CURENT

2022-2023 Research Projects Overview

2023 CURENT Industry Conference

April 18-19, 2023

Knoxville, TN

Fangxing “Fran” Li

- **James McConnell Professor, CURENT Campus Director, LTB Lead**
- **Research Interests: resilience, demand response, cybersecurity, electricity markets, machine learning for power.**
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2022-23 Research Projects/Highlights

1. CURENT Large-scale testbed (LTB) (**NSF, DOE**)
2. Near-Term Resilience and Reliability (**DOE/ORNL**)
3. Production Cost Modeling to Assess the Benefit of Geothermal Deployment (**DOE/ORNL**)
4. Model-Free Adaptive Control (MFAC) for Autonomous and Resilient Microgrids (**DOD ESTCP**)
5. WISP: Watching grid Infrastructure Stealthily through Proxies (**DOE/Raytheon**)
6. Cyber-Physical Dynamic System (CPDS) Modeling for Frequency Regulation and AGC Services of Distributed Energy Storage Resources(**NREL**)
7. Intelligent Control of Refrigerating Load for Peak Reduction (**State of TN RevV, GridFruit**)
8. Reinforcement Learning for Smart Grid Transactive Energy (**ORNL**)
9. Machine learning for identifying protective relay violations (**ORNL**)
10. Resilient distribution systems (RDS) enabled by responsive resident building loads (**ORNL, EPRI**)
11. Adaptive dynamic coordination of damping controllers through deep reinforcement and transfer learning (**NSF**, PI: H. Pulgar)

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CURENT Large-scale Testbed (LTB)

Project Objectives

- To develop a closed-loop platform that includes both dynamic and dispatch/market simulation
- To enable dispatch-dynamic interfaced co-simulation
- Co-simulation with HTB

Recent Achievements

- Documentation of ANDES, AGVIS, and DiME.
- Created GitHub page for CURENT LTB
- Created YouTube channel for CURENT LTB
- Developed initial version of AMS

Hybrid symbolic-numeric power system modeling and simulation

ANDES
Dynamic Modeling and Simulation

AGVis
Energy System Visualization

Geographical visualization for energy system

Dynamic information interfaced dispatch modeling and simulation (ongoing effort)

AMS
Dispatch Modeling and Simulation

DiME
Multi-terminal Data Streaming

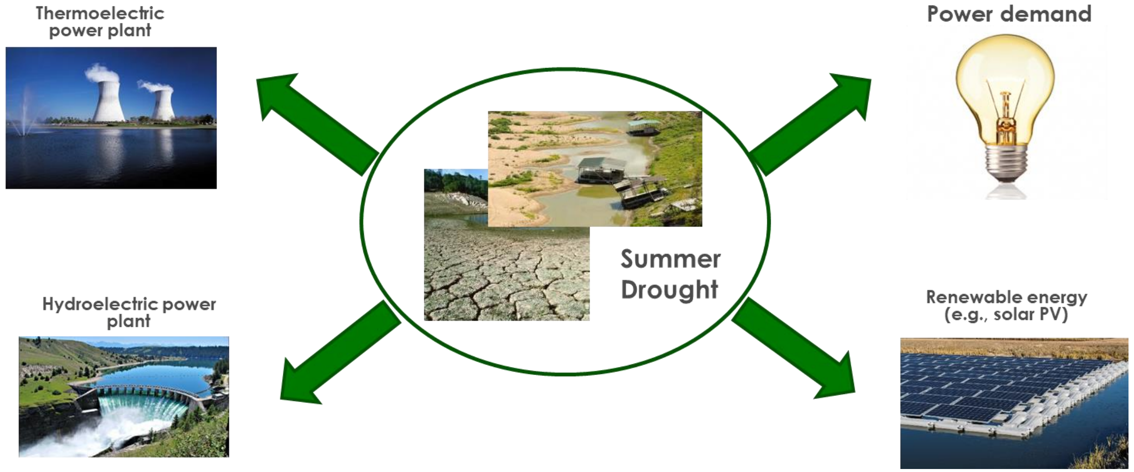
Data messaging between multiple power system components

LTB Structure

Near-Term Reliability and Resilience (NTRR)

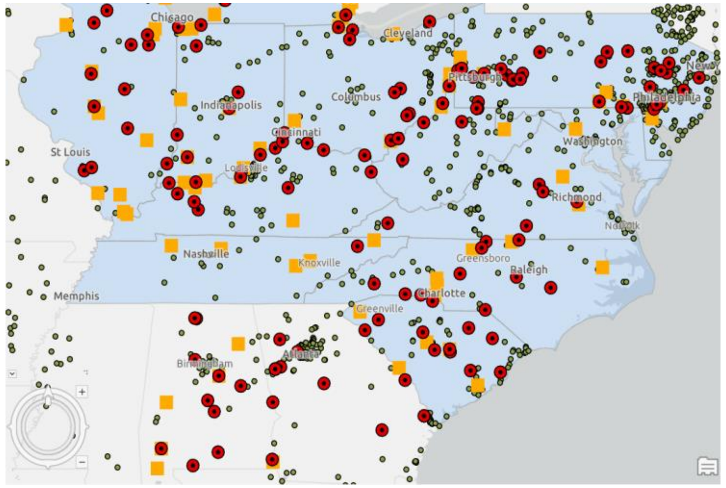
Project Objectives

- To model extreme weather impact on power generation, transmission, and load
- To study the resilience under extreme weather in the eastern US grid of extended PJM area (i.e., PJM + SERC).



Recent Achievements

- Developed summer drought impact model for at-risk generators (once-through and recirculating cooling systems)
- Developed summer drought impact model for transmission FOR (forced outage rate) and load
- Completed chronological simulation studies on the eastern US grid using different scenarios of climate changes



Open cooling thermal power plants

Recirculating cooling thermal power plants

USGS gaging stations

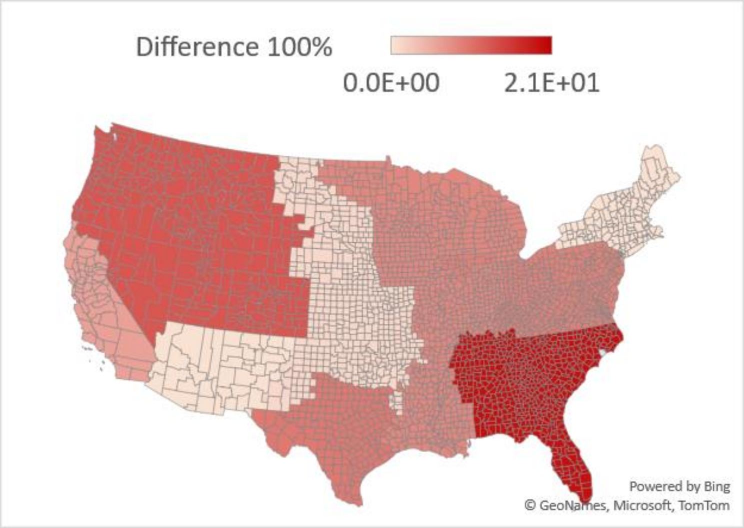
Production Cost Modeling to Assess the Benefit of Geothermal Deployment

Project Objectives

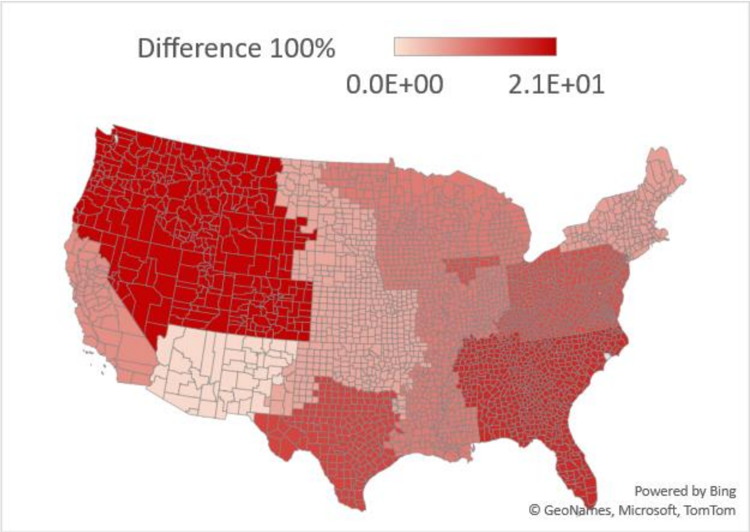
- To study the impacts of a national deployment of geothermal heat pump (GHP) systems on the U.S. electric power system in terms of energy consumption, carbon emissions, and operational resilience.

Recent Achievements

- Large-scale GHP retrofit can reduce the energy and capacity needs of the electric power system by up to 11% and 13.2%, respectively.
- Massive GHP retrofit may cut the transmission expansion need by about one-third in the scenario of a decarbonized power system.
- The GHP adoption can reduce the peak load for most zones in the USA in both summer and winter.



Peak Load Reduction of BaseGHP case wr.t. Basecase



Peak Load Reduction of DecarbGHP case w.r.t. Decarbonized case

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Model-Free Adaptive Control (MFAC) for Autonomous and Resilient Microgrids

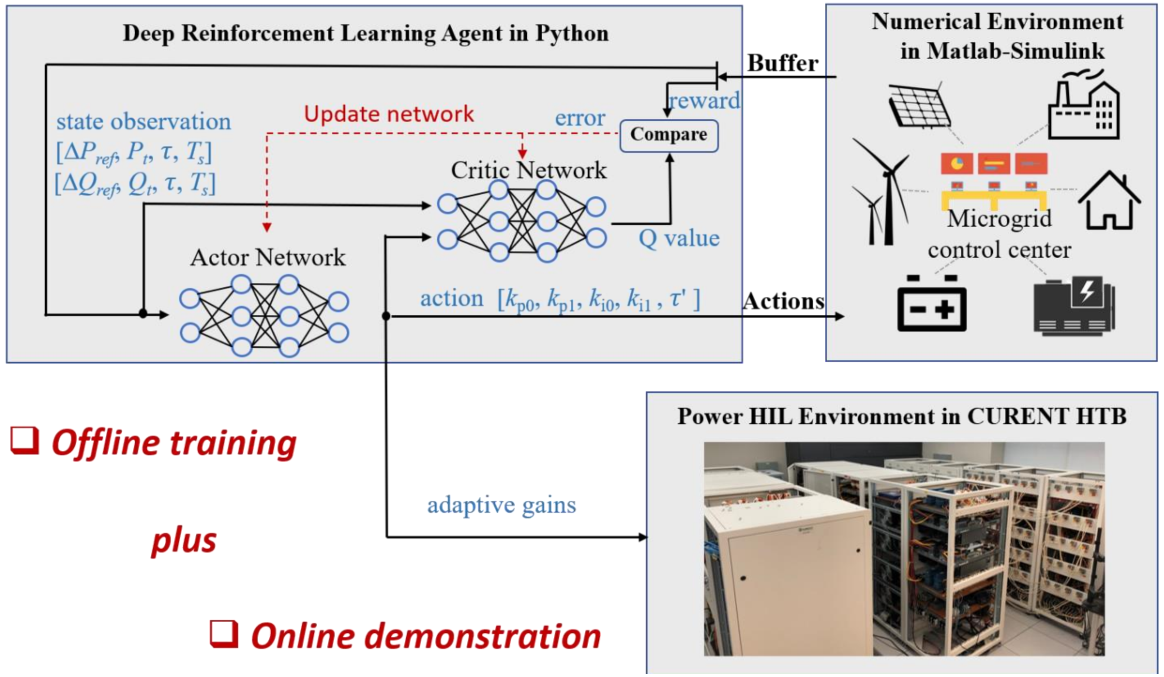
ESTCP

Project Objectives

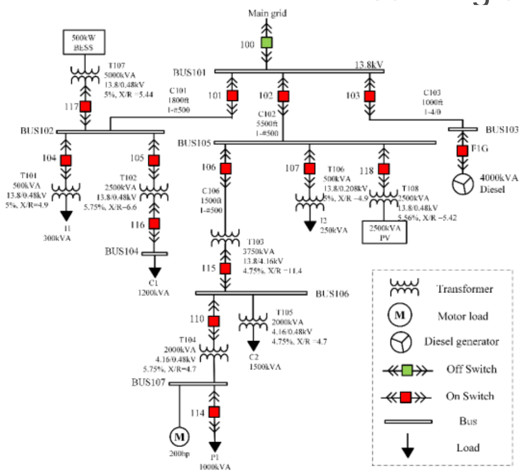
- To employ deep learning based algorithms to provide autonomous grid-following and grid-forming controls for microgrids
- To achieve minimum human involvement
- To achieve higher grid resilience

Recent Achievements

- Developed inverter PQ control for trajectory tracking using deep reinforcement learning
- Validated the PQ control in CURENT LTB
- Developed V-f control under insufficient resource capacity
- Developed virtual inertia scheduling for microgrid (ongoing effort)



Model-free adaptive PQ control based on physics-informed reinforcement learning and power HIL experiment



Modified Banshee microgrid in Simulink and CURENT HTB

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Yilu Liu

- **UT/ORNL Governor’s Chair, CURENT Deputy Director**
- **Research Interests: power grid monitoring and large system dynamic simulations, AI applications, GIC/EMP impact**
- **Liu@utk.edu 865 266 3597, powerit.utk.edu, fnetpublic.utk.edu**

2022-2023 Research Projects

1. Regional inertia estimation, EI system inertia trending study (Dominion)
2. Location analysis to initiate and damp forced oscillations (TVA)
3. Forced oscillation source location and type classification (TVA)
4. Grid Strength and voltage impact of the large-scale offshore wind (Dominion)
5. Hybrid HVDC systems (Hitachi)
6. HIL for microgrid modeling (SOCO)
7. Adaptive oscillation damping control and field test (EPRI, NYPA, TERNA, DOE)
8. EMP susceptibility characterization of generation stations (ORNL, TVA)
9. Secure timing system using pulsar signal (NSF)
10. Inertia estimation in real time (NREL, HELCO, KIUC)
11. Pump storage operation signature based inertia validation (ORNL, DOE WPTO, Dominion, PG&E)
12. Develop low cost syn-wave monitors for PV systems (ORNL, DOE, DiGiCollect).
13. OEDI Distribution state estimation, VW control, and transient data generation (ORNL, DOE SETO)
14. Virtual Operator Assistance – AI based transient stability prediction tool (ORNL, DOE AGM)
15. FNET/GridEye data transmission, visualization, and real time applications (NERC, DOE AGM)
16. Near Term Relibility and Resilience (ORNL, DOE)
17. Landfill site microgrid development feasibility study (EPB, KUB)
18. Forced oscillation source location tool (EPRI)
19. Real time grid frequency prediction (Apple)

R&D 100 AWARDS

FNET/GridEye is our 4th R&D100 Award (2022)

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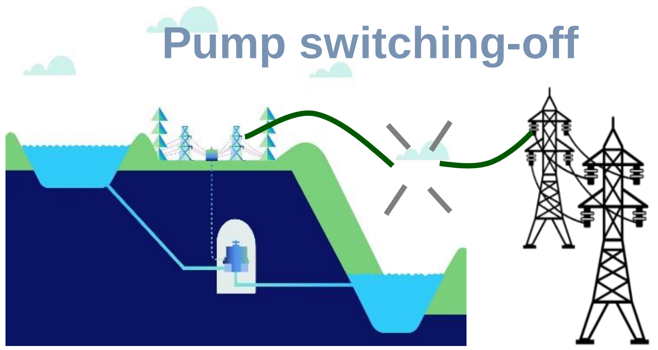
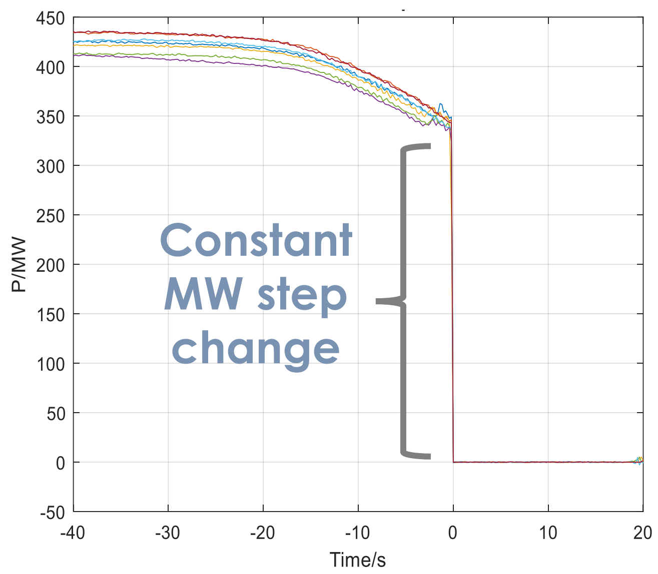
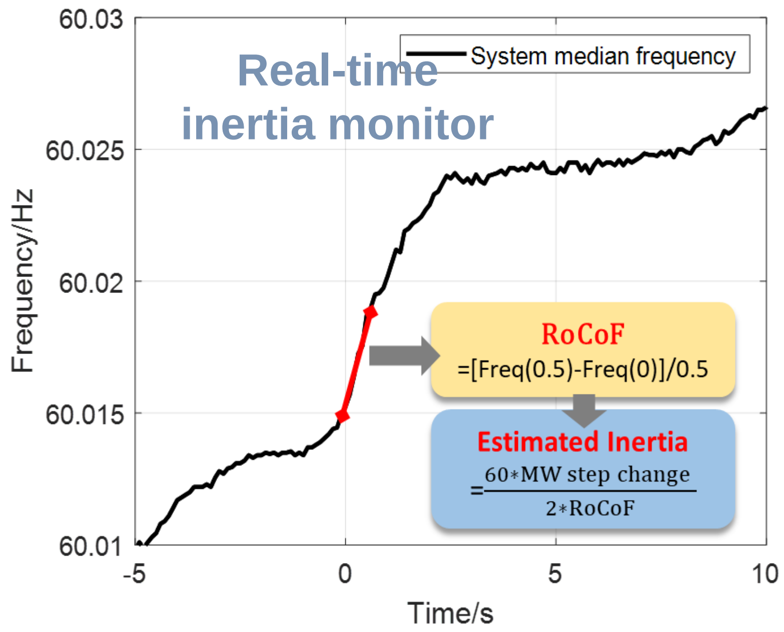
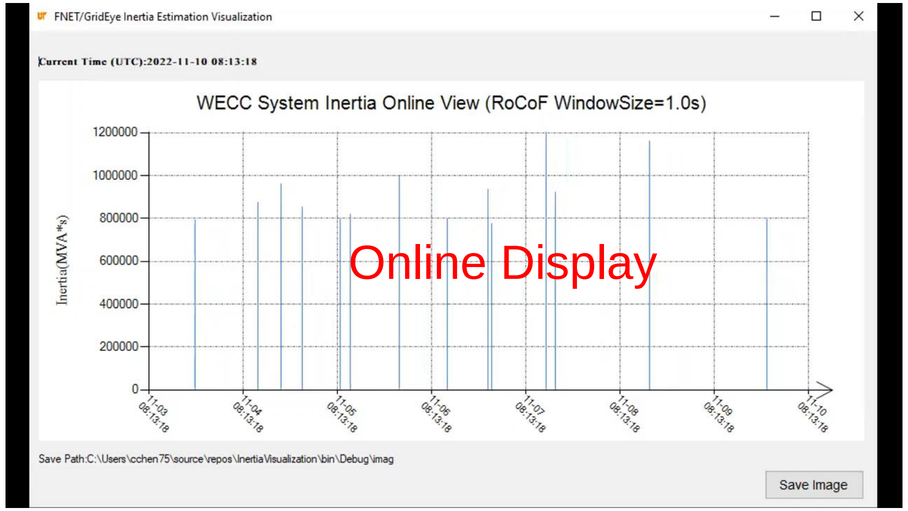
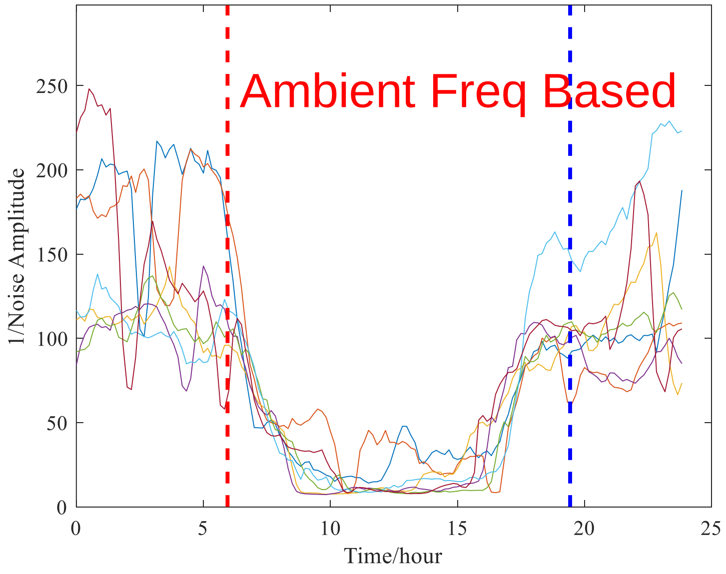
Inertia Monitoring – Regional and Whole System

