

Simulation And Study of ZVS Interleaved AC/DC Converter for Hybrid Electric Vehicles

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ABSTRACT: This paper presents the analysis and study of ZVS interleaved boost converter for traction battery in Hybrid electric vehicles. Usually HEV consists of a full bridge converter, a front end boost PFC converter and a storage battery. This stored energy is converted in to ac using an inverter and 12V dc using a buck converter for traction purpose. The presented topology consists of ac-dc converter, interleaved boost converter, and a passive auxiliary circuit for zero voltage turn on. Charging and discharging of output capacitors of MOSFETs control zero voltage turn on of switches. The operation of the presented converter is divided in to eight modes. The operation and control schemes are discussed and the simulation carried out in Matlab/Simulink.

KEYWORDS: Interleaved Boost Converter, Zero Voltage Switching, SiC switches, auxiliary circuit.

I. INTRODUCTION

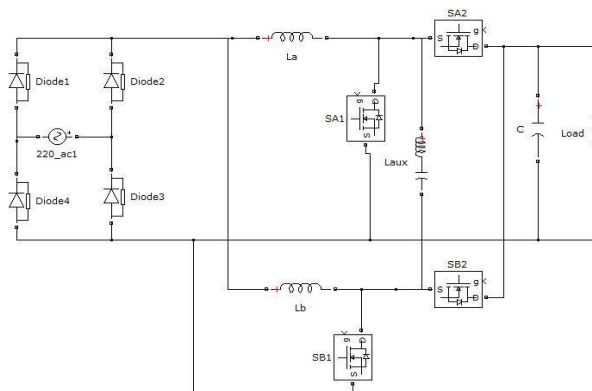
With accelerated global warming, decreasing natural resources, increasing fuel price, and economical issues, eco-friendly vehicles, such as hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs), battery electric vehicles (EVs), and fuel cell electric vehicles got more attention than any other time. These vehicles commonly use rechargeable batteries as the energy source of electric traction system [1]. Among them, PHEVs or EVs require a higher capacity and larger sized battery pack compared with other vehicles because the battery is a main energy source in PHEVs or EVs[2]. The high-energy-density battery pack in PHEVs or EVs is typically recharged from the ac utility grid via a battery charger.

Usually the battery pack of PEV or PHEV consists of an ac/dc converter. Quality of ac-dc conversion is always based on the input current shaping and output voltage regulation. Usually a combination of boost converter and rectifier are used to meet these requirements. Rectifier used is commonly an uncontrolled diode rectifier and in the case of boost converter, conventional as well as interleaved boost converters are used. Below few kilowatts conventional boost converter is used while above that interleaved boost converters are used. Presently, SiC diodes are gaining popularity in ac/dc boost converters since they have near-zero reverse recovery losses but normally SiC diodes have greater forward voltage drops, typically 2.4V and more as compared to 1.2V in Si diodes for a 600V device, which is required in this application. In addition, the thermal coefficient of SiC diodes on the forward voltage drop is positive, implying that the voltage drop increases with temperature, while the one for Si diode is negative. Thus, the use of Si diodes in very high power (3kW or more) ac/dc boost PFC converter contributes to high reverse recovery losses, while the use of SiC diodes contributes to very high conduction losses in such converters [3-5]. In this paper, a novel interleaved boost PFC converter is proposed to achieve soft switching in the main switches of the converter.

The presented converter implements soft switching through a simple passive auxiliary circuit, placed in between the two phases of the interleaved boost converter. This auxiliary circuit is able to provide reactive current to charge and discharge the output capacitors of the boost MOSFETs and guarantee ZVS. Since there are no extra semiconductors used in the auxiliary circuit, high efficiency and reliability are them a in advantages of the presented system. In addition, the proposed converter is able to optimize the amount of reactive current required to implement soft switching based on the load condition and the input voltage[6-7]. Thus, the conduction losses caused by the auxiliary circuit are minimized based on the operating condition.

II. STEADY-STATE ANALYSIS OF THE ZVS INTERLEAVED BOOST CONVERTER

Fig.1 shows the power circuit of the ZVS interleaved boost PFC converter. In this converter, two boost converters operate with 180° phase shift in order to reduce the input current ripple of converter. This 180° phase shift can be used to provide reactive current for realizing ZVS for power MOSFETs. This auxiliary circuit consists of a HF inductor and a dc-blocking capacitor. Since there may be a slight difference between the duty ratios of the two phases, this dc-blocking capacitor is necessary to eliminate any dc current arising from the mismatch of the duty ratios of the main



switches practical circuit.

