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7.5 kW Galvanically Isolated Transformerless AC-DC Converter for Energy Storage Systems with Paralleled Bidirectional GaN Devices

Shuwei He[1], Alessandro Rizzoni[1], Zhining Zhang[1], Yifan Shi[1], Jin Wang[1], Jacob Mueller[2], Luciano Andres Garcia Rodriguez[2], Stan Atcitty[2]
[1]The Ohio State University, Columbus, OH [2]Sandia National Laboratories, Albuquerque, NM

Background and Objectives

As battery energy storage systems (BESS) evolve, there is increasing demand for compact, high-efficiency, bidirectional AC-DC converters. Conventional designs relying on bulky magnetic isolation and silicon switches limit power density and high-frequency performance. Gallium Nitride (GaN)-based bidirectional switches (BDS) offer a breakthrough by enabling high switching frequency and low switching loss with inherent bidirectional voltage blocking. Their integration into energy storage systems reduces the number of passive components and significantly improves overall efficiency and power density.

The effort presented in this poster aims to advance the state-of-the-art in bidirectional AC-DC converter design for BESS. Building on the previously proposed DC-DC Converter with Semiconductor Galvanic Isolation (SGI), this work focuses on the GaN-BDS based T-type converter using simplified control[1]. Due to the current limitation of single GaN-BDS, parallel operation is required to achieve the target power rating. Double pulse test (DPT) is conducted to evaluate the suitability of GaN-BDS for parallel operation. These efforts support the development of a compact, efficient, and scalable architecture for BESS.

Proposed Circuit Topology

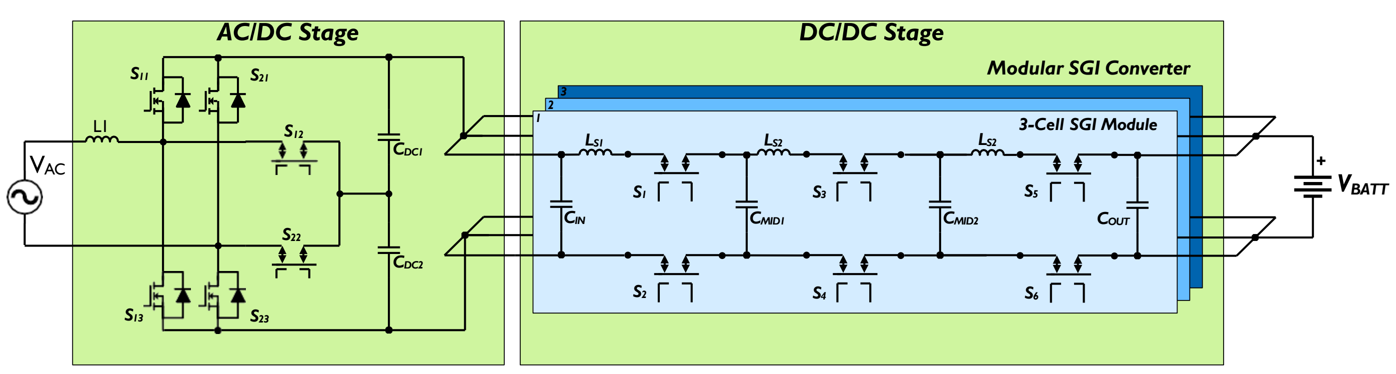

Figure (1) – Circuit diagram of the proposed transformerless galvanically isolated AC-DC converter for BESS

Table 1 – System Design Specifications

System Parameter	Value
Input Voltage	240 V_{RMS}
Output Voltage	400 V
Switching frequency (AC-DC stage)	25 kHz
Switching frequency (DC-DC stage)	1 MHz
Rated Power	7.5 kW

Figure (2) – Prototype SGI module

Operation Principle

- T-type converter based on simplified SPWM
    - In conventional T-type converter, the two horizontal switches are controlled independently using separate gate signals. The proposed simplified control strategy simultaneously turns both gates of the GaN-BDS on and off using a single control signal, thereby reducing control complexity.
- SGI converter based on resonant switched capacitor
    - With resonant switched capacitor circuit, the GaN-BDS operates when the current reaches zero, enabling zero-current switching. This minimizes switching loss and improves overall converter efficiency.

Table 2 – Switching Pattern of Simplified Control

S_{x1}	S_{x2}	S_{x3}	V_o
1	0	0	V_{dc}
0	1	0	V_{dc} / 2
0	0	1	0

[1] Z. Zhang *et al.*, "Bidirectional GaN-Based Semiconductor Galvanic Isolation (SGI) Converter for Energy Storage Application," *2024 IEEE 11th Workshop on Wide Bandgap Power Devices & Applications (WiPDA)*, Dayton, OH, USA, 2024, pp. 1-7, doi: 10.1109/WiPDA62103.2024.10773011.

