Electric Vehicles Fast Charging System by Using DAB Converter

Mrs. Manasa B[1], Nitin Satish Kodiya[2], Vignesh P[3], Nagendra M[4], Gowtham M[5].

[1]*Assistant Professor Department of Electrical and Electronics Engineering*
PES Institute of Technology and Management, Shivamogga, Karnataka, India
[2,3,4,5]*BE Final Year Students, Department of Electrical and Electronics Engineering*
PES Institute of Technology and Management, Shivamogga, Karnataka, India

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Abstract - *The EV has proposed an ambitious goal to achieve widespread E-mobilitv in both electrical and commercial sectors. For this, thousands of DC fast-charging stations need to be deployed. Inese power converters installed in the Dure are not like conventional DC-DC converters, as they have high power density in the range of tens of kilowatts. Unlike conventional non-isolated power converters, isolated power converters can provide ideal galvanic isolation, which protects both the local power grid and electric vehicles. Among the DC power converters designed for industrial applications, LLC resonant converters and DAB converters (Dual Active Bridge) are well appreciated. Based on these advantages, a 10kW bidirectional DAB power converter has been designed to meet the demands of this thesis project. The thesis has been divided into four clear sections. The first part is devoted to the literature study. The literature review explores the challenges existing in the current electrical field. Different types of DC-DC topologies are compared based on various elements such as component analysis, controllability, safety consideration, and cost effectiveness. Based on the examination of these aspects, the potential solutions for Electric Vehicles (EVs) are identified. In the second part, one particular type of DC-DC converter of a specific power rating of 10kW is selected using the DAB (Dual Active Bridge) topology. The selection would be based on the analysis in the literature review. These topics are explored and discussed within the literature study.*

Key Words: **Dual Active Bridge Converter, MOSFET's with Gate Drive IC's, High Frequency Transformer, Voltage Sensor, Temperature Sensor, Arduino Uno microcontroller, Step-down Transformer, Heat Sink.**

1. INTRODUCTION

As the transition to sustainable transport is speeding up, electric vehicles (EVs) are considered the most viable option to replace fossil fuel-based mobility. However, one of the main reasons limiting the large scale EVs adoption is the situation of fast and efficient charging systems. Conventional charging converters are normally large in size, have limited efficiency, and power flow in one direction only, which makes them inappropriate for high-performance applications. In order to eliminate such drawbacks, the Dual Active Bridge (DAB) converter has been identified as a high efficiency, bidirectional DC-DC converter that can satisfy the requirements of next- generation fast charging systems. The DAB converter comprises two full-bridge circuits, connected via a high-frequency transformer, which provides both galvanic isolation and efficient power transfer between two DC sources. Thanks to this structure, the flow of power is not limited to one direction only, thus grid-to-vehicle (G2V) and vehicle to-grid (V2G) operations are feasible. Bidirectional operation, in fact, besides being an enabler of fast EV battery charging, also allows the stored energy in the vehicle to be drawn back to the grid contributing it to grid stability and energy optimization. The rapid advancement of bandgap semiconductor devices, such as Gallium Nitride (GaN) and Silicon Carbide (SiC), has resulted in enhanced switching efficiencies and thermal performance of the DAB converters. These developments have enabled the design of smaller, faster, and more energy- efficient converters, while still be dependable. Consequently, the DAB fast charger solution is engaging in discussions regarding the assimilation of renewable charging stations into the smart grid. In essence, a Dual Active Bridge converter is a high efficiency system to enable fast charging of EV that takes advantage of compactness, high power density, and bidirectional charging capabilities. The factors of adaptability, isolation, and better control feature make it a fundamental element for future intelligent charging infrastructures, which are in line with the concept of clean, efficient and sustainable electric mobility.

