CENTER FOR ULTRA-WIDE-AREA RESILIENT ELECTRIC ENERGY TRANSMISSION NETWORKS

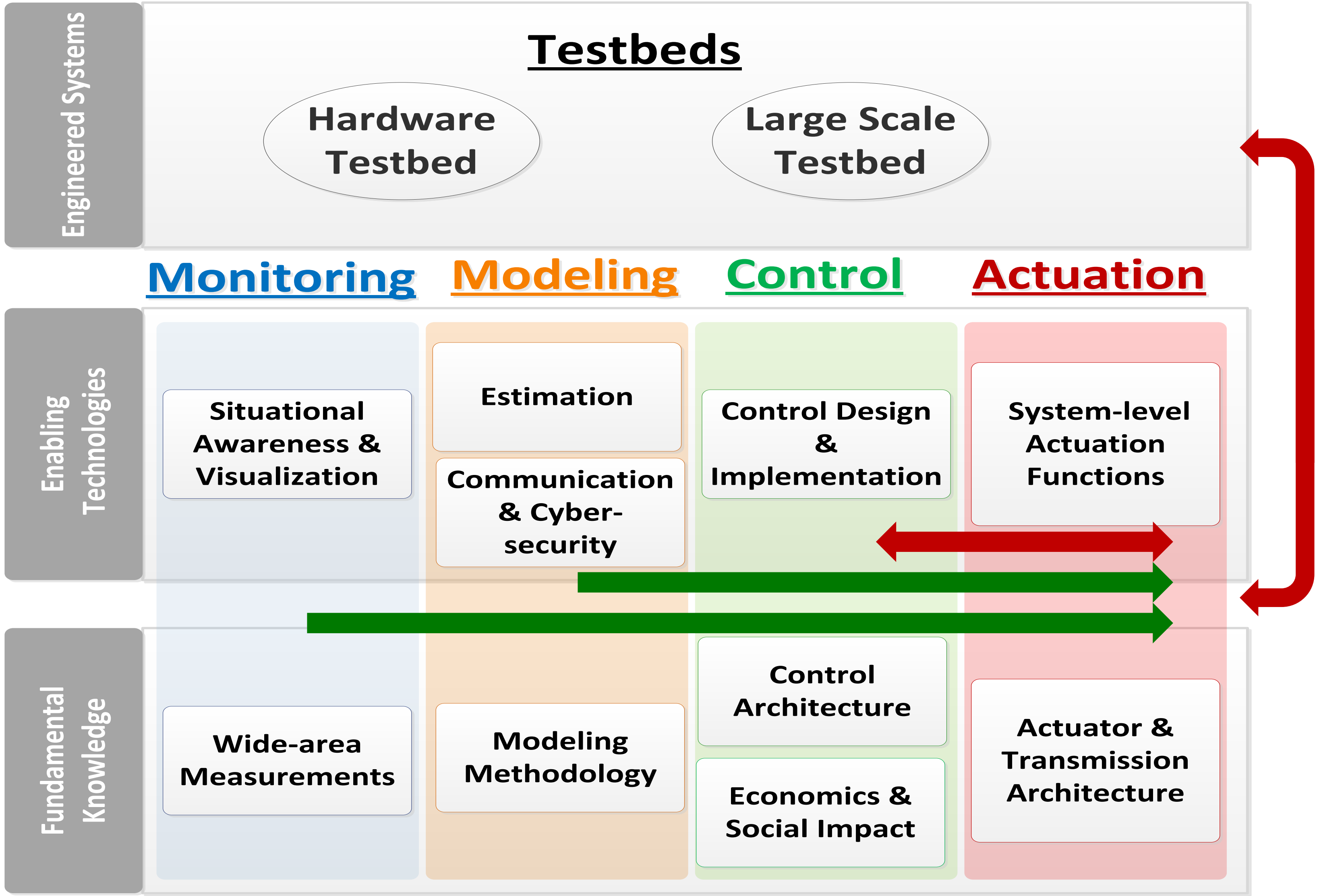
Actuation Thrust Overview

Fred Wang (UTK), Thrust Leader
Jim Glass (EPB)
Bill Giewont (EPC & UTK)

NSF-DOE Site Visit
November 9, 2020
Virtual

THE UNIVERSITY OF TENNESSEE KNOXVILLE · Rensselaer · Northeastern · TUSKEGEE UNIVERSITY

Actuation in CURENT, Linkage, and Research Focus



Objective

- Actuation methodology and system architecture to enable wide-area control of transmission grid with high % of renewables
- Power electronics for grid or other system applications

Research Focus

- Actuation functions to exploit full capabilities of existing or future actuators
- Advanced actuators and flexible & controllable transmission architecture

Actuation Thrust Intellectual Merit and Broader Impact

Intellectual Merit

- New system-level actuation functions, transmission architecture, and actuator development
- Corresponding innovative modeling, design, and control methodology development

Broader Impact

- Help proliferation of renewable energy sources, and power electronics-based power systems, controllers and loads
- Impact not only future electric transmission grids, but also distribution grids, and other complex systems: microgrids, electrified transportation systems, and even manufacturing and IT systems. Some of our work already transferred to industry

CURENT

Actuation Thrust Contributors

Faculty

- Fred Wang, Leon Tolbert, Daniel Costinett, Kevin Bai, Helen Cui, Shiqi Ji, Lin Zhu, Yiwei Ma (*UTK*); Jian Sun (*RPI*)

