# Design and Implementation of a Dual Active Bridge Converter for Battery Charging Application

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## Abstract

This work focuses on the design and implementation of a Dual active bridge converter for battery charging application as well as comparative study of different semi-conductor devices for Dual active bridge converters. The proposed converter is designed and realized for the given specifications using suitable equations. The converter operates at a switching frequency of 50KHz. The phase shift control technique is employed for closed-loop control of converter which is necessary to maintain the output voltage and current constant to charge the battery. The parameters of Silicon carbide (SiC) and Gallium nitritide (GaN) MOSFETs are considered for the comparative study of different semi-conductor devices. In this work, MATLAB Simulink software is used to simulate the converter. Also, experimental results of the converter for the required output are illustrated in this paper.

**Keywords.** Dual active bridge converter, Sic and GaN MOSFET, Bi-Directional converter.

## 1. INTRODUCTION

The rise in electricity demand, environmental concerns, and discrepancy in energy generation, modern hybrid technology for conversion of renewable energy sources have attracted more attention. It is the job of the bidirectional DC/DC converter to act as an interface between the many forms of renewable energy, such as fuel cells or photovoltaic (PV) arrays, and the various forms of energy storage, such as batteries and super capacitors [1,2]. They're used in a variety of applications, including hybrid cars, distribution networks, electric aircraft, and uninterruptible power supplies (UPS).

Isolated and non-isolated are the two categories of bidirectional DC/DC converters. In this work, a Dual active bridge converter with an isolated topology is selected. In this converter the power transfer will take place in both the directions [3,4]. This converter has a wide variety of advantages over other converters such as improved efficiency, isolation in the circuit, ability to operate at high frequencies and reliability [5].

The converter is operated at 50% duty cycle. The PWM pulses are phase shifted by some degree so that there is no zero voltage switching. The control strategy employed in this converter is phase shift control method [6]. The constant output voltage and current can be obtained by varying the phase of the PWM pulses of the secondary side bridge circuit. This study indicates that the dual active bridge converter is proposed for battery charging applications, such as those using Li-ion batteries [7]. Modern technology semiconductor devices such as SiC MOSFET are proposed, the efficiency of the converter is increased significantly. MATLAB Simulink software is effectively used to carry out simulation and analysis of the system, also necessary waveforms are observed and recorded in this work.

## 2. OPERATION AND DESIGN PROCEDURE

### *2.1. Block Diagram and Methodology*

Figure 2.1 shows the block representation for the proposed converter along with controller. The proposed converter operation is similar to that of a typical Dual active bridge converter circuit.

A DC source is given as an input to the dual active bridge converter. The output of the dual active bridge converter is connected to the battery. In this work, the topology is used for battery charging applications. The output of converter is connected to the battery so; in this application, the output current should be maintained constant to charge the battery. The controlled output current is a function of input DC voltage. The controller detects the variation in the output current and maintains a constant output current constant by varying the phase of the secondary side of the bridge with respect to the primary side of the bridge circuit.

The DC input given to the circuit is 300V. The switches used in the converter circuit are MOSFET which operate at a frequency of 50KHz. The duty cycle considered is 50 percent.