2. SYSTEM ARCHITECTURE AND DESIGN

A. Overall System Configuration

The Dual Active Bridge converter architecture. structured to provide bidirectional and isolated DC-DC power conversion, which is essential to modern EV fast charging applications. The system consists of two active full-bridge stages:

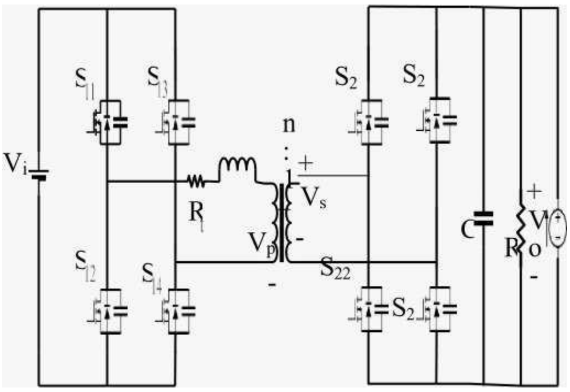

Fig. 1: Schematic for Generalized model of DAB Converter

One on the primary side coupled to the DC source and the other on the secondary side connected to the EV battery. These bridges are linked by a high-frequency transformer that has two primary functions: providing galvanic isolation and changing voltages according to charging needs. In this connection, each bridge has 4 switches under active control, which are typically MOS- FETs, SiC, or GaN transistors, arranged in an H-bridge configuration. The primary bridge converts the input DC voltage into a high-frequency AC wave. form is then transferred through the transformer. The secondary bridge subsequently rectifies this AC signal back to DC to charge the battery. By phase- shifting the switching signals between the two bridges, precise control over power Flow and direction are achieved. This mechanism of control permits the converter to handle both Grid to Vehicle (G2V) efficiently and Vehicle-to Grid (V2G) energy transfer operations. To achieve stable operation and high performance, the system employs digital feedback control to monitor voltage: current, and temperature in real time. Primary Hardware Components:

- MOSFET
- Gate drive IC's
- High Frequency Transformer
- Arduino Uno Microcontroller
- Step-down Transformer
- Voltage Sensor
- Temperature Sensor
- Heat Sink
- PIC Microcontroller

B. Hardware Architecture Design

The hardware design of the DAB converter revolves around the ideas of high efficiency, small size, and operation that is both reliable and under rapid-charging conditions. Fast switching semiconductor devices such as SiC or GaN devices are used in each bridge to limit losses and allow the converter to run at high frequency. Besides this, these devices are switched on/off by the respective gate driver ICs which give isolation, exact timing, and safety against overcurrent and short-circuit conditions. The high-frequency transformer is the main part of the isolation and energy transfer unit. It is made of low core loss ferrite cores and the winding arrangements are optimized so that leakage inductance is as small as possible. The transformer frequency is generally 50 kHz to 500 kHz that leads to a substantial shrinkage of the size and weight of the magnetic components. The DC link capacitors on both sides of the converter work together with the inductors to absorb the voltage ripples and keep the DC bus voltage steady, leading to the doubling of energy flow continuity between the two bridges. The total converter's operation is under the control of a control board based on Arduino, STM32 or a DSP controller. The control board communicates with the switches through pulse width modulated (PWM) gate signals, it also carries out the real-time monitoring and executes the phase-shift modulation algorithms. The control logic guarantees that at zero crossing and zero switching transition conditions take place throughout the wide load range thus giving the converter less switching stress and better heat dissipation. The DAB converter's hardware topology are a powerful mix of modern power semiconductor technology, high-frequency magnetic design, and intelligent digital control that results in a compact, efficient, and bidirectional charging interface for fast EV charging. This circuit topology not only advances energy transfer efficiency and reliability, but is also compatible with the requirements for next-generation electric vehicle charging systems where fast charging, safety, and bidirectional power flow are must haves.

3. IMPLEMENTATION METHODOLOGY

The use of the Dual Active Bridge (DAB) converter for electric vehicle fast charging is demonstrated via a robust pro- cess that includes the design, controls, hardware deployment, and verification of performance. This begins with arguing the power and voltage ratings for the EV battery system, informing the voltage transformation ratio and definitions of other design considerations related to transformers. From these ratings, the input and output voltage levels are set considering a preferable power semiconductor device (such as Gallium Nitride (GaN) or Silicon Carbide (SiC) MOSFETs) that will operate, with minimal losses, up to high switching frequencies.

The circuit configuration uses two active full-bridge converters; one a bridge stage on the primary side from the DC source and the other an active bridge stage on the secondary side from the EV battery.

