Multiport Multi-directional Modular and Scalable Power Conversion Platform with DC/AC Source/Storage Integration using Wide Bandgap Power Electronics

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BACKGROUND

Falling prices, better quality and increased resilience have accelerated demand for electricity in recent years. However, not all sources of energy have fallen in cost equally, and external factors such as price have discouraged widespread adoption.

MOTIVATION OF RESEARCH

This research will develop a novel power conversion platform for interconnecting energy storage and the AC grid. The proposed solution will have greater than 97% efficiency, longer mean time to failure, a 40% reduction in cost, and a 30% increase in power density compared to conventional systems. It will be easily scalable to maximize potential applications and greatly drive down the costs of grid electrification.

RESEARCH OBJECTIVES

- Investigate components and fabrication of a gallium-nitride-based power conversion system to target >95% efficiency.
  - Seamless integration of multiple energy sources with existing loads and local storage systems
  - Facilitate multi-directional power flow with reduced power conversion stages.
- Statistical regression-enabled auto-tuning of TAB control parameters for maximum efficiency tracking with voltage regulation
- Develop high-density energy storage system designed and manufactured in the USA.

PROJECT MILESTONES

Complete	In-Process	Future

Task-1: Design, control, modulation optimization, and hardware development of the three-port dc-ac-dc PCS

- **Subtask 1.1.** TAB converter modeling, component selection, and loss analysis
- **Subtask 1.2.** Switching modulation optimization for maximum efficiency tracking.
- **Subtask 1.3.** PCB layout optimization and thermal management system design

Task-2: Thermal modeling and heat management system design and development for PCS prototype

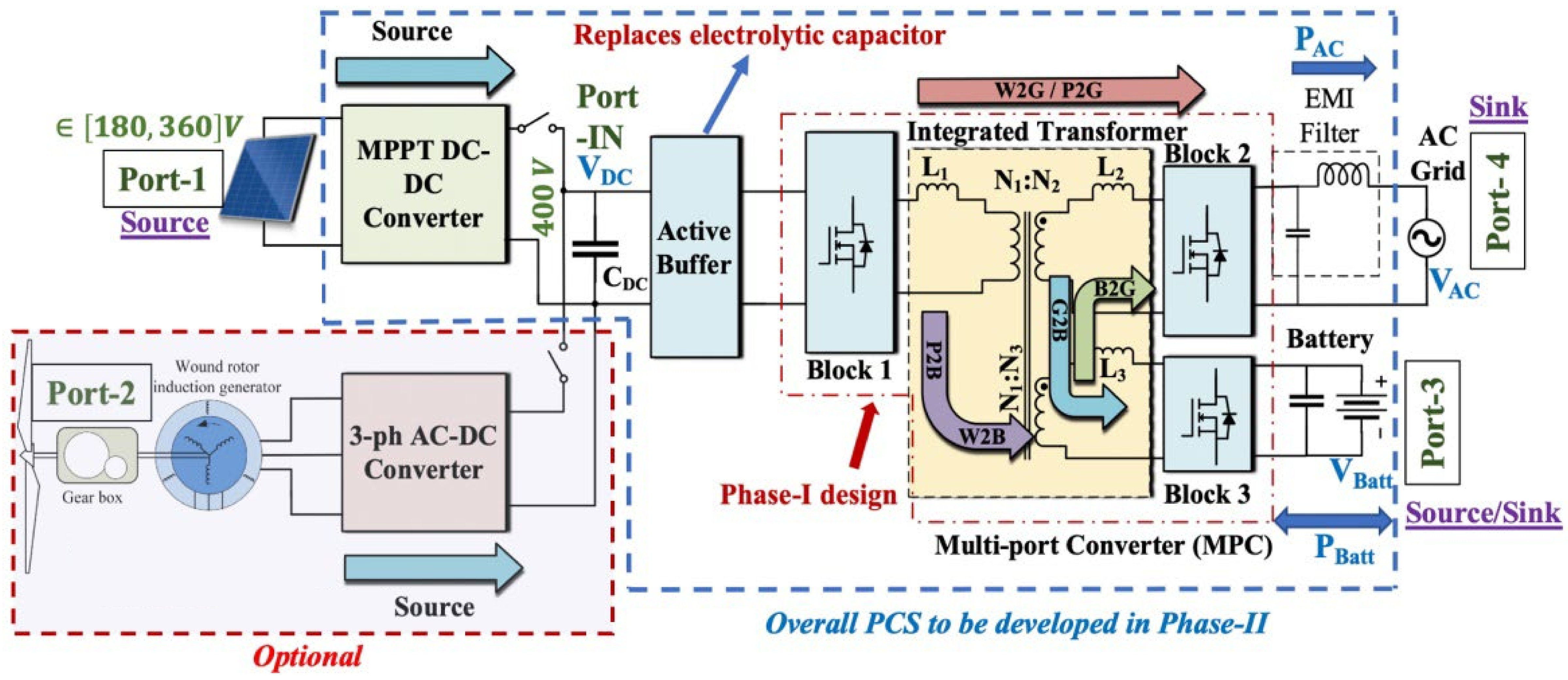
- **Subtask 2.1.** Thermal modeling of the switching network.
- **Subtask 2.2.** Thermal performance of the converter at the selected operating points.