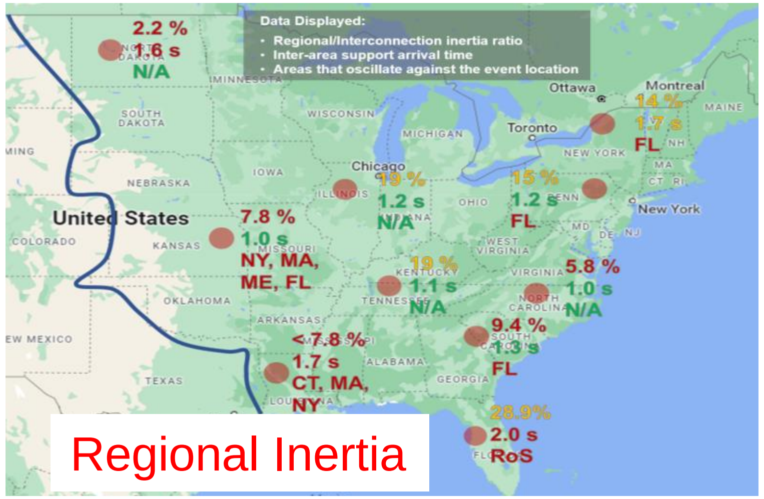




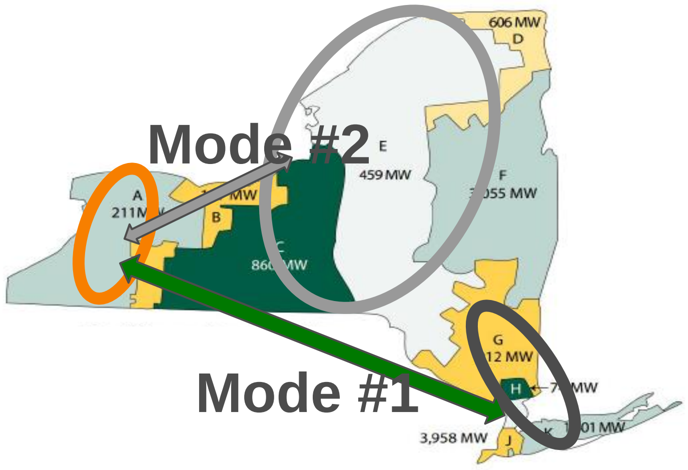


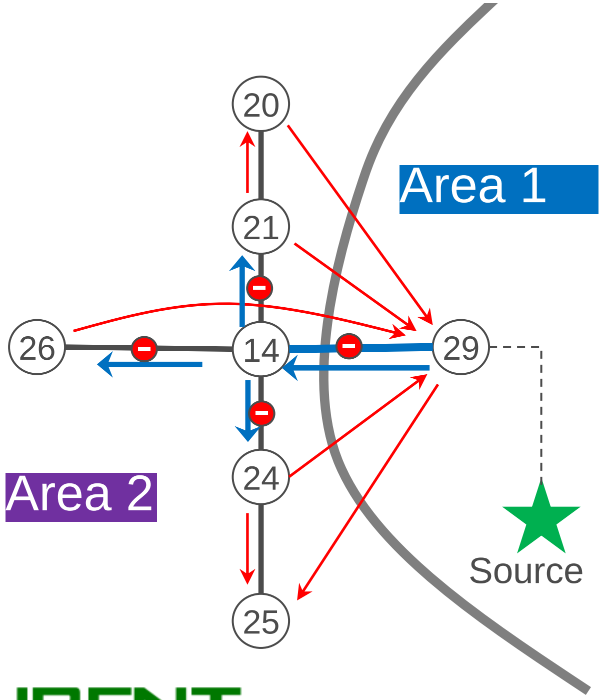


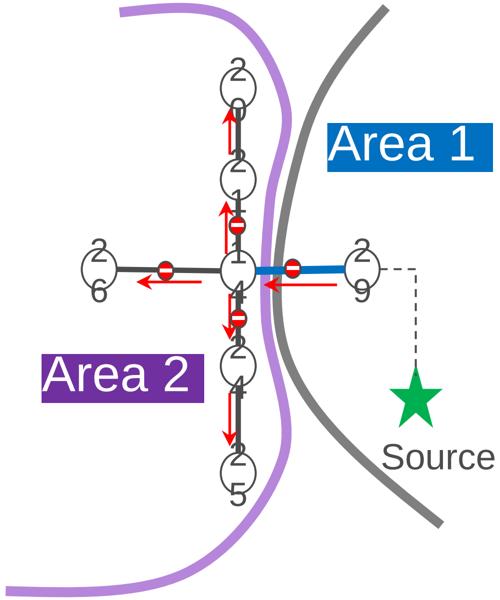


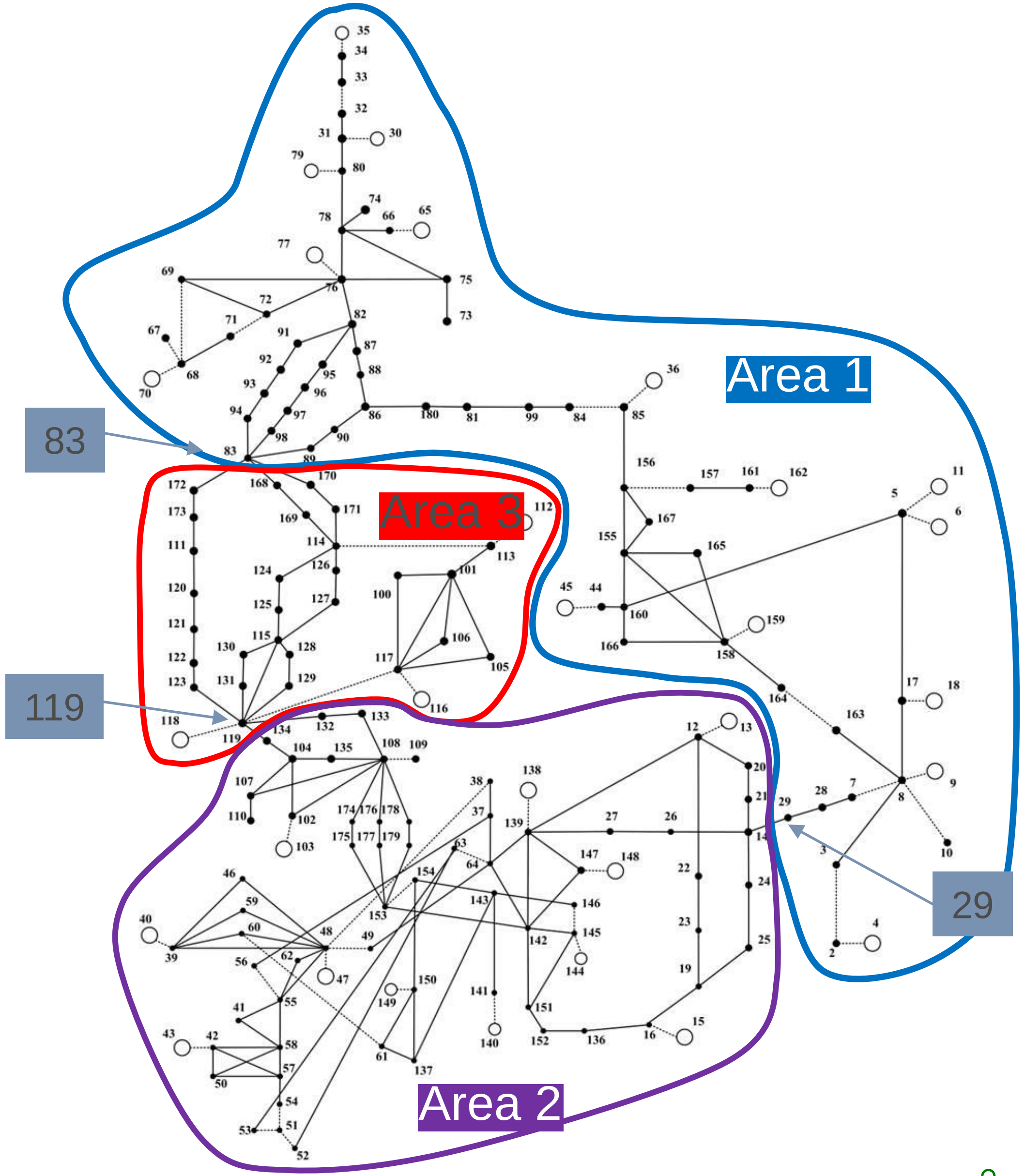


Damping Control & Forced Oscillation Location By Region



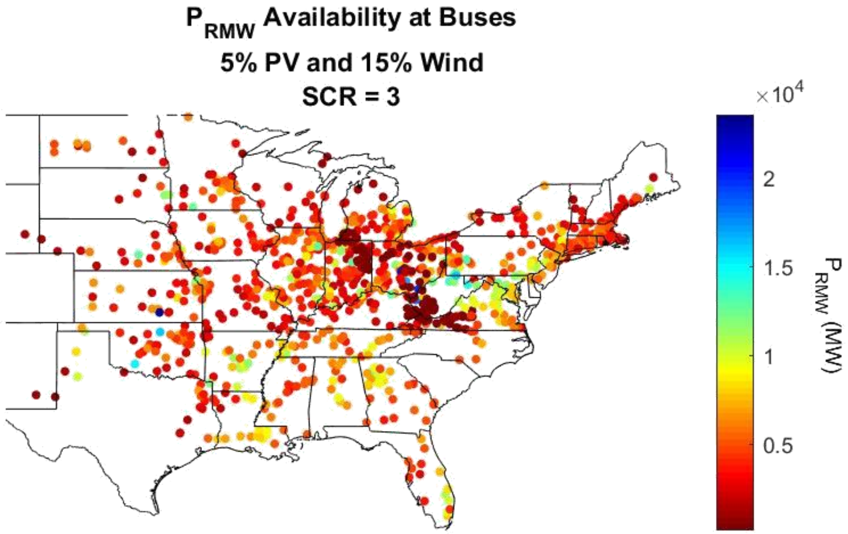


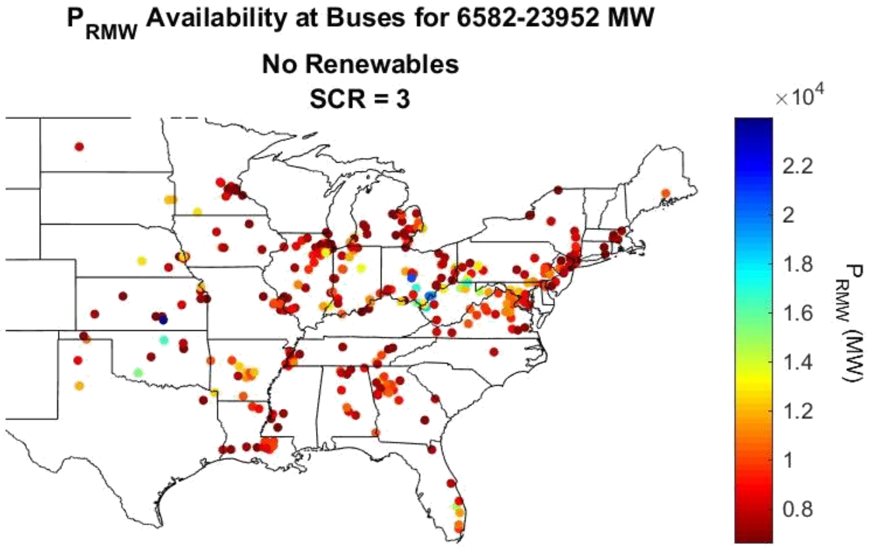


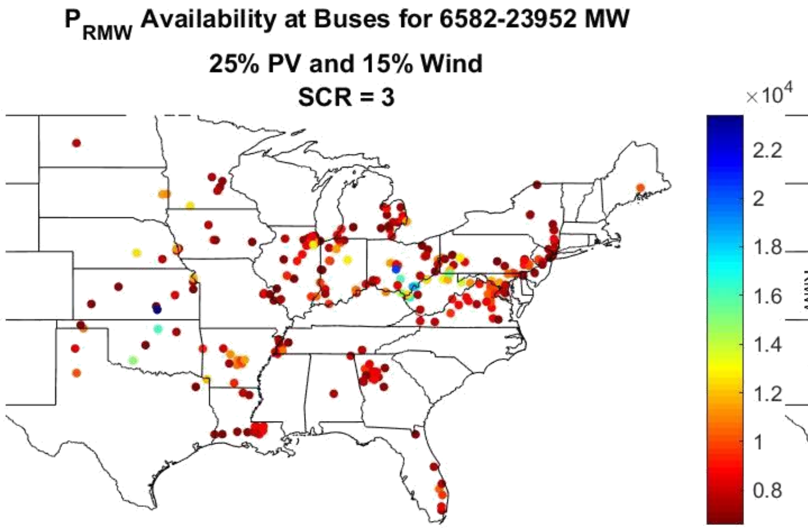


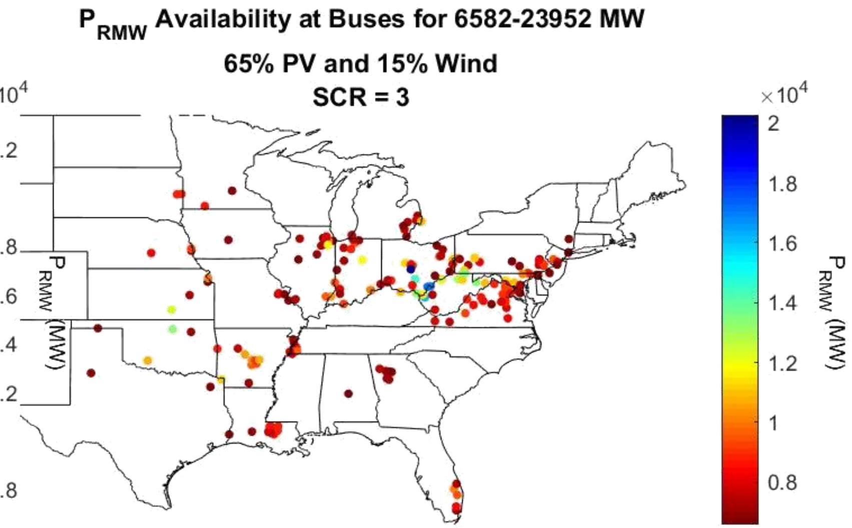
Renewable Hosting Capacity Based on Grid Strength Limit

- $SCR = \frac{SCMVA}{P_{RMW}} \Rightarrow P_{RMW} = \frac{SCMVA}{SCR}$
- Find maximum allowable IBR before SCR $\leq$ 3
- Graphed for buses 345 kV and above
- Results are preliminary for illustration purpose









New Grid Edge Monitor

- Continuous syn wave up to 36k samples/second
- Voltage and current waves
- 1440 pts/s phasor
- Harmonics, sag, flicker, SNR
- Ethernet and wireless
- GPS time synchronization
- 5G time synchronization coming….

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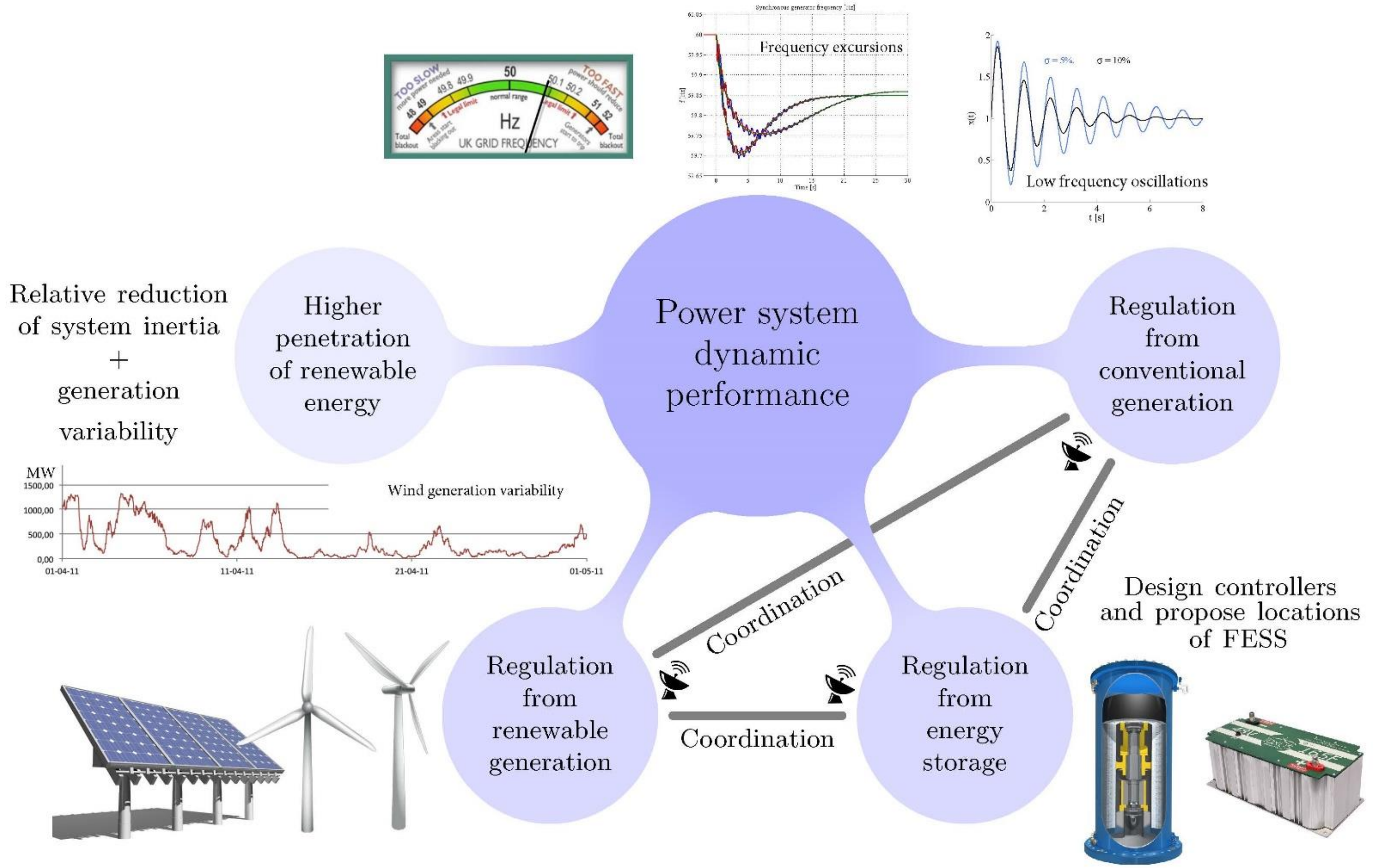
Hector Pulgar Personal Info

- **UTK Associate Professor**
- **Research Interests: Power system dynamic modeling, control design and analysis, Renewable energy and energy storage**
- **hpulgar@utk.edu**

2022-2023 Research Project

1. Coordination of damping controllers (NSF Award #2033910)
2. Design of discrete controllers (NSF CAREER Award #2044629)



