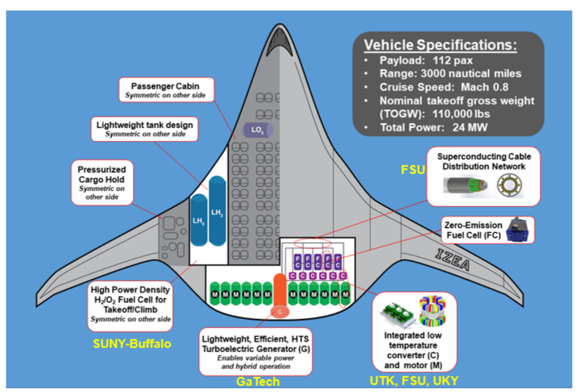
Integrated Zero-Emission Aviation using a Robust Hybrid Architecture

Project Lead: JiangBiao He (UTK) **Graduate Students and Research faculty/associates:** Farzad Y. Notash (UTK)	
Project Duration: 05/2022 – 05/2027	
Funding Source: NASA (Lead: Florida State University)	

Summary

The proposed project is an academic-industry collaboration focused on achieving zero emissions from longer-range (>3000 nautical miles) aircraft transporting at least 100 passengers. Avoidance of CO2 emission motivates novel hybrid hydrogen-electric propulsion architectures. Our approach considers hybrid electric power generation via a combination of turboelectric generators and fuel cells (FC) using liquid hydrogen. Avoidance of NOx emission, efficiency augmentation, and high-power mission segments drive consideration of liquid oxygen (LOx) during takeoff and climb. The cryogens facilitate use of superconductors to increase power density of the distribution system, generators, and motors, and the presence of multiple temperature zones from 20 to 400 K offers opportunities to decrease the impact of thermal management systems on efficiency and weight. Experts in electric power, energy storage/conversion, propulsion, cryogenics, superconductivity, thermal management, motors, power electronics and distribution, and aircraft systems with an extensive collaborative history and unmatched capabilities and facilities will conduct modeling, design trade studies and multi-disciplinary design optimization, combined with subsystem demonstrations of key components for validation and implementation.

- Program: NASA University Leadership Initiative (ULI)
- Project period: 5 years (May 2022 – May 2027)
- Total award: $10M
- Lead Org: Florida State Univ.
- **Academic partners**: UTK, UKY, IIT, Georgia Tech, SUNY-Buffalo.
- **Industry partners**: Boeing, Raytheon Technologies.



Key Objective: The UTK team's project objective is to support the hybrid-electric aircraft propulsion inverter and motor development, in addition to leading the tasks of motor control and online health monitoring of the propulsion drive systems.

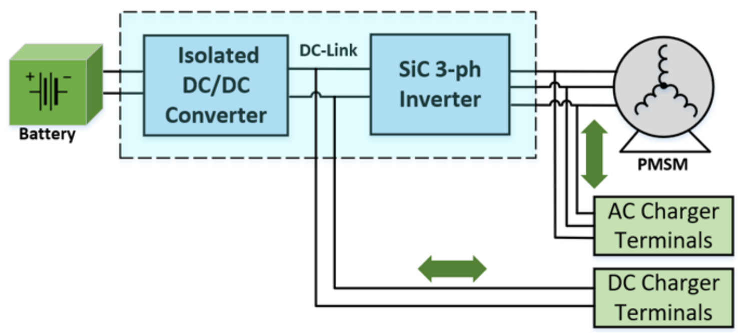
Multi-Input Integrated Smart Charger-Inverter System for Electric Vehicles

Project Lead: JiangBiao He (UTK) **Graduate Students and Research faculty/associates:** Abdel Habib (UTK)	
Project Duration: 11/2024 – 11/2027	
Funding Source: Department of Energy (Lead: Western Michigan University)	

Summary

This project is to develop integrated charger-inverter (ICI) technologies that enable existing electric vehicle (EV) inverters to serve as a bi-directional charger, while optimizing the overall system for high efficiency, high power density, and low cost, eliminating the need for on-board or off-board chargers. The elimination of a separate charger dramatically reduces overall system cost, mass, and volume while enabling the vehicles to seamlessly integrate with vehicle-to-grid (V2G) and charging while driving technologies. Advanced magnetics and dual active bridge based galvanic isolation enable real-world high-power energy transfer to the vehicle. The hardware developed will be integrated into a vehicle and validated across a range of charging, driving, and regenerative braking profiles. The project is only possible through DOE funding and it facilitates outcomes and impacts aligned with the DOE VTO/EERE mission.

