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AN IMPROVED FULL BRIDGE DC-DC CONVERTER FOR ELECTRIC VEHICLES

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ABSTRACT

The battery charger of electric vehicles plays a very important role in their development. This project focuses on the DC-DC converter for the electric vehicle battery charger which is the second stage of a two stage on-board charger. The first stage is a power factor correction rectifier used to transform the 50Hz electrical quantities into DC quantities with a good input power factor. The second stage is a zero voltage switching full bridge dc-dc converter which adjusts the levels to the values required by the battery and moreover provides a galvanic isolation. The main objective of this project is to process and deliver power efficiently, to minimize the charger size, to reduce the switching losses, to guarantee fast operation and to reduce the cost of electricity drawn from utility.

Keywords-- DC-DC converter, full bridge, electric vehicle, zero voltage switching (ZVS), battery charger

I. INTRODUCTION

Fossil fuels have been extensively used in past several years and if this trend continues we would end up completely exhausting them and it would lead to a situation where we would face scarcity of such fossil fuels. Use of electric energy for vehicles is one of the alternative as well as ecological solutions instead of using fossil fuels. Due to the exhaustible oil reserves and harmful environmental impacts of burning oil, it is essential to find alternative energy sources in the field of transportation. Alternative vehicle technologies to replace conventional vehicles consist of electric vehicles, hybrid electric vehicles (HEVs), plug in hybrid electric vehicles (PHEV) or else commonly called battery electric vehicles (BEVs), and fuel cell vehicles (FCVs).

Advantages of electric cars over conventional internal combustion engine automobiles include a considerable reduction of local pollution, a large reduction in total greenhouse gas and other emissions, and less dependence on foreign oil. Battery Electric Vehicles (BEV's) refer to vehicles propelled exclusively by electric motors. The source of power stems from the chemical energy stored in battery packs which can be recharged on the electricity grid. The scope of such vehicles strongly depends on the battery and battery charger developments.

EV battery chargers can be classified as on-board and off-board with unidirectional or bidirectional power flow. Unidirectional charging limits hardware requirements, simplifies interconnection issues, and tends to reduce battery degradation. A bidirectional charging system supports charge from the grid, battery energy injection back to the grid, and power stabilization with adequate power conversion.

In order to make the charging easy, on-board chargers [1]- [2] have been developed. The charger should to be able to plug into a socket and moreover, it should to be a grid friendly in order not to pollute the electrical network.

The most general charger topologies includes an ac–dc converter with power factor correction (PFC) [3] followed by an isolated dc–dc converter. There are many high efficiency full bridge dc-dc converters [4]-[6] that can be used as the second stage converter. Phase shifted gating scheme [7]-[9] for full bridge dc-dc converter is most commonly used. Soft switching for the switches is achieved using an external inductor in addition to the leakage inductance of the transformer and the output capacitance of the switch. This converter has many improvements [10]-[11] but these improvements increase the number of components and also losses.

Current fed topologies with capacitive output filter naturally minimize diode rectifier

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ringing since the transformer leakage inductance is effectively placed in series with the supply side inductor [12]–[13]. In addition, high efficiency can be achieved with ZVS, using pulse width modulation technique.

II. THE PROPOSED TWO STAGE BATTERY CHARGER

The proposed on-board charger is shown in Fig. 1.The proposed charger consists of a front end power factor correction converter and a second stage full bridge dc-dc converter.

A. Front-End First Stage AC-DC PFC Rectifier

The interleaved PFC consists of two CCM boost converters in parallel, which operate 180° out of phase [15] –[16] .The input current is the sum of the inductor currents in LB1 and LB2. Since the inductor ripple currents are out of phase, they tend to cancel each other and reduce the input ripple current.

B. Second Stage ZVS Full-Bridge DC-DC Converter

The primary side of the second stage converter consists of a full-bridge inverter. However, instead of driving the diagonal bridge switches simultaneously, the lower switches (Q3 and Q4) are triggered at a fixed 50% duty cycle and the upper switches (Q1 and Q2) are pulse width modulated.

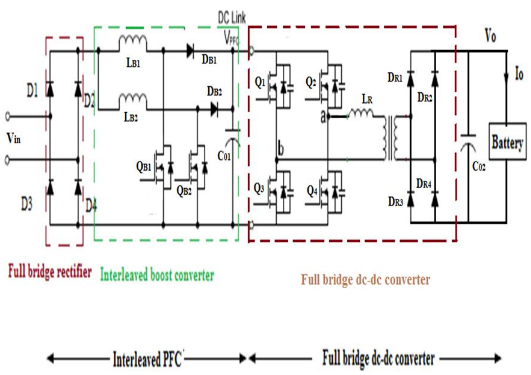

Figure1.The proposed electric vehicle battery charger

This converter has six operating intervals. The operating waveforms of full bridge dc-dc converter with timing intervals are shown in Figure 2. The operating intervals are determined by the ON/OFF states of the four primary switches. In the analysis that follows, the power semiconductor switches have been modeled with parallel diodes and parasitic capacitances. The rectifiers are assumed to be ideal and the resonant inductor includes the transformer leakage inductance.

