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Bidirectional Single Stage Three Phase AC-DC Converter

Keerthi N S[1], Leesha Paul[2]

Student, Electrical and Electronics Engineering, NSS College of Engineering, Palakkad, India[1]

Professor, Electrical and Electronics Engineering, NSS College of Engineering, Palakkad, India[2]

Abstract: Every battery charger used for electric vehicle should contribute a bidirectional power flow capability. Converter suitable for an energy storage system should have an isolation. Several multi stage topologies are familiar to us which contribute the following application. An AC-DC single stage three phase power converter with high-frequency isolator is discussed here. Mostly Dual Active Bridge (DAB) converters are used because of their high-power density, better efficiency, and application in medium power. Here a bidirectional charger using dual active bridge topology based on the single-stage conversion of AC-DC is presented. The detailed analysis of the system operation with simulation results confirms the analytical predictions.

Keywords: Bidirectional Converter, Dual Active Bridge (DAB), Single-stage Conversion.

I. INTRODUCTION

Researchers extended their areas to wind power, solar power, wave power, and Vehicle-to-Grid (V2G) due to the depletion of fossil fuels, increasing oil prices, and the reduction of greenhouse gases. V2G means Plug-in Hybrid Electric Vehicles (PHEV) and Electric Vehicles (EV) are connected to the grid and can consume or supply power. Vehicle to Grid technology can also be used for peak load shaving, voltage regulation, and reactive power compensation. For reducing emissions and improving fuel economy, we are developing electric, hybrid electric, and plug-in hybrid electric vehicles. Power electronics is an enabling technology for the development of these environmentally friendlier vehicles and implementing the advanced electrical architectures to meet the demands for increased electric loads [1]-[2].

Our conventional chargers have multiple stages for the power conversion and they contribute complexity to the system as shown in Fig. 1. They use an AC-DC rectifier followed by an isolated DC-DC converter [3]. The AC-DC converter simply converts the AC power to DC and a DC-DC converter followed by a dc link electrolytic capacitor will result in transformer size reduction. There may be an energy storage device such as an electric double-layer capacitor that is directly connected to a dc side of the dc-dc converter without any chopper circuit. But the overall power density of the system is reduced when multiple stages of conversion is used.

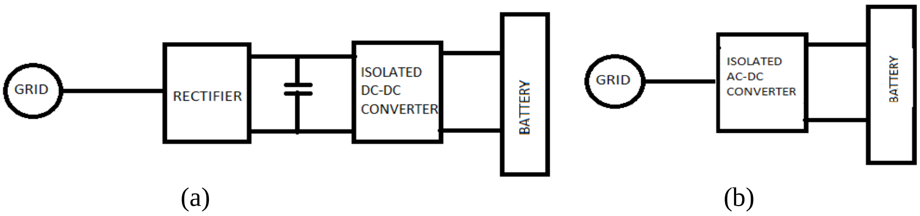

Fig.1. (a) Typical two-stage battery charger (b) single-stage battery charger

The drawbacks of multi-stage led to the development of single-stage converters which transfer active power without any intermediate stage. They have a better power density and reliability due to the exclusion of the DC link electrolytic capacitor [4]-[5]. A dual active bridge (DAB) converter is usually considered as an isolated dc–dc converter owing to its simple circuit structure and continuous power flow reversal capability. However, the converter suffers from some drawbacks, such as limited zero-voltage switching range and high circulating current, under a wide voltage variation. But this type of power conversion is suited for high voltage and medium power applications. A bidirectional DC-DC

converter applies to V2G operation. This converter enables and controls the amount and the direction of the power flow between the electric vehicle battery and the DC bus of the microgrid. The bidirectional DC-DC converter that has been selected is the Dual Active Bridge (DAB) converter. This topology offers galvanic isolation which is mandatory by many standards, inherent zero voltage switching characteristics [6]-[7]. Furthermore, it presents a high-power density, a low number of passive components and a fast-dynamic response.

The dual active bridge converter has some of the advantages such as low device and component stresses, small filter components, low switching losses (under the virtue of zero voltage switching), high-power density and high efficiency, bidirectional power flow, buck-boost operation, and low sensitivity to system parasitic [8]. The converter uses active devices on both the input and output sides to realize a minimal topology that has low device stresses, no extra reactive components and uses the transformer leakage inductance as the main energy transfer element. The ripple current levels in the input and output filter capacitors are also seen to be reasonable. The topology also permits high-frequency operation as a result of zero voltage switching for all the devices over a reasonable operating range. Consequently, the DAB topology is considered to be more attractive, especially where power density is important.