- Project period: 3 years (2024 – 2027)
- Total project award: $3.179M
- Lead Org: Western Michigan Univ.
- **Academic partners & national lab**: UTK, UKY, ORNL
- **Industry partners**: John Deere Corporation, and BorgWarner Inc.



Key Objective:

The UTK team's project objective is to develop and demonstrate a 150-kW integrated charger-inverter system that contains multiple input interface for both AC and DC fast charging, compatible for both 400V and 800V EV systems, at high efficiency (>98%) and high power density (>10kW/L).

Electric Machines with Adaptive Surge Impedance

Project Lead: JiangBiao He (UTK)

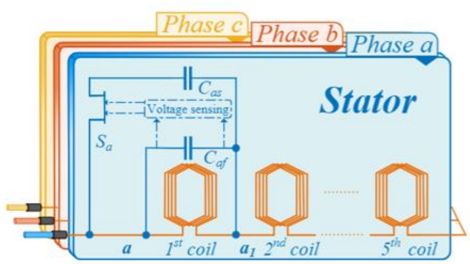
Graduate Students and Research faculty/associates: Mohamed Farag (UTK)

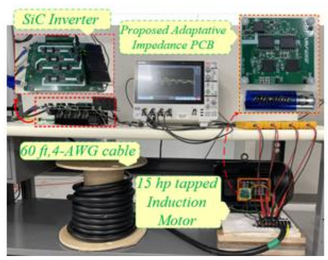
Project Duration: 04/2022 – 07/2026

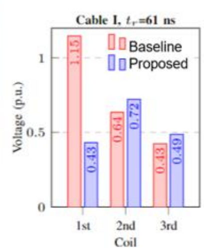
Funding Source: Office of Naval Research (ONR)

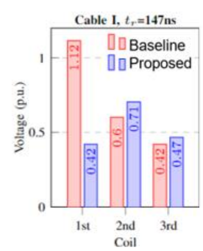
Summary

Recent advancements in power electronics have enabled more-electric propulsion systems, realizing higher efficiency, lower acoustic noise, lower emissions, and less operating costs. Furthermore, power electronic devices with higher voltage levels such as medium-voltage DC (MVDC) and faster semiconductor switches are desired to design electric propulsion systems to achieve higher efficiency and power density. The combination of these desired technologies results in undesired technical challenges for propulsion motor designers. The high voltage rate creates traveling waves in the cables between the drive and motor, and thus, generates high-frequency voltage ringing across the stator windings with high-voltage spikes. This voltage stress has adverse effects on the motor, including motor insulation stress and harmful bearing currents. Though this is a known phenomenon, the trend toward using wide bandgap (WBG) switches, such as Silicon Carbide (SiC) and Gallium Nitride (GaN) power transistors, in propulsion systems requires novel solutions to mitigate the high-frequency high-voltage stress that degrades the motor lifetime. The voltage stress on motor insolation can conduct to incipient faults, a cascaded propulsion system's failure, and extra expenses associated with unexpected maintenance. We propose an adaptive surge impedance solution to enhance motor performance in WBG-based motor-drive systems, which adaptively matches surge impedance of the cables and the motor.









Key Objective:

This project aims to develop an adaptive surge impedance technology for propulsion AC motors that can mitigate any reflected surge voltages, without compromising the power density and efficiency of the motor-drive systems in safety-critical propulsion applications such as electric ships. Specifically, the motor coil surge impedance can be automatically adjusted in the adaptive surge impedance technology by implementing a parallel variable impedance branch based on WBG switches. The merit of the proposed technology is eliminating the need for any bulky and lossy passive filters.

