High Efficiency Bidirectional Dual Active Bridge DC/DC Converter for level 3 Electric Vehicle Charging

Abstract— **This paper present a design of Dual Active Bridge(DAB) bidirectional DC/DC converter for level 3 electric vehicle (EV) charging application. Modularity and symmetrical structure in the DAB allow for stacking converters to achieve high power throughput and facilitate a bidirectional mode of operation to support battery charging and discharging applications. Simulation done in PLECS, experimental result verify the performance of the proposed DC/DC converter with over 93% full load efficiency, secondary voltage of 350 V-500 V DC. The design is beneficial where power density ,cost, weight, galvanic isolation, high voltage conversion ratio, and reliability are critical factors.**

Keywords—Bidirectional, DAB, DC/DC converter ,electric vehicle(EV)

I. INTRODUCTION

The electric vehicle charging standards governed by the Combined Charging System and CHAdeMO are constantly changing and are pushing for faster battery charging rates requiring typically less than 30 minutes spent at a charging station for one full charge of an electric vehicle. The DC charging station is typically a Level 3 charger which can cater to a very high power level between 120–240 kW. These DC charging stations are standalone units which house AC/DC and DC/DC power conversion stages. A number of power conversion modules are stacked together inside of a charging station to increase the power levels and enable fast charging. DC fast-charging stations provide a high power DC current to an electric vehicle's battery without passing through any onboard AC/DC converter, which means the current is connected directly to the battery. Most cars on the road today can handle only up to 50 kW. Newer cars have the ability to charge at greater rates of power. As EVs come with higher range and batteries get bigger, DC charging solutions are being developed to support long-range EV batteries through fast charging stations up to 250 kW or more.

The DC/DC converter must be capable of handling high power levels. In addition to this, the converter must be modular, which enables single power stage converter units to be paralleled, whereby the output power throughput can be scaled to higher levels as required by DC charging station standards. Current trends in the charging station are moving toward converters that can handle bidirectional power flow. New practices, such as Vehicle-to-Grid (V2G), involve power transfer between the battery of an electric vehicle and the AC grid. Bidirectional DC/DC converters enable charging of the battery in the forward mode of operation and facilitate flow of power back to the grid from the battery during reverse mode of operation, which can be used to stabilize the grid during peak load periods.

The dual-active-bridge (DAB) topology [1] is ideally suited for high-power galvanic isolated dc–dc conversion. It has advantages of high power density, zero-voltage switching (ZVS), bidirectional power transfer capability, a modular and symmetric structure, and simple control requirements. It can also be used for multiport operation [2], [3], a feature that is useful in interfacing several dc sources and loads using a single converter. Details of DAB operation and comparison with other topologies can be found in [1] and [4]–[6]. Although several other bidirectional isolated dc–dc converter topologies have been proposed in literature, the simple symmetric structure and simple control mechanism of the DAB are unique attributes. Small-signal modeling for the DAB with phase-shift modulation has been presented in [7]. The DAB converter has also been proposed as a building block for modular high-power converters [8], [9].

The rest of the paper is organized as follows, Section II introduces the basic DAB converter. In Section-III a high-efficiency bidirectional DAB DC/DC converter circuit is proposed. Section IV examines the simulation outcomes and section V concludes the paper.

II. BASIC DAB CONVERTER

Power transfer between the two bridges in a dual active bridge is analogous to the power flow between two voltage buses in a power system. Consider two voltage sources connected by a line reactance as shown in figure [1]

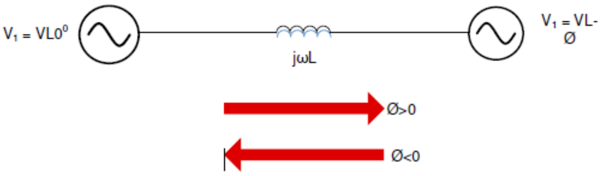

Fig.1. Power Transfer Between Voltage Bus

Figure [1] shows that the voltage source on the right is lagging with respect to the voltage source on the left.

Hence, the power transfer takes place from the left towards the right .

Similarly, power transfer happens in a dual-active bridge where two high-frequency square waves are created in the primary and secondary side of the transformer by the switching action of MOSFETs. These high-frequency square waves are phase shifted with respect to each other. Power transfer takes place from the leading bridge to the lagging bridge, and this power flow direction can be easily changed by reversing the phase shift between the two bridges. Hence, it is possible to obtain bidirectional power transfer with ease in a dual-active bridge as shown in Figure [2]

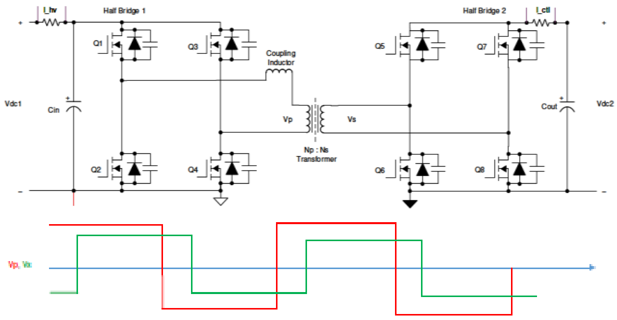

Fig. 2. Dual Active Bridge

III. PROPOSED BIDIRECTIONAL DAB DC/DC CONVERTER

In this section, we explained the proposed bidirectional converter. This design consists of four main sections that intercommunicate:

A power board comprising the power stage SiC MOSFETs, a high-frequency transformer,current sensing electronics, gate drivers, voltage and current sensing, and the system power tree.