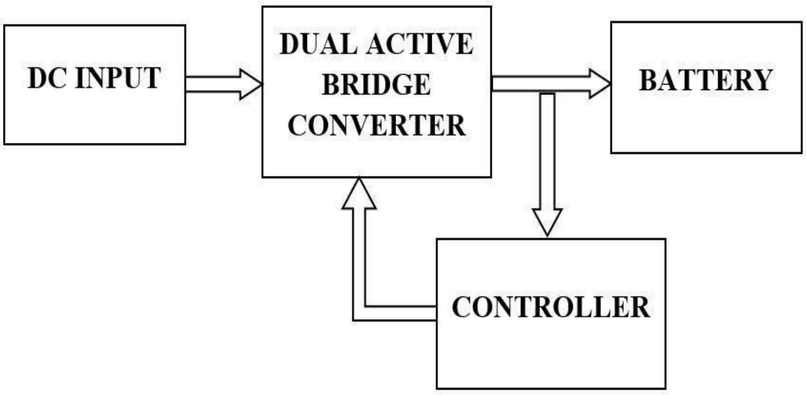


Figure 2.1. Block Diagram for the proposed converter

### *2.2. Dual Active Bridge Converter*

The dual active bridge converter circuit consists of eight MOSFET switches, a high-frequency transformer, an energy transfer element which is an inductor, and dc-link capacitors for bi-directional, controllable, high-power dc-to-dc converter. Simply put, the converter is a standard full-bridge with a programmable rectifier. Due to the symmetry of the primary and secondary bridges, this converter can regulate power flow in both directions. [9,10].

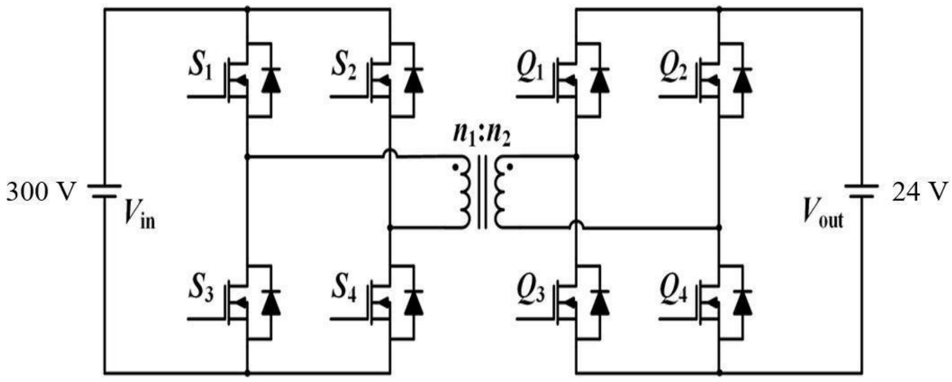


Figure 2.2. Schematic for Dual active bridge converter

The converter is comprised of two bridges: the primary bridge and the secondary bridge. The primary side bridge circuit functions as an inverter, while the secondary side bridge circuit functions as a rectifier. The isolation of the circuit is provided by the high-frequency transformer, which is connected to both bridges.

In a dual-active bridge converter, both the primary and secondary bridges are simultaneously controlled. All switches operate at a duty cycle of 50 percent. The diagonal switches turn on and off simultaneously, resulting in a square wave at the output of each bridge.

In the figure 2.3 the switching waveform of a conventional dual active bridge converter is depicted. S1, S2, S3 and S4 are the switches for the primary side circuit of dual active bridge converter. Q1, Q2, Q3 and Q4 are switches for the secondary side circuit of the dual active bridge converter. At a time four switches are turned ON. The switches operate in four intervals which is as follows. S1, S2, Q2 and Q3 are triggered in the first interval. In second interval S1, S4, Q1 and Q4 are triggered. In the third interval S2, S3, Q1 and Q4 are triggered. In the fourth interval Q2, Q3, S2 and S3 are triggered. There is a phase difference between the triggering of pulses from primary to secondary side [11,12]. The phase difference is usually maintained in the range 0 degree to 30 degrees.