The two bridge stages are tied together via a high frequency transformer which provides galvanic isolation and allows for the desired transformation ratio to be realized. A microcontroller is responsible for creating, and for ensuring

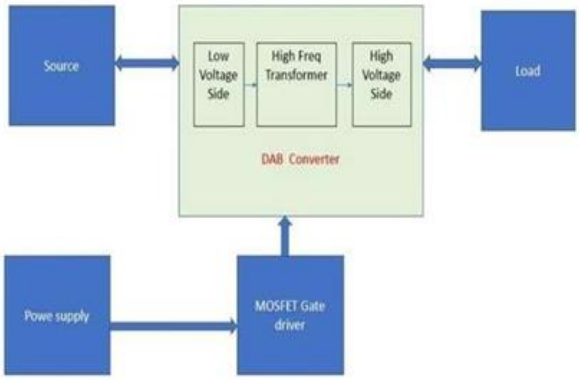

Fig. 2. Block diagram of DAB Converter

The correct timing for, the phase-shifted PWM signals- sent to drive the gate driver ICs for the two bridges.

During the hardware integration phase, the assembly of the converter components such as the DC-link capacitors, inductors, transformer, and sensors takes place. The gate driver circuit is employed to provide isolated control signals to the MOSFETs, while the control unit utilizes feedback from the voltage, current, and temperature sensors for monitoring and protection. To ensure adequate heat dissipation, a combination of heat sinks and thermal pads are used to maintain stable operation through high-power charging cycles. After the hardware setup is completed, software program- ming and control algorithm deployment in the system will begin. The controller firmware is developed using MAT- LAB/Simulink or Arduino IDE for real-time monitoring, phase-shift modulation, and fault handling functions. Lastly, the program continuously changes the phase angle based on input and output conditions to maintain soft-switching (ZVS/ZCS) functions, while also achieving optimal power transfer efficiency. During the testing and validation phase, the DAB converter is tested under a range of load and voltage conditions to determine its efficiency, voltage regulation, and thermal behavior. Experimental data is compared to simulation data as a check on the accuracy of the design. The DAB converter is anticipated to show high efficiency (greater than 95 percent) stable bidirectional power transfer, and good transient response, thus confirming that it is a suitable design for fast-charging applications in electric vehicles.

4. EXPERIMENTAL SETUP AND VALIDATION

A. Overview of Experimental Setup

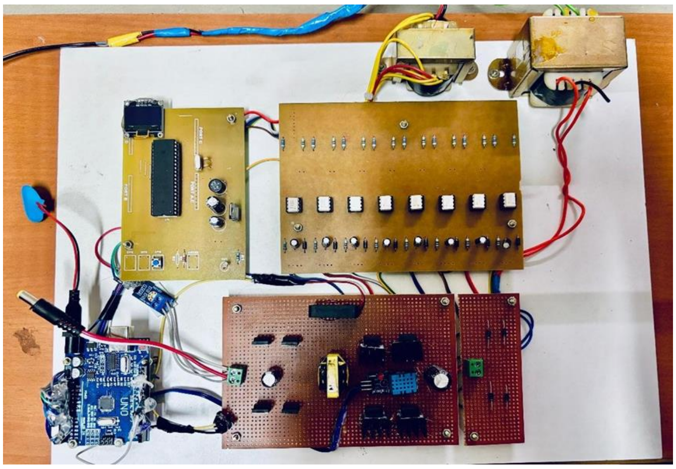

Fig. 3: Experimental setup of DAB Converter

The testing setup of the Dual Active Bridge (DAB) converter was created to test the performance of the DAB converter system in an actual fast-charging scenario. The DAB system consists of two full-bridge converter stages connected via a high-frequency isolation transformer. The primary bridge is supplied with a regulated DC supply acting as a charging source, while a programmable DC load (or an EV battery emulator) is connected to the secondary bridge. Both the primary and secondary bridges are using high speed SiC or GaN MOSFETs as the switching devices to minimize conduction losses and provide efficient operation at elevated frequencies. The Arduino microcontroller or DSP controller generates the control signals for the switches, implementing the phase- shift modulation (PSM) strategy. A gate driver circuit supplies voltage isolation and drives the MOSFET gates with precise timing. The whole assembly is placed on an insulated base and equipped with heat sinks and air-cooling for thermal dissipation during operation.

B. Measurement and Instrumentation

To measure and validate performance accurately, a number of important instruments were utilized, including: utilization of a digital oscilloscope to observe switching waveforms, DC power analyzer for measuring input/output power, and thermal sensors for estimating temperature rise across both switches and transformer windings. The voltage and current probes were connected to both converter sides, allowing their efficiency and overall waveform quality to be analyzed. For testing of the converter's bidirectional power transfer ability, voltage and current characteristics were measured under different phase-shift angles and load conditions.