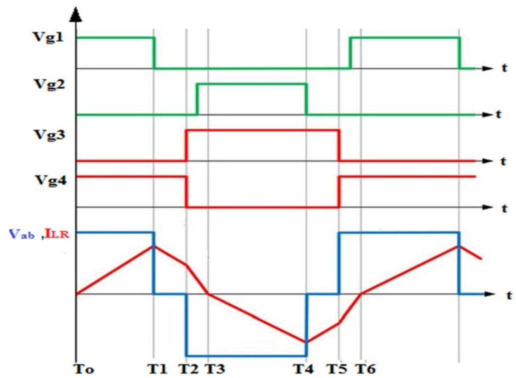

Figure 2.Timing interval for full bridge dc-dc converter

A. Interval 1

In interval 1, switches Q1 and Q4 are ON and Q2 and Q3 are OFF. The primary current flows through Q1, resonant inductor L_R, transformer primary and Q4, which is shown in Fig.3.The rate of change of current (di/dt) through L_R depends on the difference between the input voltage Vin and the output voltage Vo. During this mode power flows to the output through rectifier diodes D_{R1} and D_{R4} and also energy is stored in L_R. The resonant inductor current $i\ (t)$ using initial condition $i\ (0) = 0$ is given by $i\ (t) = \frac{\quad}{\quad}(t - T\ )$

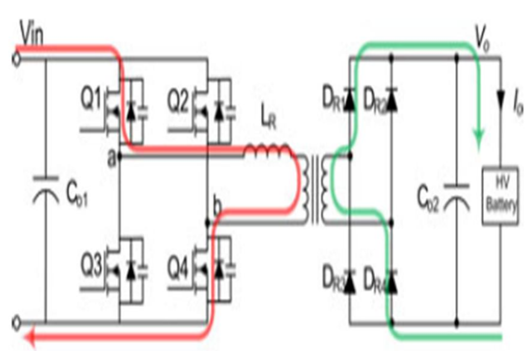

Figure 3.Equivalent circuit for Interval 1

B. Interval 2

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During Interval 2 the current through the inductor L_R does not reach zero on reaching the instant T2 and the rectifier diodes D_{R1} and D_{R4} are ON. At the end of this interval,

$$i\ (t) = i$$

The equivalent circuit for this interval is as shown in the Fig.4.

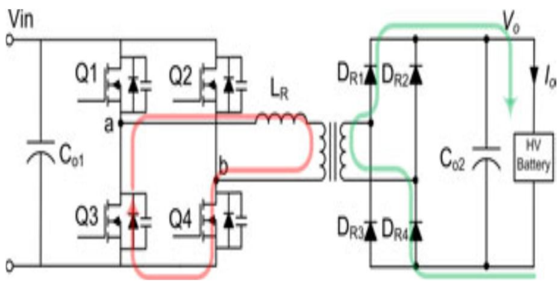

Figure 4.Equivalent circuit for Interval 2

C.Interval 3

At T2, Q3 turns ON and Q4 turns OFF. This toggle time depends on the resonant delay that occurs prior to Q2 turning ON. When Q3 is ON and Q4 OFF, the inductor current which flows through Q4 finds an alternate path by charging/discharging the parasitic capacitances of switches Q4 and Q2 until the body diode of Q2 is forward biased. Switch Q2 can be turned ON with ZVS if the resonant delay is properly set. At T3 the complete energy stored in L is transmitted to the output and the current becomes zero and the rectifier diodes D_{R1} and D_{R4} turn OFF. The resonant inductor current i (t) using initial condition i (0)= I is given by

$$(\ ) = \quad - \frac{+ -}{\quad}(\ - \quad)$$

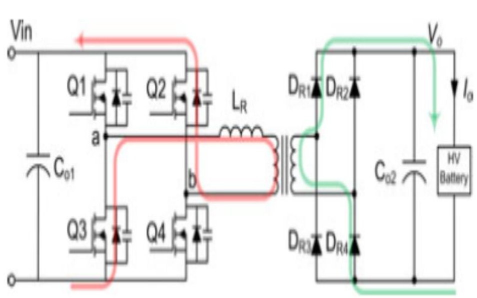

Figure 5.Equivalent circuit for Interval 3

D. Interval 4

In interval 4, switches Q2 and Q3 are ON and Q1 and Q4 are OFF. The primary current flows through Q2, inductor L_R, transformer primary and Q3. The rate of increase of the current (di/dt) through L_R is proportional to the difference between the input voltage V_{in} and the output voltage Vo. In this mode power is transferred to the output through output diodes D_{R2} and D_{R3} and moreover energy is stored in L_R. The equivalent circuit for this interval is as shown in the Fig.6.