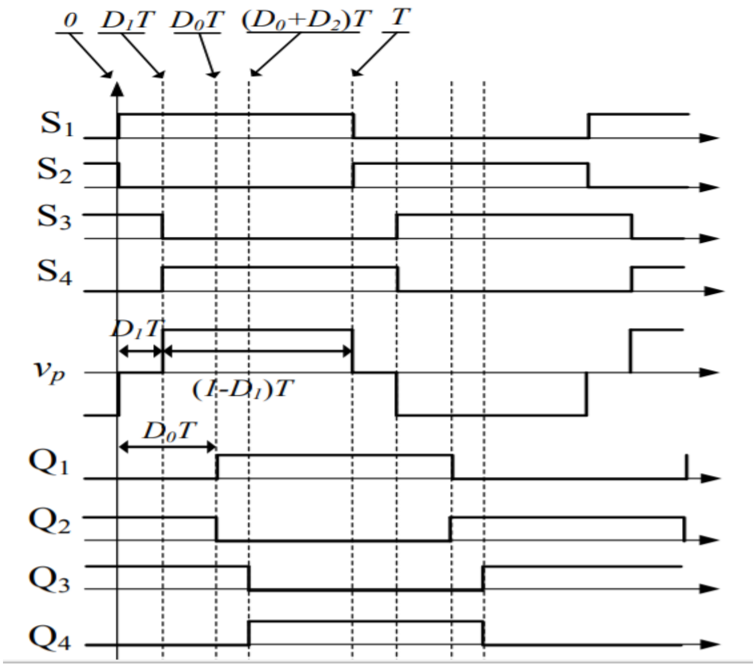


Figure 2.3. Switching waveforms for Dual active bridge converter

# 3. CONVERTER DESIGN

## *3.1. Converter Specification*

- Input voltage range : 300 V
- Switching Frequency : 50 kHz
- Output Voltage : 24V
- Output Current : 10A
- Current Ripple : 20%
- Voltage Ripple : 1%

Abbreviations:

| | | | |
|---|---|---|---|
| $V_i$ | : Input voltage | $f_s$ | : Switching frequency |
| $V_o$ | : Output Voltage | $V_L$ | : Voltage across the inductor |
| $D$ | : Duty Cycle | $I_{ripple}$ | : Window factor |
| $V_{ripple}$ | : Voltage Ripple | $T_s$ | : Switching Time |
| C | : Capacitance | $B_{max}$ | : Maximum permeability |
| $A_c$ | : Area of cross section | | |

## 3.2. Calculation

$$Turns\ Ratio\ (n) = \frac{N_s}{N_p} = 0.1 \tag{3.1}$$

$$V_L = V_i \frac{N_s}{N_p} - V_o \tag{3.2}$$

$$V_L = 6V \tag{3.3}$$

$$D = \frac{1}{2} \times \frac{24}{30} = 0.4 \tag{3.4}$$

$$I_{rippl} = 0.2A \tag{3.5}$$

$$L = \frac{V_L\ D\ T_s}{I_{ripple}} = 24\mu H \tag{3.6}$$

$$V_{ripple} = 1\%\ of\ 24 = 0.24V \tag{3.7}$$

$$C = \frac{I_{ripple}\ D\ T_s}{V_{ripple}} = 66.67\mu F \tag{3.8}$$

## 3.3. Transformer design

For the operation below 500 KHz core material with permeability of 2000 to 2500 is selected. High frequency transformers favour ferrite cores due to their high resistance to high current, low eddy current losses, and high permeability.

Core shape selected is EE core and Area of cross section is 1.54 cm$^2$.

$$N_p = \frac{V_i \times 10^8}{4 \times f \times B_{max} \times A_c} = 29 \tag{3.9}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} \tag{3.10}$$

$$N_s = 7 \tag{3.11}$$

In this work, winding the transformer, wire used is 19SWG copper wire which has an area of cross section of 1.016mm and current carrying capacity of 3.2A.

## 3.4. Closed loop control

The phase shift modulation approach is used to build closed loop control for the dual active bridge converter. The duty cycle of the primary side of a Dual Active bridge converter is phase-shifted in reference to the secondary side in phase shift modulation. The output voltage and current are regulated as needed by varying the phase shift angle [13].

In this work, a digital controller is used for closed loop control. A Matlab function block is implemented in Matlab Simulink in which the programme is written to control the output voltage and current of dual active bridge converter. By changing the PI controller to a discrete PI controller, the programme is developed. The Matlab function block detects the output current, and if the output current varies, the Matlab function block adjusts the phase of the secondary side of the bridge until the current reaches the desired value.

# 4. SIMULATION, HARDWARE IMPLEMENTATION AND RESULTS

## *4.1. Simulation and Results*

Simulation for the dual active bridge converter circuit is carried out using Matlab Simulink software. The simulation circuit for dual active bridge converter and switching waveforms for the dual active bridge converter are illustrated in Fig. 4.1 and Fig. 4.2 respectively.