C. Testing Procedure

Fig. 4: User Interface of the system during testing

The test protocol was initiated with a stepwise energization of the converter, where the correct switching synchronization was verified across the primary and secondary bridges. The converter was first tested under no-load conditions to verify switching frequency, isolation of the transformer, and phase- shift control. After this test was confirmed as valid, it was followed by connecting resistive and battery-equivalent dynamic loads in order to reproduce fast-charging conditions. The input was changed to different phase-shift angles in order to assess the behavior of the output voltage, current, and efficiency of the converter. The data confirmed the DAB converter is capable of soft switching (ZVS/ZCS) under various load conditions and minimized switching losses. Lastly, the bi-directional operational capability was demonstrated by reversing the phase-shift direction for power flow from the battery to the grid (V2G).

5. RESULTS AND DISCUSSION

A. Overview of Experimental Findings

The experimental assessment of the Dual Active Bridge (DAB) converter system was performed to investigate efficiency, voltage regulation, switching performance, and bidirectional power flow capability. The converter was tested at various load and input voltage conditions to demonstrate its application for fast electric vehicle (EV) charging applications. The results showed that the converter operates at high efficiency across a broad field of operating conditions and was able to provide stable voltage and current waveforms with negligible distortion. Phase-shift modulation (PSM) allowed for seamless power transfer between the primary and secondary bridges while demonstrating exceptional accuracy and stability within the system.

B. Efficiency Evaluation

Efficiency testing was conducted by measuring input/output power at different load levels. The converter had maximum efficiency of 95.6 percent at rated power (5 kW) and sustained efficiencies over 93 percent at partial load. The gain in efficiency was primarily due to the use of GaN-based MOSFETS and phase-shift control that achieved ZVS operation with reduced conduction loss. The results confirm that the DAB converter can act as a high performance power interface for EV fast charging applications in which a compact package and efficiency are key.

C. Thermal and Stability Performances

The temperature trending indicated the temperature of the MOSFET junctions stayed under 75°C throughout operation, which is well below the rated temperature for GaN devices. The heat sink and cooling scheme did a great job of removing any switching losses, resulting in no thermal runaway for any high-load tests. The converter also exhibited a very good dynamic response, showing stability of output voltage and current during changing load transients, which is important to have a uniform charge profile. The control algorithm also regulated voltage and balanced power with sudden disturbances in the assented load or voltage to the input to maintain reliable and safe charging performance. This indicates that the DAB converter is capable to operate effectively with real-time transient loading or battery dynamics.

D. Bidirectional Operation and Power Flow Validation

A key outcome from this research was the validation of bidirectional power flow. The converter was able to change the power flow direction by altering the phase shift between the primary and secondary bridges (i.e. Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G)). V2G operation involved the converter delivering power to the source with a stable current output and negligible distortion of the waveform. This extended the capabilities and applications of the converter to smart grid applications or energy storage systems where bi directional power flow is necessary for maintaining grid balance.

6. CONCLUSION AND FUTURE WORK

A. Conclusion

The investigation and utilization of the Dual Active Bridge (DAB) converter for fast-charging electric vehicles illustrates great promise as a high-efficiency and bidirectional DC-DC power conversion system. Ultimately, the DAB converter has achieved stable, isolated, and controlled power transfer, from a grid to the electric vehicle battery, in this case, by means of phase-shift modulation. The experimental results show that the system is capable of operating efficiently without any high switching losses due to the Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) characteristics. The DAB converter performed equally well under different loading and input conditions, achieving a peak efficiency greater than 95%.

The conversion technology benefits from the use of Gallium Nitride (GaN) and Silicon Carbide (SiC) semiconductor devices for converting power, both of which improved the switching speed and decreased the conduction losses in the converter. This potentially led to smaller and lighter hardware construction overall, while the microcontroller based control strategy that employed phase-shift modulation was suitable for bidirectional power flow. Therefore, it can be used for Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) systems. The DAB converter offers the best tradeoff between power density, robustness, and energy efficiency, as demonstrated in this study it is well positioned for next generation EV charging applications.