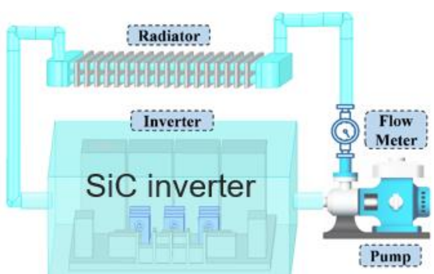
Advanced Immersion Cooled Power Electronic Converters

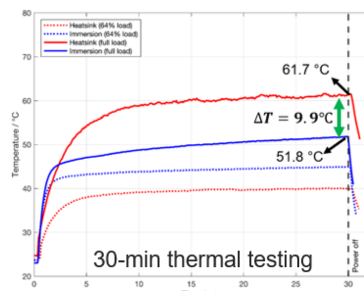
Project Lead: JiangBiao He (UTK) **Graduate Students and Research faculty/associates:** Yiju Wang (UTK), Reza Ilka (UTK)
Project Duration: 07/2023 – 08/2026
Funding Source: Valvoline Global Operations

Summary

Power electronic converter is a critical power management unit interfacing battery energy storage and traction motor for electric propulsion systems in transportation vehicles (ground vehicles, aircraft, ships, etc.). Generally, the most important criteria to evaluate the technical performance of a power converter include: energy efficiency, reliability, cost, and power density (i.e., size and weight). The conventional air cooling or indirect liquid cooling technologies significantly constrain the further improvement of power converters' efficiency, reliability, and power density. Thus, it is indispensable to develop novel cooling technologies.

Based on the continuous support from Valvoline Global Operations, our team has investigated the thermal management capability of immersion cooled power converters, in comparison to conventional air-cooled power converters. Our multi-physics modeling, simulation, and preliminary experimental verifications show that the immersion cooled power converters have significant advantages over the traditional cooling methods, such as homogenous cooling for all the power devices, elimination of thermal runaway risks, and dramatically improved dielectric insulation capability.





Key Objective: (1) Conduct comparative experiments between the immersion cooling and the conventional cold plate based indirect liquid cooling. Under the same operating conditions, we plan to characterize the specific benefits of immersion cooled power electronics versus its counterpart with cold plate based indirect liquid cooling. (2) Considering that immersion cooling is much more homogenous on thermal management of power electronics, which is expected to mitigate the aging/fatigue of soldering joints on the power circuit boards or semiconductor modules. (3) Dielectric insulation testing to demonstrate the merits of immersion cooled SiC converters.

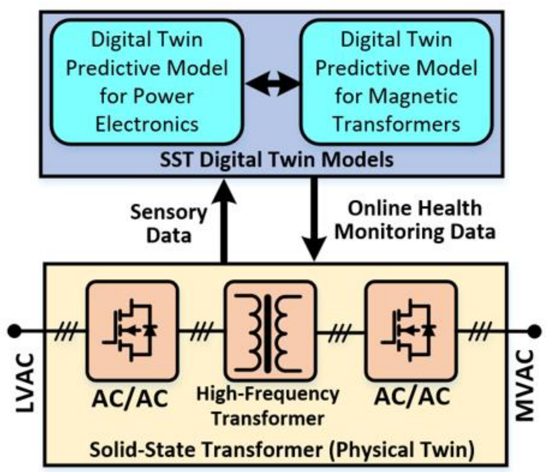
Digital Twin Predictive Health Monitoring of Solid-State Transformers

Project Lead: JiangBiao He (UTK) **Graduate Students and Research faculty/associates:** Xin Gao (UTK)	
Project Duration: 09/2023 – 09/2026	
Funding Source: National Science Foundation (NSF)	

Summary

Solid state transformer (SST), a new type of smart power electronic transformer which is much more compact than the conventional electromagnetic transformer, has been deemed as a revolutionary technology for future-generation power systems. However, one major technical barrier that constrains the further development of SST is the low reliability compared to the conventional electromagnetic transformers, due to the large number of semiconductor devices utilized. Currently, the reliability of SST has received little attention. To address this challenge, this project will develop a comprehensive systematic framework of online health monitoring for resonant SSTs, in order to significantly improve the reliability to electric failures.