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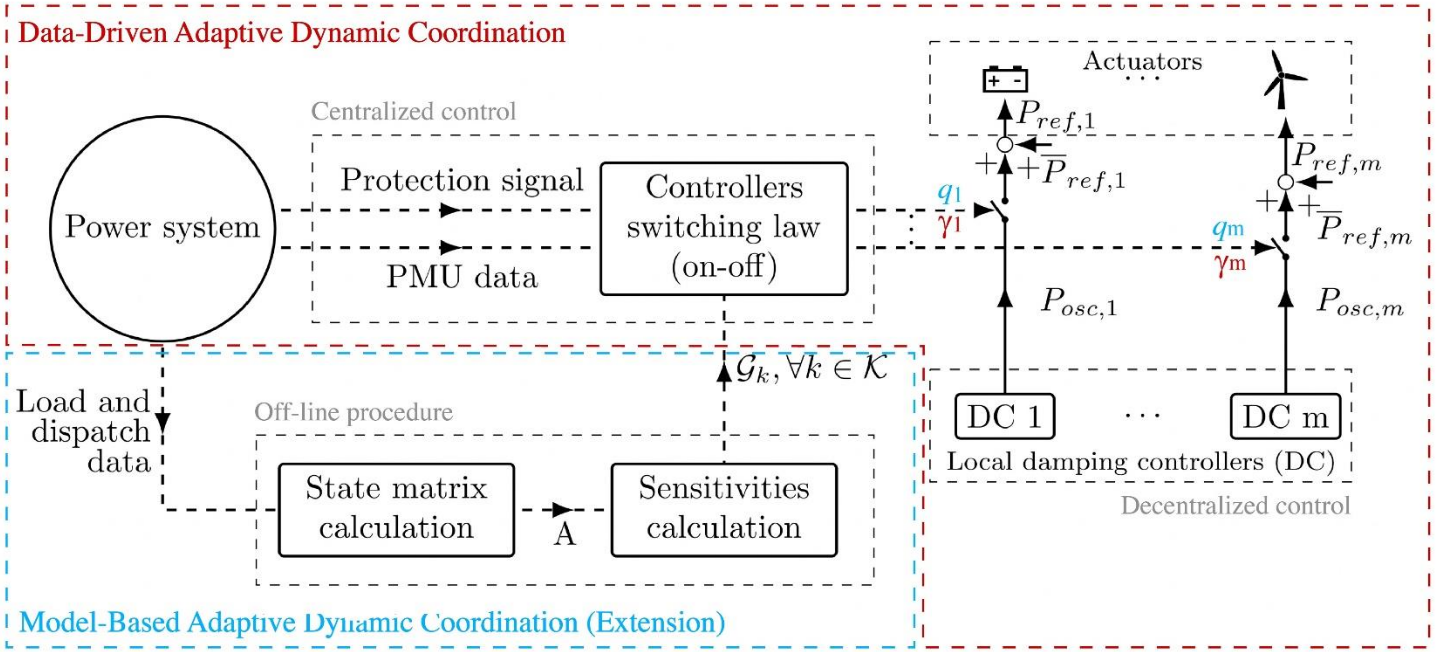
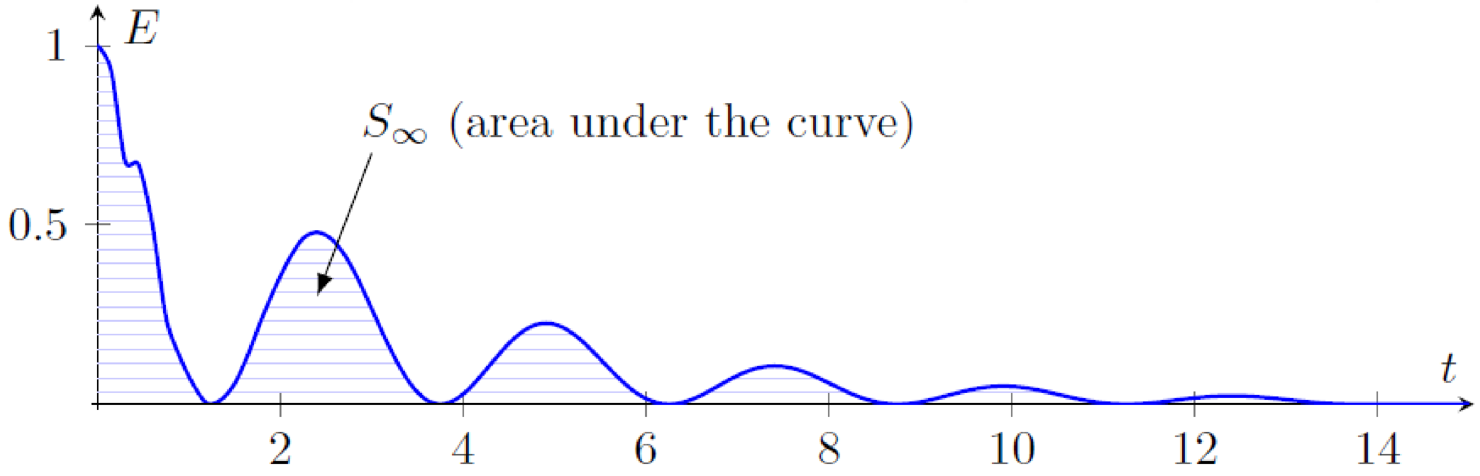
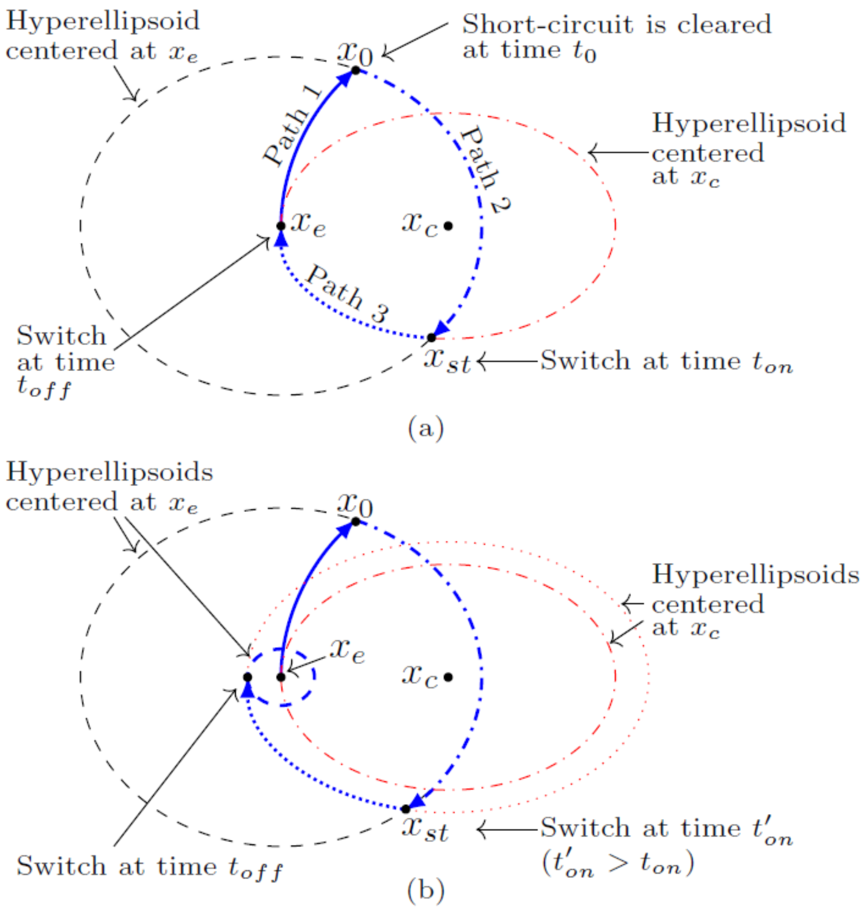
Coordination of Damping Controllers

- Adaptability to faults, and operating conditions
- Model-based approach
- AI-based approach
- Increase system stability

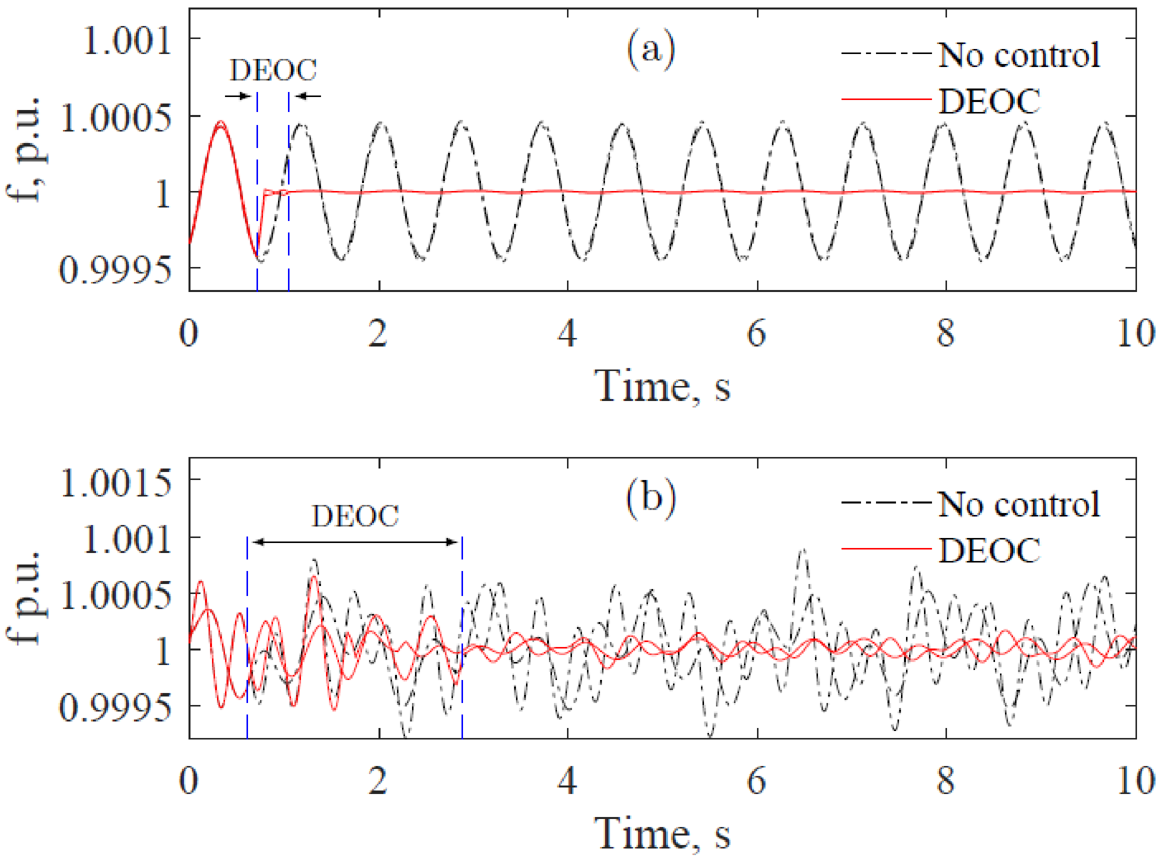


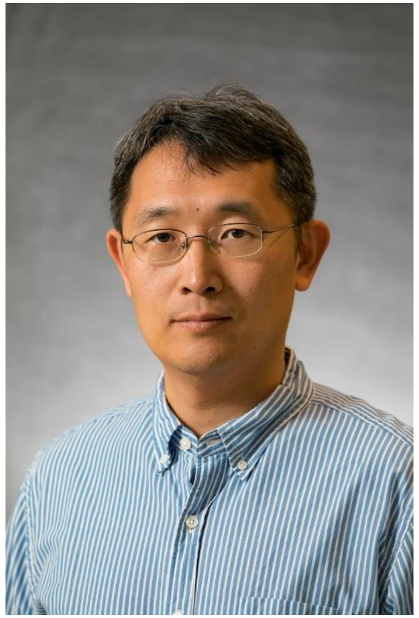


Design of Discrete Controllers



- Step changes in the power output of controllable components
- Enable in components with limited control capabilities





Kai Sun Personal Info

- **UTK Professor in Power Systems**
- **Research Interests: Power system stability, dynamics and control; cascading outages; renewable integration**
- **kaisun@utk.edu**

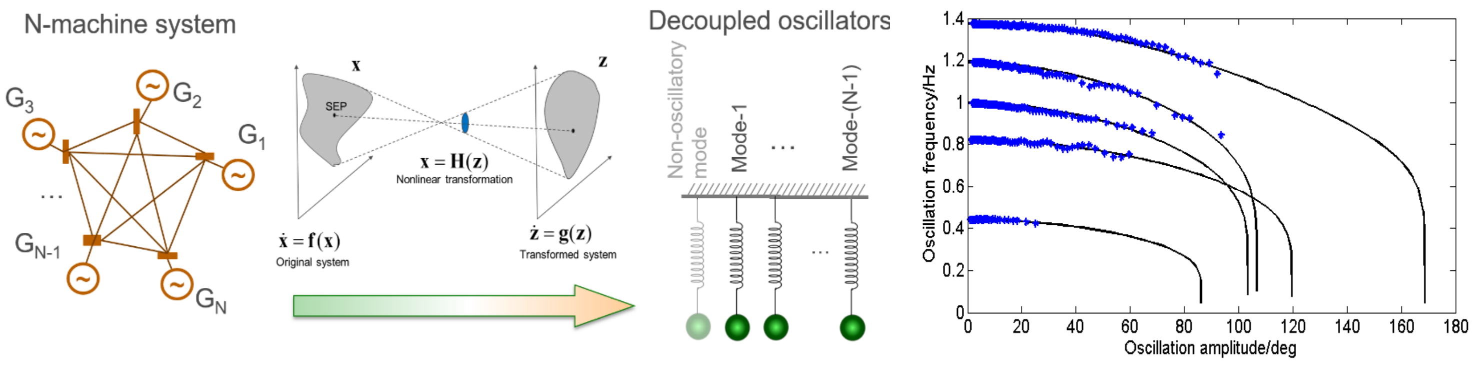
2021-2022 Research Projects

1. Nonlinear Modal Decoupling and Control for Resilient Interconnected Power Systems (NSF)
2. Intelligent Phasor-EMT Partitioning (I-PEP) for Accelerated Large-scale IBR Integration Studies (SETO/NREL)
3. Semi-Analytical Simulation to Accommodate Multi-timescale Grid Dynamics with Increasing Power Electronics Devices (ANL)
4. Mitigation of Cascading Outages Using a Multi-Layer Interaction Graph Model (ORNL)
5. Parallel-in-Time Power System Simulation (ORNL)

Nonlinear Modal Decoupling and Control for Resilient Interconnected Power Systems

Project Objectives

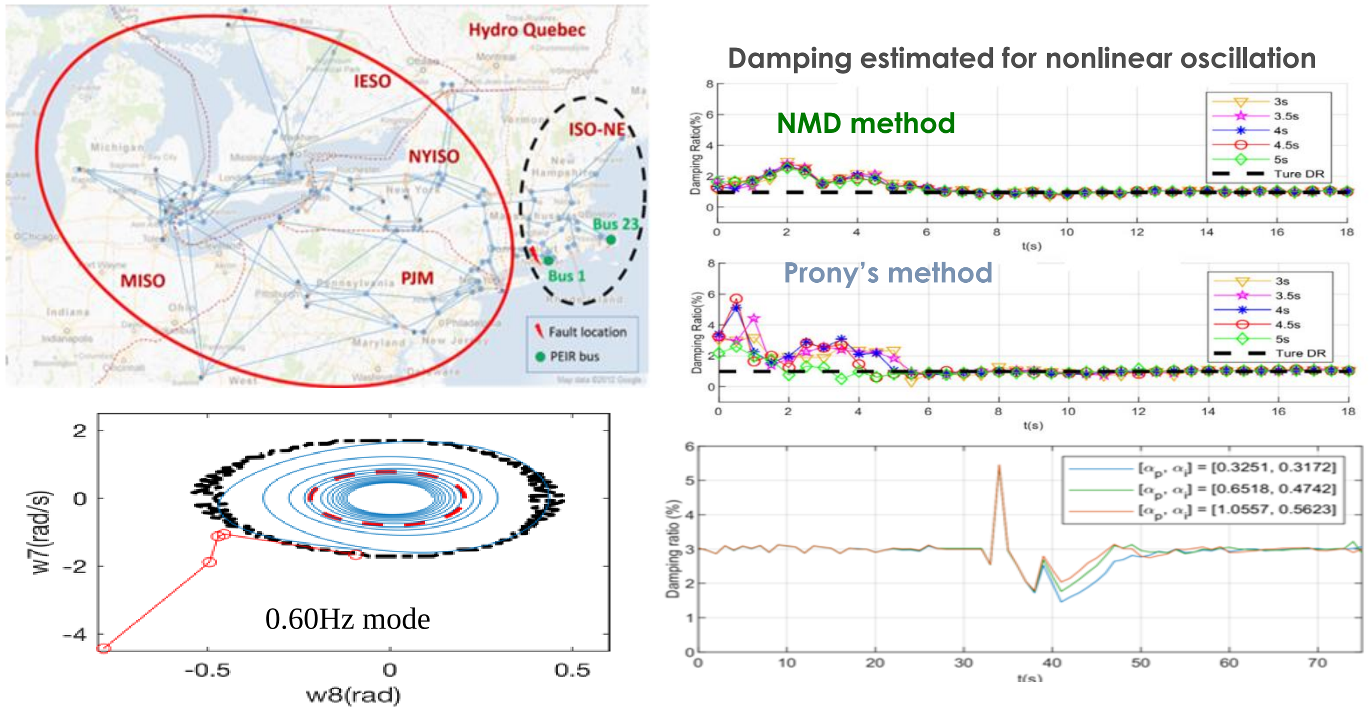
- Characterizing and decoupling nonlinear power system modes for direct transient stability analysis under large disturbances.
- Real-time prediction of transient instability using wide-area measurements.
- Real-time damping estimation and control for nonlinear power system oscillations.



Nonlinear modal decoupling of a grid into 1-DOF oscillators

Recent Achievements

- Demonstrated real-time transient stability prediction on the NPCC LTB.
- Developed a real-time measurement-based damping estimation method for both small and large disturbances.
- Developed an IBR-based direct damping feedback controller for grid stabilization under a large disturbance.



Transient stability monitoring and control for NPCC LTB

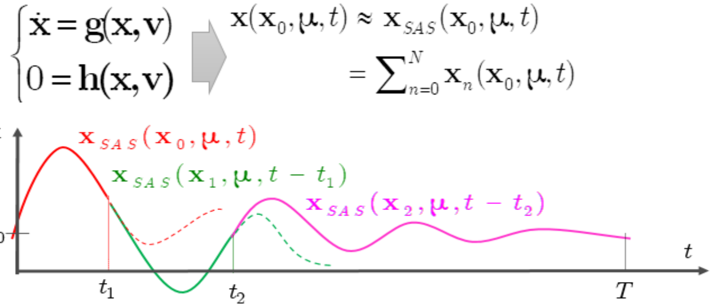
Semi-Analytical Solution Methods to Accelerate Simulations of Future Power Grids with IBRs

Project Objectives

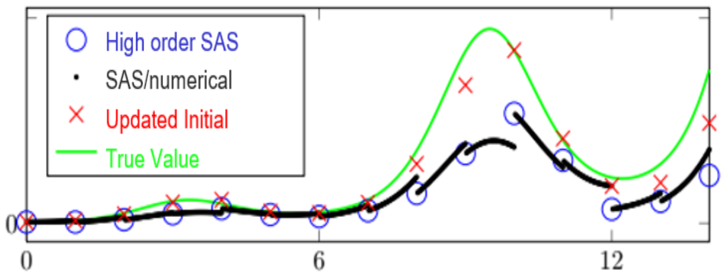
- Variable-step variable-order semi-analytical solvers for power system simulation.
- Faster-than-real-time parallel simulators.

Recent Achievements

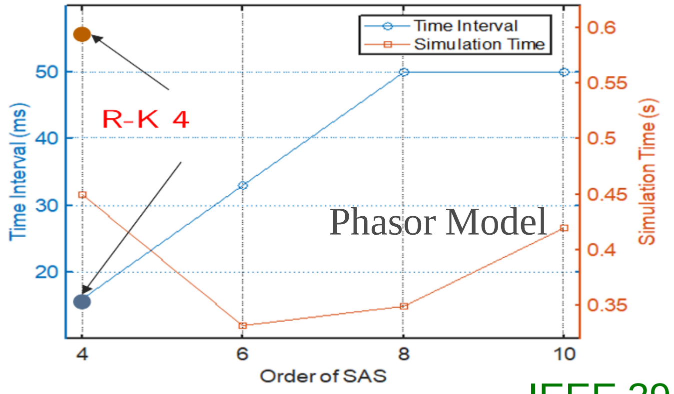
- Developed semi-analytical solutions (SAS) for both phasor and EMT models.
- Accelerated phasor simulation of Polish 2,383-bus system by at least 10x, and EMT simulation of IEEE 39-bus system by 3-4x.
- Released **PowerSAS** (Semi-Analyitcal Solution based Power Grid Analysis Toolbox) with ANL
- Integrated SAS with ORNL's parallel-in-time platform **RAPID** (Resilient Adaptive Parallel sImulator for griD) for simulating 70,000-bus EI model on supercomputers.
- Integrated SAS with NREL's **ParaEMT** platform for EMT-phasor co-simulation of WECC 240-bus system.

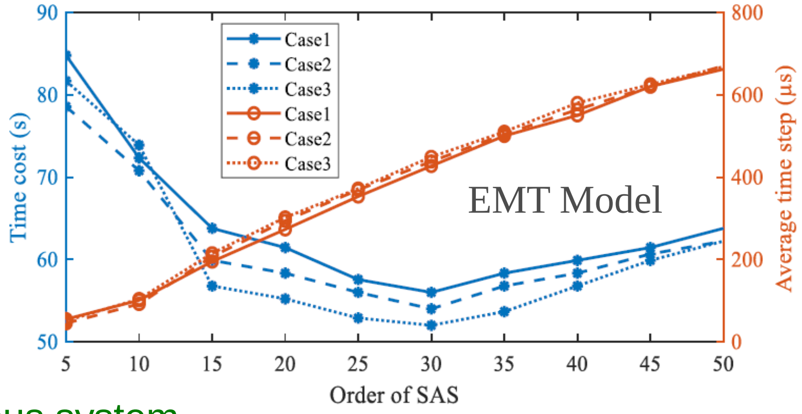


Semi-analytical solution

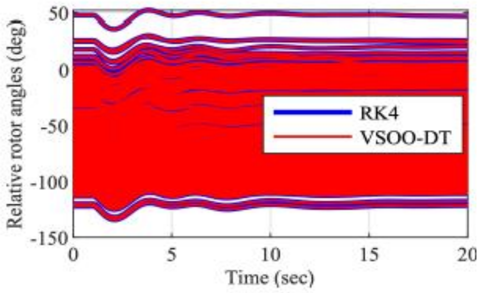


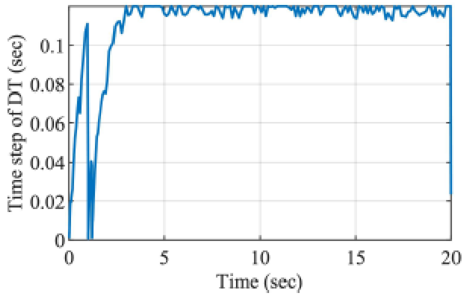
Parallel-in-time simulation

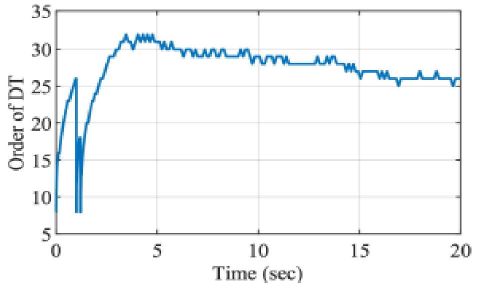




IEEE 39-bus system







Polish 2383-bus system

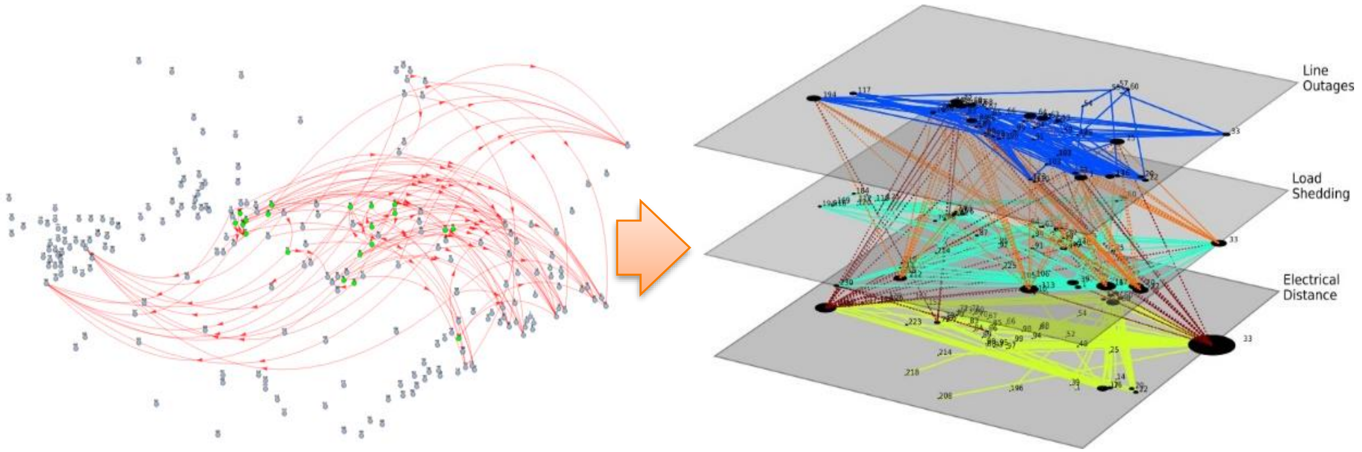
Prediction and Mitigation of Cascading Outages Using Multi-timescale Simulations and Multi-Layer Interaction Graphs

Project Objectives

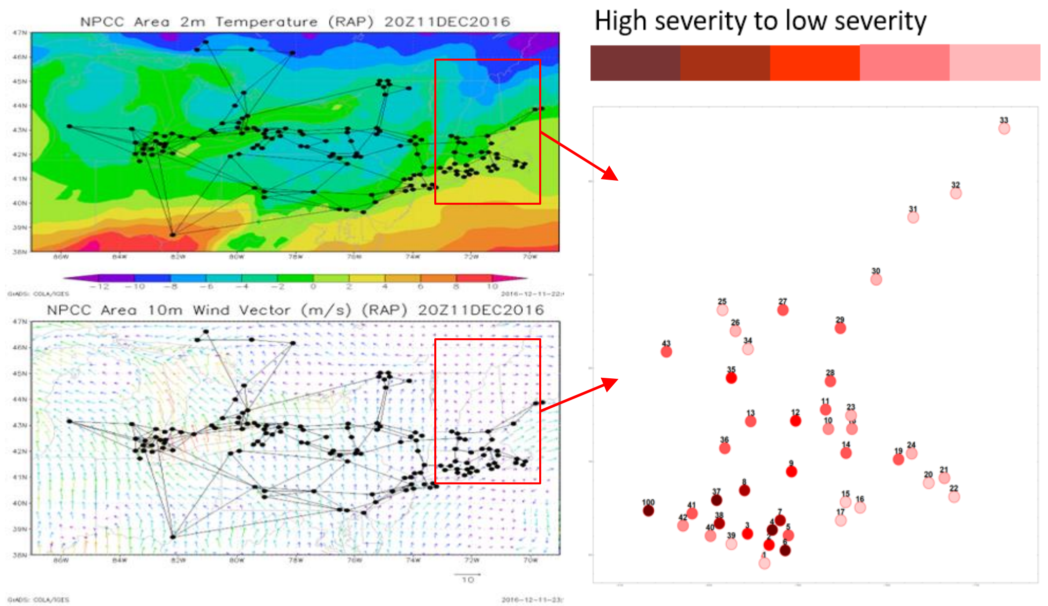
- Multi-timescale cascading outage simulations.
- Data analytics on failure interactions to predict outage propagation paths.
- Effective mitigation strategies against cascading outages.
- Actionable visual information for operators' decision support under emergency.