Postdocs & Research Staff

- Jingxin Wang, Cheng Nie, Ruirui Chen, Robert Martin, He Yin, Bill Giewont

Industry & Other Sponsors/Partners

- ABB, Boeing, GE, Eaton, EPC Power, ORNL, Keysight, Southern Company, EPB, EPRI, NI, Green Energy Corp., TVA, NCSU Power America, NCSU, DOE AMO, ARPA-E, Powerex, Wolfspeed
- Pietro Caroli, Jing Xu, Sandeep Bala (ABB); Shengyi Liu, Eugene Solodovnik (Boeing); Rajib Datta (GE); Bill Giewont (EPC Power); Ben Ollis, Sonny Xue (ORNL); Bernhard Holzinger (Keysight); Jim Galss, Lilian Bruce (EPB); Bruce Rogers, Jane Shi (EPRI); Peter Gregory (GEC); Isaac Panzarella, Ted Spencer (NCSU); Clifton Black (Southern Company)

Actuation Thrust Roadmap and Key Milestones

	Generation I (Years 1-3)	Generation II (Years 4-6)	Generation III (Years 7-10)
System-level Actuation Functions	• Renewable energy sources, HVDC & FACTS for frequency and voltage control • Multi-terminal VSC HVDC grid for off-shore wind farms	• Renewable energy sources, HVDC, FACTS for grid support (e.g. oscillation damping) • Multifunctional power flow controller (stability, energy storage)	• System-level actuation functions across wide area and time scales for RES, HVDC & FACTS, energy storage, and loads considering operating modes (normal, unbalance, abnormal)
Actuator and Transmission Architecture	• Renewable converters as compensators • DC grid component technology	• UHV DC trunk lines and regional multi-terminal DC grids • DC grid system technology (protection, fault location and isolation, control)	• Power electronics converter-rich system architecture (related modeling, analysis, control, and design, e.g. stability) • Advanced power electronics actuators for DC grid, RES and other sources/controllable loads

Year 9 Tasks and Connections to Testbeds & Other Thrusts

Year 9 Tasks

- **System-level actuation functions**
  - Dynamic model of power electronics interfaced loads **(Testbeds, Modeling, Control)**
- **System architecture**
  - Stability analysis and design of power electronics based power systems **(Testbeds, Modeling, Control)**
- **Advanced actuators**
  - Inverter design considering grid conditions
  - SiC impact on grid power electronics

  (Testbeds, Modeling, Control)

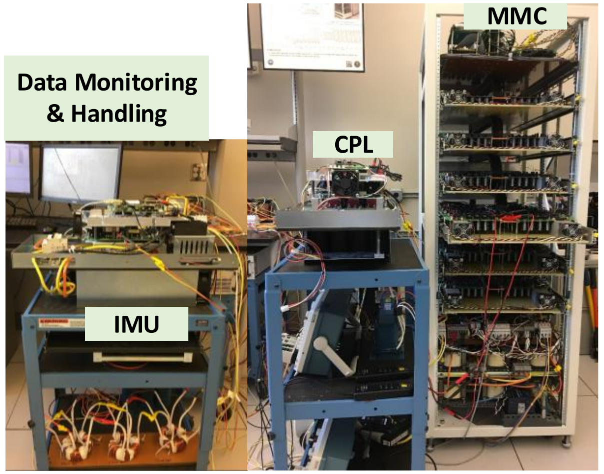
Associated and Focused Research Projects

- GaN and SiC based converter and protection
- Sensor technology for WBG
- WBG traineeship
- Flexible microgrid & controller **(Monitoring, Testbeds)**
- SiC PCS for asynchronous microgrid flexible CHP
- Stability for large-scale power electronics grid

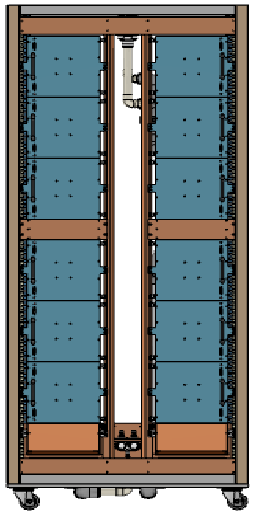
Year 9 Achievement Summary

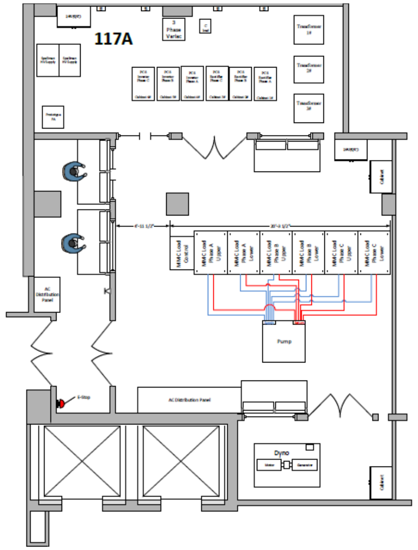
- Developed a dynamic model for power electronics interfaced charging station suitable for power system transient analysis
- Implemented a DC impedance tester and incorporated stability and transient performance requirements into power electronics-rich system design
- Developed models and methods in considering transient behaviors in SiC based actuator benchmark study and inverter design
- Close to completing an operational flexible microgrid and world’s first 10 kV SiC based 13.8 kV PCS converter for asynchronous microgrid through associated projects; Made progress on tech transfer (six awarded/filed patents)
- Made significant progress on facility upgrading for sustainability