Parallel Operation Validation of GaN-BDS

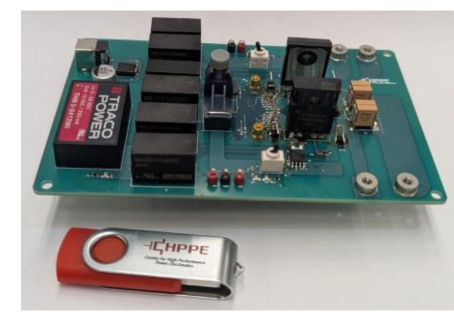

Figure (3) – DPT board

The state-of-the-art GaN-BDS with cascode structure features an on-resistance of 55 mΩ and is packaged in TO-247. The current-handling constraint of single GaN-BDS makes the parallel configuration essential for meeting the specified system power rating. DPT is conducted to validate the feasibility of parallel operation.

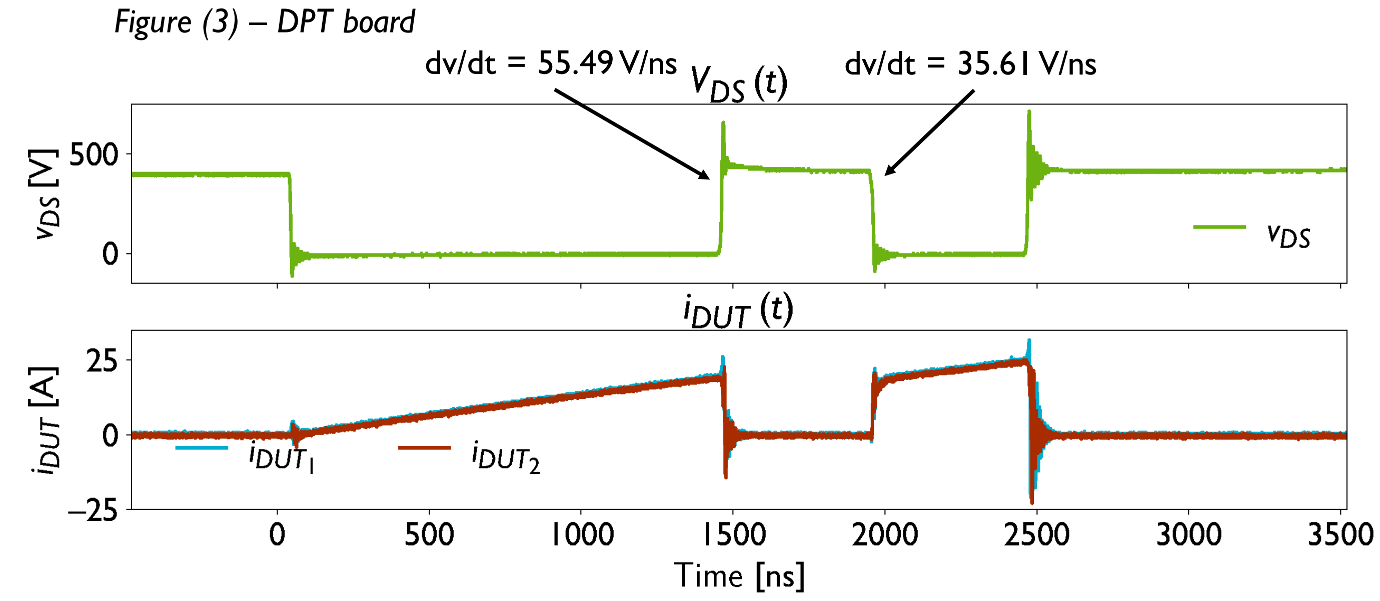

Figure (4) – DPT waveforms

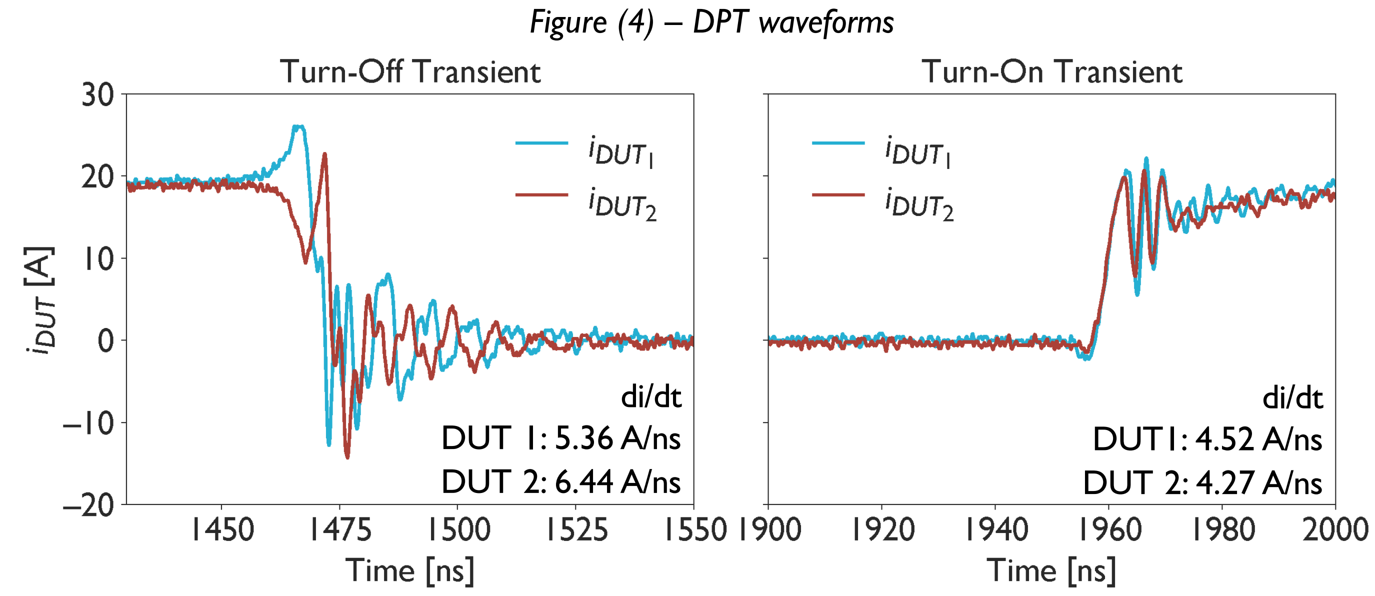

Figure (5) – Zoomed-in view of i_{DUT} during turn-off and turn-on transients

Economic Benefits

The simplified control strategy impacts hardware requirements for the system implementation. Considering power switches in the TO-247 package, an analysis comparing net footprint area of components used for both traditional and simplified control shows potential impact to power density and panelization economics resulting from use of GaN-BDS in addition to the PCB cost reduction of over 95% from [1].