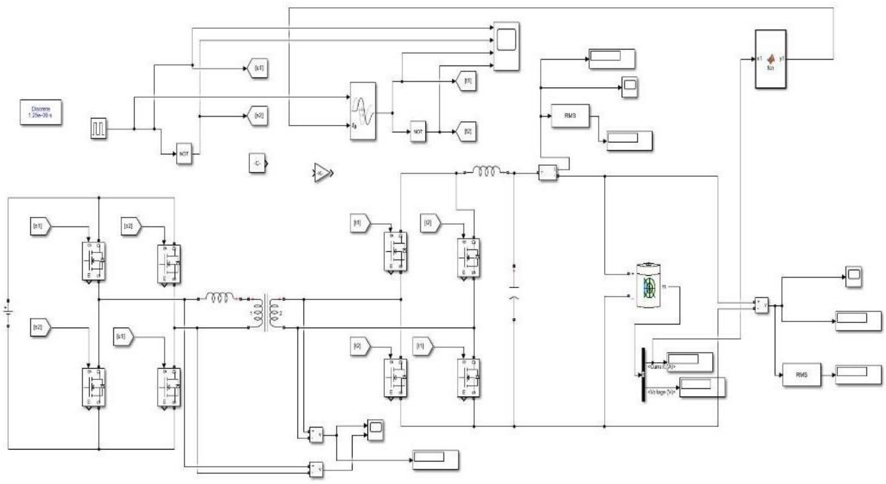

Figure 4.1. Simulation model for the closed loop control

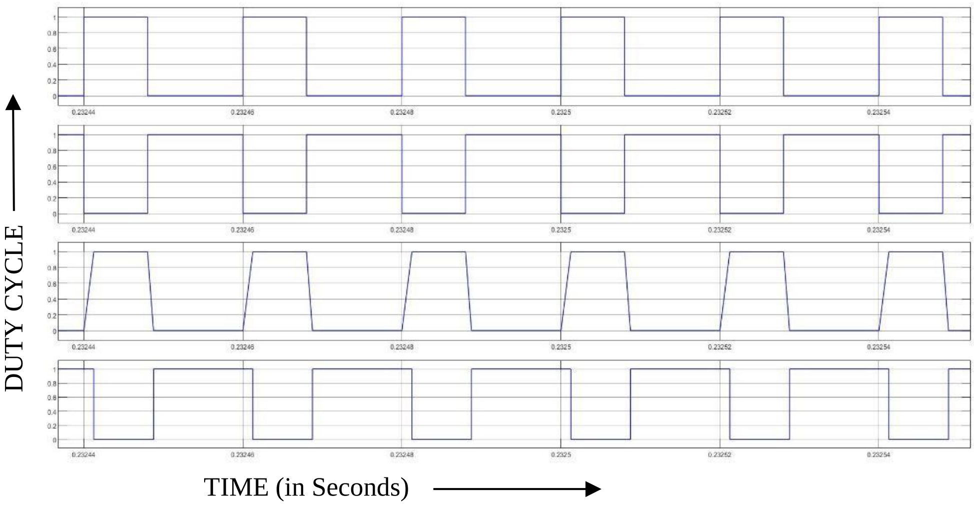


Figure 4.2. Switching waveforms for the dual active bridge converter

The Fig. 4.3 depicts the graph for variation in input voltage in reference to the output current for battery charging. The input voltage ranges between 260V and 360V, so that the output current remains constant at 10A.