The proposed health monitoring framework will include online prognosis and diagnosis of potential electrical faults that could occur to SST, targeting at common semiconductor switching faults and health degradation in the high-frequency magnetic transformers. Specifically, a portfolio of critical SST parameters will be monitored through a smart gate driver that will be integrated with the power electronic building blocks, so any degradation in the semiconductor modules can be predicted and diagnosed during the fault incipient stage. Active power cycling lifetime extension method for semiconductor modules through improved control strategies will also be developed and implemented, if the estimated lifetime of power converters degrades below a pre-determined threshold target. For the high-frequency transformer within the SST, advanced health monitoring digital twin model will be established, so major electrical aging in the transformer windings and magnetic cores can be predicted online.



Key Objective:

- Develop digital twin based predictive health monitoring models for SST power electronics.
- Develop digital twin based predictive health monitoring models for the winding insulation degradation of the high-frequency transformers in SSTs.
- Experimental verifications of the digital twin models.

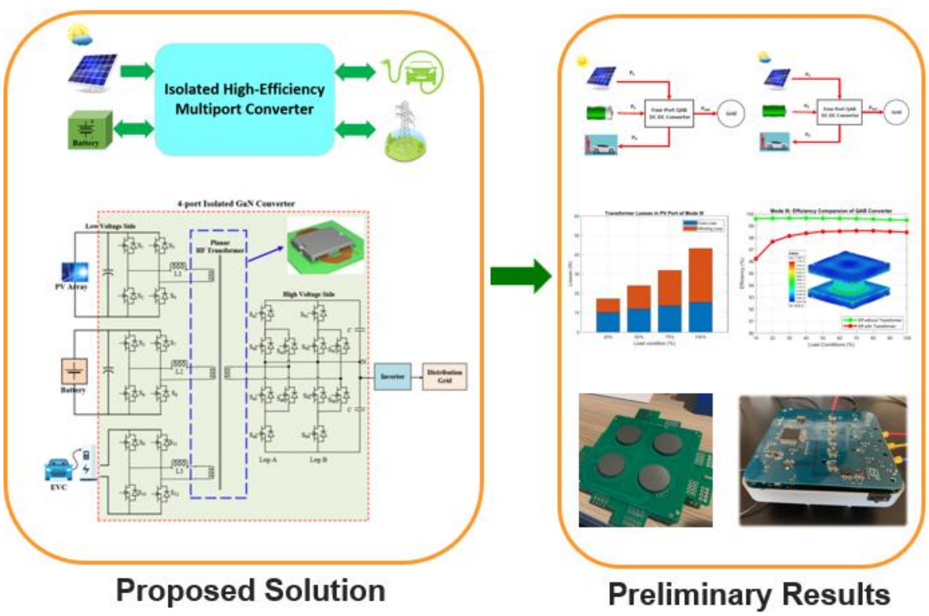
Multiport Quad-Active-Bridge Converters for PV-Battery-EV-Grid Systems

Project Lead: JiangBiao He (UTK) **Graduate Students and Research faculty/associates:** Aaqib Sheikh (UTK), Jim Camp (UTK)
Project Duration: 11/2024 – 09/2026
Funding Source: Department of Energy (DOE)

Summary

The net-zero energy buildings (NZEBs) market is expanding rapidly and is projected to significantly increase in value, highlighting the critical role of innovative energy solutions in achieving sustainable development and reducing global energy disparities.

The proposed Quad-Active-Bridge (QAB) DC-DC converter and high-frequency planar transformer technologies are cost-effective and scalable solutions to form a multiport converter to meet the market challenges for isolated high-efficiency and low-cost power converters. They offer an efficient way to interconnect distributed solar power, energy storage, and EV charging stations, providing a modular, scalable, and high-efficiency energy management solution. These technologies enhance energy distribution and utilization and align with the growing market demands, particularly in net-zero energy buildings.



Key Objective:

- GaN based 15-kW QAB converter hardware prototyping
- Multiport high-frequency planar transformer design and optimization
- QAB converter testing at various operation modes to meet the interconnection standards of distribution grid