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Simulation, Analysis and Hardware Implementation Strategy of DAB Converter

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***Abstract*—The paper presents the Simulation and Hardware Implementation Strategy of a Dual Active Bridge (DAB) Converter. The Study focuses on optimizing Efficiency, Power Density and Bi-Directional Power Flow while ensuring Zero Voltage Switching (ZVS). The Simulation is performed in PLECS and the Hardware Implementation Strategy is demonstrated. The results demonstrate the efficiency of Dual Active Bridge Converter in wide range applications.**

***Keywords*—dual active bridge, electric vehicle, microcontroller, zero voltage switching.**

I. INTRODUCTION

Electricity is one of the most important resources in the modern world. Everything from our smartphones to electric cars (EVs) and renewable energy systems depends on efficient power conversion. However, raw electrical energy from sources like solar panels, batteries, or power grids cannot be directly used by most devices. It must be converted, regulated, and transferred efficiently. Power electronics plays a crucial role in shaping, controlling, and optimizing electricity flow. One such technology is the Dual Active Bridge (DAB) Converter, which is used to convert power between different voltage levels efficiently while ensuring smooth energy transfer.

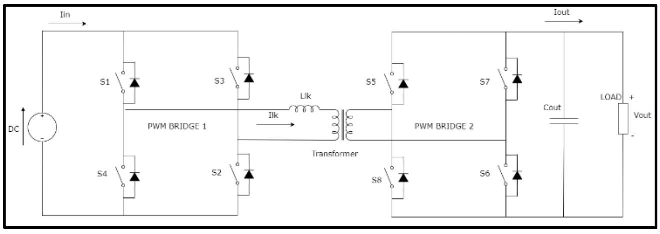

Fig 1: DAB Circuit Diagram

A. Understanding Power Conversion Problems

Traditional power converters used in electric vehicles and renewable energy systems often face the following issues:

1. High Energy Losses
   - Conventional converters waste power in the form of heat.
   - This leads to reduced efficiency and higher electricity costs.

2. Limited Bidirectional Power Flow
   - Many converters can only transfer power in one direction (e.g., charging a battery).
   - DAB converters allow power to flow in both directions, making them ideal for battery charging and discharging.

B. Objective.

The objective of this paper is:

- To develop a Simulation model in PLECS.
- To implement a hardware strategy.
- Comparison of Dual Active Bridge Converter with Conventional Power Converters.
- To present an efficient and reduced long-term costs Converter.

II. ARCHITECTURE

The Dual Active Bridge (DAB) Converter is a high-efficiency, bidirectional DC-DC converter that enables seamless power transfer between two different voltage sources. It is widely used in renewable energy storage, electric vehicles (EVs), and high-power industrial applications. The architecture mainly consists of two active full-bridge circuits, a high-frequency transformer.

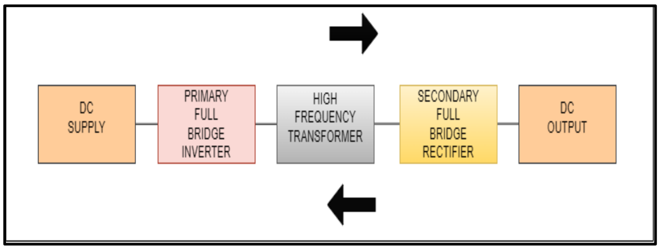

Fig 2: Block diagram of DAB

The key components include Primary Full-Bridge Inverter, High-Frequency Transformer, Secondary Full-Bridge Rectifier and Phase-Shift Controller.

The Primary Full-Bridge Inverter consists of four MOSFETs or IGBTs. Its function is that it converts DC Voltage into an AC square wave to feed the transformer. Phase-Shift PWM controls power transfer here. The function of High-Frequency Transformer is that it transfers power from the primary to the secondary side while providing galvanic isolation. High frequency operation allows for a smaller transformer size, reducing weight and volume. The Secondary Full-Bridge Rectifier consists of diode rectifiers. Its function is that it converts high-frequency AC back to dc for output voltage. Phase-Shift Control is implemented using STM32 series microcontroller. Its function is it controls power flow between input and output and adjusts phase difference between primary and secondary bridges to regulate output voltage.

III. COMPARISON

The Bidirectional Dual Active Bridge Converter stands out for high efficiency, power handling, and wide voltage range adaptability, making it ideal for high-power, modern applications like EV charging and renewable energy systems. In contrast, simpler converters like Flyback, Forward, or Push-Pull are more suitable for low to medium power levels, where cost and design simplicity outweigh the need for high efficiency or power density. Cuk/SEPIC/Zeta converters offer more versatility for low-to-medium power systems but lack the advanced soft-switching and scalability of the DAB converter.