The DAB topology can operate efficiently when all the switching devices operate under zero-voltage switching (ZVS) for the entire power range. Such an efficient operation is possible only when the voltage conversion ratio is equal to one. When the voltage conversion ratio differs from one, the converter cannot operate under ZVS in the entire power range, and the DAB converter efficiency is greatly reduced. A switching control strategy that minimizes the effects of this drawback by extending the DAB converter soft-switching operating range and converter power losses for each required output power and voltage conversion ratio is analysed based on the switching strategy with consideration of the semiconductor devices and transformer. Based on this analysis, a new algorithm to control the power flow and minimize the total power losses of the DAB topology is presented in [9].

A matrix-based three-phase AC-DC converter is discussed in [10] and a modulation scheme named as Switched Rectifier Inverter (SRI) scheme is presented in this paper. The modulation scheme will use asymmetrical and fewer number of switching instances compared to traditional SPWM based matrix converter and will have reduced current and voltage slew rates leading to superior performance.

In this paper, a single stage converter discussed here results in a simple conversion of three phase AC to DC with DAB topology. Section II describes the proposed circuit diagram. It is followed by the parameter design of the converters. To verify the theoretical analysis, in Section III simulations are conducted. Finally, a conclusion is drawn in Section IV.

II. CIRCUIT DESCRIPTION

This section presents a detailed analysis of the three-phase AC-DC dual active bridge converter, as shown in Fig. 2, with a modulation technique, derivation of closed-form expressions of important quantities such as DC power transferred and soft switching mechanism. The input Converter is a three-phase to single-phase matrix converter supplied by the AC voltages. The single-phase side of the matrix converter is connected to the primary winding of a single-phase high-frequency transformer (HFT). It consists of six four-quadrant switches, SaA, SbA, ScA, SaB, SbB, ScB, comprised of two common-emitter connected IGBT's. The AC input side has a low pass LC filter (Cac and Lac) between the source and the three-phase to single-phase matrix converter to suppress current harmonics drawn from the grid. The turns ratio of the single-phase transformer is 1: n. In this analysis, the magnetizing inductance, winding resistance and core losses of the transformer are neglected. The primary and secondary leakage inductances are lumped together on the secondary as L. The output converter is an H-bridge connected to the secondary of the single-phase transformer and consists of four two-quadrant switches S1, S2, S3, S4. There is a DC filter connected at the output side of the converter. A DC source of voltage Vo is connected to the H-bridge. All switches are considered to be ideal in this analysis.