DC impedance measurement unit



MW MV tester construction & lab renovation underway



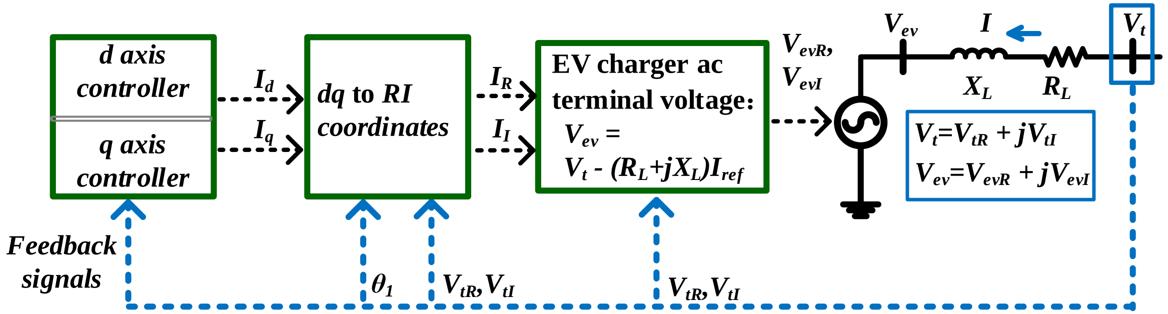


CURENT

Dynamic Model of Power Electronics Interfaced Load

- **Objective**: Develop generic power electronics (PE) interfaced load model for transient stability (TS) studies in large-scale power network which emphasizes electromechanical transients (EMT) and oscillations
- Fast electric vehicle (EV) charger generic model accurately reflects relatively slow dynamics of PE devices, and can be flexibly adapted to other types of PE interfaced loads.

Modeling principle of fast EV charger unit generic model:

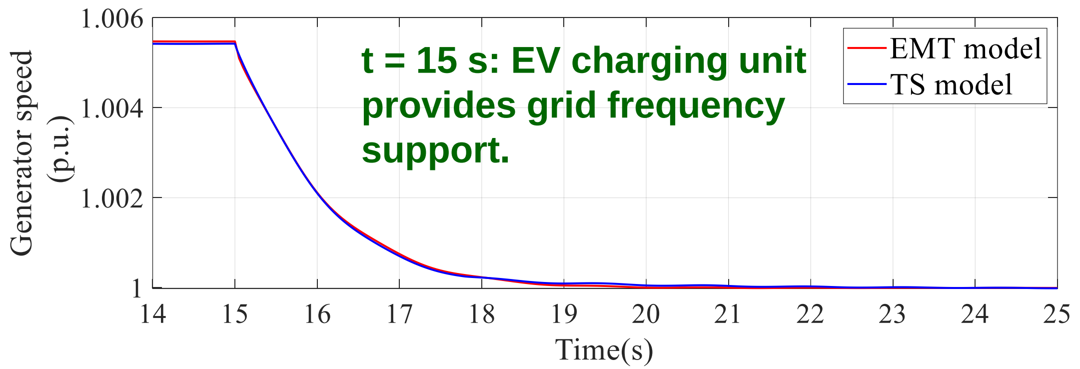


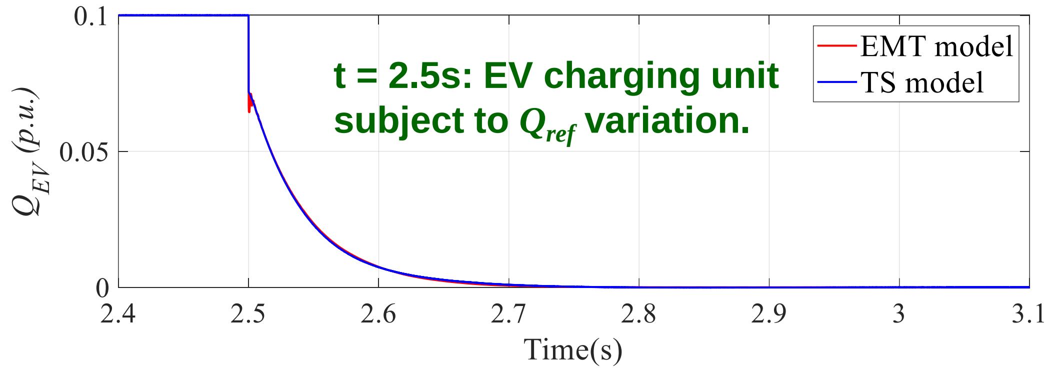
d axis controller:
- ✓ Constant DC link voltage control
- ✓ Grid frequency support control

q axis controller:
- ✓ Power factor control
- ✓ Reactive power control
- ✓ *q* axis current control

Model validation example:

- Generic TS model compare with EMT benchmark model:

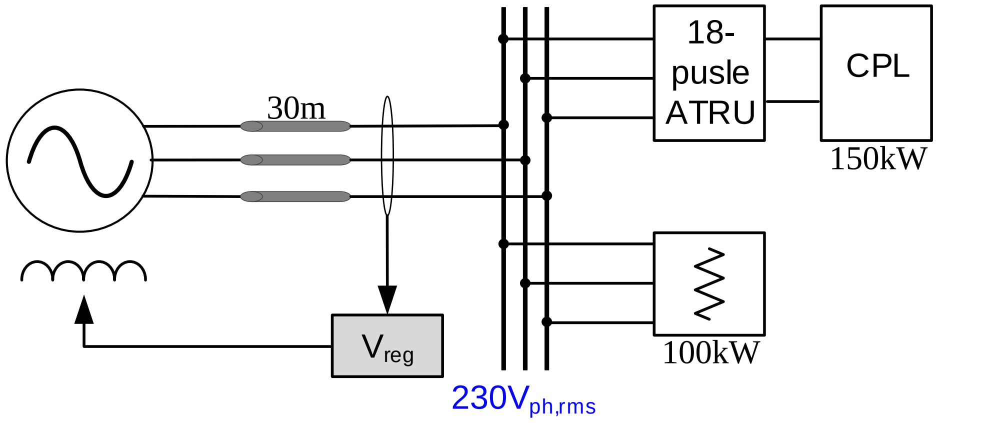


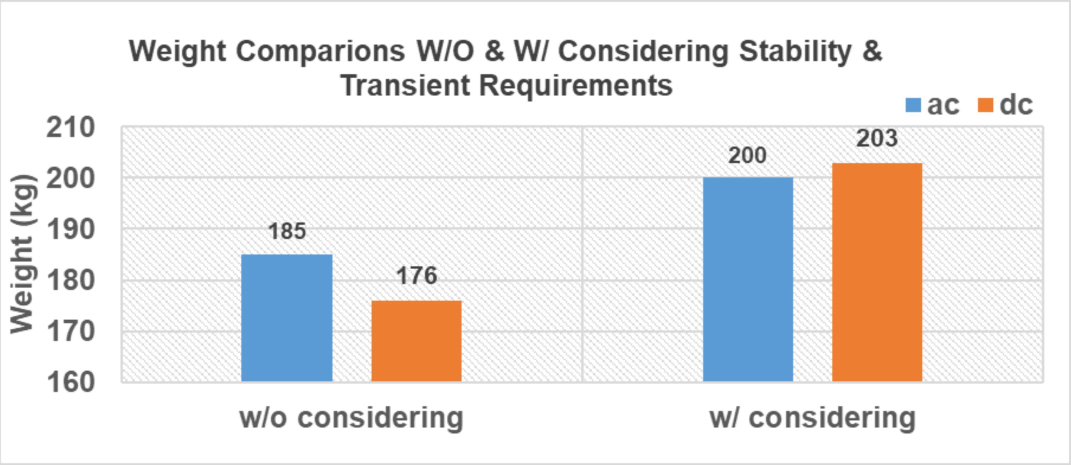


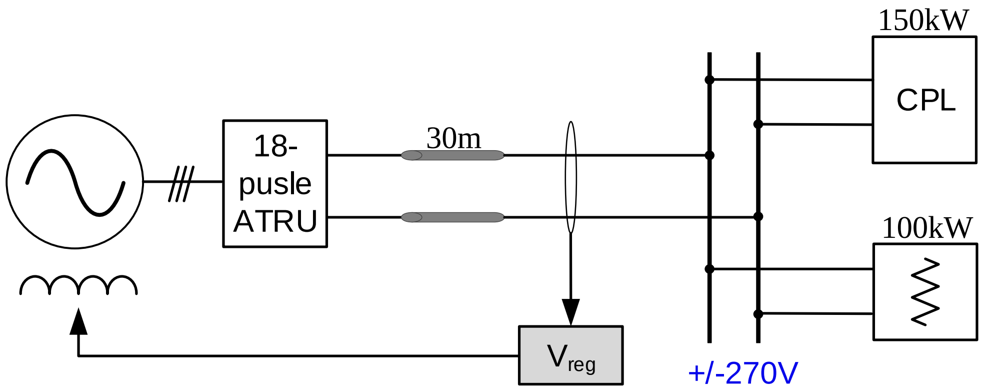
CURENT

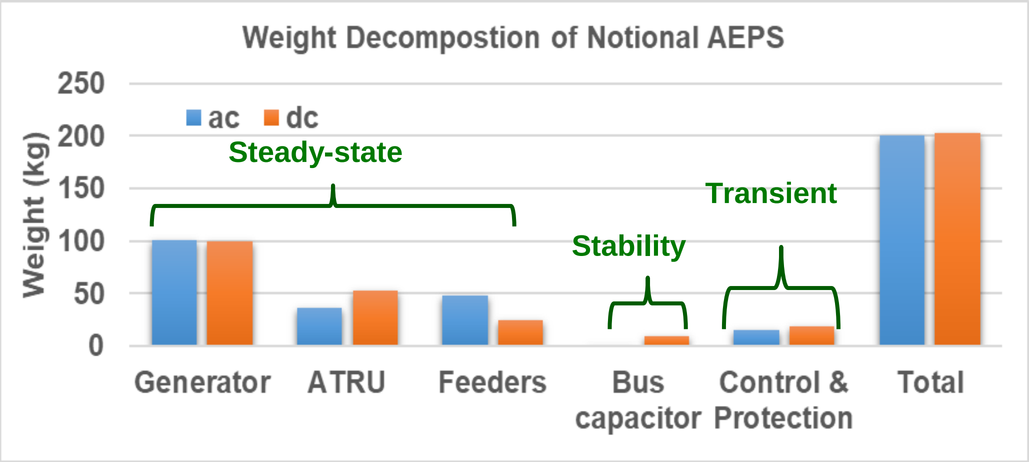
Stability Analysis and Design of Power Electronics Based Power Systems

- **Objective:** Stability design of power electronics power systems (PEPS), converter design approach for stable grid integration
- Developed an easy-to-use DC impedance measurement unit using an existing 2L-VSC in the system; analyzed the impact of small-signal stability and large-signal stability on power system design, in addition to system steady-state requirements