Table 3 – Relative Improvement in Net Footprint Area

Number of Horizontal Switches (AC/DC Stage)	Simplified GaN-BDS vs. Simplified Unidirectional	Simplified GaN-BDS vs. Traditional GaN-BDS	Simplified GaN-BDS vs. Traditional Unidirectional	Simplified Unidirectional vs. Traditional Unidirectional
1	3.89%	8.05%	22.85%	20.77%
2	6.10%	7.90%	30.96%	26.47%
3	7.53%	7.81%	35.02%	29.73%
4	8.53%	7.74%	37.66%	31.85%

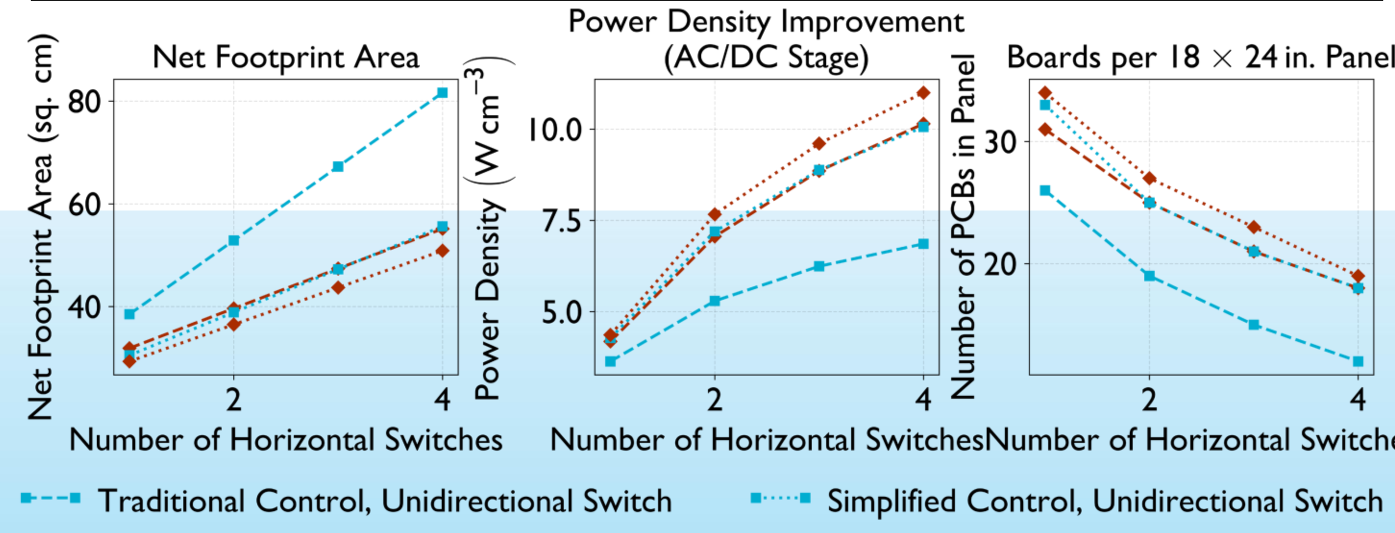

Figure (6) – Economic impact of GaN-BDS

Conclusions

Parallel operation of GaN-BDS has been validated through simultaneous turn-on and turn-off, ensuring sufficient current-handling capability to meet the target power. In addition, the proposed simplified control strategy reduces control complexity and offers a cost-effective solution for high power density bidirectional AC-DC converter in BESS.

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