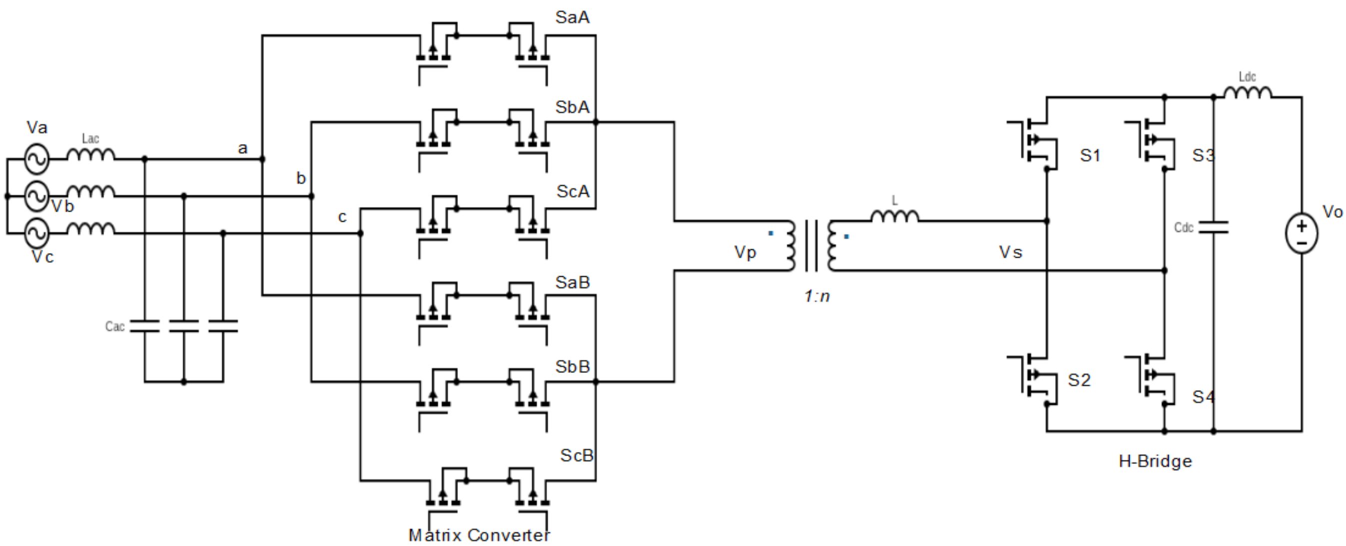

Fig. 2. Single Stage AC-DC Converter

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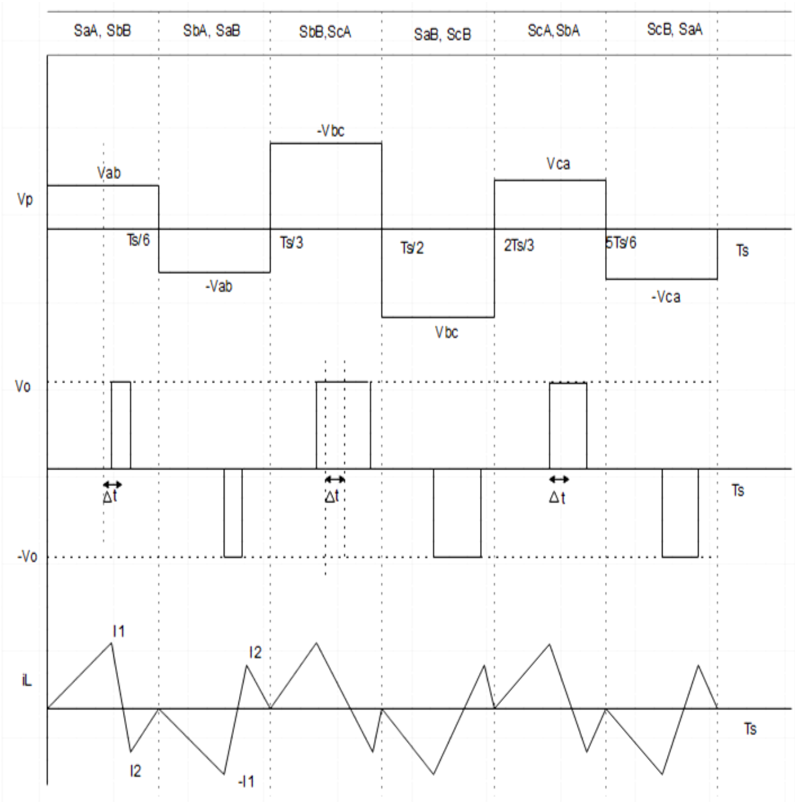

Fig. 3. Typical waveform over a switching cycle Ts.

III. SIMULATION RESULTS

MATLAB is used for simulating the proposed modulation strategy. The simulation circuit is shown in Fig. 4. It can be observed that the inductor current is close to zero at the transitions of Vp, demonstrating ZCS in the primary side converter, while the inductor current polarities at switching transitions in vs show that ZVS occurs in the secondary side H-bridge. Both the AC and DC side currents have high frequency harmonics starting at switching frequency. The input AC currents for all the three phases are sinusoidal and balanced. The phase A voltage Van and the current Ia are nearly in phase confirming unity power factor operation. The transformer primary and secondary voltages and the inductor current obtained after simulation are shown in Fig. 5.