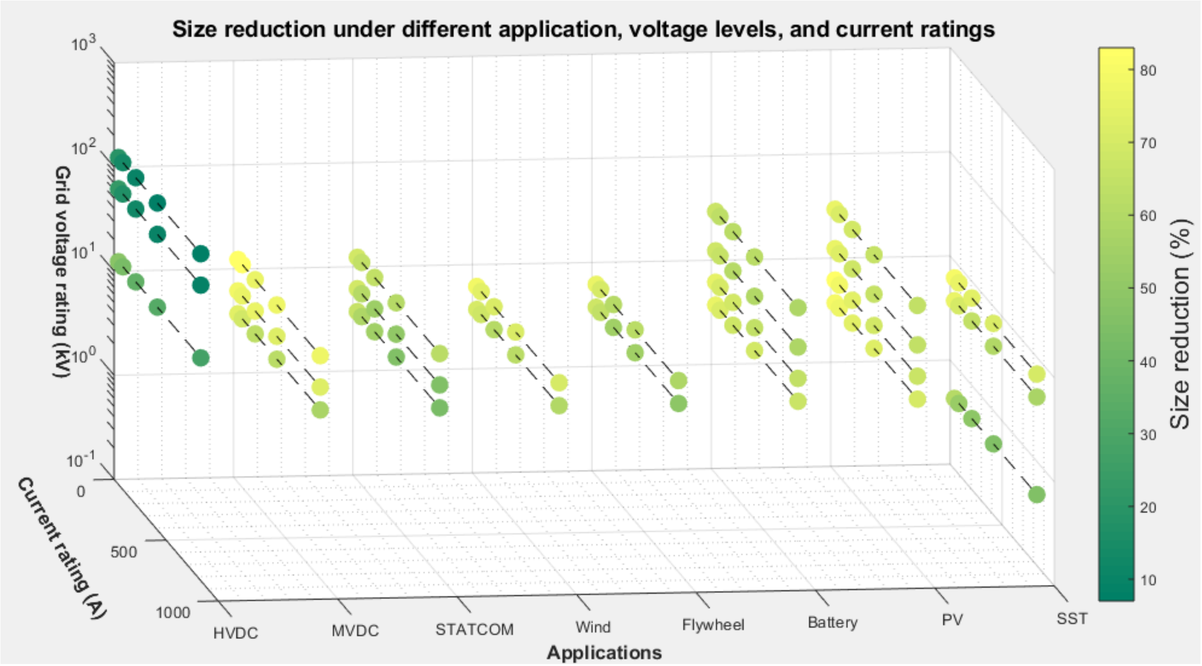




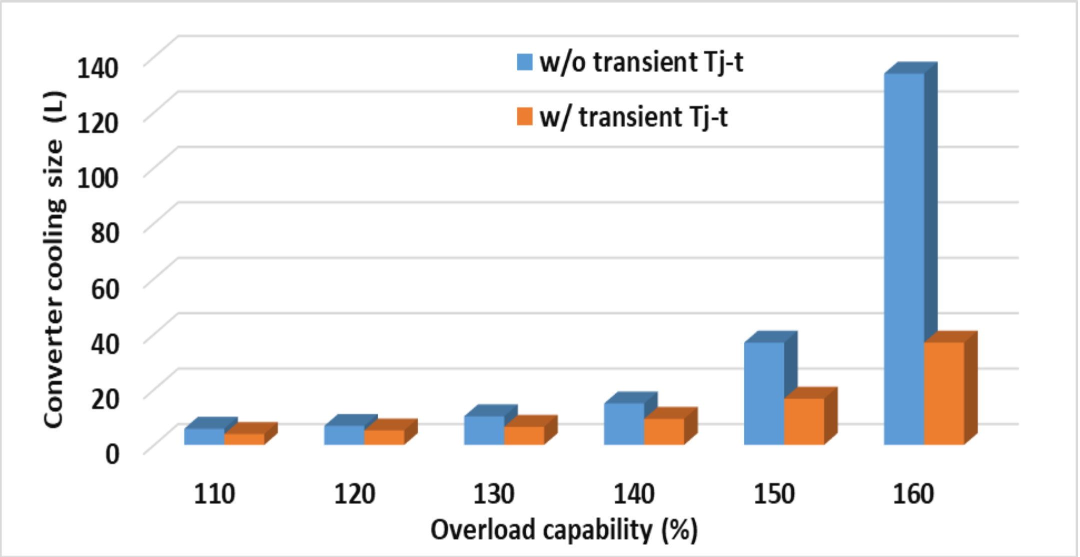


Impact of SiC and Grid Conditions on Power Electronics Converters

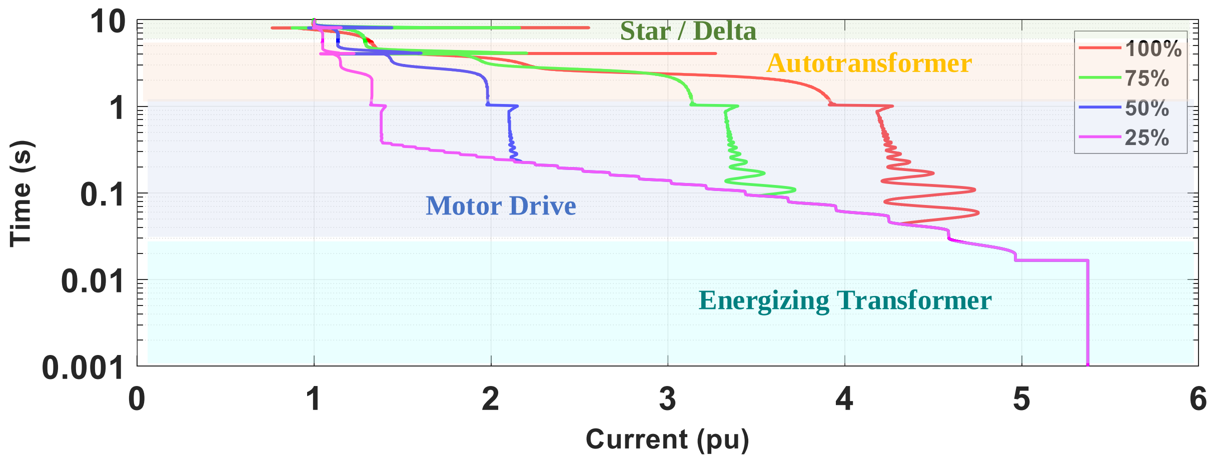
- **Objective**: Benchmark SiC and understand transients' impact on T&D and source converters
- Developed design comparison methodology between Si and SiC based converters
- Benchmarked across applications & topologies under different voltage and power levels
- Converter design considering transients