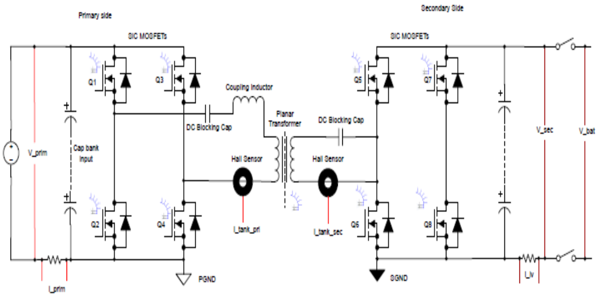

Fig.3. Block Diagram of Dual Active Bridge DC/DC Converter

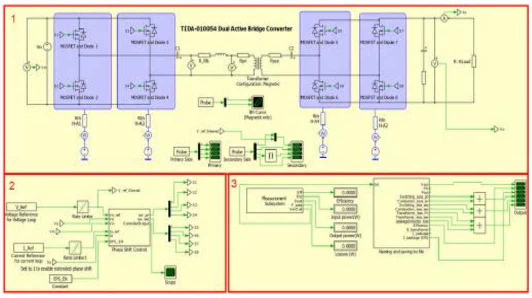

Fig. 4. PLECS Simulation Deck

The PLECS simulation deck consists of three major parts:

1.Power converter:

a. Contains power converter, with silicon carbide field-effect transistor (SiC-FET) models

b. Heat sinks for thermal analysis

c. Primary scope for analyzing switch node waveforms

d. Secondary scope to analyze output voltage, current, and power

e. BH Curve to analyze magnetic behavior of the transformer

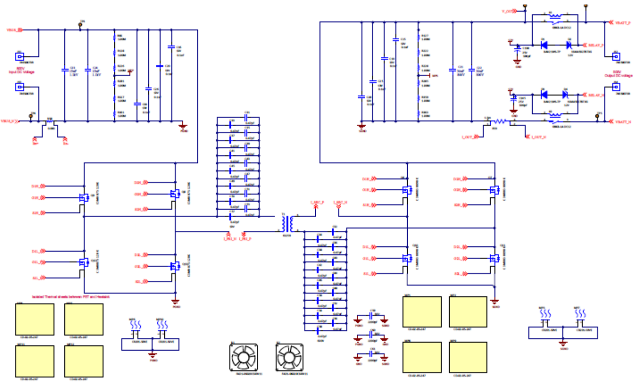

Fig.5. Power Stage

The primary side of power stage consists of 1200-V, 75-mΩ silicon carbide FETs to block a DC voltage of 800 V, and the secondary side consists of 900-V, 30-mΩ silicon carbide FETs to block DC voltage of 500 V. The full bridges are connected with a high-frequency switching transformer (T1). Four heat sinks in combination with two fans are used to cool the FETs. Insulation sheets are used between the FETs and the heat sinks to provide necessary insulation and a good thermal interface.

2. Phase shift control:

a. Contains controller for voltage and current loop. Allows to switch between voltage and current loop by opening Phase Shift Control block and changing the configuration of the controller.

b. Extended phase shift modulation can be enabled by setting EPS_EN = 1 in the initialization script.

3. Measurement subsystem:

a. Measures and adds up losses in the system, to calculate efficiency

b. Displays to see input power. Output power efficiency and losses while simulation is running

c. Naming and saving to a file block, to name signals from the measurement subsystem.

IV. SIMULATION RESULTS

The system-level circuit of the converter have been simulated using PLECS software. Simulation results are performed with 700 V- 800 V input voltage range with 100 kHz PWM switching frequency.

Figure 6 shows the primary scope and is used to evaluate switching waveforms . Here primary voltage is around 800V, secondary voltage around 500V.The leakage inductor voltage and current values determine the losses occurred in the system, thus getting efficiency of the system around 93%.Figure 7 shows the secondary scope and is used to observe output voltage, current and power, as well as the output voltage ripple and current. Output voltage is around 500 V, output current around 20 A. Maximum power output of 10kW.Voltage ripple less than 5%.