Project Achievements

- Developed a fast multi-timescale (quasi-steady-state/ dynamic) simulation platform that considers operators' control actions (AC-OPF), generation/line protections, UVLS, UFLS, transient instability, line temperature evolution with NWP weather data, etc.
- Developed multi-layer interaction graph models to visualize and predict outage propagation in terms of load loss, number of failures, propagation distance, etc.
- Developed proactive control strategies (relay blocking, generation redispatch, RAS, controlled islanding)
- Provided simulated, practical cascading failure datasets for machine learning and data analytics.



Multi-layer NPCC Interaction Graphs on outage propagation paths



Visualization on vulnerable components

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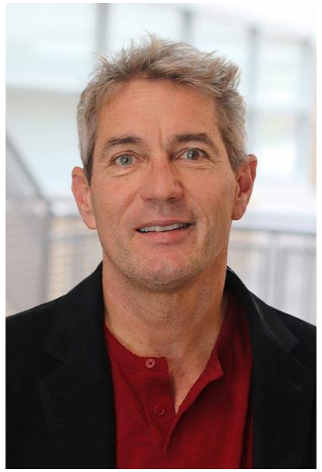
Oak Ridge National Laboratory



Kevin Tomsovic

- **Chancellor's Professor and CTI Professor, CURENT Director**
- **Research Interests: control, optimization, renewable energy integration, demand response, resilience, cybersecurity.**
- **tomsovic@utk.edu**

2022-23 Research Projects/Highlights

Recently Completed

1. Continuously variable series reactor (CVSR) (**DOE, ORNL, ConEd, UCF**) (PI: Z. Li, co-Pis: F. Wang, A. Dimitrovski)
2. WISP: Watching grid Infrastructure Stealthily through Proxies (**DOE, Raytheon**) (PI: F. Li PI; co-PI: J. Sun)
3. National Transmission Resilience and Reliability (**DOE**) – (PI: F. Li)

Recently awarded and on-going

1. CPS: Medium: Secure Constrained Machine Learning for Critical Infrastructure CPS (**NSF**) (PI: J. Sun, co-PI: H. Qi, H. Lee)
2. A Novel Approach to Mitigating Communication Failures (**NSF**) (co-PIs: S. Djouadi, F. Taousser)

Major proposals submitted

1. University Consortium on Grid Resilience (**DOE**) (11 Domestic Universities, 4 International Universities and 4 National Labs)

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A New Approach to Control under Network Communication Delays

Project goals and previous accomplishments

- A new mathematical method to estimate the maximum allowed communication delay that does not violate the stability and performance of the power system.
- Manage continuous and discrete dynamics as switching between a continuous-time subsystem (when the communication occurs without any interruption) and a discrete-time subsystem (when the communication fails) by introducing time scales theory.

Recent activities

- A stability criteria has been derived to estimate bounds of the communication loss duration, which guarantees the stability of the system.

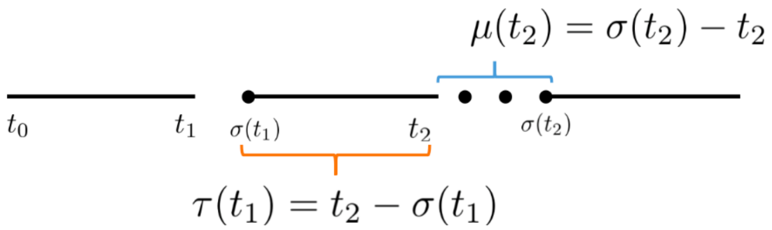
Future works

- Test stability criteria in larger system with considering communication failure.

PIs – Djouadi, Taousser and Tomsovic (PI)

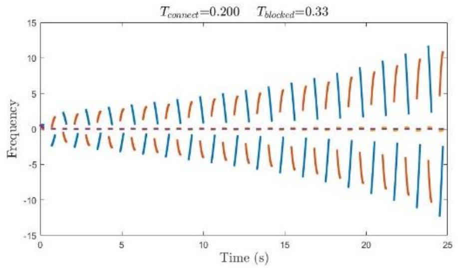
Students: Yichao Wang

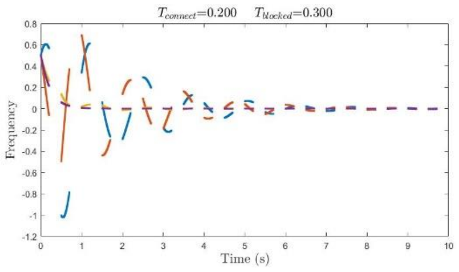
Time scales

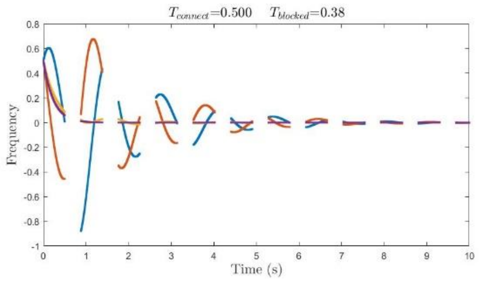


Switched system

$$x^{\Delta}(t) = \begin{cases} (A+BK)x(t), & t \in \cup_{i=0}^{\infty}[\sigma(t_i), t_{i+1}) \\ \left(\frac{e^{A\mu(t)}-I}{\mu(t)}\right)\left(I + A^{-1}BK\right)x(t), & t \in \cup_{i=0}^{\infty}\{t_{i+1}\} \end{cases}$$







Exploring Physical-Based Constraints in Forecasting: A Defense Mechanism Against Cyberattack

Project goals and previous accomplishments

- Concern with Cyber attacks in machine learning systems.
- Physical-based constraints can provide obstacles that makes attacks more difficult.
- Attacker needs to meet the constraints imposed by the physical/topology of system and evade any built-in detection mechanisms in the system.

Recent activities

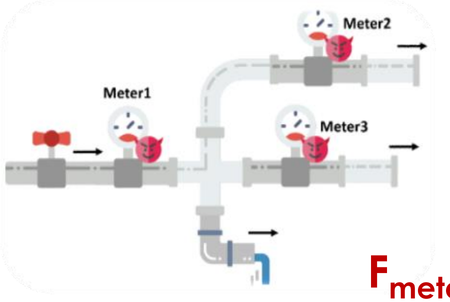
- Proposed a framework to spatially investigate STLF for a defense mechanism (also for traffic systems).
- Applied similarity measures to explore physical-based constraint.
- Outperformed of SAX method, showing more sensitivity to false data injection.

Future works

- Test stability criteria in larger system with considering communication failure.

PIs – Han, Qi, Sun (PI) and Tomsovic

Students: Mojtaba Dezvarei, Farhin Farhad Riya, Ony Hoque, Diyi Liu, Lanmin Liu, Quan Zhou



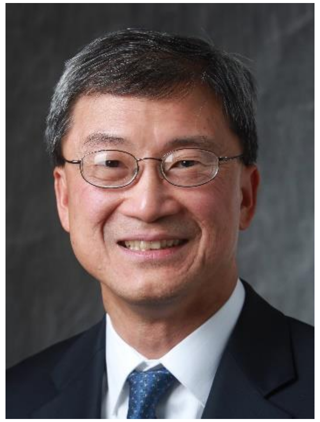
linear equality/
inequality constraints

$F_{meter1} > F_{meter2} + F_{meter3}$

Water flow measurement

Spatial correlations

- Correlation-based distance: $d_{COR}(X,Y) = \sqrt{2(1 - COR(X,Y))}$
- Periodogram-based distance: $d_p(X,Y) = \sqrt{\sum_{j=1}^{[\frac{N}{2}]} [\rho_x(\omega_j) - \rho_y(\omega_j]^2}$
- Autocorrelation-based distance: $d_{ACF}(X,Y) = \sqrt{(\hat{\rho}_{X_T} - \hat{\rho}_{Y_T})^T \, \Omega \, (\hat{\rho}_{X_T} - \hat{\rho}_{Y_T})}$
- Symbolic representation SAX: Time series transforming into a string.
- Euclidean-based distance: $d_{EUC}(X,Y) = \sqrt{\sum_{j=0}^{N-1} (x_i - y_i)^2}$



Joe Chow Personal Info

- **Institute Professor in Electrical, Computer, and Systems Engineering, RPI; CURENT ERC RPI Site Director & Control Thrust Lead**
- **Research Interests: Large-scale power system dynamics and control, phasor measurement data analysis, control of renewable resources**
- **chowj@rpi.edu**

2020-2023 Research Project

1. Risk Segmentation and Portfolio Analysis for Pareto Dominance in High Renewable Penetration and Storage Reserves (ARPA-E PERFORM) – co-investigator: Dr. Denis Osipov

Risk Segmentation and Portfolio Analysis for Pareto Dominance in High Renewable Penetration and Storage Reserves

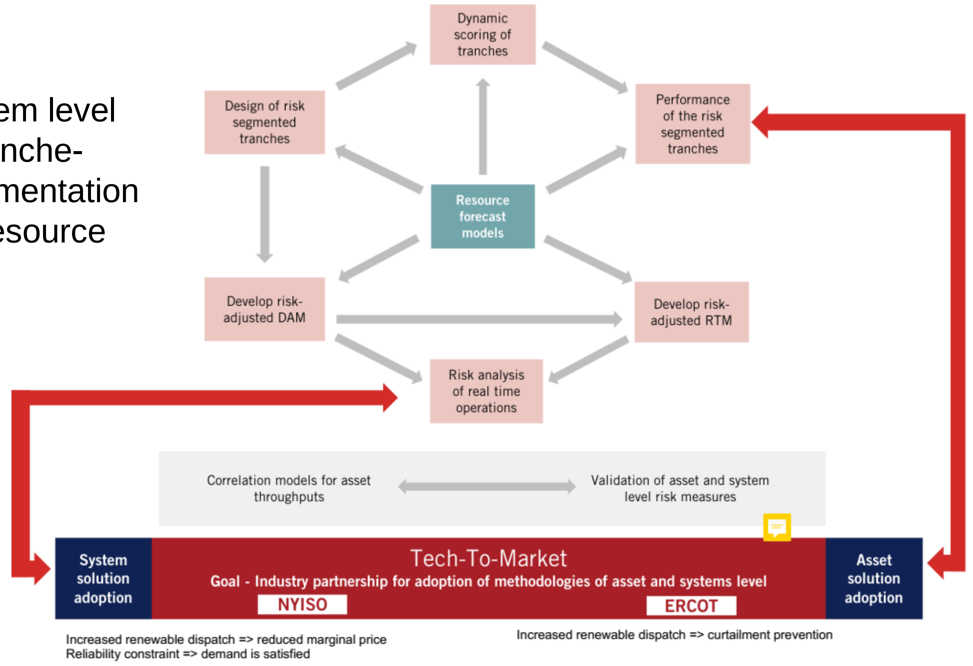
Project Objectives

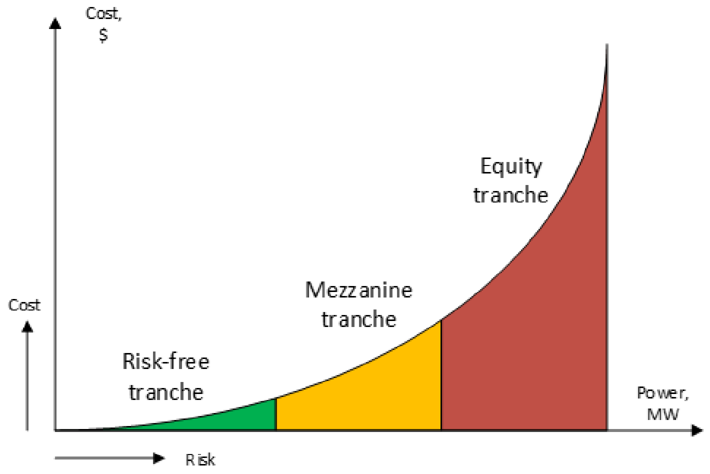
- Design risk-segmentation bidding strategy for renewable assets and integrate them into the risk-adjusted day-ahead market (DAM) and the real-time market (RTM)
- Design risk-adjusted unit commitment and economic dispatch solutions using tranches
- Develop reserve requirements under high renewable penetration
- Develop risk scoring for tranche-level optimal dispatch ensuring robustness against transient instabilities

Recent Achievements

- Implemented risk-adjusted DAM and RTM unit commitment and economic dispatch formulation using EGRET (python-based grid optimization package)
- Tested the solution using synthetic NYISO 1700-bus system and synthetic ERCOT 7000-bus system models for 2020 scenarios; will proceed to 2030 scenarios
- The risk-adjusted formulation increases participation of renewable resources in DAM, which leads to:
  - Increase in the total revenue for renewable resources
  - Decrease in the total cost for the consumers

Asset and system level approach to tranche-based risk-segmentation of renewable resource bidding





DAM renewable resources tranche-based energy bids

Kevin Bai Personal Info

- **UTK Associate Professor in power electronics**
- **Research Interests: Wide bandgap power electronics, power electronics for electric transportation**
- **kevinbai@utk.edu**

2022-2023 Research Projects

1. GaN 800V Module with Double Sided Cooling in a 3L Half Bridge Configuration (Volkswagen Group of America)
2. A High-Efficiency, High-Power-Density Integrated DC/DC with OBC for Electric Vehicles (Hella/Forvia)
3. A Smart and Highly Compact Power Electronics Box to Provide Universal Charging Technologies (OBC, Wireless and DCDC) (Magna Powertrain)
4. Using FPGA to Control Six-phase PMSMs Fed by WBG Inverters (Mercedes Benz)
5. Design and Test A 800V/>50kW Three-level Active Neutral Point Clamping Motor Drive Inverter using 650V/60A GaN HEMTs for Electric Vehicles (PowerAmerica)
6. Scalable Second-life Battery Energy Storage System (Phase 1) (Volkswagen Group of America)

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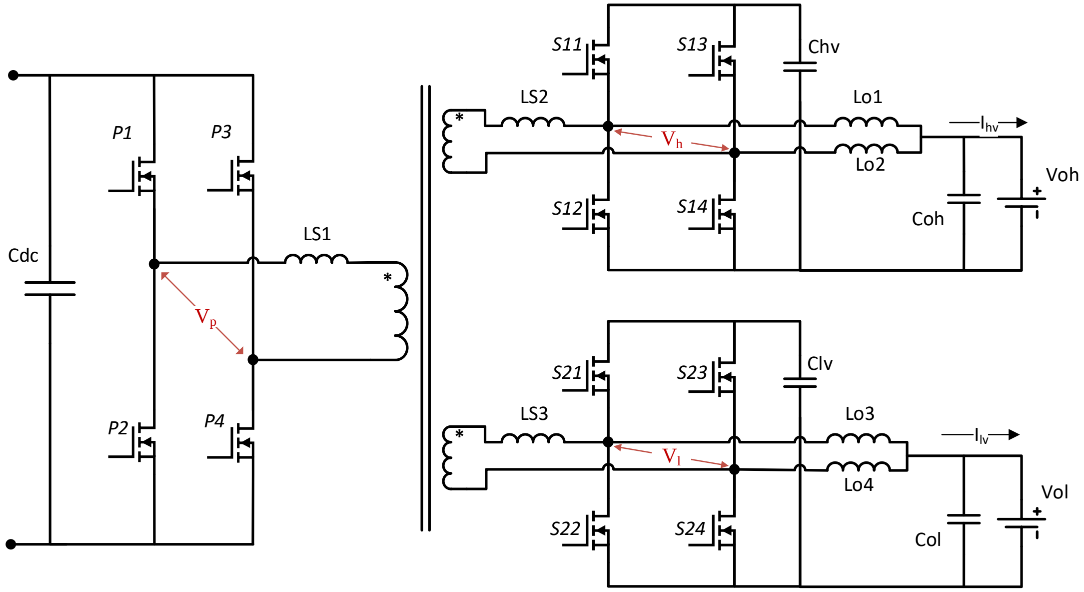
A High-Efficiency, High-Power-Density Integrated DC/DC with OBC for Electric Vehicles

Project Objectives

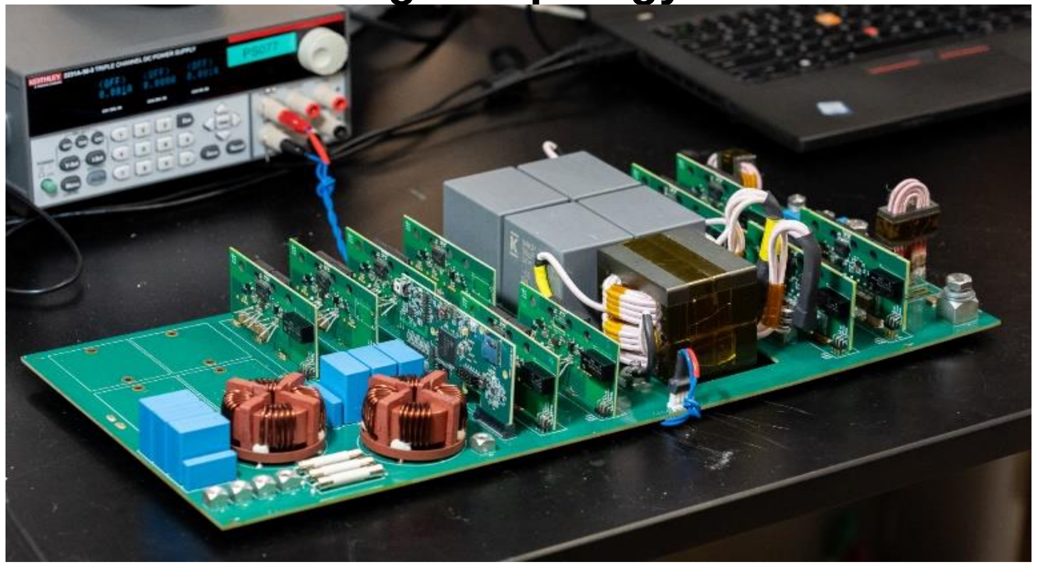
- To integrate a DC/DC converter with EV on-board charger (OBC) thereby saving the size and cost;
- To use wide-bandgap (WBG) devices aiming at higher efficiency;
- To explore new magnetics solutions (transformer) in EV applications.