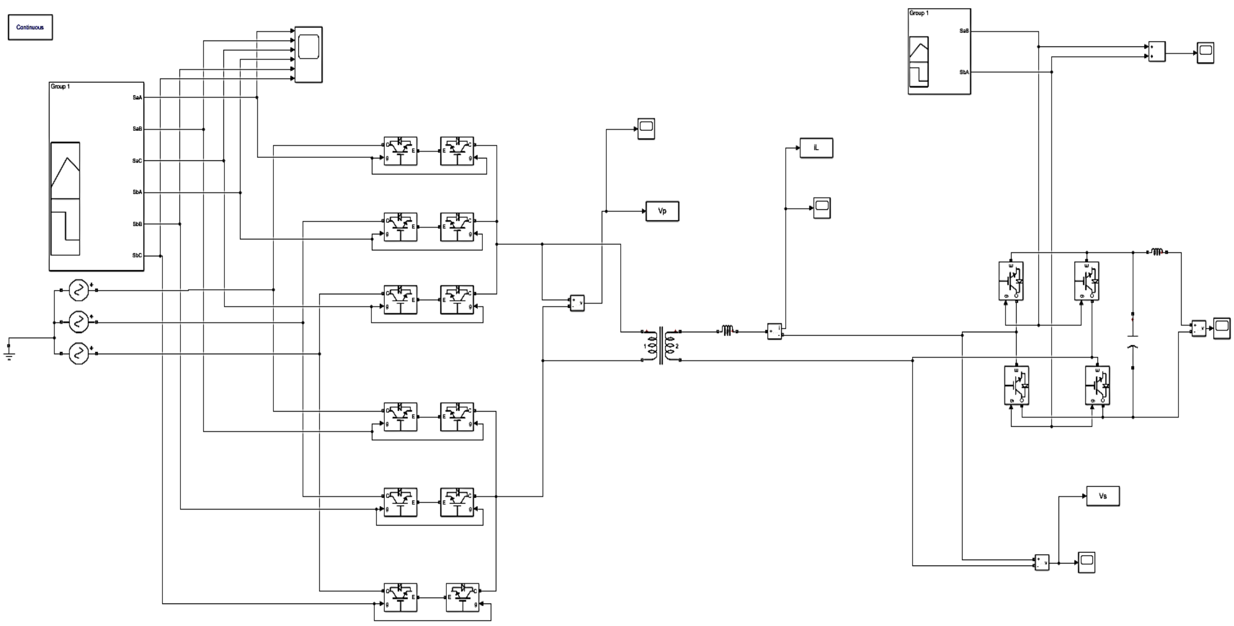

Fig. 4. Simulation circuit of the AC-DC converter

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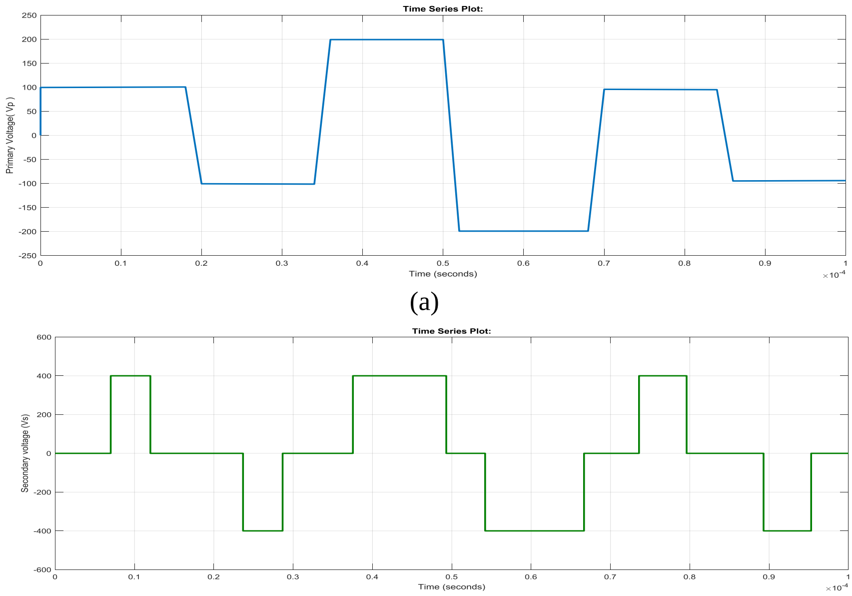

(a)

(b)

Fig. 5. Simulation results (a) Primary voltage of transformer (b) Secondary voltage of transformer

To demonstrate the accuracy of the analysis done for power transfer and RMS currents, the system was simulated for different modulation indices and phase shift values. It is observed that the simulation results follow the analytical values closely.

IV. CONCLUSION

A Dual Active Bridge-based single-stage three-phase AC-DC converter is presented. The main features of this are (a) single-stage power conversion (b) Bi-directional power flow (c) soft switching of primary and secondary side converters. Due to loss-less switching, the switching frequency of the converter may be increased leading to high power density. Moreover, due to bidirectional power flow capability, high power density and loss less switching, it applies for the vehicle to grid application. The analysis of the system is performed and the simulation results are discussed.

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