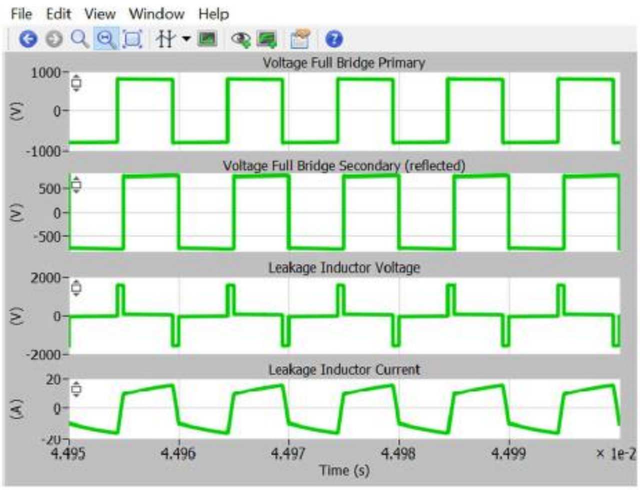

Fig.6. PLECS- Primary Scope

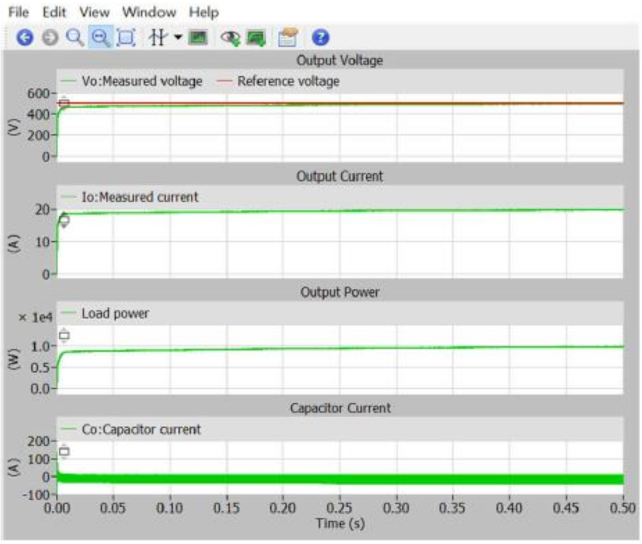

Fig.7. PLECS- Secondary Scope

V. SUBJECTIVE COMPARISON OF THE PROPOSED CONVERTER

The table I shows a subjective comparison corresponding to different parameters. It can be clearly observed that the proposed converter offers high efficiency, has higher voltage range and can support long range electric vehicles.

Parameters	**Proposed Level 3**	**Level 1**	**Level 2**
Efficiency (%)	93	75-80	80-85
Voltage Range	250-500-V DC	120 V AC	240 V AC
Charging Speed	Fast	Slow	Medium

Table : I Subjective Comparison of Parameters Proposed Level3 Vs Level 1&2

VI. CONCLUSION

A bidirectional dual active bridge DC/DC converter for level 3 EV charging has been proposed. The design works for high voltage range , 93% full load efficiency, less voltage ripple <5% , high power throughput leading to high power density. The design can work for both single and extended phase shift control. This design is reliable for long range EVs where the size of the battery gets bigger and fast charging is required around 30-40 minutes.

REFERENCES

[1] R.W.A.A.De.Doncker, D.M.Divan and M.H.Kheruwala, “A three-phase soft-switched high-power-density dc/dc converter for high-power applications,” *IEEE Trans. Ind.Appl.*,vol.27, no. 1, pp. 63-73, Jan./Feb. 1991.

[2] C. Zhao and J.W.Kolar, “A novel three-phase three-port ups employing a single high-frequency isolation transformer,” in Proc. 35th *IEEE Power Electron.Spec.Conf.(PESC2004)*, Aachen, Germany, Jun. 200 4, vol. 6, pp. 4135-4141.

[3] J.L.Duarte, M. Hendrix and M.G. Simoes, “Three-port bidirectional converter for hybrid fuel cell systems,” *IEEE Trans. Power Electron*., vol. 22, no. 2, pp. 480-487, Mar. 2007.

[4] M.H.Kheraluwala, R.W.Gascoigne, D.M.Divan and E.D.Baumann,”Performance characterization of a high-power dual active bridge dc-to-dc converter,*” IEEE Trans. Ind. Appl.*, vol. 28, no. 6, pp. 1294-130, Nov./Dec. 1992.

[5] R.Steigerwald, R.De.Doncker and M.H.Kheraluwala,”A comparison of high power dc to dc soft switched converter topologies,” *IEEE Trans. Ind. Appl.*, vol. 2, no. 6, pp. 1139-1145, Sep./Oct. 1996.

[6] R.De.Doncker,” High power galvanically isolated dc/dc converter topology for future automobiles,” in Proc. 34th *IEEE Power Electron. Spec. Conf. (PESC2003*), Acapulco, Mexico, Jun. vol. 1, pp. 27-32.

[7] F.Kismer and J. Kolar,” Accurate small signal model for the digital control of an automotive bidirectional dual active bridge,”*IEEE Trans. Power Electron*., vol. 24, no. 12, pp. 2756-2768, Dec. 2009.

[8] H. Krishnamurthy and R.Ayyanar,” Building block converter module for universal(ac-dc, dc-ac, dc-dc) fully modular power conversion architecture,” in Proc.38th*IEEE Power Electron. Spec.Conf. (PESC2007)*, Orlando, FL, Jun., pp. 483-489.

[9] S. Inoue and H.Akagi, “A bidirectional isolated dc-dc converter as a core circuit of the next-generation medium-voltage power conversion system,” *IEEE Trans. Power Electron*., vol. 22, no. 2, pp. 535-542, Mar. 2007.