Recent Achievements

- Tested iCharger at 14kW (11kW OBC + 3.5kW DCDC);
- Developed a novel control algorithm allowing the power to flow freely among power grid, HV battery and LV battery;
- Licensed one global patent to Hella/Forvia through UTRF;
- Filed another global PCT on ultra-wide-input-range (200~950Vdc) DC/DC converter with Hella/Forvia through UTRF.



iCharger Topology



Prototyped iCharger (11kW OBC+3.5kW DCDC)

PI: Kevin Bai

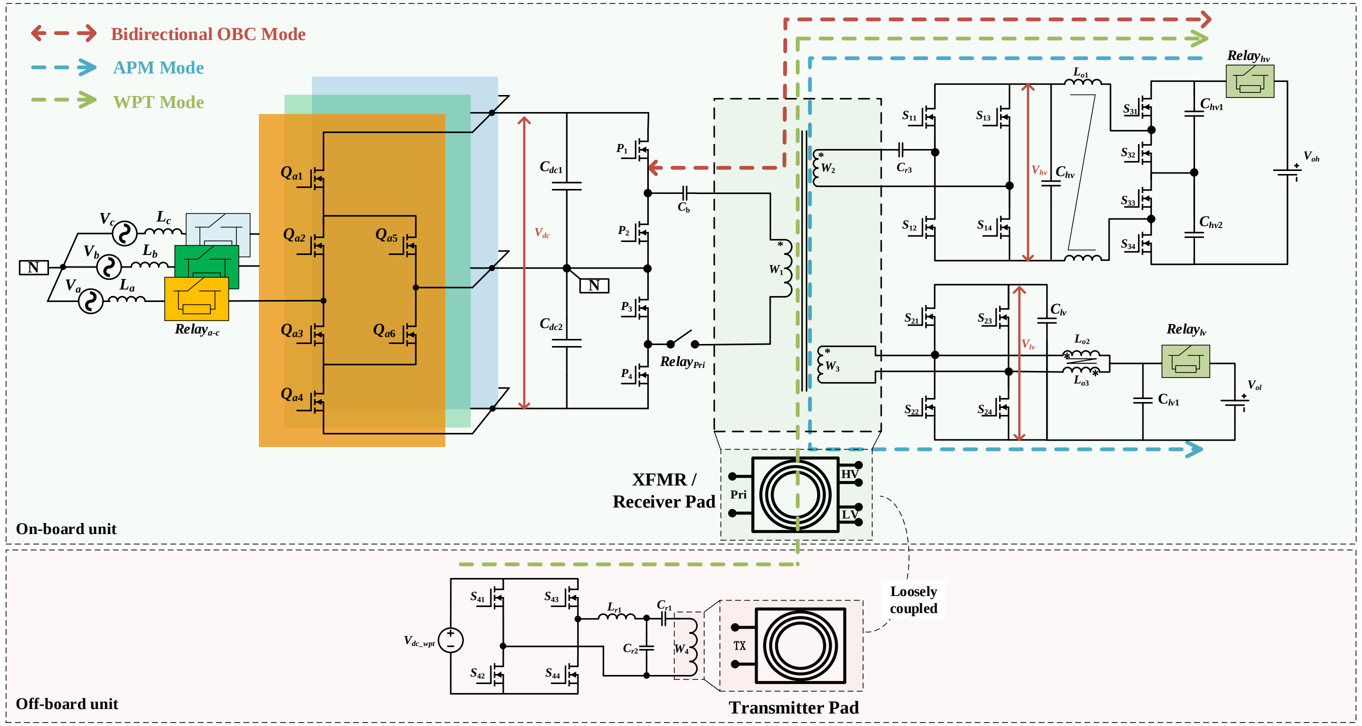
A Smart and Highly Compact Power Electronics Box to Provide Universal Charging Technologies

Project Objectives

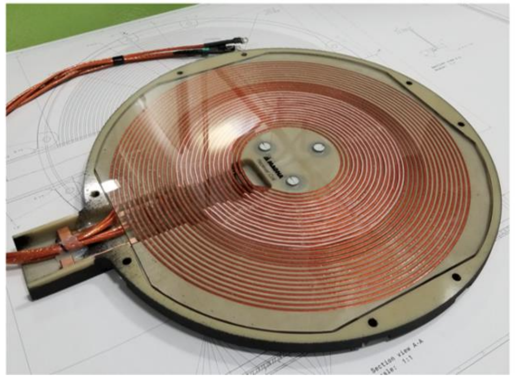
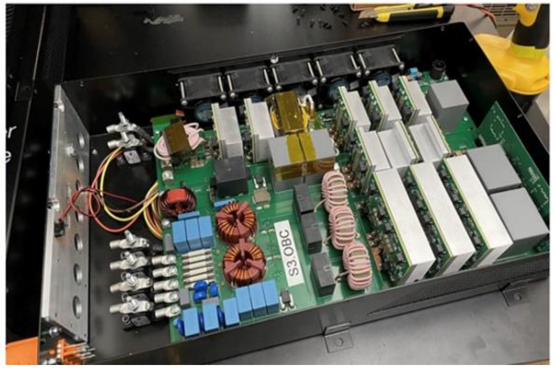
- To integrate DC/DC, OBC and WPT thereby saving the size and cost and offering more charging convenience;
- To provide universal charging for EV drivers;
- To only use GaN devices as a benchmark comparison with Si and SiC.

Recent Achievements

- Finalized the 6.6kW test of OBC, WPT and V2L modes;
- Developed a novel magnetics coupler;
- Filed one PCT with Magna through UTRF.



The Overall Topology

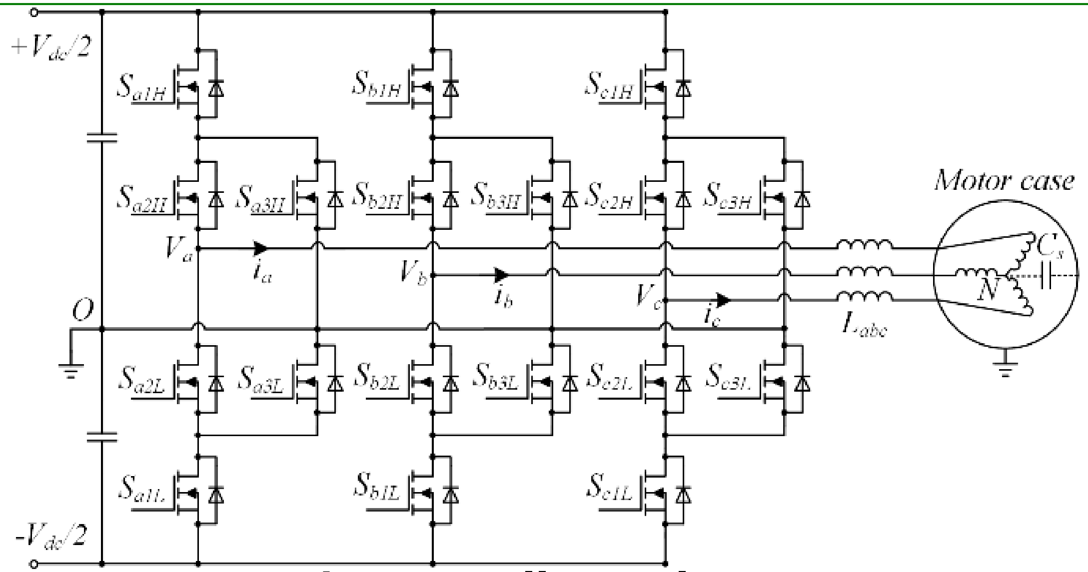
Prototypes

PIs: Kevin Bai, Daniel Costinett

An 800V/>50kW Three-level Active Neutral Point Clamping EV Motor Drive Inverter Using GaN HEMTs

Project Objectives

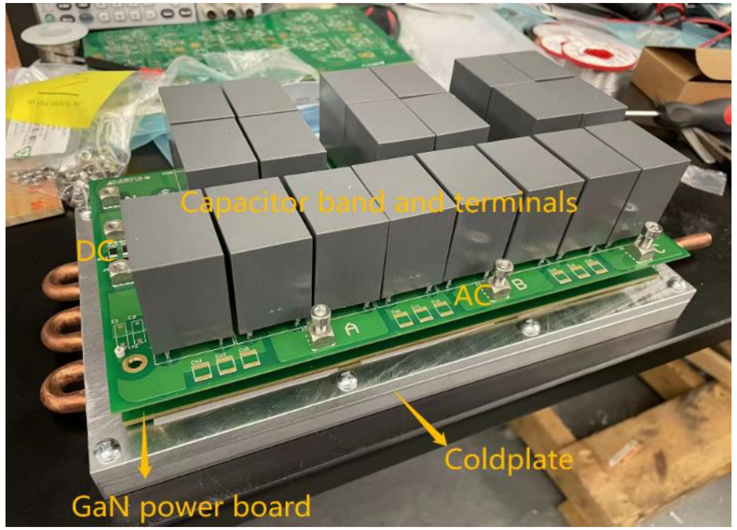
- To explore possibility of using GaN in EV tractions inverters;
- To understand three-level inverter benefits on CM reduction;
- To demonstrate 75kW test to PowerAmerica members.

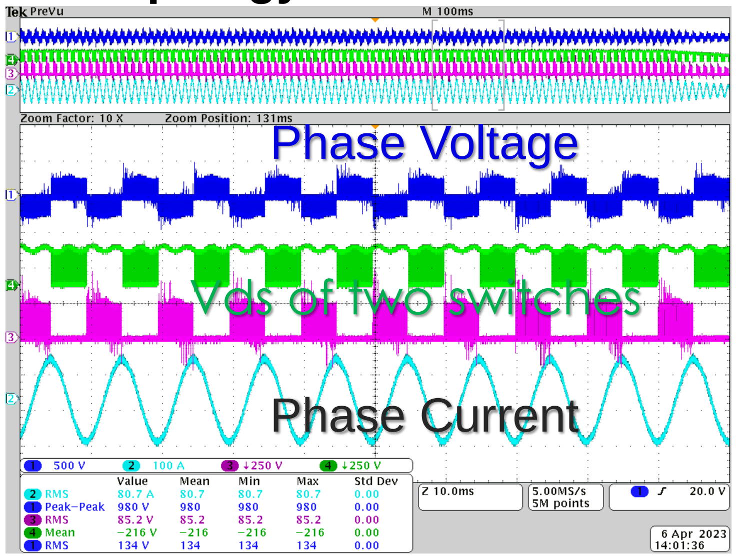


The Overall Topology

Recent Achievements

- Finalized the 1st prototype;
- Tested the inverter up to 50kVA.



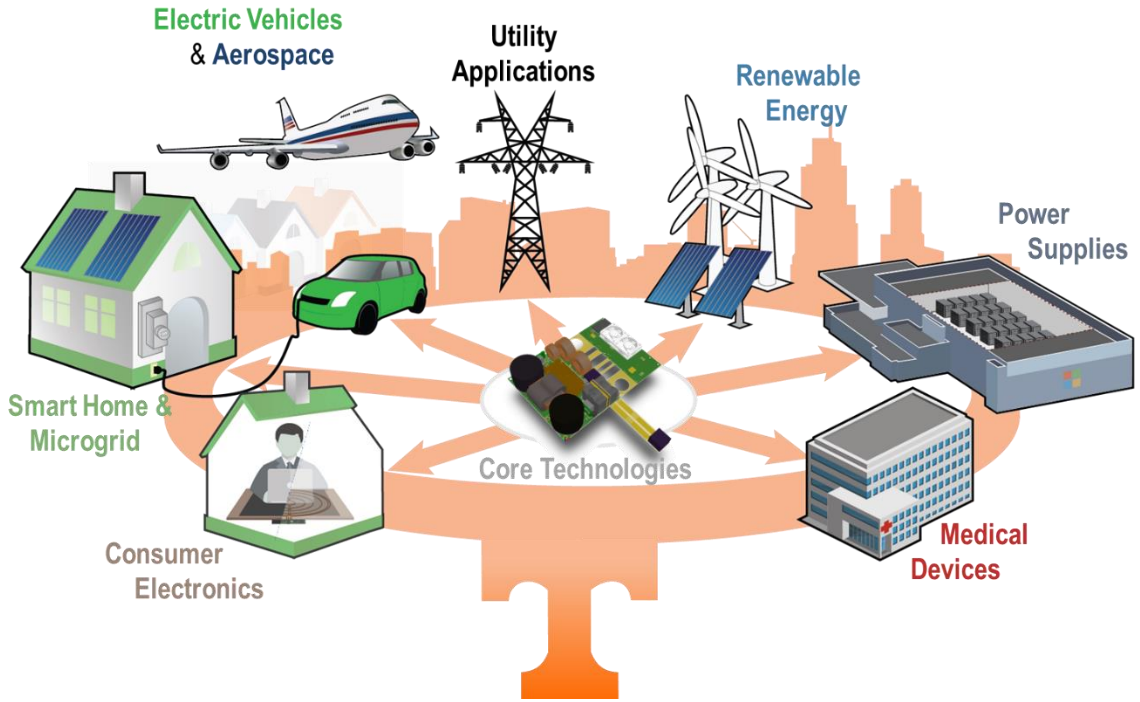


Prototypes and 50kVA Testing

PIs: Kevin Bai, Leon Tolbert and Fred Wang

Daniel Costinett Personal Info

- **UTK Associate Professor in power electronics**
- **Research Interests: Advanced design and control techniques for power supplies, wireless power transfer, PMIC, medical devices, electric vehicles**
- **Daniel.costinett@utk.edu**



Recent Research Projects

1. Unified Design Framework for Advanced Power Electronics (NSF CAREER)
2. High Frequency 6.6 kW Wireless Charging for EVs (II-VI Foundation)
3. High-Power 120 kW Wireless Charging for EVs (Volkswagen)
4. Multi-Receiver Wireless Power for Consumer Electronics (Intel, Power America)
5. Reducing Levelized Cost of Energy of Residential PV Inverters Through Dynamic Hardware Allocation (DOE)
6. Lightweight wireless power receivers for UAVs (ARL)
7. Integrated High-Current Battery Chargers for Mobile Electronics (Texas Instruments)

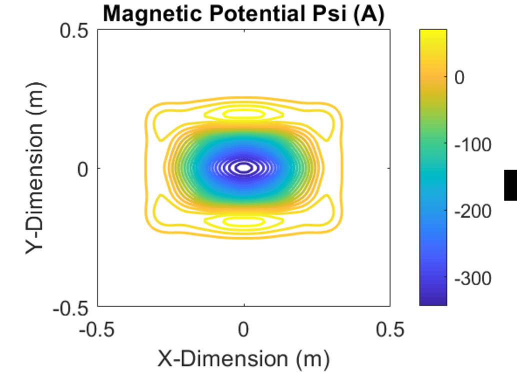
CURENT

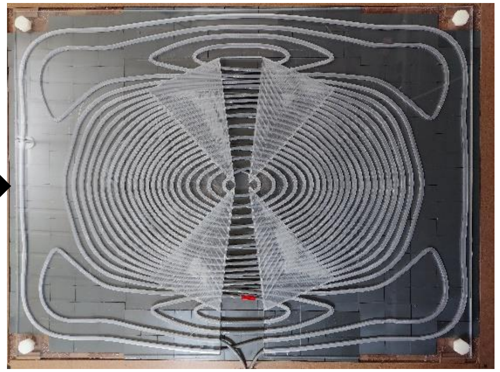
Wireless Power Transfer

Achievements

- Successfully demonstrated two different 6.6 kW Level-II wireless chargers for EVs with over 95% efficiency
- Showcased new control and synchronization design for wireless receivers
- Named one of Power America annual “success stories” for high-efficiency, high-density wireless charging desk

High Power Wireless EV Charger





Low stray-field coil design and optimization

OAK RIDGE National Laboratory

Multi-Receiver Wireless Workstation

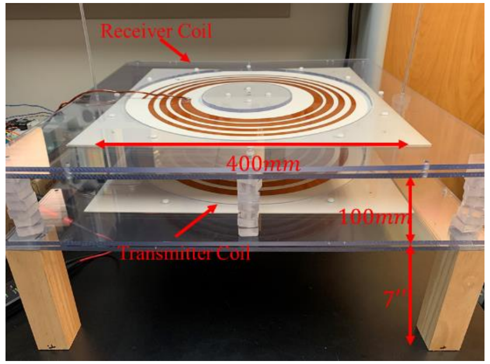
Multi-receiver 100 W workstation with 92% end-to-end efficiency

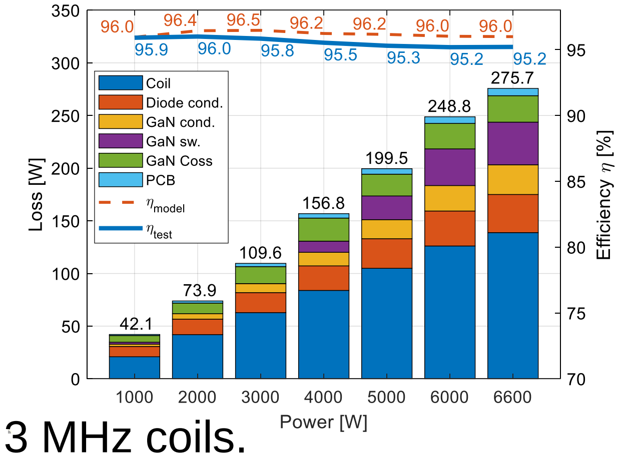
CURENT

intel

POWERAMERICA

High Frequency Wireless EV Charger





Low-profile, self-resonant 3 MHz coils.

95.2% efficiency at 6.6 kW

II-VI Foundation

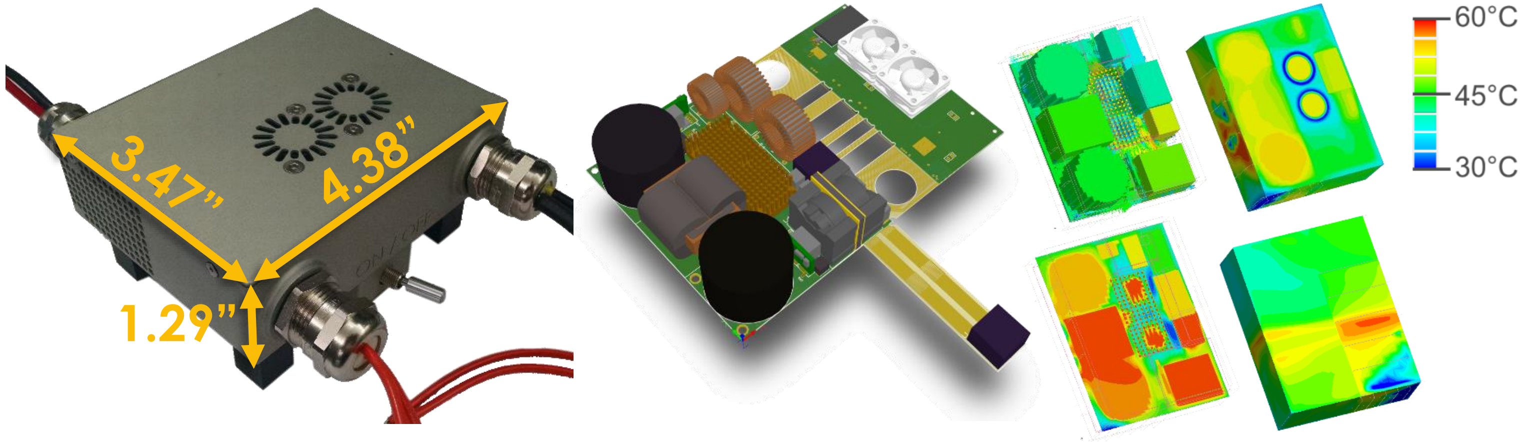
LCOE-Optimized Solar Inverter

Project Objectives

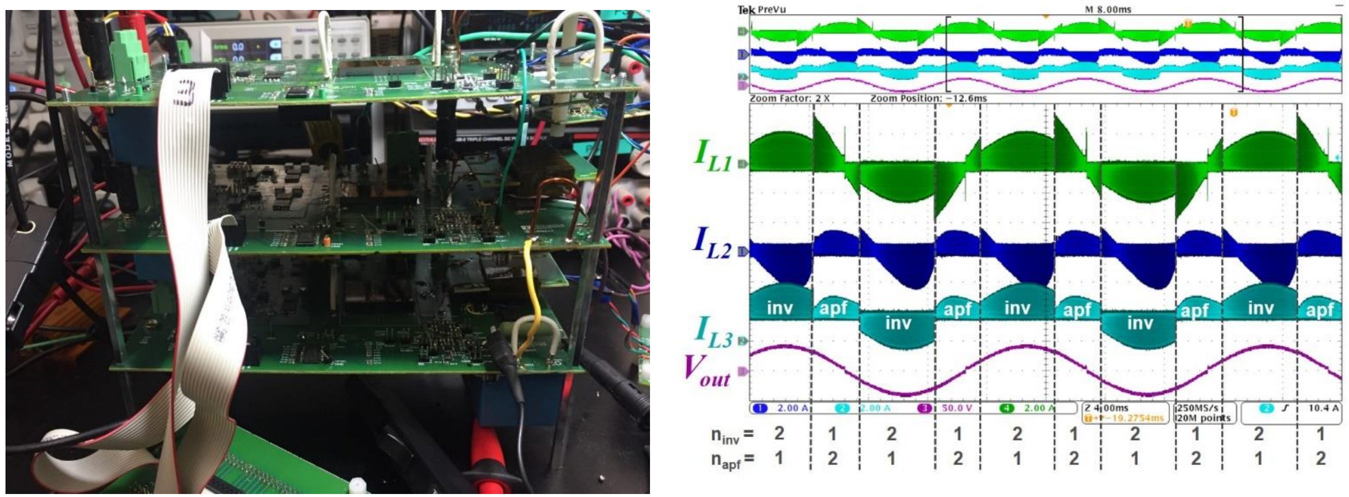
- Develop a Lifetime Cost of Energy optimization for residential single-phase inverter
- Showcase optimal tradeoff between cost, lifetime, and efficiency

Achievements

- Demonstrated modular topology using Dynamic Hardware Allocation (DHA)
- DHA allows functional hardware to be repurposed after a module failure to extend life
- Designed prototype based on LCOE optimization