Benchmark results of SiC vs. Si



Converter cooling size under 1s overload conditions



Time-current curves for equipment energization

CURENT

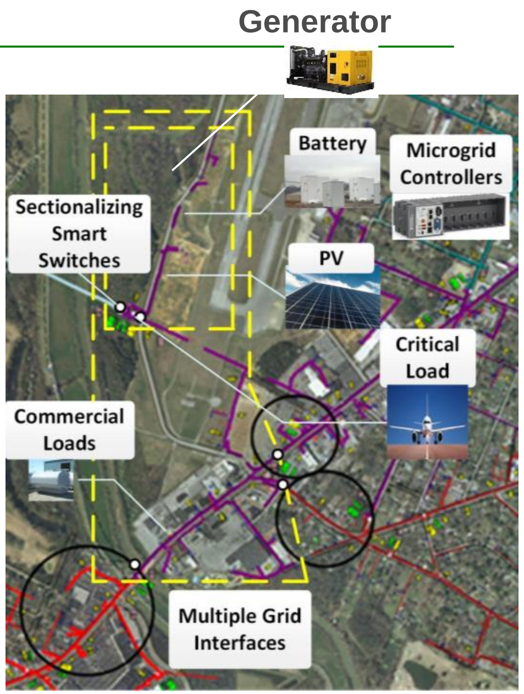
Smart and Flexible Microgrid with Low-cost Open Source Controller

Previous years: Focused on flexible microgrid and controller design

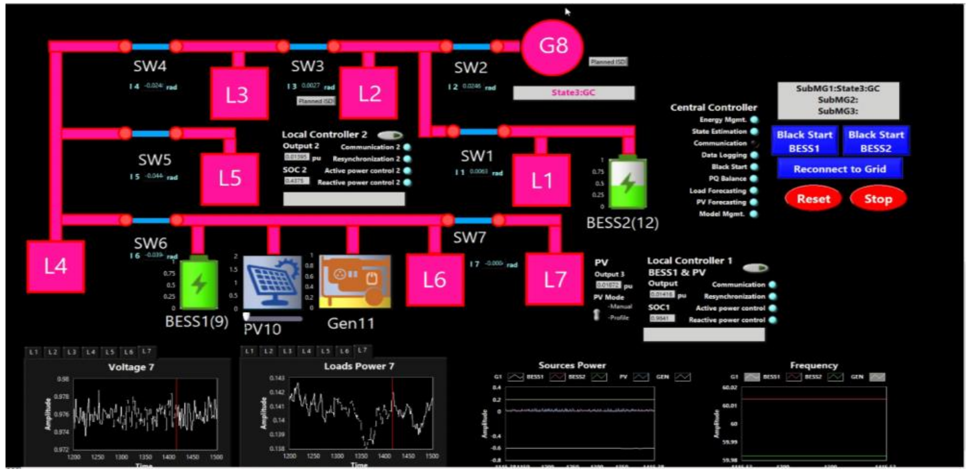
- Designed/implemented a community-based microgrid at EPB with 99% improvement on reliability and 34.5% improvement on energy use efficiency
- Developed a design guideline for flexible microgrid with dynamic boundary
- Developed a microgrid controller capable of realizing dynamic boundary
- Tested controller in Opal-RT Hardware-In-the-Loop (HIL) setup and CURENT HTB.
- Released open source software of the basic version

Year 9: Focusing on an operational flexible microgrid

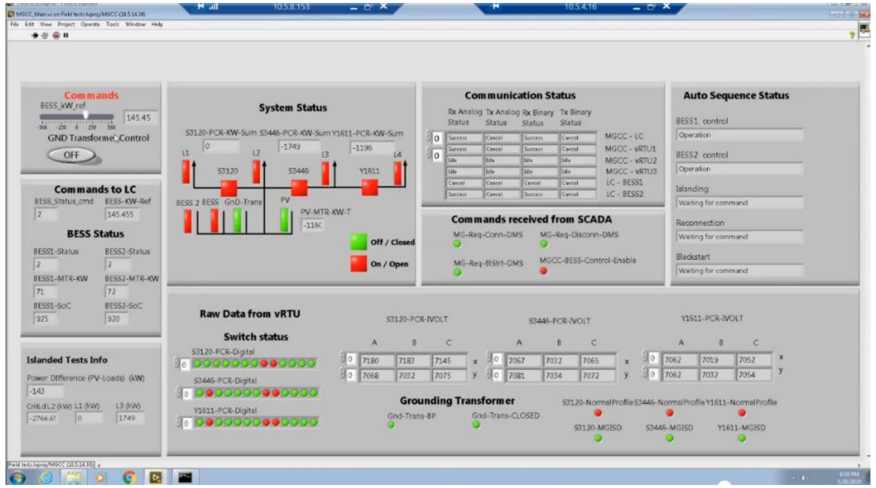
- Enhanced design guideline & controller microgrids with dynamic boundary considering sources in multiple locations
- Tested controller in Opal-RT HIL setup and CURENT HTB. Preparing for final field test and operational flexible microgrid commissioning



Field Test Location



Visualization for controller test on CURENT HTB



Field test via Webex on May 28, 2020

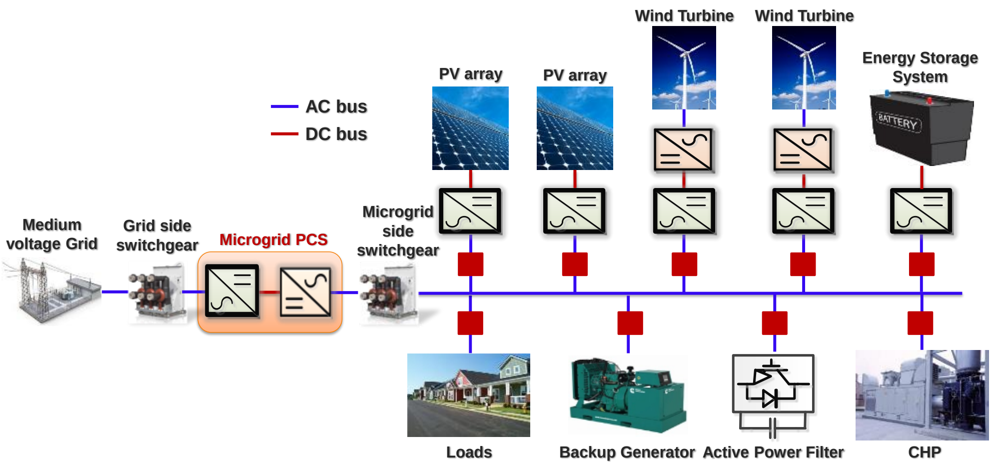
SiC-based Multifunctional Power Conditioning System (PCS) for Asynchronous Microgrid