Task-3: Enclosure fabrication and EMI+UL qualification tests for the three-port PCS prototype

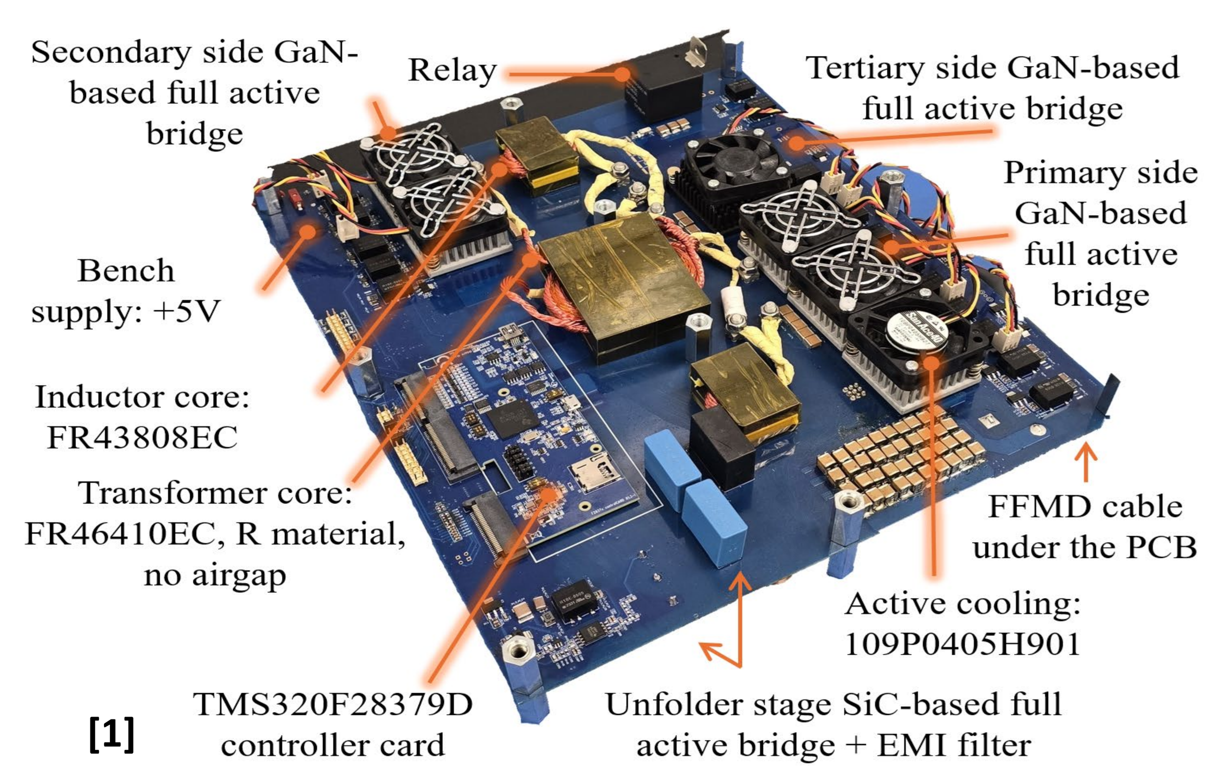
- **Subtask 3.1.** Development of the enclosure using SolidWorks for the PCS hardware prototype
- **Subtask 3.2.** Fabrication and verification of the unit compliance with relevant EMI and UL standards.