Google Little Box finalist 2kVA single-phase inverter



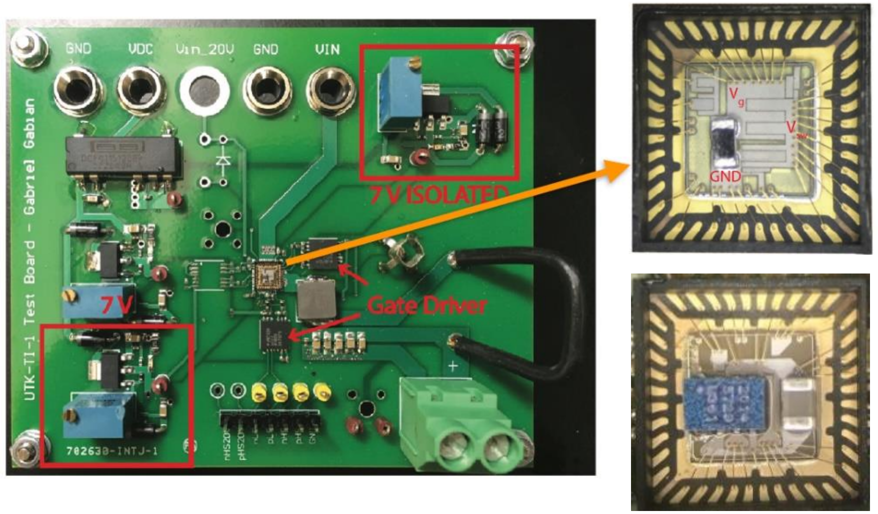
LCOE-optimized inverter employing dynamic hardware allocation

CURENT

High Current Battery Charger Integrated Circuits

Project Objectives

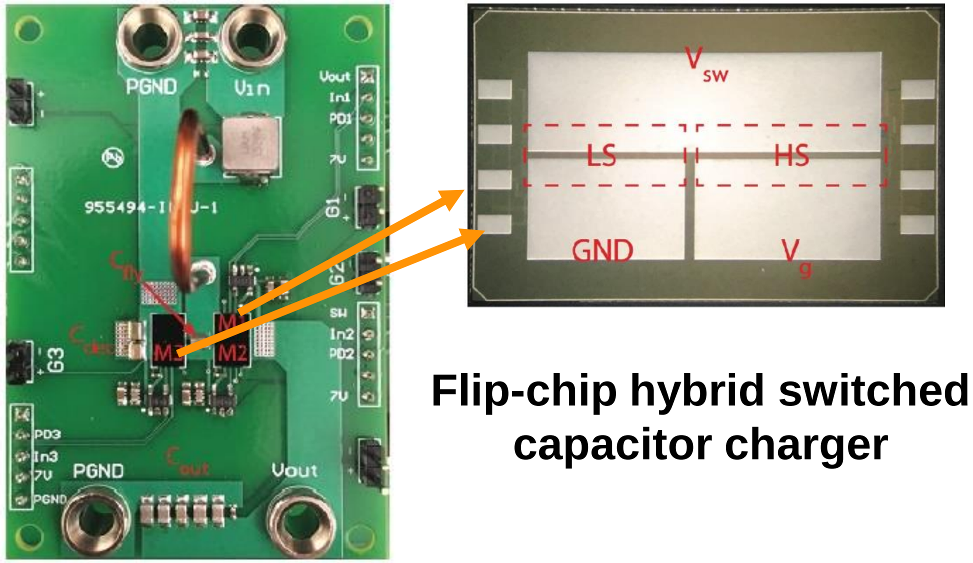
- Increase continuous charging power of monolithic solution to 40W (2x increase over existing parts)
- Develop integrated charging and balancing for multi-cell packs
- Achieve high density using inductorless topology



Co-packaged high-current chargers

Achievements

- Optimized novel hybrid switched capacitor topology for high-current charging
- Demonstrated 40W charging using silicon integrated circuit
- Demonstrated new topology with independent control of charging and balancing currents for multi-cell packs



Flip-chip hybrid switched capacitor charger

CURENT

Texas Instruments

Helen Cui Personal Info

- **Assistant Professor in power electronics since 2020**
- **Research Interests: high frequency magnetics design, modeling and optimization, high-density power module integration**
- **helencui@utk.edu**

2021-2023 Research Projects

1. A multiscale physics-based magnetics design framework for ship scale power electronics (ONR)
2. Embedded GaN Power Module for High Frequency 400V/>20A Operation with Double-Sided Cooling and Integrated Gate-Drive Circuit (PowerAmerica)
3. Magnetic Field Probe for Current Measurement in Power Modules (Keysight)
4. Design, Scalability, and Optimization of Combinational Rogowski Coil (Keysight)
5. Superconducting Motor and Cryo-cooled Inverter Engine (RTRC, with Fred Wang and Kevin Bai)

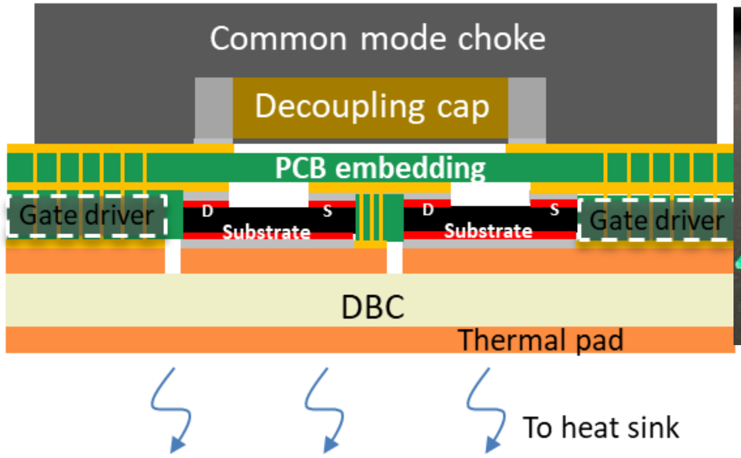
Embedded GaN Power Module for High Frequency 400V/>20A Operation with Double-Sided Cooling and Integrated Gate-Drive

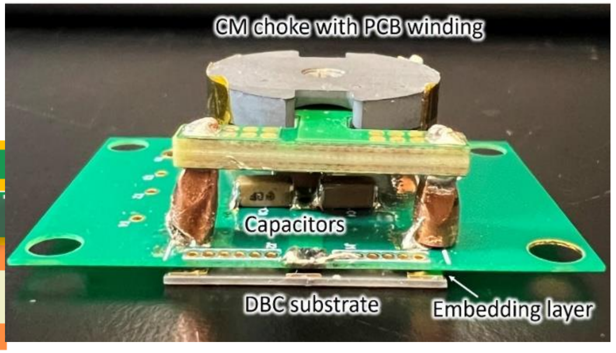
Project Objectives

- Constructed a 2-die GaN half-bridge power module with highly compact design that integrates gate drive, decoupling capacitor, achieving:
  - ✓ high density: total size is 1.8 cm × 2.7 cm.
  - ✓ Low junction-to-case impedance of 0.35 K/W with double-sided cooling
  - ✓ continuous switching at 1 MHz and 4.5 kW output power
  - ✓ Up 50 dB more EMI noise attenuation achieved by the integrated EMI filter

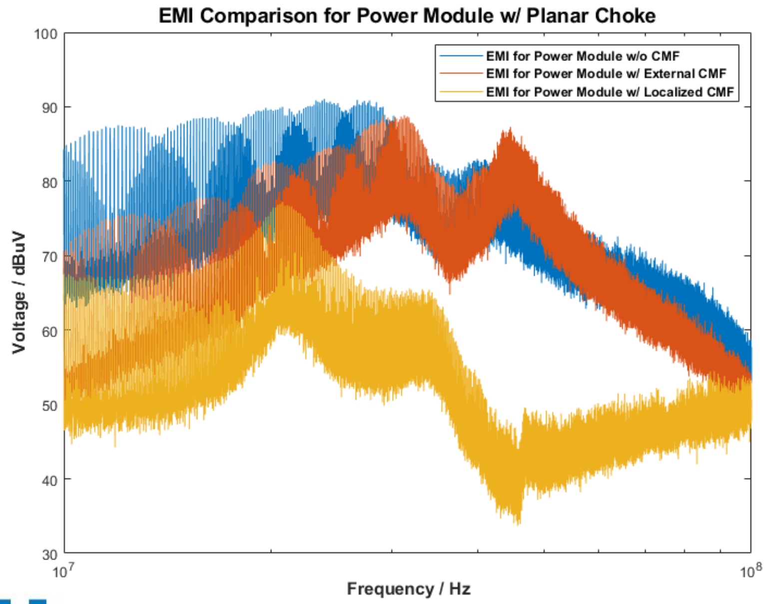
Recent Achievements

- Double pulse test performed on power module under 400V/25A at 25^{o}C and 90^{o}C with low parasitic inductance of 1.03 nH and less than 5% voltage overshoot
- Thermal modeling and thermomechanical evaluations accomplished and improved with better substrate





PCB + DBC packaging prototype

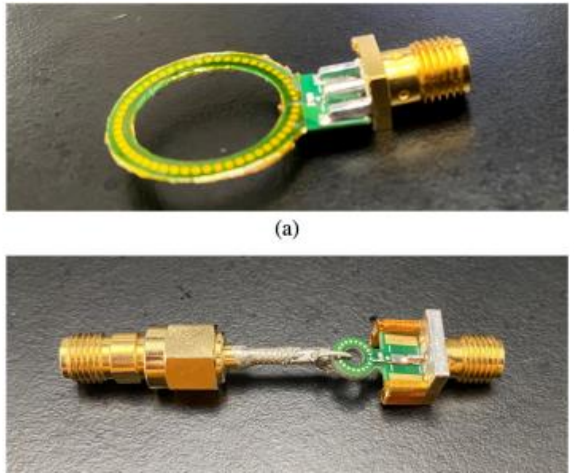


Integrated CM filter showing larger noise attenuation than non-integrated counterpart

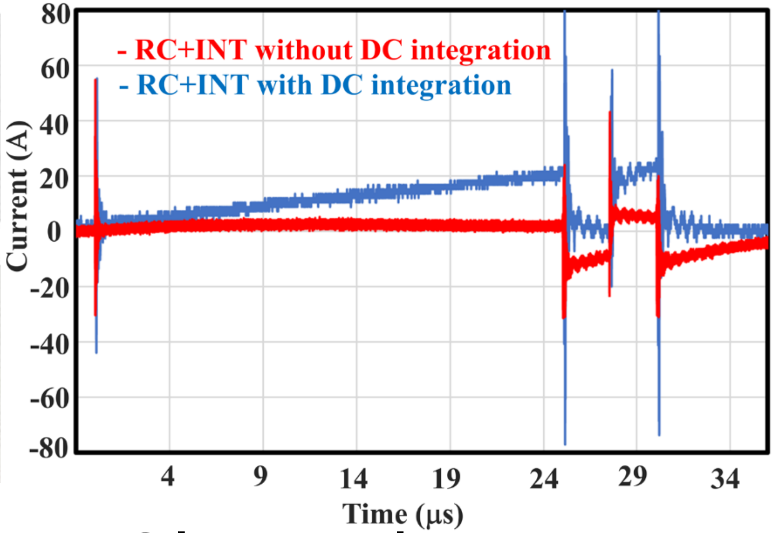
Design, Scalability, and Optimization of Combinational Rogowski Coil

Project Objectives

- Improve the state-of-the-art Rogowski coils for high frequency current measurement used for WBG device applications, achieving
  - ✓ small size and low insertion inductance
  - ✓ dc sensing integration
  - ✓ demo in WBG power module integrated with current sensor
  - ✓ high measurement bandwidth for fast response and high-frequency measurement



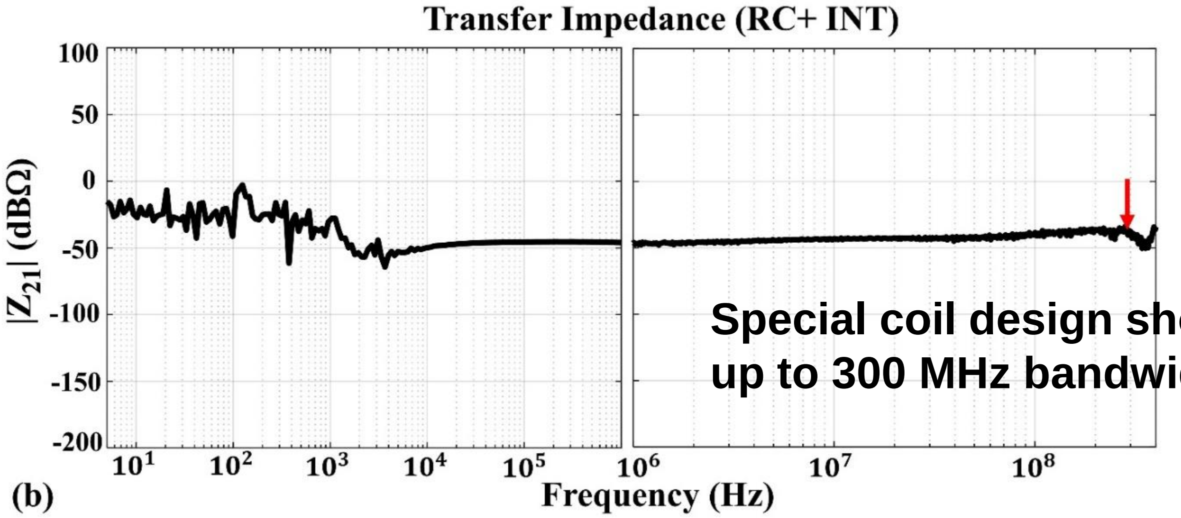
PCB based Rogowski coil for current sensing



DC integrated measurement results

Recent Achievements

- Completed modeling of combinational Rogowski coil with shielding layer
- Conducted parameter sensitivity analysis and design scalability study for more general applications

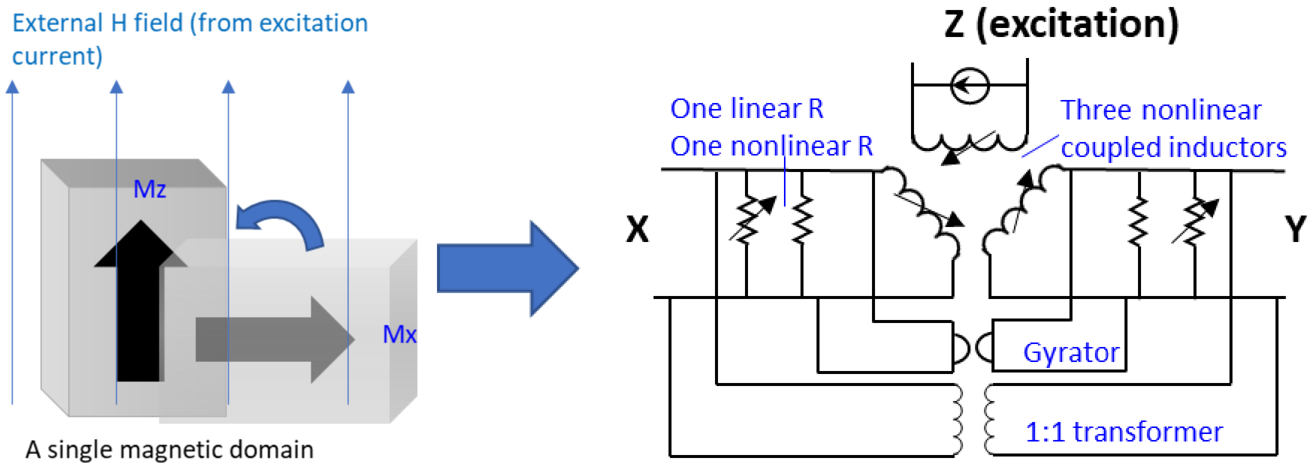


Special coil design showing up to 300 MHz bandwidth

A Multiscale Physics-based Magnetics Design Framework for Ship Scale Power Electronics

Project Objectives

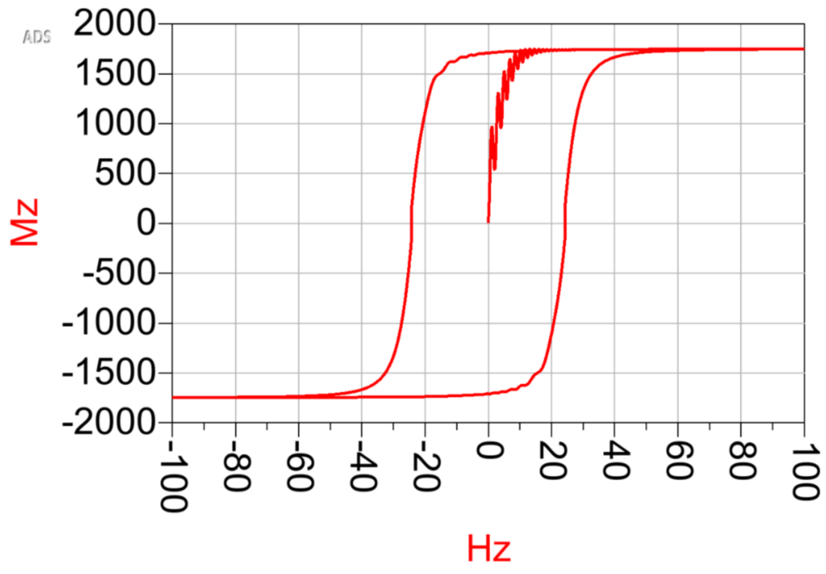
- Using physics-based modeling for magnetic material and component to
  - ➢ Optimize high-frequency magnetic component design trade-offs by understanding material-component characteristics relations;
  - ➢ Propose high-permeability, low-loss, and high-saturation materials solutions (e.g. for high-frequency transformers for naval-rated high voltages);
  - ➢ Benchmark emerging material concepts/strategies for efficient inductors and transformers via virtual prototyping



Equivalent circuit model for magnetic domain movement

Recent Achievements

- Derived and improved the equivalent circuit for the LLG equation to describe the single domain movement
- Implemented the equivalent circuit in ADS to visualize the domain rotation and hysteresis



Magnetization and hysteresis loop simulated from circuit model based on physics (for the first time)

CURENT

Leon Tolbert – The University of Tennessee

- **Chancellor’s Professor and Min H. Kao Professor**
  Adjunct Participant at ORNL

- **Research Interests: Power electronics for grid and transportation applications, microgrids, energy storage, wide bandgap power electronics applications**

- tolbert@utk.edu

2022 Research Projects

1. Emulation of Asynchronous Hybrid AC/DC Microgrid with Power Conditioning System (DOE)
2. Microgrid Platform Development for Testing Inverter-based Generation Control Parameters (DOD)
3. High Short-Circuit Fault Current Contribution to Enable Legacy Overcurrent Protection for Islanded Microgrids (ORNL)
4. Fault Detection Method by Utilizing Instantaneous Power Theory for Inverter-based Distributed Generation
5. SOC Management for PVSS considering LVRT Operation
6. Secondary Use of EV Batteries for Grid Energy Storage (Volkswagen, EPB)
7. Embedded GaN Power Module for High Frequency 400V/>20A Operation with Double-Sided Cooling and Integrated Gate Drive (PowerAmerica - NREL, GaN Systems)
8. WBG Graduate Student Traineeship (DOE)

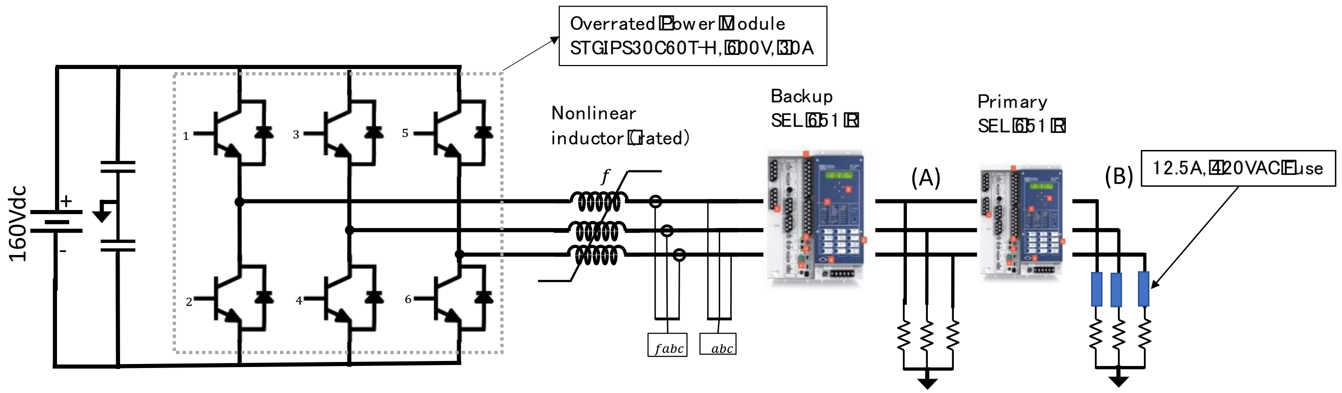
High Short-Circuit Fault Current Contribution to Enable Legacy Overcurrent Protection for Islanded Microgrids

Project goals

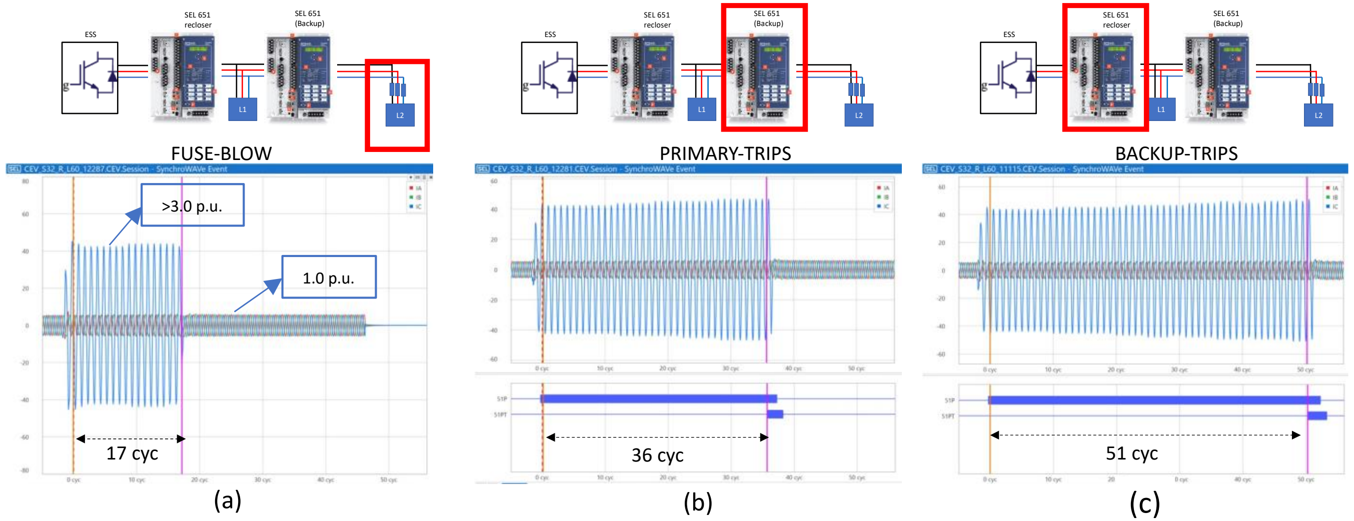
- Examine ways to allow existing overcurrent protection to be used in grid-connected microgrids so they also can work in island mode.