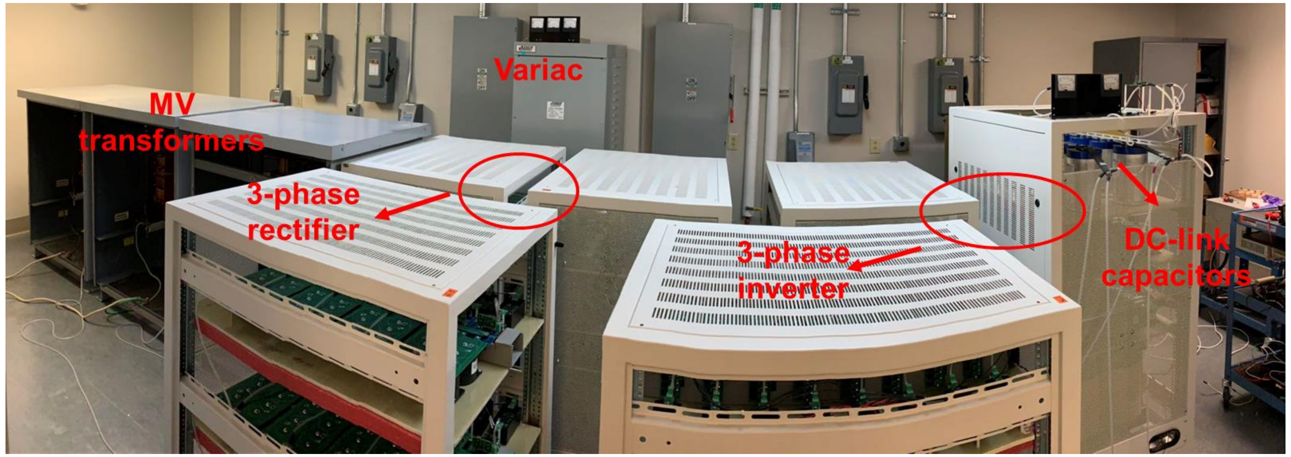
Previous years

- A 10 kV SiC MOSFET based, 100 kVA/13.8 kV three-phase four-wire PCS DC/AC converter built and tested at nominal AC output with >10 kHz equivalent switching frequency.
- Grid functions of the PCS, including ride through, active power filter, unbalance load support, grid stabilizer, etc., validated on HTB.

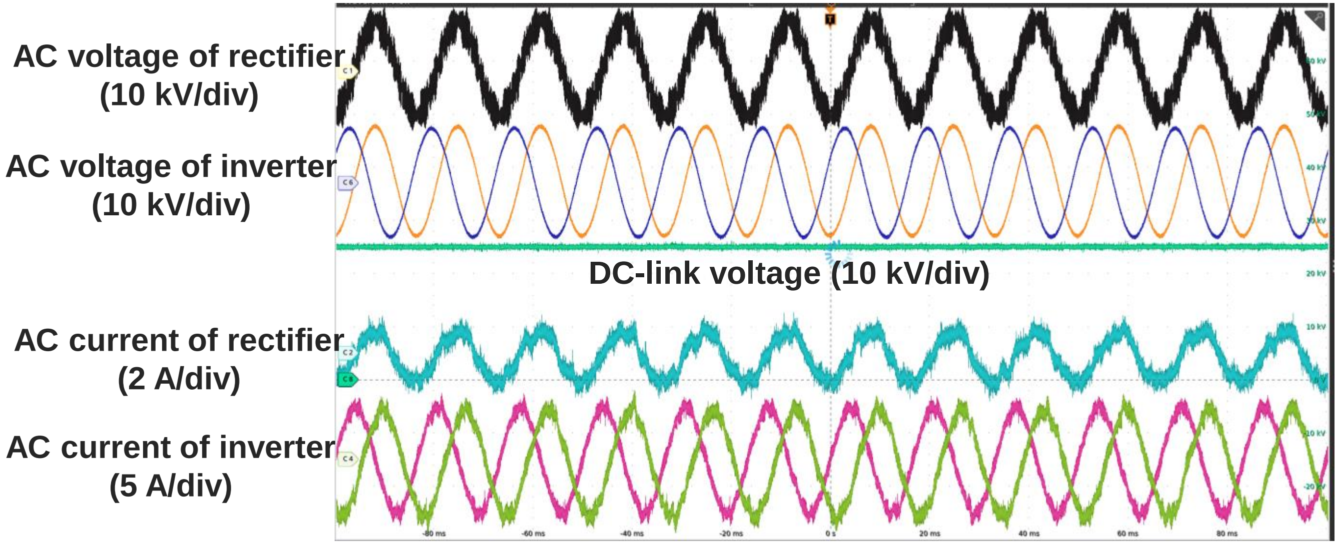
Year 9

- The back-to-back connected PCS built and tested at full voltage (25 kV DC, 13.8 kV AC).
- Grid supporting functions (unbalanced load support, etc.) realized on the actual PCS at rated voltage.