IV. SIMULATION

The simulation of a Dual Active Bridge (DAB) Converter in PLECS begins with defining the system's operating parameters. The input voltage Vin is set to 95V, and the output voltage V-output is set to 400V, with the power transfer ranging from an initial value of 1.5 kW P-initial to a final value of 3 kW P-final. The switching frequency (f) is configured to 250 kHz to enable high-speed operation and minimize the size of passive components. The load resistance R-load is calculated based on the desired power and output voltage.

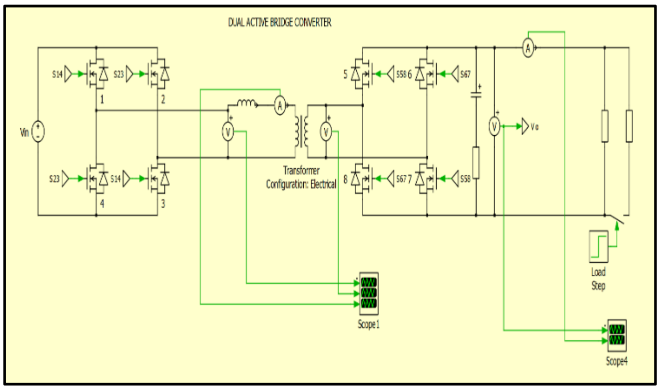

Fig3: DAB Simulation in PLECS

The transformer, a key component of the DAB, is modelled with a turn ratio (n) of 4:1 to step up the voltage effectively. Its parameters, including cross-sectional area (Ae), flux path length (Le) are defined.

The leakage inductance (Llk)is set to 1.052 µH to control the energy transfer between the primary and secondary sides, while the output capacitance (Co) of 30 µF smooths the output voltage ripple. To further refine performance, the output capacitor's equivalent series resistance (ESR) is modelled with a value of 3.2 mΩ.

The converter uses MOSFETs with Diode for the primary and secondary bridge circuits, chosen for their ability to handle high-frequency switching with minimal losses.

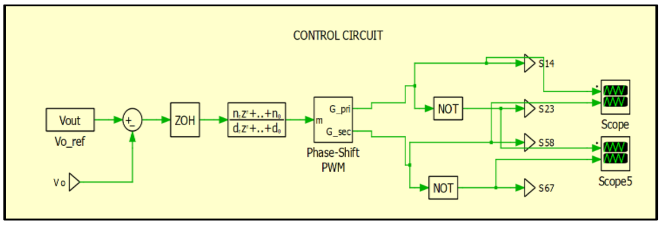

Fig4: DAB Control Circuit in PLECS

A digital PI controller regulates the converter's performance, with proportional gain (Kp), integral gain (Ki), and derivative gain (Kd) values calculated to ensure stability and fast response to load variations. The controller's sampling time (Ts) is derived from the switching frequency to maintain synchronization with the converter's operation. Its digital PI Controller's values are calculated and set accordingly.

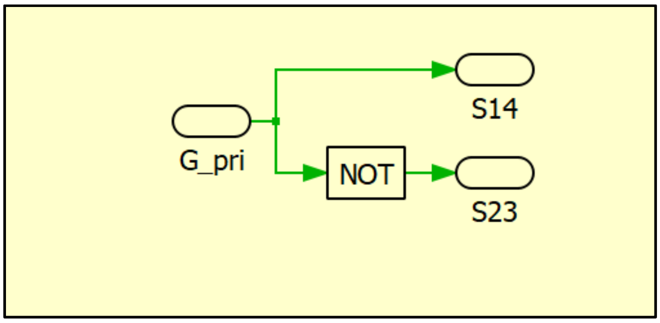

Fig5: Primary Gate Control in PLECS

This is a simple Logic built for Primary Gate. It states that when S14 is enable, then S23 should not be enabled. Similarly for Secondary Gate also, this logic is executed. They are then connected to Scope for Observations.

A. Output Waveforms and Observations

The input voltage waveform remains steady at the defined value of 95V. The primary current exhibits a high-frequency pulsating waveform due to the switching of the MOSFETs in the primary bridge. This waveform is triangular in nature.