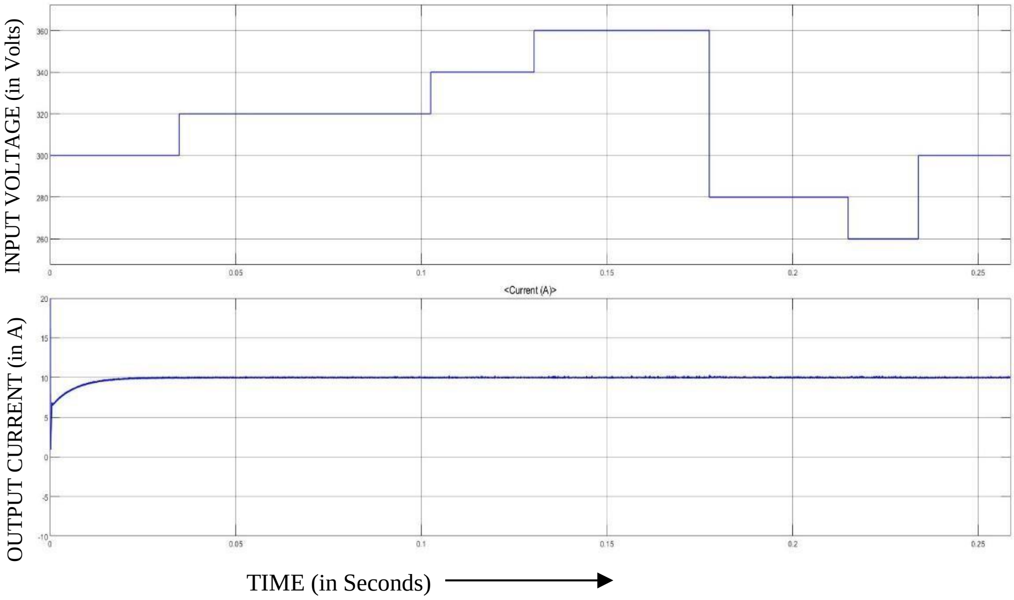


Figure 4.3. Input voltage variation vs Output current for battery charging

### *4.2. Comparative analysis of semiconductor devices*

The comparison is made between (Silicon carbide) SiC MOSFET and (Gallium nitride) GaN MOSFET. The Resistance between drain and source (Rdson) parameter of the MOSFET is considered from the datasheet. In Matlab Simulink, the Rdson parameter is altered in the MOSFET parameter section, and the resulting parameter change are analysed and recorded in the table 4.1. It is observed from the table 4.1 that SiC MOSFET is comparatively exhibits better performance tha GaN MOSFET switch.

Table 4.1. Comparison between SiC and GaN MOSFET

| PARAMETER | SiC MOSFET | GaN MOSFET |
|---|---|---|
| Rds in Ω | 0.107 Ω | 0.190 Ω |
| Output Voltage ($V_o$) | 22.35 V | 18.04 V |
| Output current ($I_o$) | 8.93 A | 7.183 A |

### *4.3. Hardware Implementation*

In this work, PWM pulses for the dual active bridge converter are generated using the TMS320F28335 digital signal processor. The processor's enhanced pulse width modulation (epwm) pins are responsible for generating the pulses. The MOSFET employed in the converter is a PSM20N50CT with Vds=500V and Id=20A current carrying capacity. A driver IC, TC4420, which is a non-inverting type MOSFET driver IC, is selected for the efficient switching of the MOSFET switch. In this work, the duty cycle considered is 50 percent for testing purpose.

Complimentary PWM pulses are generated having a duty cycle of 50% for the primary side bridge circuit as illustrated in the Figure 4.4.

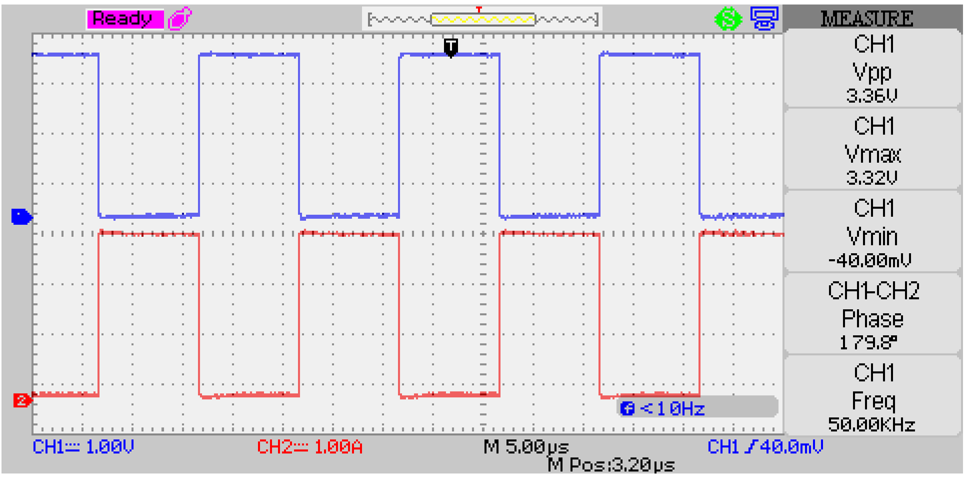


Figure 4.4. Complimentary PWM pulse generated with a duty cycle of 50%.