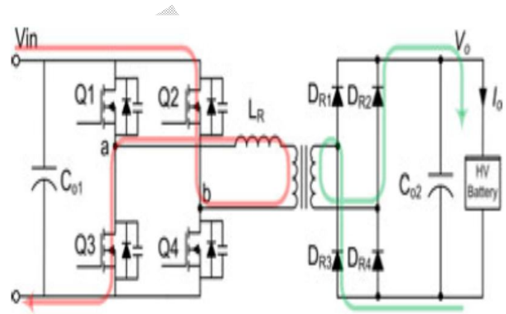

Figure 6.Equivalent circuit for Interval 4

E. Interval 5

During Interval 5 the current through the resonant inductor does not reach zero and the rectifier diodes D_{R3} and D_{R4} are ON. The equivalent circuit for this mode is shown in Fig.7

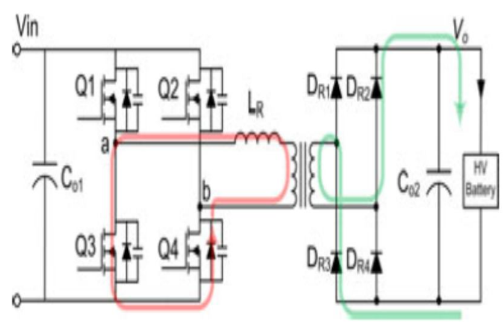

Figure 7.Equivalent circuit for Interval 5

F. Interval 6

This interval is the negative equivalent of the interval 3 as shown in Fig.8.

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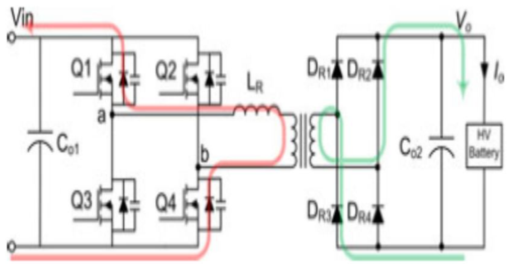

Figure 8.Equivalent circuit for Interval 6

III. SIMULATION

A.Simulation Without Power factor Corrector

The simulink circuit diagram of the system without PFC is shown in Fig.9.

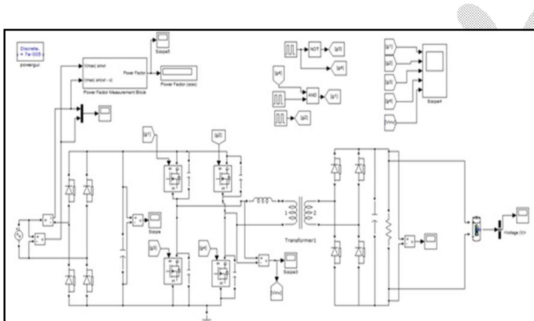

Fig.9 Simulink circuit without PFC

B.Simulation With Power factor Corrector

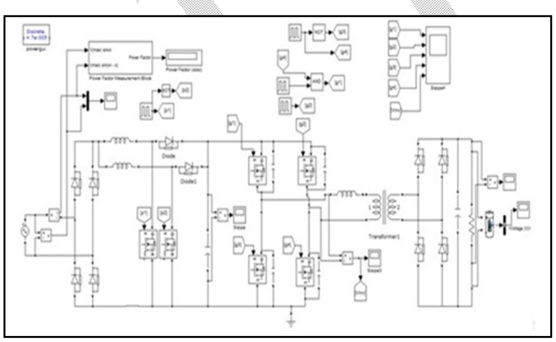

Fig.10 Simulink circuit with PFC

Fig.10 illustrates the simulink circuit diagram of the system with PFC. The power factor measurement block is shown in Fig.11.

