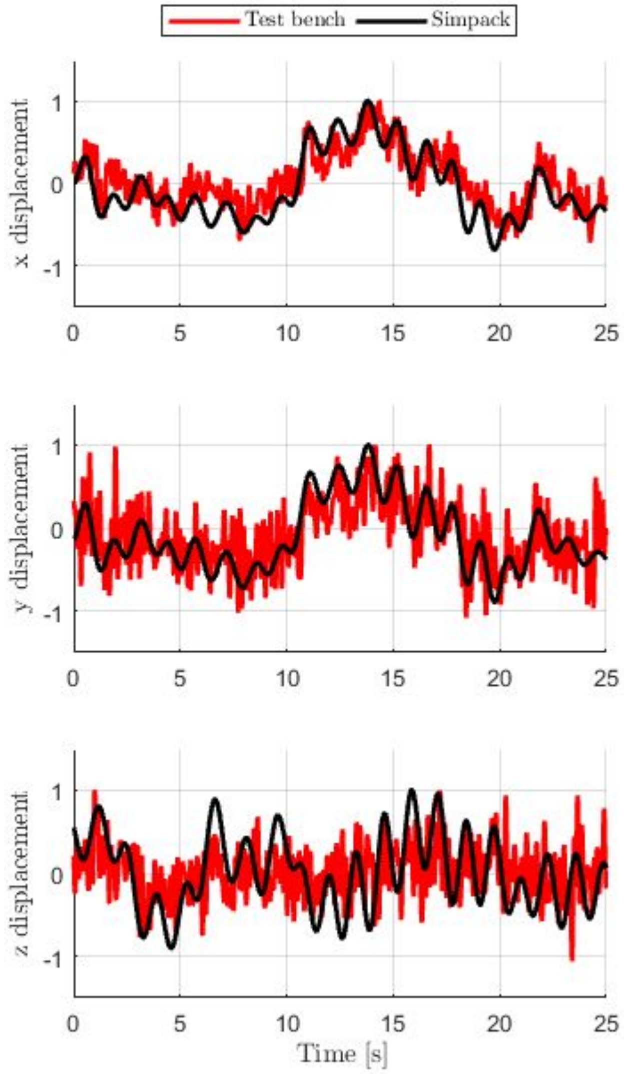
- Torque
- Speed
- Main Shaft Loading

Validation: Dynamic Loading

LAU Displacements



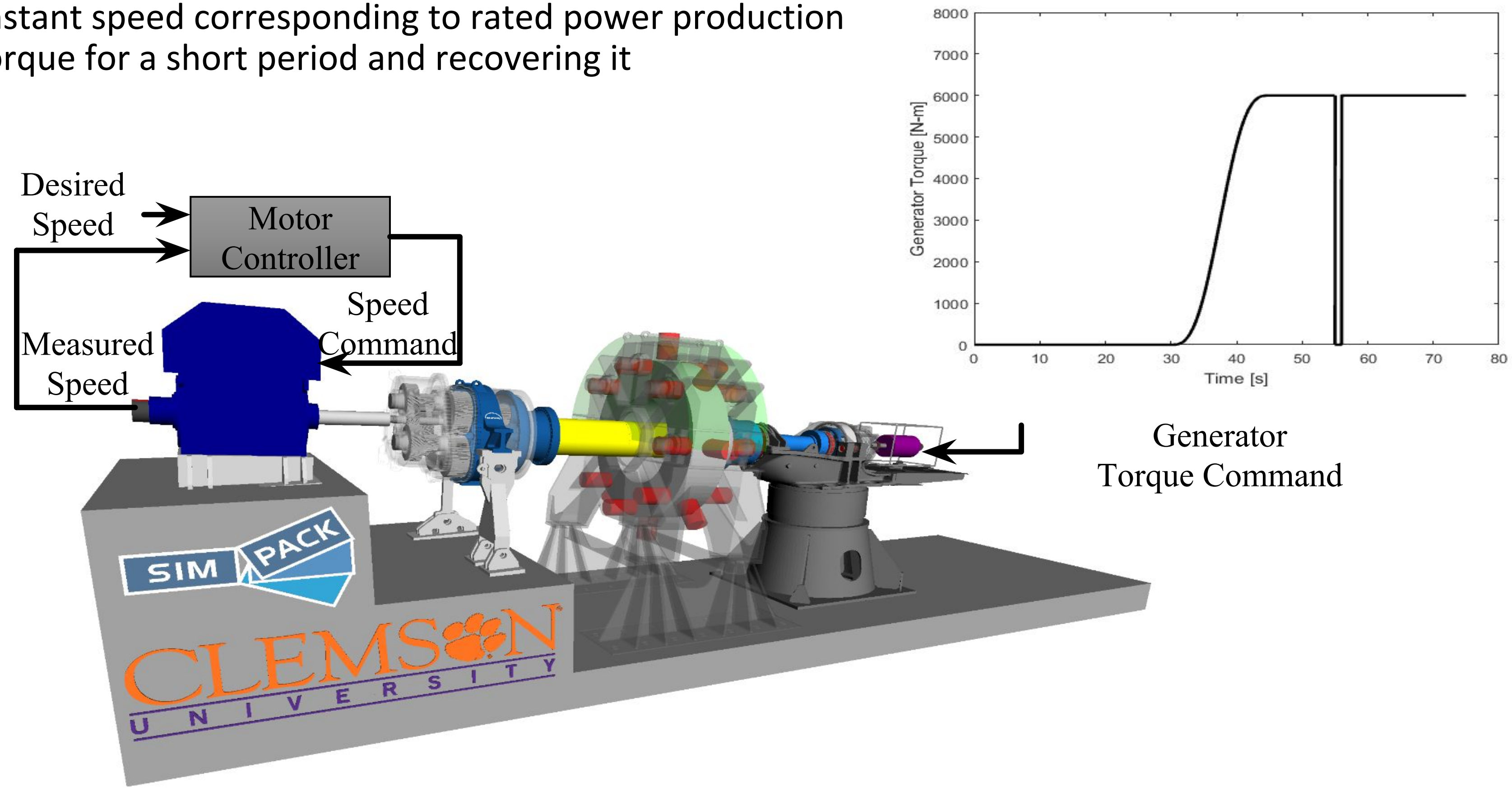
Test Article Gearbox
Support Displacements



Panyam, M., Bibo, A. and Roach, S., 2018, September. On the Multi-Body Modeling and Validation of a Full Scale Wind Turbine Nacelle Test Bench. In *ASME 2018 Dynamic Systems and Control Conference* (pp. V003T29A005-V003T29A005). American Society of Mechanical Engineers.

Case Study: Wind Turbine LVRT

- Low Voltage Ride-Through is an essential feature in all modern turbines to prevent outages due to voltage drop or grid faults
- IEC standard (61400-21) specifies tests to assess power quality characteristics of grid connected turbines
- Testing involves tracking a constant speed corresponding to rated power production and dropping the generator torque for a short period and recovering it

