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DYNAMIC PHASE ANGLE AND DEAD-TIME COMPENSATION FOR HIGH-EFFICIENCY DUAL ACTIVE BRIDGE CONVERTERS

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Abstract. Dual Active Bridge (DAB) DC-DC converters have emerged as a critical technology in high-power applications requiring bidirectional energy transfer and galvanic isolation, particularly in electric vehicle (EV) charging systems and renewable energy integration. The research demonstrates that intelligent dead time management significantly reduces switching losses while maintaining zero-voltage switching characteristics, addressing a critical challenge in high-frequency SiC-based DAB implementations.

Keywords: dual active bridge, DC-DC converters, phase angle modulation, dead time optimization, digital signal controllers, silicon carbide MOSFETs, electric vehicle charging, bidirectional power flow.

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Introduction. The fundamental operation of a DAB converter involves two active H-bridges interconnected through a high-frequency transformer and a series inductor. Power transfer is primarily regulated through phase shift modulation between the two bridges. In contrast, the dead time between complementary switches within each bridge is crucial for preventing shoot-through conditions and ensuring soft switching operation.

The adoption of wide bandgap semiconductors, particularly Silicon Carbide (SiC) MOSFETs, has enabled significant performance improvements in DAB implementations. Modern DAB demonstrations, such as Microchip's 11 kW platform, leverage these devices to achieve remarkable efficiency levels of 98.5 % at switching frequencies of 100 kHz.

Literature Review & Research Gaps.

1. Current State of DAB Research.

Recent research in DAB converters has primarily focused on modulation techniques and performance optimization strategies. The conventional Single-Phase Shift (SPS) modulation remains widely adopted due to its implementation simplicity, but suffers from reactive power circulation and limited soft-switching range, particularly under light-load conditions. In response, researchers have developed advanced modulation strategies, including Dual Phase Shift (DPS), Extended Phase Shift (EPS), and Triangular Modulation schemes that provide additional control degrees of freedom.

2. Identified Research Gaps

Despite substantial progress in DAB research, several significant gaps remain unaddressed in current literature:

Limited Research on Combined Phase Angle and Dead Time Optimization.

Inadequate Adaptive Dead Time Strategies for Wide Operating Ranges.

Limited Practical Implementation Studies Using Digital Control Platforms.

Problem Statement. This research aims to develop and validate an integrated optimization methodology that simultaneously addresses phase angle modulation and dead time control using modern digital signal processing capabilities, with specific focus on maintaining high efficiency across the entire operational range of high-power DAB converters.

Methodology.

1. Experimental Setup and System Architecture

To address the research problems, a comprehensive testing and validation methodology based on Microchip's 11 kW DAB demonstration platform was developed. The system architecture, incorporates the following key components:

PIC33CK512MP608 Digital Signal Controller: This 100 MHz single-core DSC serves as the primary control processor, implementing the phase shift modulation algorithms and adaptive dead time control strategies.

SiC MOSFET Power Stage: Utilizing 1700 V, 750 mΩ silicon carbide MOSFETs in a dual active bridge configuration, capable of operating at switching frequencies up to 100 kHz.

Gate Driver Circuitry: Isolated gate drivers with programmable dead time capability, enabling precise switching transition control.

Measurement and Sensing Systems: High-precision current and voltage sensors are used to monitor input/output characteristics, inductor current, and switching node behavior.

Table 1 – System Specifications of the 11kW DAB Demonstration Platform

Parameter	Min	Typical	Max	Units	Conditions
Input Voltage	700	–	900	VDC	–
Output Power	–	–	11	kW	–
Switching Frequency	–	100	–	kHz	–
Efficiency	–	98.5	–	%	–
Galvanic Isolation	4	–	–	kV	–
Ambient Operating Temperature	0	–	50	°C	–

Results and Discussion

1. Efficiency Measurements Across Operating Range.

Implementing optimized phase angle control and adaptive dead time strategies resulted in significant efficiency improvements across the operational range, particularly at light-load conditions where conventional DAB implementations typically exhibit substantial performance degradation.

The data demonstrates that the optimized adaptive control strategy provides particularly significant benefits at light-load conditions, where efficiency improvements exceeding 2.2 % were achieved. This improvement is primarily attributed to reduced reactive power circulation through optimized phase angle control and the minimization of switching losses through adaptive dead time compensation.

Table 2 – Efficiency Measurements at Different Load Conditions

Load Condition	Input Voltage (V)	Conventional SPS (%)	Optimized Adaptive Control (%)	Improvement
Light Load (20 %)	700	94.2	96.5	+2.3 %
Medium Load (50 %)	700	97.1	98.2	+1.1 %
Heavy Load (100 %)	700	98.3	98.5	+0.2 %
Light Load (20 %)	800	94.5	96.7	+2.2 %
Heavy Load (100 %)	800	98.4	98.6	+0.2 %

2. Thermal Performance and Switching Characteristics.

Thermal measurements revealed substantial improvements in device temperatures, particularly for the SiC MOSFETs in the primary bridge where switching losses dominate. At 50 % load condition with an input voltage of 800 V, the peak device temperature was reduced from 78 °C to 68 °C, representing a 12.8 % reduction in temperature rise. This improvement correlates with the extended lifetime expectation of power semiconductor devices, as every 10 °C reduction in operating temperature typically doubles device lifetime.

3 Dynamic Response and Mode Transition.

The dynamic response of the DAB converter with optimized control parameters was evaluated through load step changes and input voltage variations. The results demonstrated that the adaptive control strategy maintained stability and performance during transitions, with the system successfully identifying operational mode changes and applying appropriate control parameters.

Conclusion. This research has demonstrated the significant performance benefits achievable through coordinated optimization of phase angle control and dead time management in Dual Active Bridge DC-DC converters.

Several promising directions emerge from this work for future research. First, extending the optimization methodology to multilevel DAB topologies would leverage the additional degrees of freedom available in these architectures for further performance improvements. Second, developing machine learning-based optimization approaches could enhance the adaptability and robustness of the control strategies across varying operating conditions and component aging.

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PHASE ANGLE AND DEAD TIME IN DUAL ACTIVE BRIDGE DESIGNS FOR ELECTRIC VEHICLES AND SOLAR CHARGE INVERTERS

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Abstract. This paper presents a detailed analytical and simulation centered study of two widely used timing methods / controls in the implementation of Dual Active Bridge (DAB), that is Dead Time and Phase Angle. In this research paper, we will delve deeper into trying to have a well-informed understanding on the impact and relationship between the switching times experienced during the Phase Angle (phase shift) and the Dead Time against the