The phase shifted PWM pulses with a phase shift of 30 degrees are generated for the secondary side of the bridge circuit as illustrated in Figure 4.5.

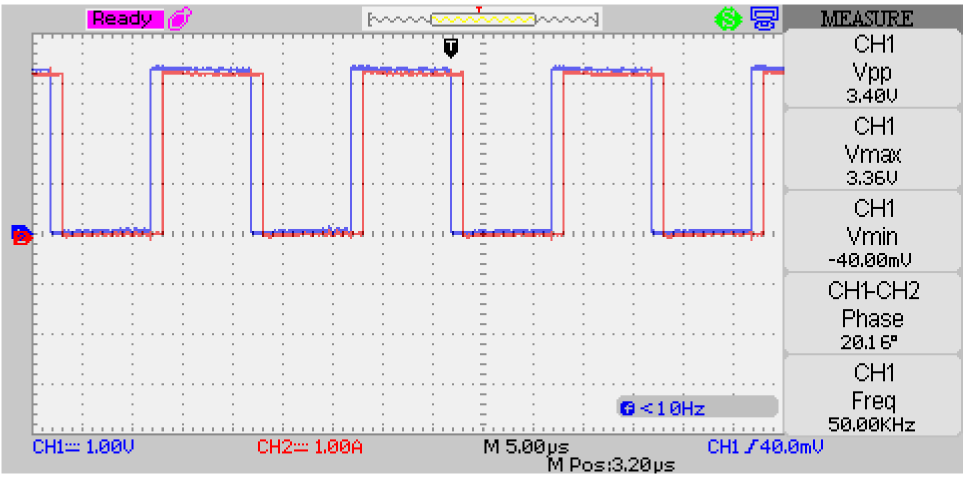


Figure 4.5. 30° Phase shifted PWM pulses.

The hardware setup for testing the driver IC TC4420 for the MOSFET switch is effectively implemented out and presented in Figure 4.6.