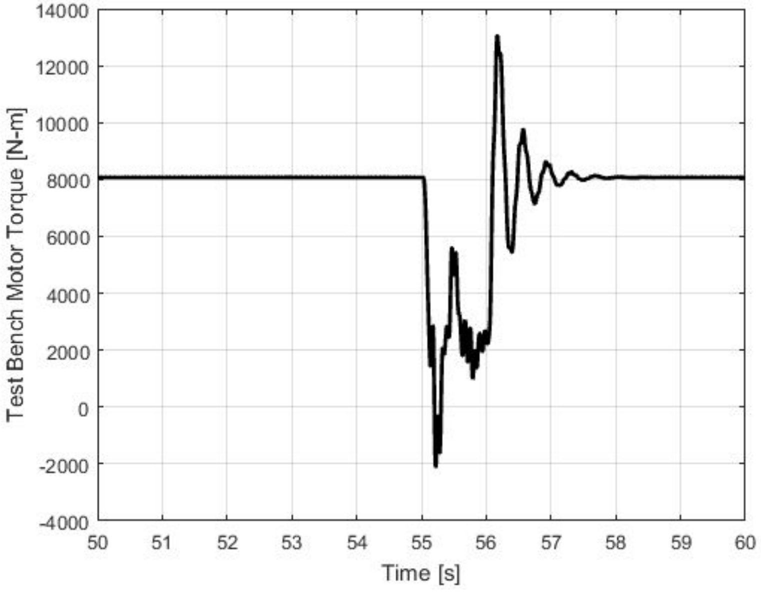


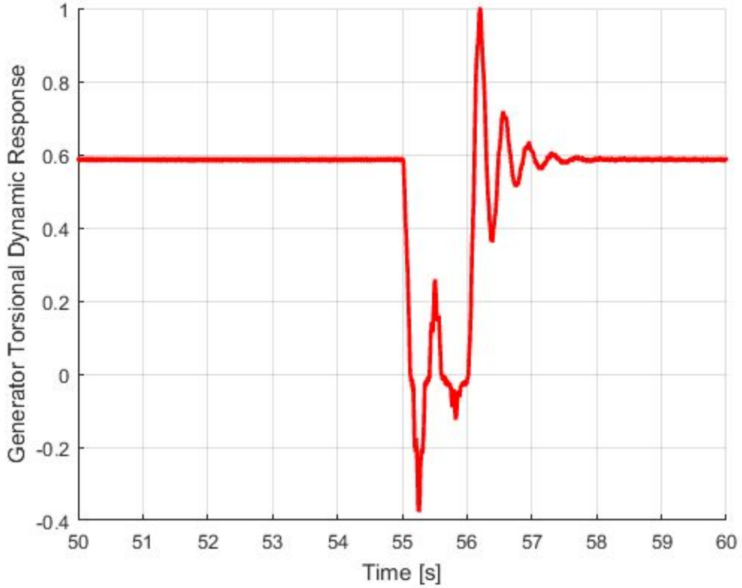
Case Study: LVRT Emulation

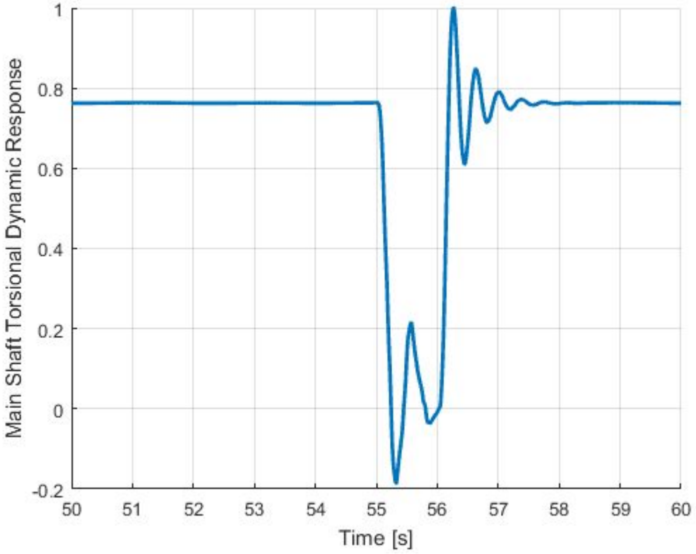
- At the instant of generator torque loss, test bench motor applies a large counter torque
- Large responses observed at main shaft and generator due to torque reversal