Accomplishments

- Tested inverter with nominal rated devices and overrated devices (3X current rating for IGBTs and diodes) for short circuit interruption.
- Developed control technique to compensate for inverter filter saturation during short circuit event.
- Cost increase to overrate power electronics <10% overall inverter cost.



Inverter with overrated power electronic devices (IGBTs and diodes)



Short circuit interruption with inverter providing 3X fault current

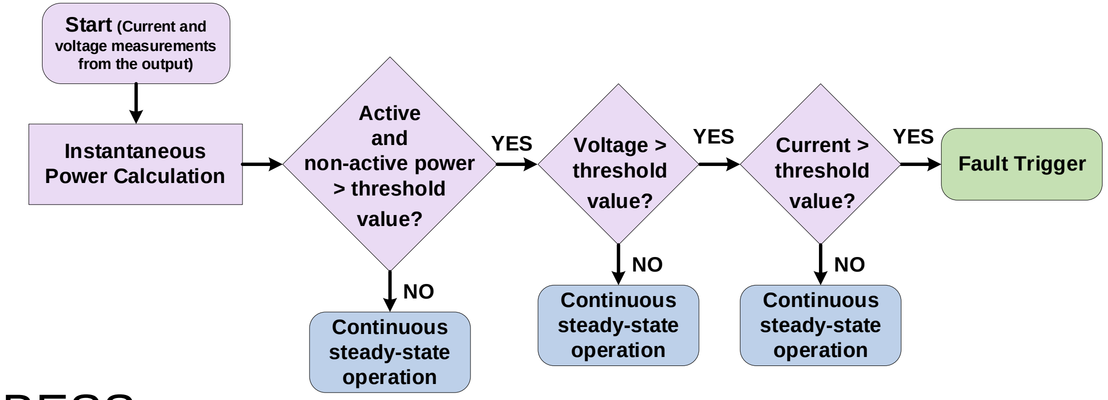
Fault Detection Method by Utilizing Instantaneous Power Theory for Inverter-based Distributed Generation

Project Objectives

- Develop fault detection method for Inverter-based Distributed Generation.
- Test fault detection method in a HTB microgrid system.
- Verify performance of fault detection method.

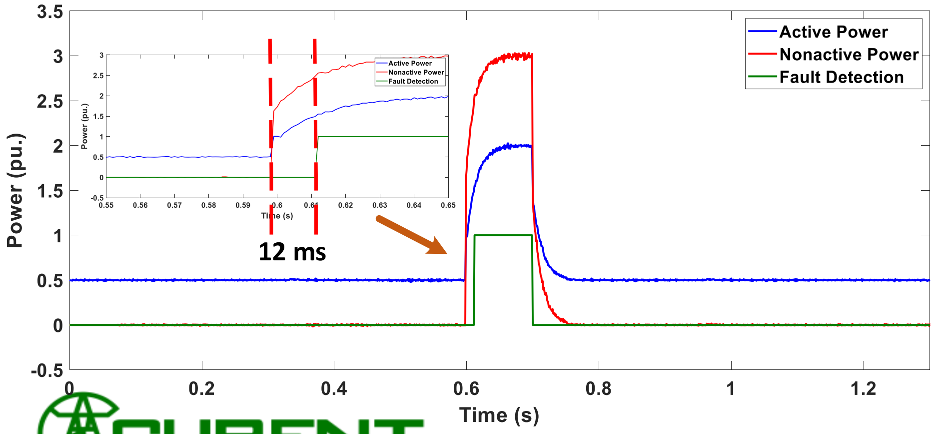
Recent Achievements

- Fault detection method has been implemented in control of BESS located in microgrid.
- Faults have been emulated at different buses.
- All faults in the microgrid have been detected accurately and quickly.

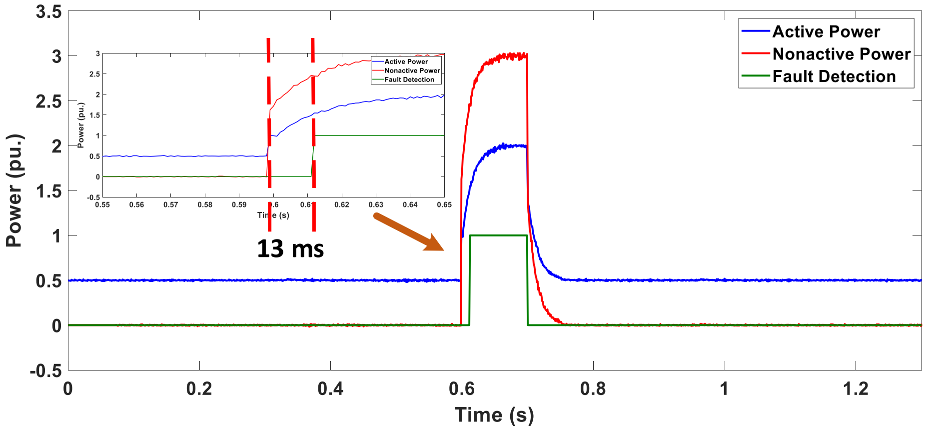


Fault Detection Method

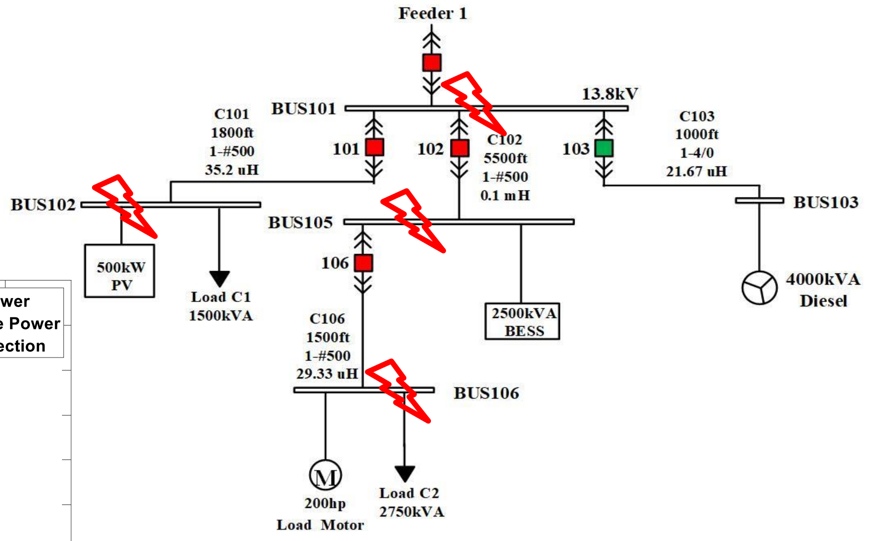
BESS instantaneous power calculation and fault detection during a fault



BUS 102



BUS 105



Fault emulation in HTB

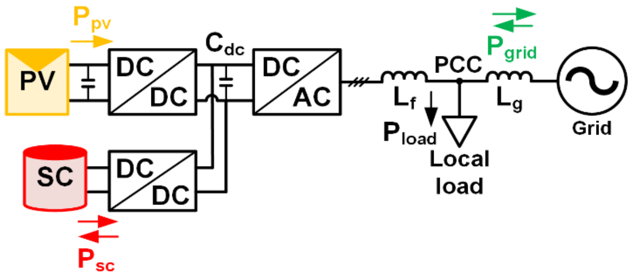
SOC Management for PVSS Considering LVRT Operation

Project Objectives

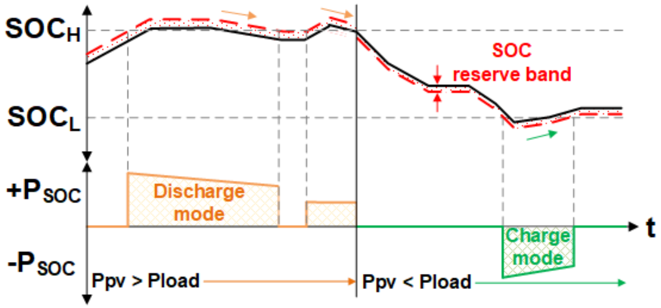
- Propose a SOC reserve concept for a grid-connected PV with supercapacitor system (PVSS) to provide low-voltage ride-through (LVRT) operation.
- Proposed SOC management control considers grid conditions by implementing voltage sensitivity factor, PVSS converters' ratings, and supercapacitor rating (voltage, current, temperature) to safely operate and maximize the PVSS capacity while not violating the grid voltage limits. Thus, the SC can be available for the next events as soon as possible.

Key Takeaways

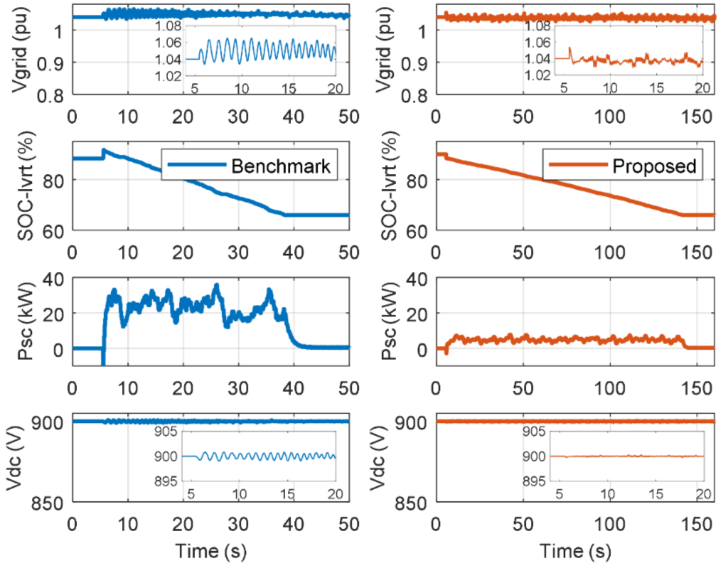
- Availability of the SC can be ensured during LVRT operation to avoid the slow response of PV curtailment that reduces the stability of PVSS during grid faults.
- The proposed scheme can provide dynamic SOC reserve levels rather than the fixed reserve margin under different PVSS operating conditions to effectively utilize the use of the SC.
- The proposed SOC management is developed to fully utilize the SC capacity by incorporating the SC thermal model to determine the SC current according to the SC thermal limitation.



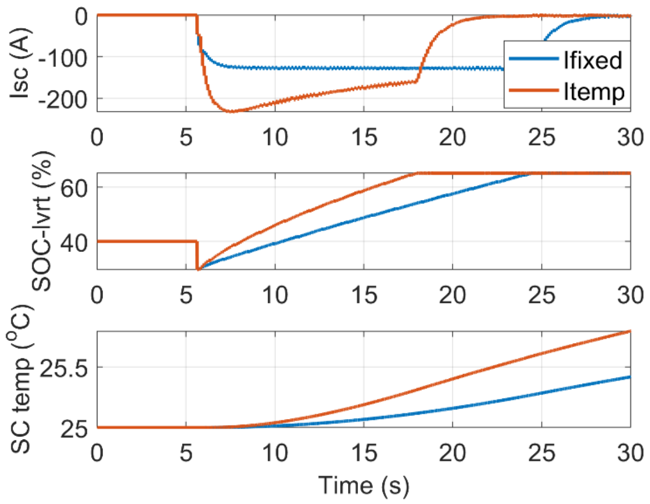
Schematic of a grid-connected photovoltaic with supercapacitor system (PVSS).



SOC reservation concept for LVRT operations



Experimental results of SOC management based on the constant setpoint power (blue) and the proposed method with adjusted power based on grid condition (red).

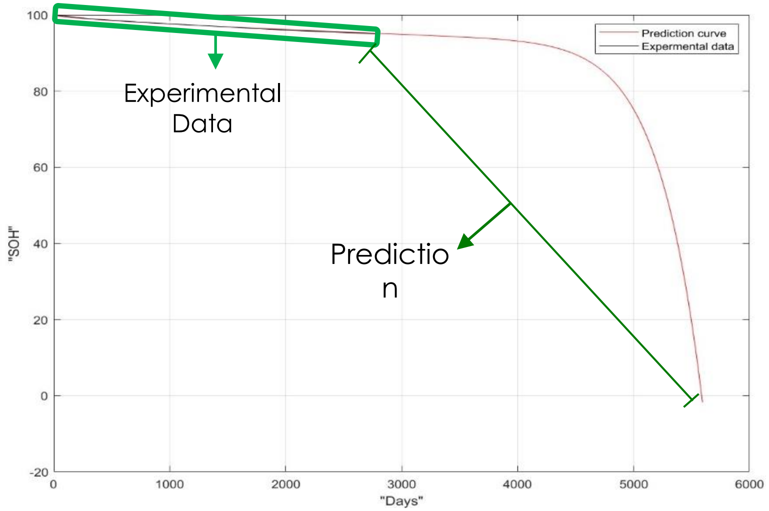


Experimental results of SOC management based on the fixed current (blue) and the current depending on the SC temperature (red).

Secondary Use of EV Batteries for Grid Energy Storage

State of Health (SoH) estimation

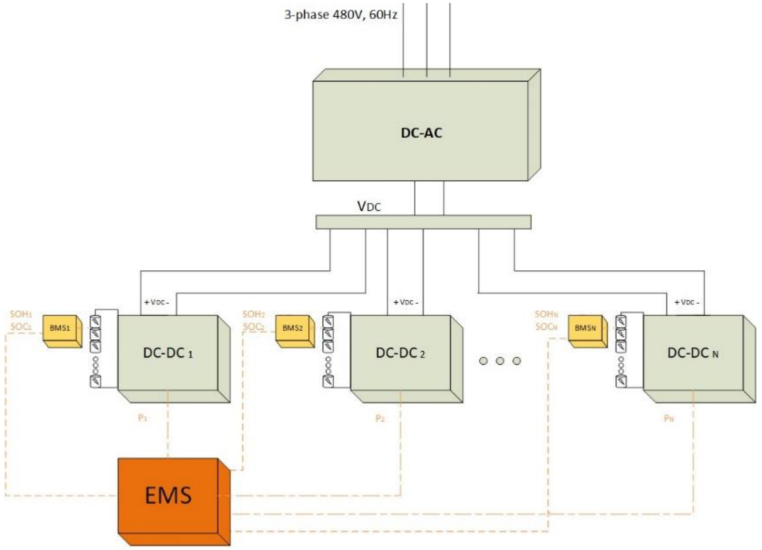
- Battery health plays a significant role to know if battery is properly functioning.
- Battery degrades due to both calendar ageing and cycling ageing.
- Considering both ageing mechanisms, the accelerated lifetime of battery can be implemented to predict the lifetime of battery.



Expected lifetime of the battery using accelerated life test method

BESS architecture

- Build a modular BESS, with building blocks of 50 kW scaling up to 500 kW-1 MW.
- Accommodate more than one type of battery (different characteristics and voltage window).
- Power share control based on SOH and SOC.
- Use off the shelf power converters, based on a cost-benefit analysis.



BESS topology

CURENT

VOLKSWAGEN GROUP OF AMERICA

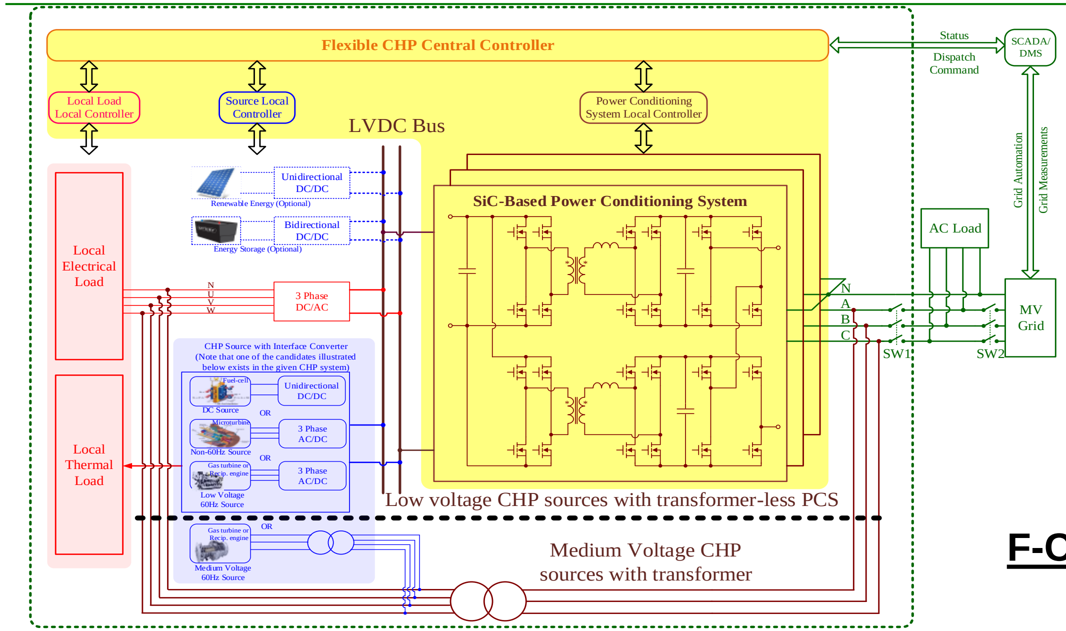
Fred Wang Personal Info

- **UTK Professor and Condra Chair of Excellence in Power Electronics, CURENT Technical Director, ORNL joint faculty**
- **Research Interests: Wide bandgap power electronics, power electronics for grid and transportation applications**
- **fred.wang@utk.edu**

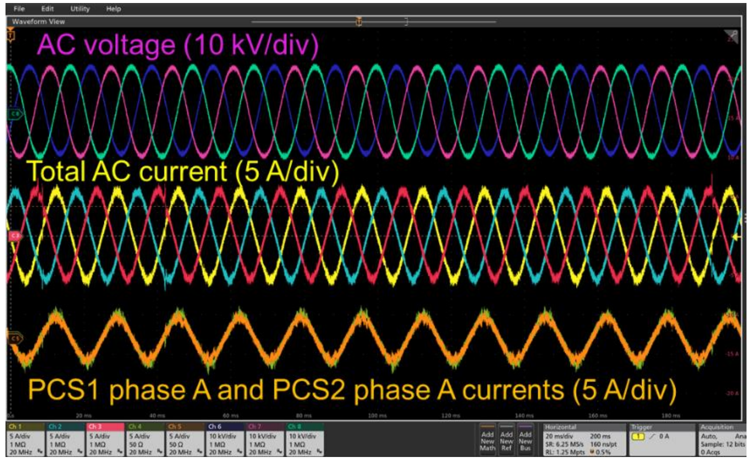
2022-2023 Research Projects

1. SiC based transformer-less MW-scale PCS and control for flexible CHP (DOE)
2. SiC based modular transformer-less MW-scale PCS and control for flexible manufacturing plants (DOE)
3. Operation and control of large-scale power electronics based power grids (ORNL)
4. Transient Modeling and Controls of Power Electronics-Based Power Grids (ORNL/DOE SETO)
5. Resilient Operation of Networked Community Microgrids with High Solar Penetration (ORNL/DOE SETO)
6. A Low Cost Hybrid AC/DC Scheme for Increased Transmission Capacity (ORNL/DOE)
7. Ultra-Light Tightly-Integrated Modular Aviation-Transportation Enabling Solid-State Circuit Breaker (ARPA-E, Boeing)
8. Development of High-density and High-efficiency AC/AC Converter using Wide-band-gap Devices (Boeing)
9. Power electronics based MW universal tester (UTK internal)

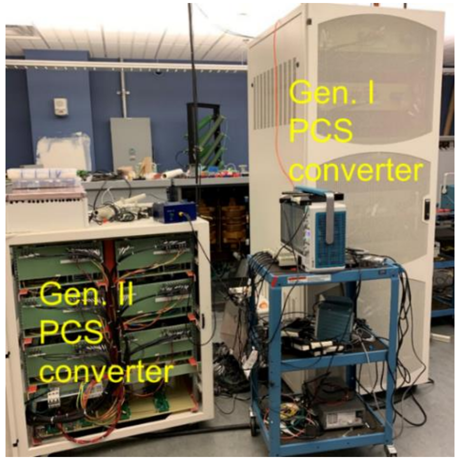
10-kV SiC Based Modular Transformer-less MW-Scale Power Conditioning System & Control for Flexible CHP (F-CHP) and Flexible Manufacturing Plant