Task-4: Experimental verification of the three-port PCS prototype testbed

- **Subtask 4.1.** P2G (2.5kW) and P2B (1.1kW) modes
- **Subtask 4.2.** P2BG mode (2.5kW + 1kW)
- **Subtask 4.3.** PB2G mode



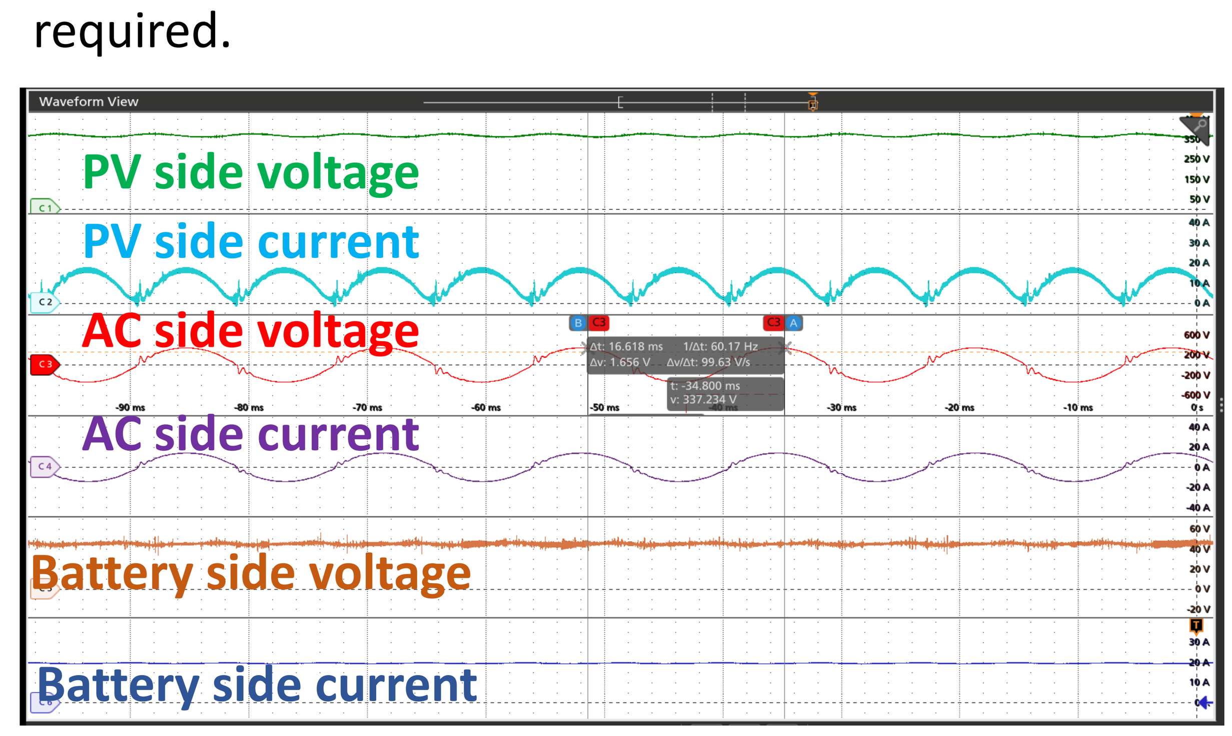
PHASE-I HARDWARE PROTOTYPING



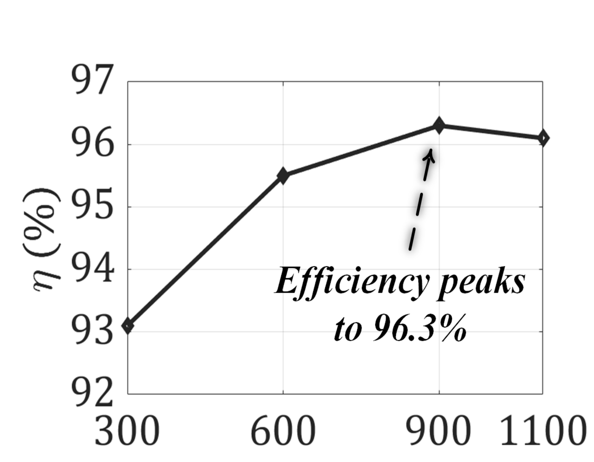
[1]