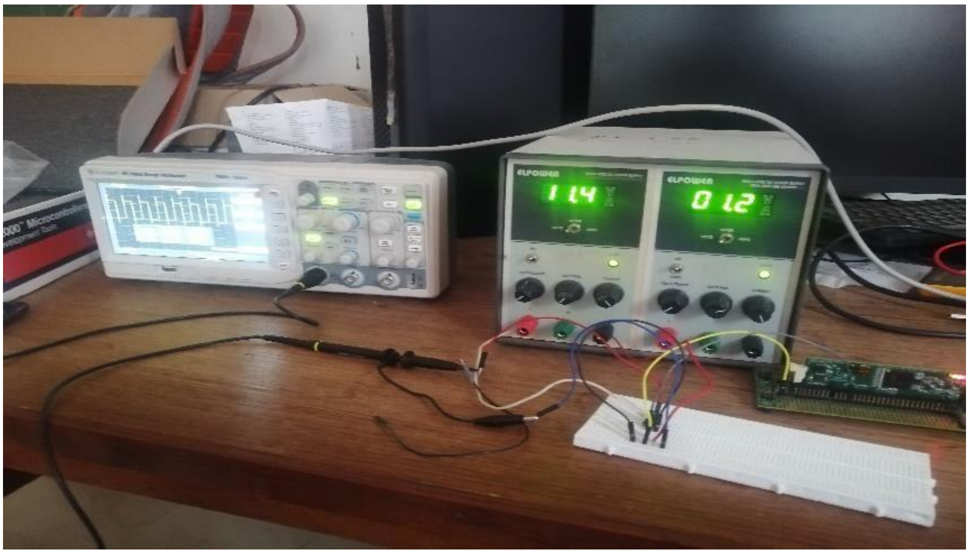

Figure 4.6. Experimental setup for MOSFET driver testing

## 5. CONCLUSION

Dual active bridge converter for battery charging application is designed and simulated using MATLAB Simulink software. Simulation model also provides a closed loop control for the Dual active bridge converter which maintains the output current constant at 10A. Further the comparative study between different power semiconductor devices (Sic and GaN) has been carried out using the MATLAB Simulink software. Also in this work, the PWM pulses are effectively generated using TMS320F28335 digital signal processor. At present work is carried out using PSM20N50CT MOSFET switches and hardware implementation of the same is performed. However, GaN and SiC MOSFET switches are a bit expensive and it is proposed as future work. Further the parameters in the simulation study for the GaN and SiC switching devices are very much limited. Hence limited comparative study between SiC and GaN switches is carried out.

## 6. REFERENCES


[1] D. Costinett, R. Zane and D. Maksimovic, "Discrete time modeling of output disturbances in the dual active bridge converter," 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014.

[2] Dongzhi Wang, Weige Zhang and Jingxin Li, "PWM plus phase shift control strategy for dual-active-bridge DC-DC converter in electric vehicle charging/discharging system," 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), 2014.
[3] V. Karthikeyan and R. Gupta, "Closed-loop control of isolated dual active bridge converter using dual phase shift modulation," IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, 2015.
[4] S. Hazra et al., "High Switching Performance of 1700-V, 50-A SiC Power MOSFET Over Si IGBT/BiMOSFET for Advanced Power Conversion Applications," in IEEE Transactions on Power Electronics, vol. 31, no. 7, pp. 4742-4754, July 2016.
[5] M. S. Ullah Khan, A. I. Maswood, H. D. Tafti, M. M. Roomi and M. Tariq, "Control of bidirectional DC/DC converter for back to back NPC-based wind turbine system under grid faults," 2016 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET), 2016.
[6] Anping Tong et al., "Power flow and inductor current analysis of PWM control for Dual Active Bridge converter," 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), 2016.
[7] M. Ishigaki, J. Shin and E. M. Dede, "A Novel Soft Switching Bidirectional DC–DC Converter Using Magnetic and Capacitive Hybrid Power Transfer," in IEEE Transactions on Power Electronics, vol. 32, no. 9, pp. 6961-6970, Sept. 2017.
[8] A.Vazquez, A.Rodriguez, M.R.Rogina and D.G.Lamar, "Different Modular Techniques Applied in a Synchronous Boost Converter With SiC MOSFETs to Obtain High Efficiency at Light Load and Low Current Ripple," in IEEE Transactions on Industrial Electronics, vol. 64, no. 10, pp. 8373-8382, Oct. 2017.
[9] F. Yazdani and M. Zolghadri, "Design of dual active bridge isolated bi-directional DC converter based on current stress optimization," 2017 8th Power Electronics, Drive Systems & Technologies Conference (PEDSTC), 2017.
[10] D. Mahajan and S. Khandelwal, "Impact of p-GaN layer Doping on Switching Performance of Enhancement Mode GaN Devices," 2018 IEEE 19th Workshop on Control and Modeling for Power Electronics (COMPEL), 2018.
[11] G. Brando, A. Del Pizzo and S. Meo, "Model-Reference Adaptive Control of a Dual Active Bridge dc-dc Converter for Aircraft Applications," 2018 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2018.
[12] C. Peng et al., "SiC MOSFET switching characteristic optimization and application in battery charging/discharging," 2019 IEEE 10th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2019.
[13] A. Platon, S. Oprea, A. Florescu and S. G. Rosu, "Simple and Digital Implementation of PI Controller Used in Voltage-Mode Control," 2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 2018.
[14] F. D. Esteban, F. M. Serra and C. H. De Angelo, "Control of a DC-DC Dual Active Bridge Converter in DC Microgrids Applications," in IEEE Latin America Transactions, vol. 19, no. 8, pp. 1261-1269, Aug. 2021.