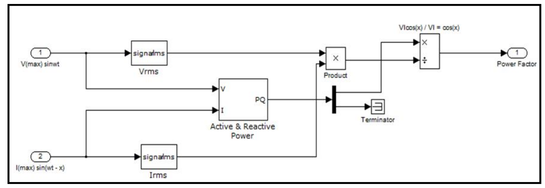

Fig.11.Power factor measurement block

C.Simulation Results

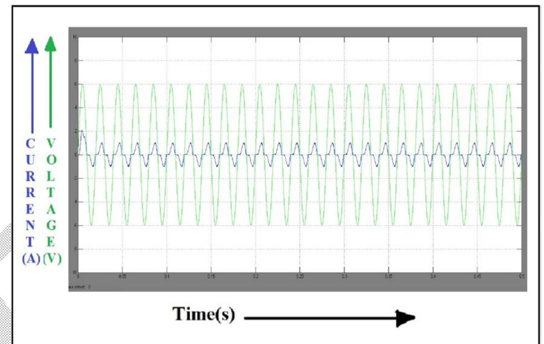

Fig 12 Input voltage and current

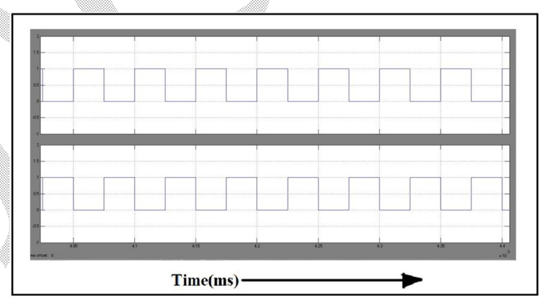

Fig.13 Pulses to Interleaved Boost Converter

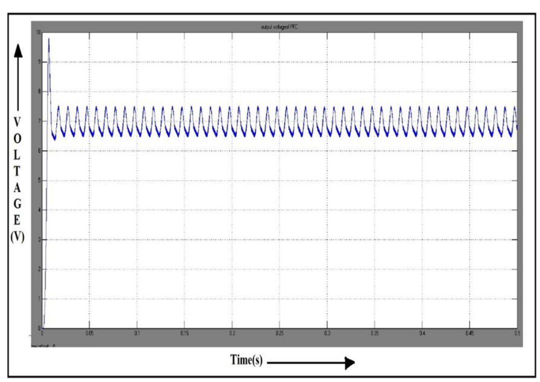

Fig.14. Power factor corrector output voltage

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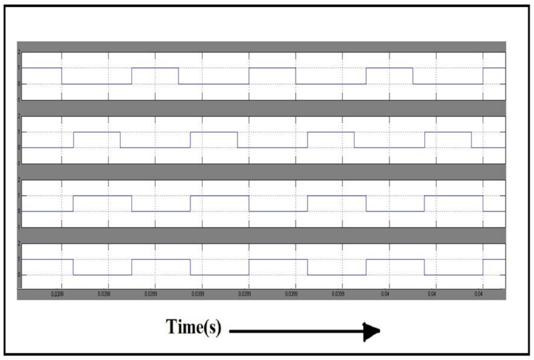

Fig.15 Pulses to the ZVS converter

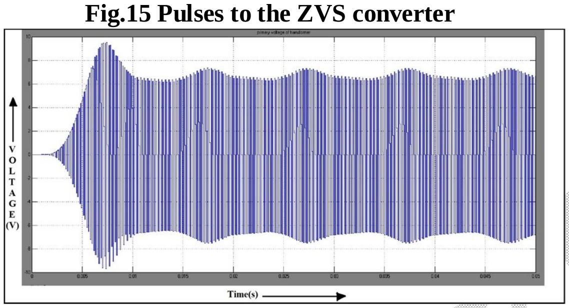

Fig.16 Voltage Across Transformer Primary Windings

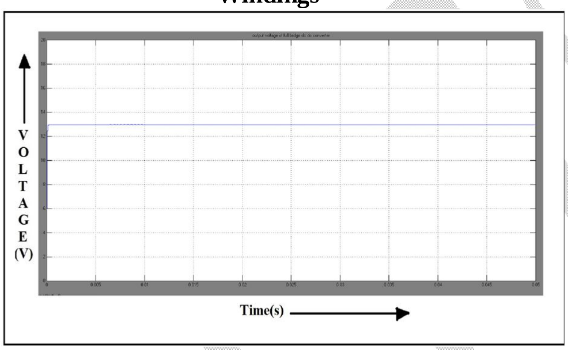

Fig.17 Output DC Voltage across Full Bridge DC-DC Converter

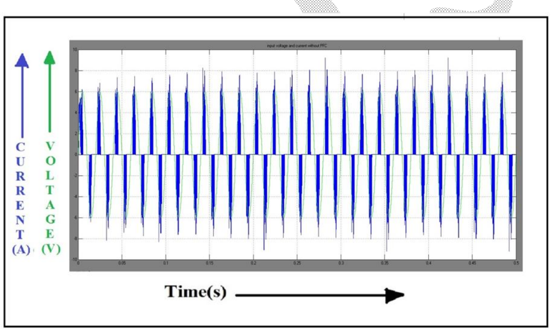

Fig.17 Input AC Voltage and Current without PFC

VII. CONCLUSIONS

The project presents an electric vehicle battery charger using an improved ZVS full bridge dc–dc converter with capacitive output filter. The detailed operating intervals were considered and the simulation results were examined. The input power factor with and without PFC has been discussed and compared. The second stage of the proposed charger attains soft switching for the full-bridge primary switches, clamps the voltage across the output rectifier to the output voltage and the current through the rectifier diodes has a low (di/dt), which helps to reduce reverse recovery losses.

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