Source: [180-360]V; Grid: 120V/240V ac rms; Battery: 48V

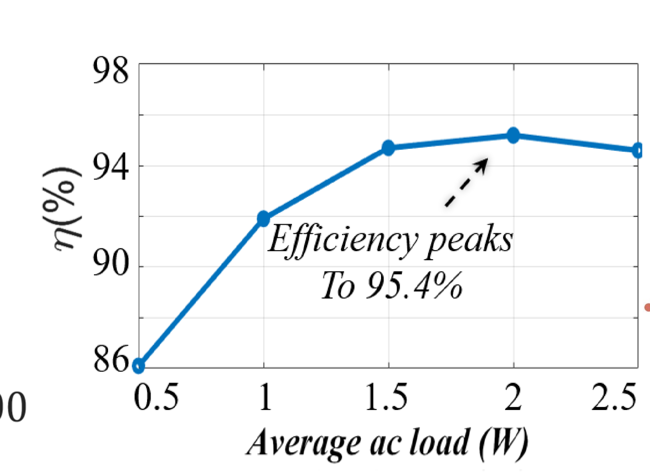
Power-dense PCB design to meet >97% efficiency consisting active cooling heatsinks with ≈2.5cm total height, with laterally-fed DSP control card configuration, and the three-winding transformer and magnetics installed in the middle of the board. Reduced production and maintenance costs, and increased design flexibility, incorporating a relay on the battery side to connect/disconnect the port when required.



Experimental waveforms of the three-port power conversion (P2BG) at the nominal operating conditions, i.e., 360V input voltage, 240V_{rms} at 2.5kW on the AC side, 48V_{dc} at 1kW on the DC side, resulting in 96.9% efficiency and 5.9% THD on the AC port.

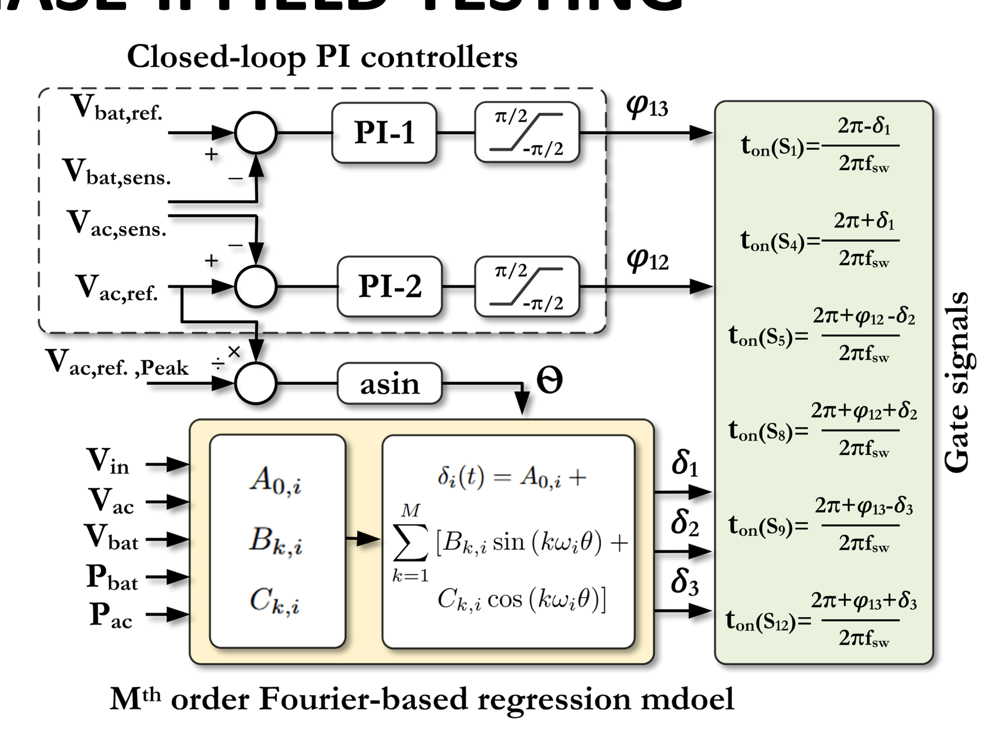


P2B mode (Two port)