100 kVA/13.8 kV back-to-back connected PCS converter



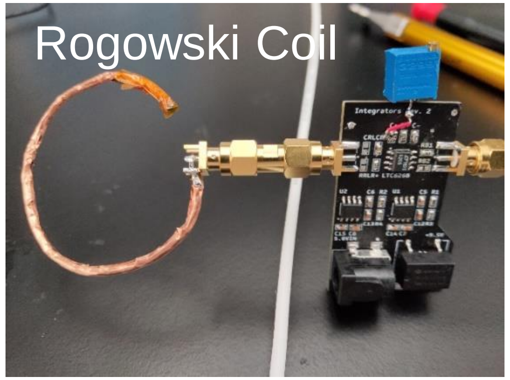
Back-to-back PCS tested at 25 kV DC, 13.8 kV AC

Other Focused Research, Fellowship, and Associated Projects

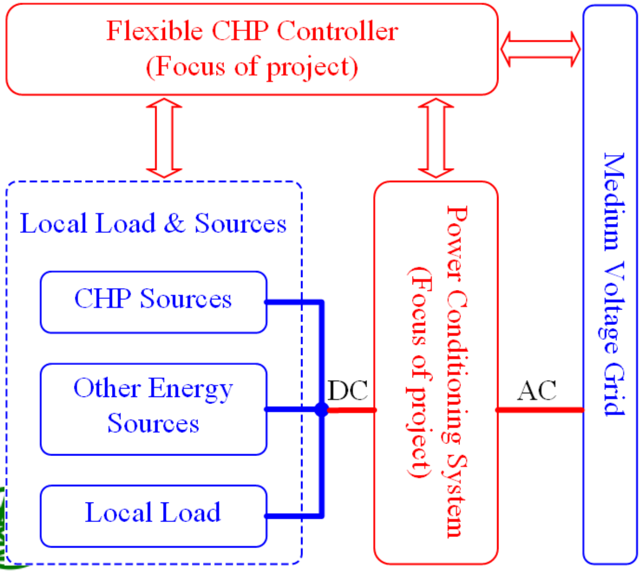
1 kV, 500A SiC based SSCB

GaN SSCB

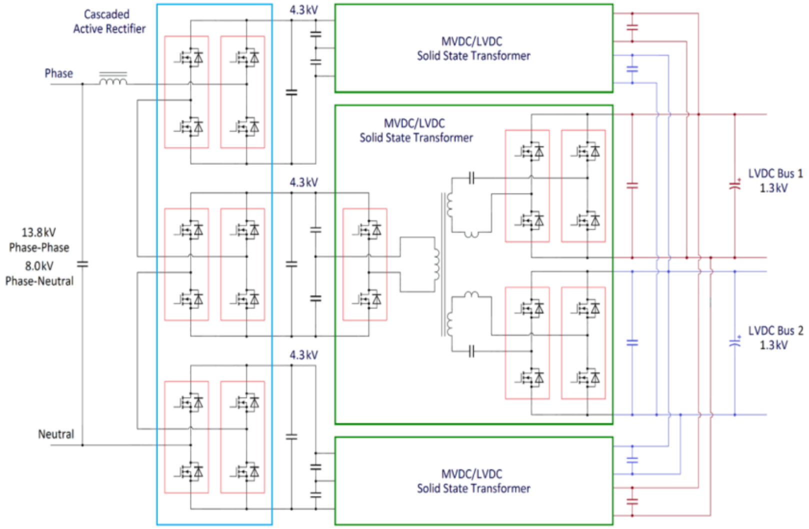
Current sensor for WBG devices



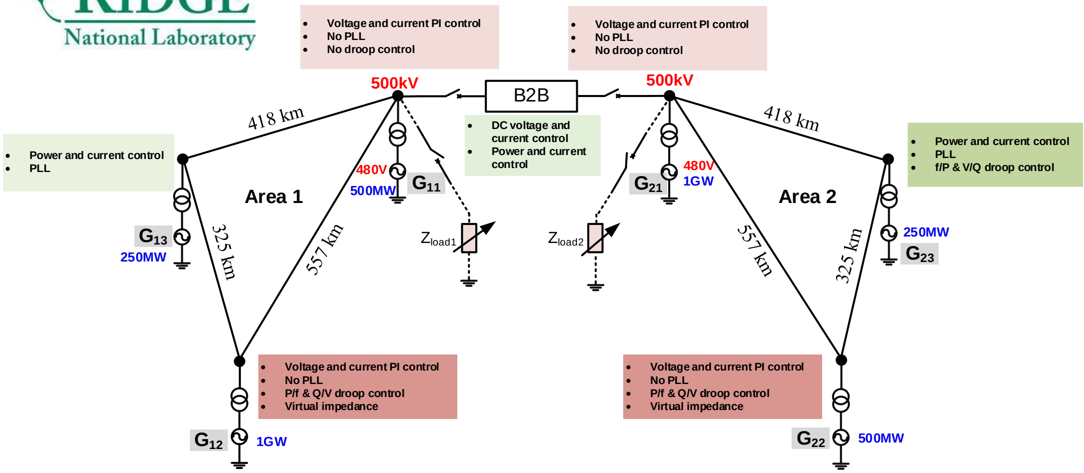
Flexible CHP



MW fast EV charger



Power electronics grid stability



Actuation Thrust Plan for Year 10

	Year 10
System-level Actuation Functions	• Power electronics interfaced loads and energy storage • Actuation functions of microgrids/distribution grids
Transmission Architecture	• Power electronics-rich AC and DC grid design and analysis
Advanced Actuators	• High-voltage SiC converter design technology • Converter design considering transient conditions

Actuation Thrust Research Directions beyond Year 10

1. **Actuation functions:** converter based control and grid/system support
2. **System architecture:** Power electronics based/enabled grid/system
   - Design, modeling, control and protection of PE system
   - DC grid, microgrid, autonomous system, charging station, etc.
3. **Advanced actuators:** Power electronics converters (source, load, storage, PCS) for grid/system applications
   - WBG based power converters
   - Grid-compliant power converters
4. **Other focused/fellowship research**

CURENT

Acknowledgements

This work was supported primarily by the ERC Program of the National Science Foundation and DOE under NSF Award Number EEC-1041877 and the CURENT Industry Partnership Program.

Other US government and industrial sponsors of CURENT research are also gratefully acknowledged.