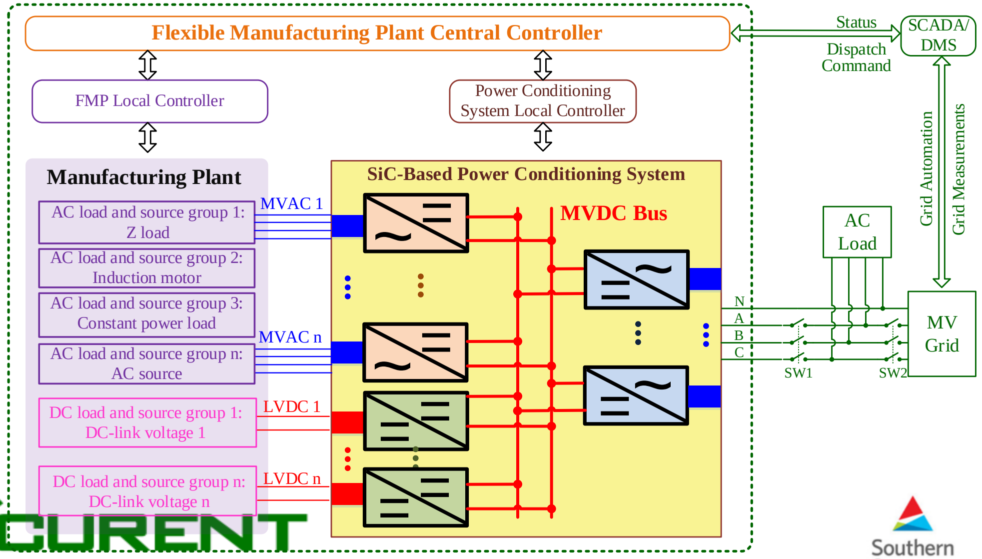
F-CHP and FMP system configuration

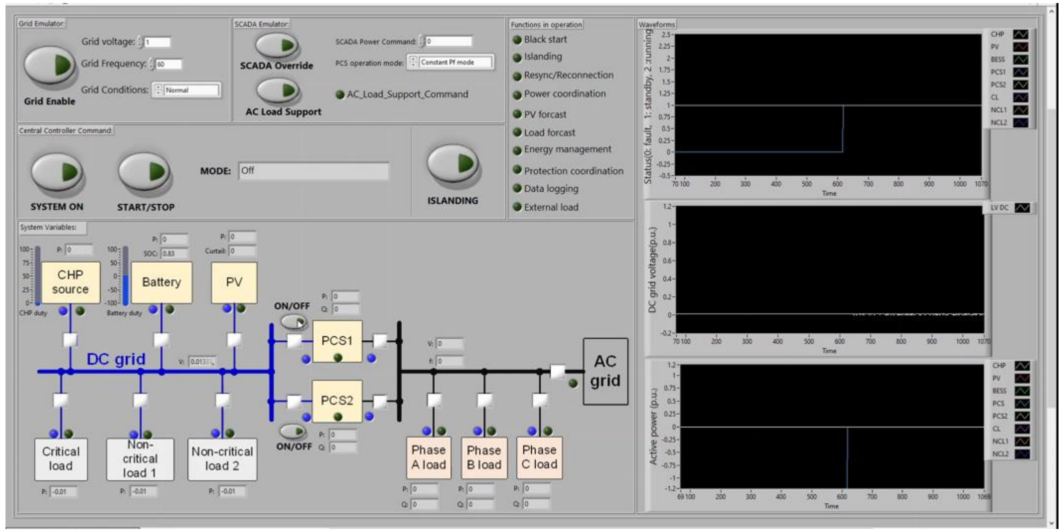


F-CHP PCS converter waveforms @ 13.8 kV/200 kVA



F-CHP PCS converter prototypes



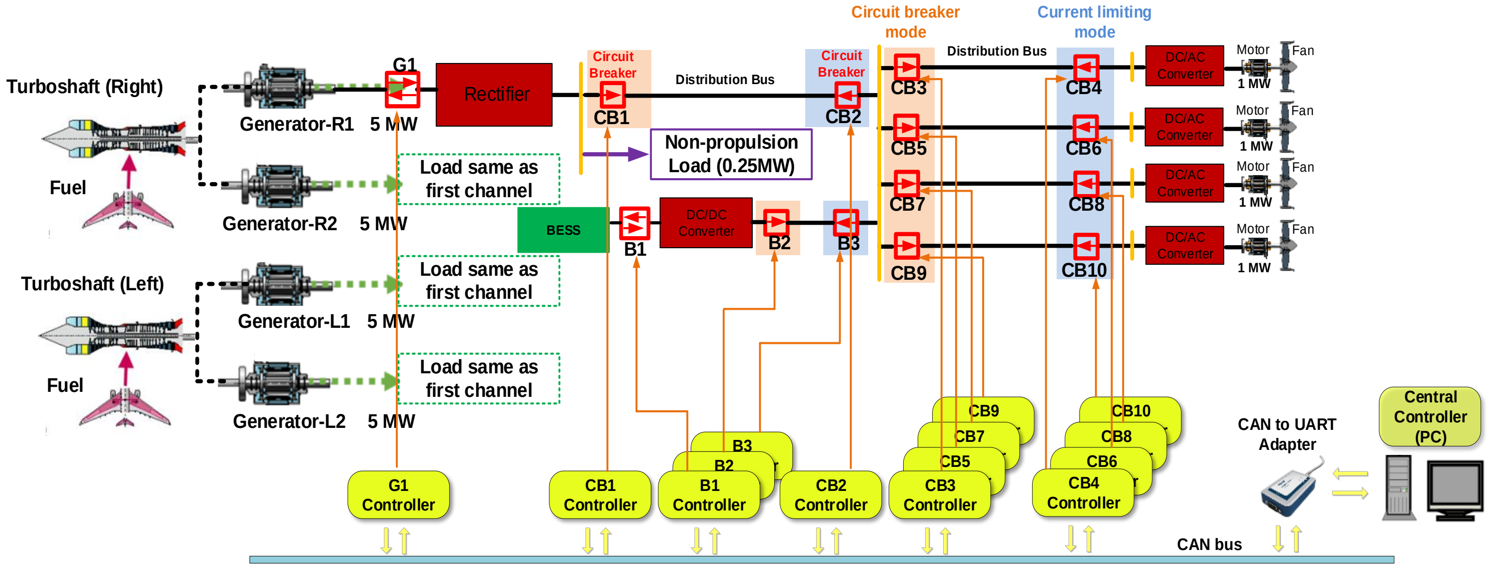


F-CHP PCS controller HTB test interface

Ultra-Light Tightly-Integrated Modular Aviation-Transportation Enabling Solid-State Circuit Breaker (ULTIMATE SSCB)

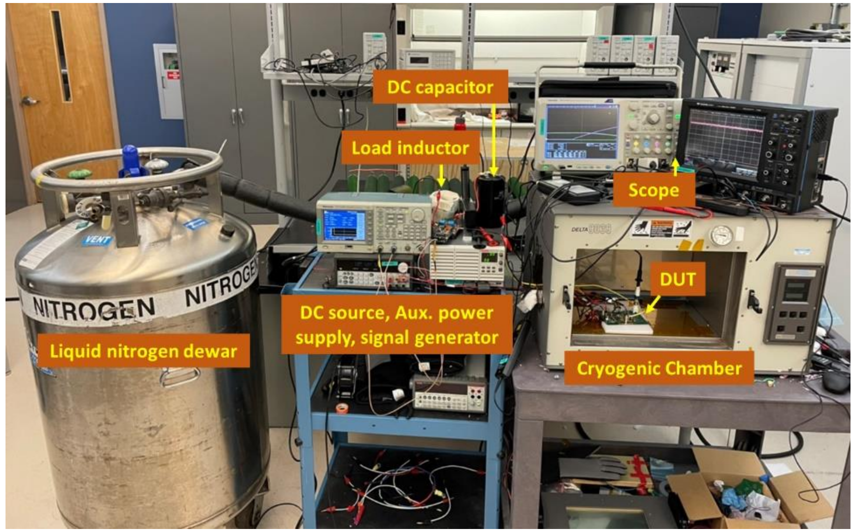
Project Objectives

- Develop a 10 kV, 100A, solid-state circuit breaker for future medium voltage electrified aircraft propulsion (EAP) system.
- Cryogenic cooling by liquified natural gas (LNG) or liquid hydrogen fuel of future EAP utilized to achieve >99.9% efficiency and >300 kW/kg module power density.
- Design to work reliably at 40,000 ft altitude.

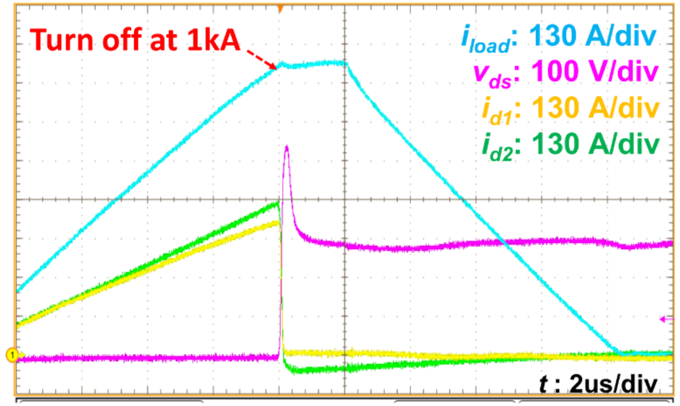


EAP system model under study

Cryogenic test bench setup



Developed SSCB module



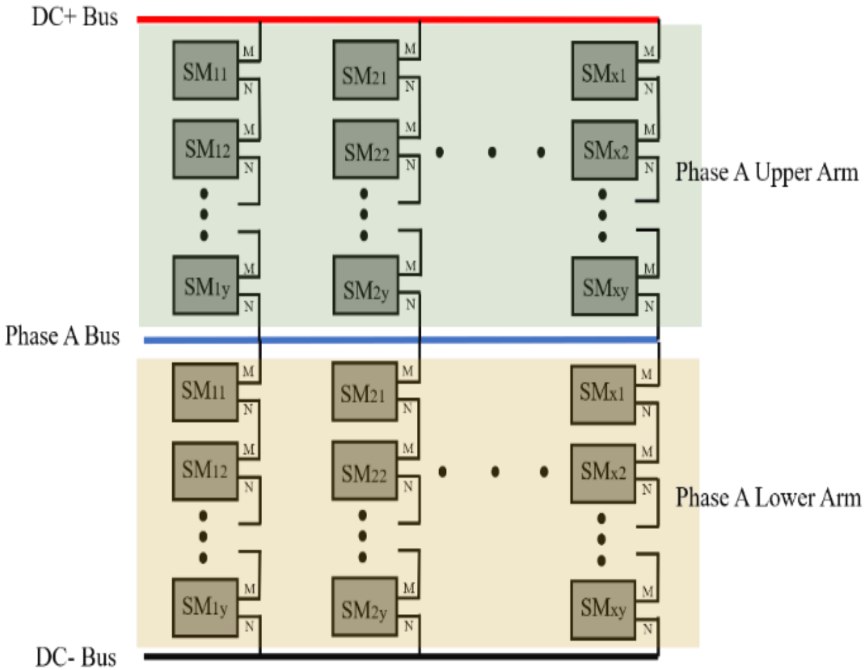
1kA turn-off test of the SSCB module @-180°C

CURENT | THE UNIVERSITY OF TENNESSEE KNOXVILLE | UNIVERSITY OF HOUSTON | CLEMSON | BOEING

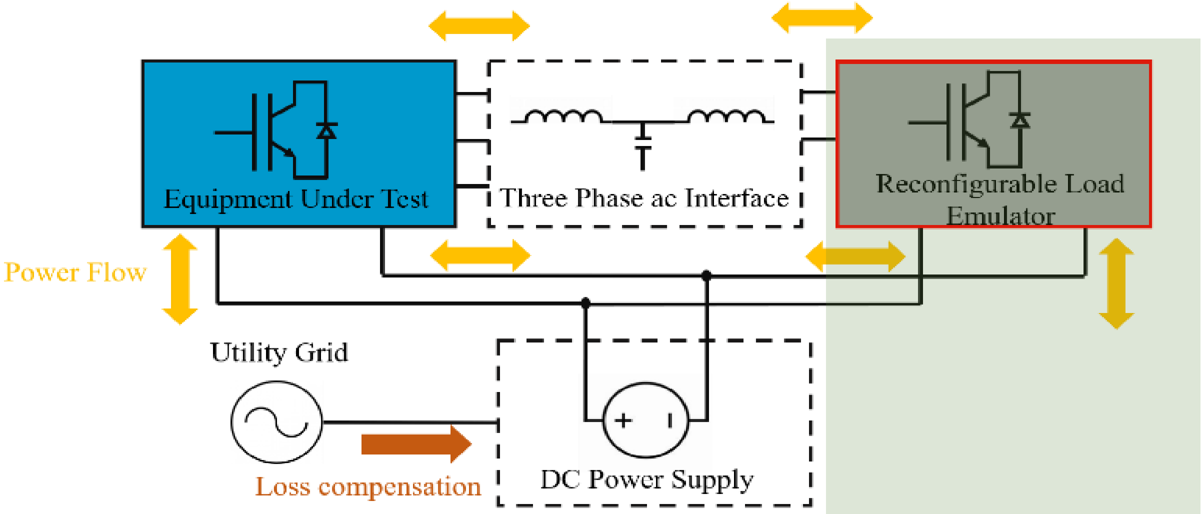
Mega-Watt Power Electronics Based Universal Power Tester

Project Introduction

- Develop a versatile testing platform at MW level with different voltages (480 V to13.8 kV) and frequencies (10 to 3000 Hz)
- Based on MMC topology to enable flexible reconfiguration for covering wide operation range



Power tester topology (Phase A, B, C are identical)



Test set up with universal power tester

Fully assembled modules under testing

CURENT

Chien-fei Chen Personal Info

- **Research Associate Professor, CURENT Education/Diversity Director**
- **Research Interests: energy justice, environmental sociology, social-technological integration, community resilience**
- **cchen26@utk.edu**

2022-23 Research Projects/Highlights

Recently Completed

1. Co-PI, "SRS RN: Connecting Rural and Urban Environments for Equitable Access to Transportation, Telecommunications and Energy (CREEATTE)", **NSF**; 11/1/2021-10/31/2022.

Recently awarded and on-going

1. Lead PI, "A Community Co-Designed Weatherization and Microgrid Plan for Equitable Energy Security and Environmental Health, Wellcome Foundation, London; 8/1/2023-5/31/2026.
2. Co-PI, Smart Connected Community (SCC-IRG) Track 1: "Advancing Human-Centered Sociotechnical Research for Enabling Independent Mobility in People with Physical Disabilities," NSF, 10/2022-9/2025.
3. Co-PI, "Strengthening American Infrastructure (SAI-R): Community-centered Decision-making Framework for Microgrid Deployment to Enhance Energy Justice and Power System Resilience," NSF; 9/2022-8/2026.

Major proposal in process: NSF Global Center Track 1 for Resilient, Equitable, ENergy Systems for ALL (GREEN for ALL).

Energy burdens, utility hardship and health

Project goals and previous accomplishments

- Investigate energy burdens, utility hardship and environmental health among low-to-moderate income households from 2014-2018 and 2020 based on DOE LEED tool and census tract data
- Examine the link between social vulnerability factors and energy burdens

Recent activities

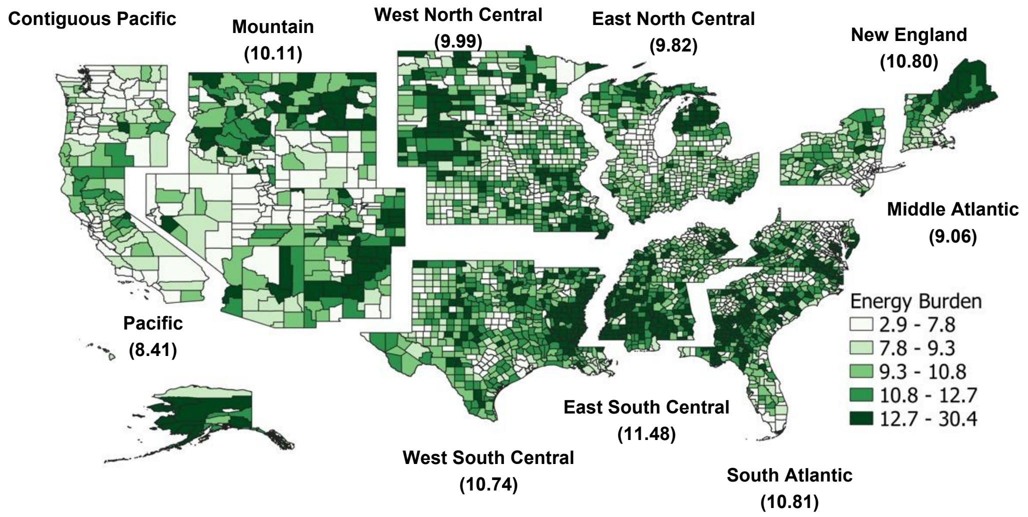
- Collected three samples in CA, FL and New York during the pandemic to understand energy and internet burdens, energy use patterns, technology adoption intention, and experiences of utility hardship (tradeoff, disconnected utility, unsafe temperature), indoor environment quality & health impacts
- Collected energy justice data in the UK

Future works

- The impacts of energy and internet and transportation burdens on physical and mental health

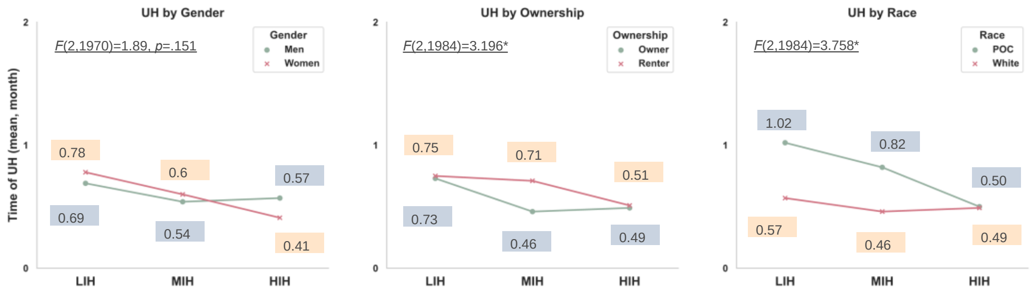
Pi-Chien-fei Chen

Students: Johnathan Shield



Utility Hardship *and Interaction of* Income* Gender / Ownership / Race

How many month has the participants experienced UH from March to June 2020 (within 4 month)



- **LIH women** have the highest UH. HIH men have higher UH than women.
- **LIH renters** have the highest UH than owners.
- **LIH POC** have highest UH. No significant difference between HIH POC and white residents.

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Strengthening American Infrastructure: Community-centered Decision-making for Microgrid Deployment to Enhance Energy Justice & Power System Resilience

Project goals and previous accomplishments

- Energy justice and the conflicts between altruism for LIHs and self-interest has not been explored in the deployment of microgrids or renewable technology adoption

Recent activities

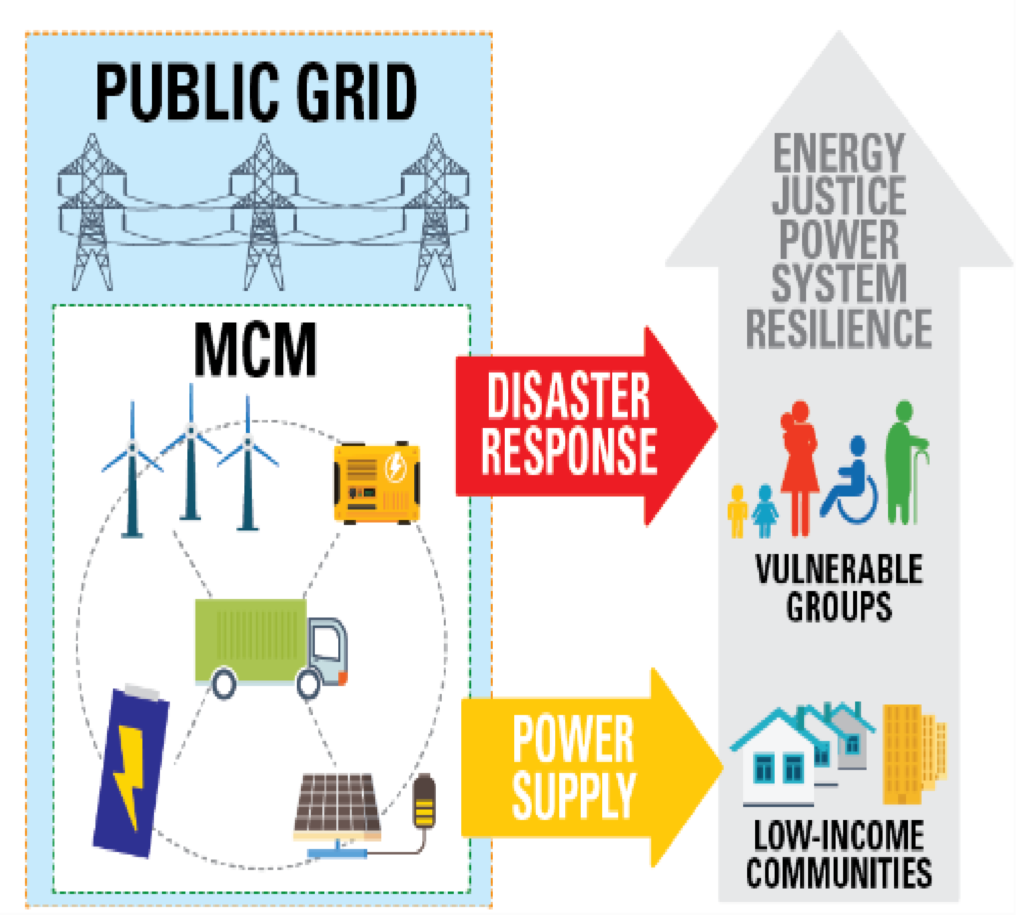
- Develop a collective decision-making framework to understand the barriers influencing Mobile Community Microgrid (MCM) adoption
- Design MCMs to assist disaster responses for low-income Households (LIHs); consider the factors of enhancing power system resilience and energy justice.
- Estimate social-psychological (trust, sense of community) and behavioral factors influencing willingness to pay for MCM
- for LIHs.
- Develop community co-design approaches and explore the impact of behavioral interventions on the MCM acceptance

Future works

- Survey and community engagement

Pis – Yu Wang, Chien-fei Chen

Students: Julia Cavas



MCM Concept for Assisting Low-income Households lead by Iowa State & University of Tennessee