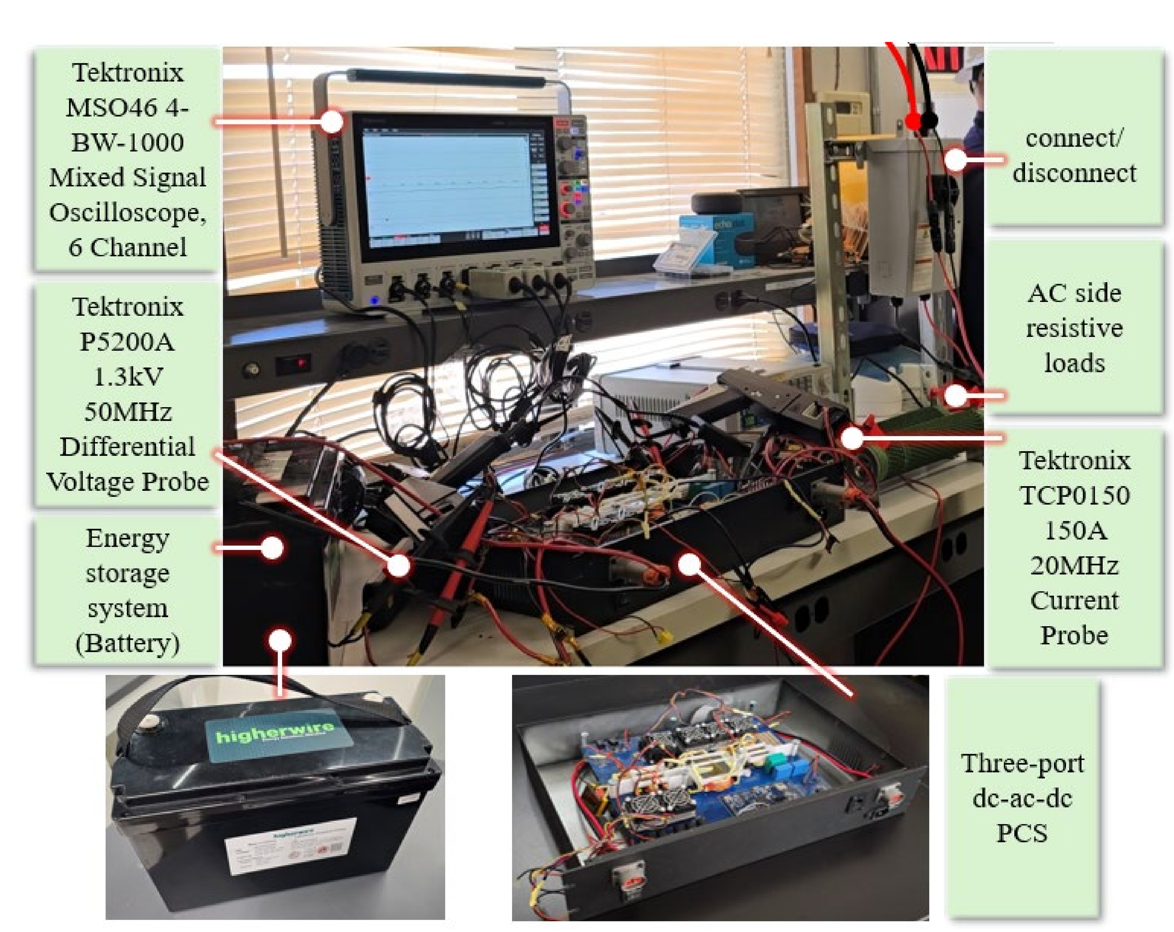


P2G mode (Two port)

PHASE-II FIELD TESTING



The control algorithm generates and stores optimized auxiliary modulation variables (AMVs) for varying operating points. To minimize memory use, a third-order regression model approximates duty cycles based on voltage gain variations, supporting real-time control.



Test conditions:
Battery side: 27V at 100W - AC side: 120V_{rms} at 150W
Outcomes:
Jump start: 250W - Efficiency: 92.3% - THD: 4.35%

Award No. DE-SC0022600

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[1] Payam Morsali, Ayan Mallik, "Multivariable-Modulation-Based Loss Optimization in a Hybrid Series-Resonant Triple Active Bridge DC-AC Converter," doi.org/10.36227/techrxiv.175021656.67373797/v1