Generator and Main Shaft and Torsional Responses

Test bench motor torque





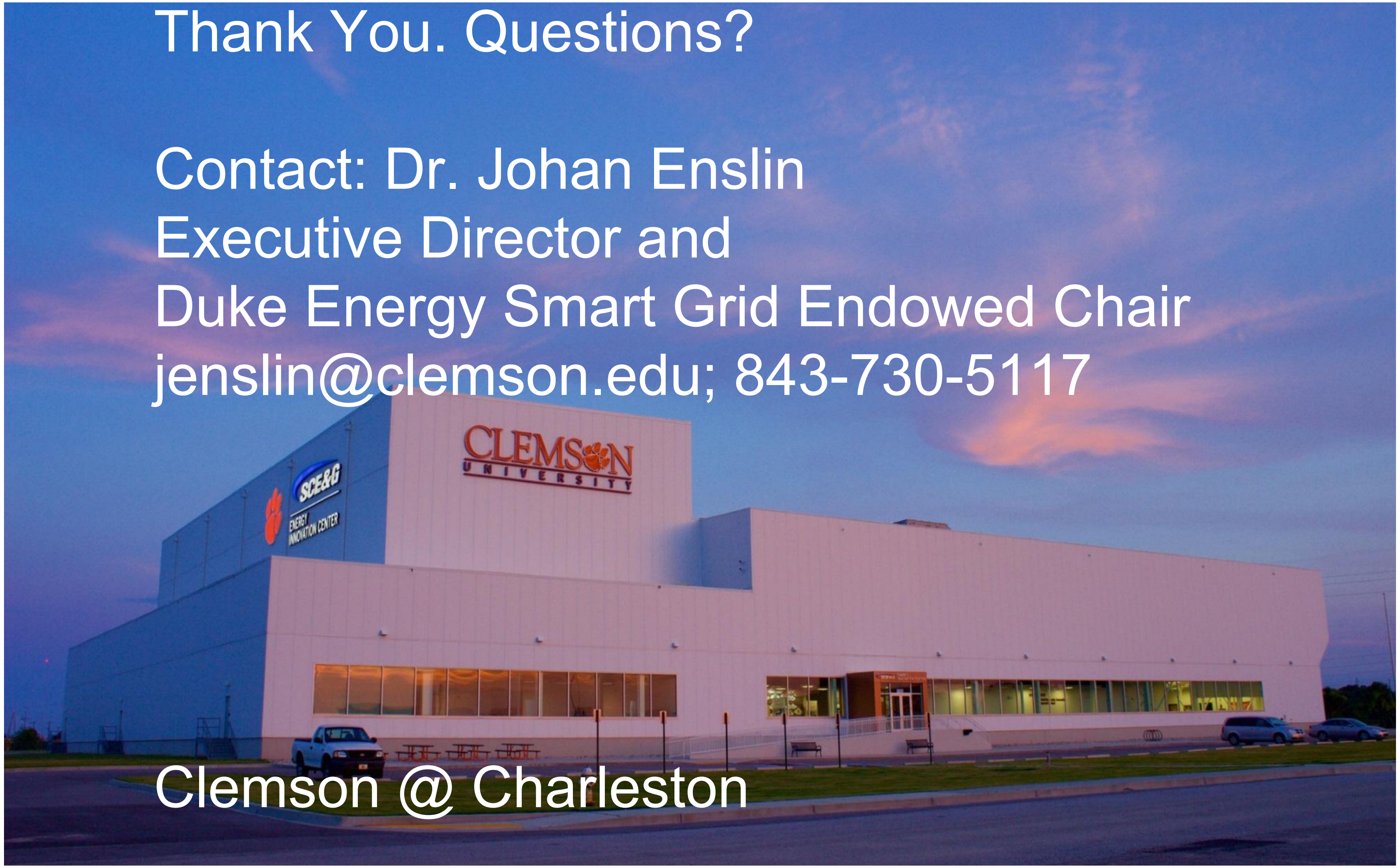


Conclusions

- Utilities are investing through regulatory process in Digital Grid technologies.
- Digital Twin models need validation and real-time parameter verification.
- Examples for validating PV Inverters, Energy Storage System and Wind Turbine Models for Digital Twins are discussed.
- A Digital Twin implementation is described for the EIC wind drive train testbeds.
- Need for new and updated interconnection and operational standards
- Digital Twins important for System Operations and DER Visibility

Thank You. Questions?

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



Clemson @ Charleston