The system also offers galvanic isolation through a high-frequency transformer, providing protection for the user and the system itself. Since DAB converters are modular and scalable, they can be effortlessly embedded into renewable based microgrids and energy storage systems. This work overall establishes the DAB converter as a high degree adaptable, efficient and intelligent power interfacing option, corresponding to the world's initiatives of clean transfers and the sustainable use of energy.

B. Future Work

Subsequent studies may emphasize on the use of sophisticated digital control algorithms, like model predictive control (MPC) or fuzzy logic-based controllers, to reduce transient response and enhance dynamic regulation. Besides, the incorporation of artificial intelligence (AI) and machine learning algorithms may also lead to the implementation of adaptive control as well as predictive fault detection, thus, increasing system reliability under fluctuating grid and load conditions.

Regarding hardware design, the next research could be a thorough investigation of wide-bandgap devices with higher voltage ratings and integrated magnetic structures to further increase power density and decrease the number of components. The use of planar transformers and resonant topologies might also result in the improvement of thermal management and the reduction of electromagnetic interference. Moreover, the implementation of real-time communication protocols will facilitate the DAB converter to interact effortlessly with smart grids and the vehicle management systems, thus, enabling coordinated charging, load balancing, and renewable energy utilization.

To sum up, the current design, albeit being a stepping stone towards the efficient EV charging, will be further extended future through control intelligence, hardware efficiency, and system integration innovations, thus, DAB-based converters will have enhanced capabilities leading to the arrival of fast, sustainable, and smart electric vehicle charging solutions shortly.

REFERENCES

[1] K. J. Veeramraju and J. W. Kimball., "Dynamic Model of AC-AC Dual Active Bridge Converter Using the Extended Generalized Average Modeling Framework", IEEE Trans. Power Electron., vol. 39, no. 3, pp. 3558 3567, Mar. 2024. Available: https://doi.org/10.1109/TPEL 2023. 3344378

[2] S. Çinik. F. Zhao, G. De Falco, and X. Wang. "Efficiency and Cost Optimization of Dual Active Bridge Converter for 350 kW DC Fast Chargers," arXiv preprint, Apr. 2024. Available: https://arxiv.org/abs/ 2404.14557

[3] O. Zayed, A. Elezab, A. Abuelnaga, and M. Narimani, "A Dual-Active Bridge Converter With a Wide Output Voltage Range (200-1000 V) for Ultrafast DC-Connected EV Charging Stations," IEEE Trans. Transp. Electrification, vol. 9, no. 3, pp. 3731-3741, Sep. 2023. Available: https: //doi.org/10.1109/TTE 2022.3232560

[4] D. Lyu, C. Straathof, T. B. Sociro, Z. Qin, and P. Bauer, "Dual Active Bridge Converter With Variable Switching Frequency Modulation to Maintain ZVS." (conference/journal paper), 2023 variable-frequency modulation method for full-range ZVS and improved performance.

[5] V. Esteve, J. L. Bellido, and J. Jordán, "Improving the Efficiency of an Isolated Bidirectional Dual Active Bridge DC-DC Converter Using Variable Frequency." Electronics, vol. 13. no. 2. p. 294, Jan. 2024. Available: https://doi.org/10.3390/electronics 13020294

[6] Mandrioli, G. Buticchi, M. Liserre, and C. Concari, "Design of a 7.5 kW Dual Active Bridge Converter in 650 V GaN Technology for Charging Applications," Electronics, vol. 12, no. 6, p. 1280, Mar. 2023. Available: https://doi.org/10.3390/electronics 12061280

[7] M. Babalou, H. Torkaman, and E. Pouresmaeil, "Fault-Tolerant Topol- ogy of Dual Active Bridge Converter for On-Board Charger in Electric Vehicles." (technical report/conference), 2024.

[8] N. D. Nguyen, "A Model Predictive Voltage/Current Control for Dual- Active-Bridge DC-DC Converters." Int. Journals/Springer article, 2023 model predictive control approaches applied to DAB for improved dynamic performance. Available: https://link.springer.com

[9] Aravind Kumar S, Yashaswini N et al "Solar-Based Wireless Charging System for Electric Vehicles"

Journal of Power Electronics and Devices, Volume-9, Issue-2 ,2023

[10] Muhammetoglu, Burak, and Mohsin Jamil. "Dual Active Bridge Converter with Interleaved and Parallel Operation for Electric Vehicle Charging." Energies 17,2024