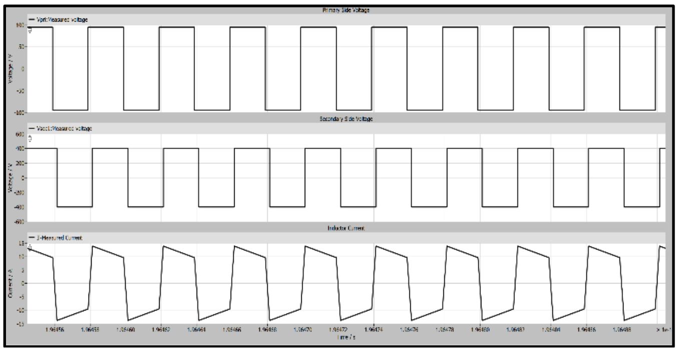

Fig6: Vpri, Vsec and Icurrent

This Output Waveform Shows Primary Side Voltage, Secondary Side Voltage and Inductor Current. The expected Output results as per input is getting delivered. We can also observe the phase shifting between them.

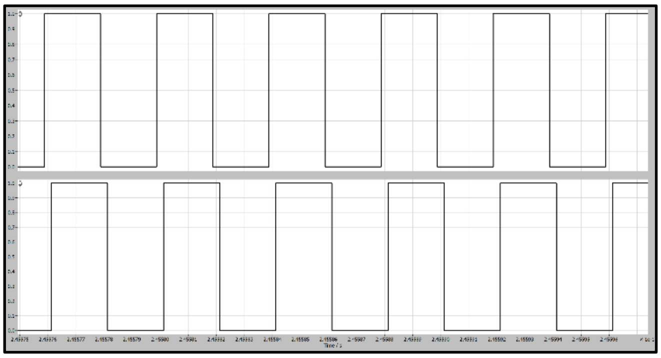

Fig7: Phase Shift

Here, observations of Scope S14 and S58 for which we built a simple Logic. We can observe the Phase Shifting.

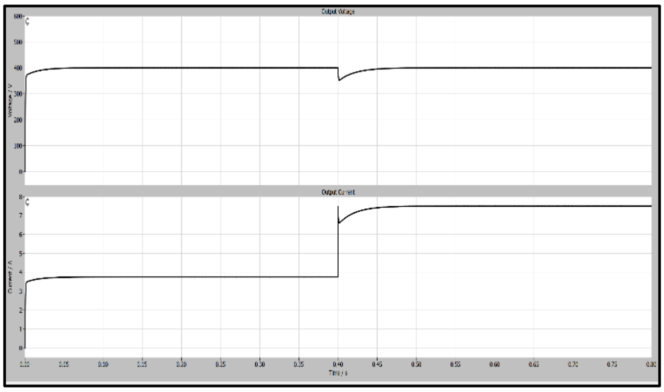

Fig7: Output Voltage and Current

The output voltage is regulated at 400V, as determined by the transformer turn ratio (n) and the control logic. The waveform remains steady due to the filtering effect of the output capacitor (Co=30 µF), which minimizes voltage ripple. A small residual ripple at the switching frequency (f=250 kHz) may be observed, attributed to the finite capacitance and the equivalent series resistance (ESR) of the output capacitor.
The output current waveform corresponds to the load power and is relatively smooth due to the low ripple in Vout.

At a load power of 1.5 kW, Iout is approximately:

Iout = Pload/Vout=1500/400=3.75 A.

When the power increases to 3 kW, Iout doubles to approximately 7.5 A. These values are consistent with the load resistance (Rload) and verify that the converter delivers the expected power.

V. HARDWARE IMPLEMENTATION STEPS

The hardware implementation of the Dual Active Bridge (DAB) Converter for Renewable Energy and EV Applications is an important phase of the project. This stage involves designing, assembling, and testing various components to ensure efficient power conversion, bidirectional energy transfer, and improved thermal performance. The hardware setup is divided into three primary sections:

1. Primary Side: Full-Bridge Converter with Phase-Shift Control

2. High-Frequency Transformer (HFT) for Isolation and Voltage Scaling
3. Secondary Side: Synchronous Rectification with a Dedicated MOSFET Driver Card

The hardware is designed to handle up to 3 kW output power, and key considerations include high-efficiency switching, thermal management, and PCB layout optimization.

VI. CONCLUSION AND FUTURE SCOPE

The input and output waveforms of the DAB Converter validate its capability to achieve efficient and reliable power transfer. The system maintains a stable DC output with minimal ripple, handles dynamic load changes effectively, and operates with ZVS to optimize efficiency. These characteristics make it well-suited for applications requiring high-power, bidirectional energy conversion, such as renewable energy integration and EV power management. The future scopes include Increased power ratings, Integration with smart grids, Use of advanced semiconductor technologies, Adaptive control strategies and Thermal management innovations.

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