Fig :1 ZVS interleaved boost converter

Mode I ($t_0 < t < t_1$):

Mode -1, the gate pulse is applied to S_{A1} . Once the voltage is above the threshold voltage, S_{A1} is turned ON under zero voltage. During this mode of operation both the switches S_{A1} and S_{B1} are ON. Hence the voltage across the auxiliary inductor is zero is due to the short circuit between phase A and phase B. This mode ends once the gate voltage has been removed from S_{B1} .

Mode II ($t_1 < t < t_2$):

Mode-2 provides a dead time between the phases B MOSFETs. Here the voltage across the inductor is zero due to the charging and discharging of output capacitance of phase B MOSFETs. Therefore, the current through phase B inductor remains constant at its peak value. $t_2 - t_1 = t_d$ is the dead time between S_{B1} and S_{B2} . To ensure zero voltage switching, output capacitance of phase B MOSFETs must be fully charged and discharged. Hence the mode ends when the dead time is over.

Mode III ($t_2 < t < t_3$):

In this mode, the gate signal is applied to the switch S_{B2} and S_{B2} is turned ON under ZVS. During this interval, the voltage across the auxiliary circuit is negative.

Mode IV ($t_3 < t < t_4$):

During this mode, the output capacitor of S_{B2} is charging from zero to V_o and the output capacitor of S_{B1} is discharging from V_o to zero. This period is actually the dead time between S_{B2} and S_{B1} ($t_4 - t_3 = t_d$). This mode ends once the gate signal is applied to S_{B1} .

Mode V ($t_4 < t < t_5$):

In this mode starts when the gate signal is applied to S_{B1} , results S_{B1} is turned ON under ZVS. During this interval S_{A1} and S_{B1} are ON, resulting in zero voltage across the auxiliary inductor. The auxiliary inductor current remains constant at its peak value, $I_{Aux,p}$. This mode ends once the gate signal is removed from S_{A1} .

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Mode VI ($t_5 < t < t_6$):

This period provides the dead time between phase A MOSFETs ($t_6 - t_5 = t_d$). The output capacitor of S_{A1} is charge whereas the output capacitor of S_{A2} is discharge during dead time. The current through the boost inductor L_A remains constant at its peak value. This mode ends once the output capacitors have completely been charged and discharged.

Mode VII ($t_6 < t < t_7$):

During this mode, the voltage across the auxiliary circuit is V_o . The phase A MOSFET channel S_{A2} is conducting and current flows through the load. This mode ends once the current in the switch i_{SA2} reaches to zero.

Mode VIII ($t_7 < t < t_8$):

In this mode, the current through L_A is at its minimum value and the excess current from the auxiliary circuit charges and discharges the output capacitors.

The gain of boost converter is given by

$$V_o/V_d = 1/(1-D) \quad (1)$$

The L_A and L_B can be calculated using the equation

$$L_A = L_B = T_s V_o D(1-D)/2I_{LB} \quad (2)$$

The auxiliary inductor should be designed so as to provide enough energy to neutralize the energy in the boost inductor as well as charge and discharge the output capacitors of the MOSFETs.

III. SIMULATION RESULTS

The EV charging system given in Fig:1 has a diode rectifier and an interleaved boost converter. The auxiliary circuit which use passive components is the main attraction of the charging circuit. The operation of the converter is divided in to eight modes. After each mode ends, a dead time is provided to ensure the zero voltage turn-on of active switches. The main losses that occur in EV charging system are turn-on losses and reverse recovery losses. By using ZVS turn-on and SiC switches, these drawbacks can be overcome. The pulses are given for a particular duty ratio. The presented converter can operate in CCM as well as DCM.

The simulation of the presented converter is done using Matlab/Simulink. $L_1=L_2=270\mu\text{H}$, MOSFETs output capacitance, $C_0 = 315\text{nF}$, $L_{\text{aux}}=120\mu\text{H}$ and $C_{\text{aux}}=1\mu\text{F}$. The circuit consist of a input rectifier and interleaved boost converter. Open loop control is used for the switching of interleaved converter switches. The output capacitor is made large to obtain higher voltage at the output.

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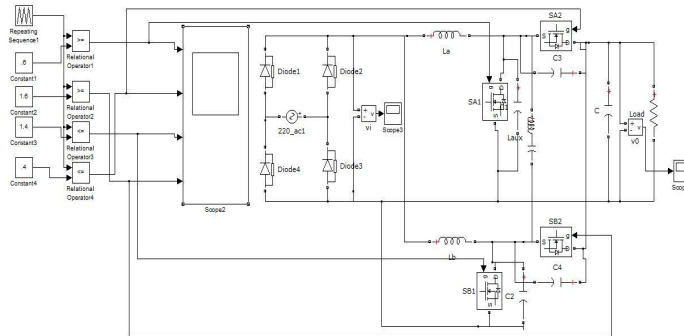


Fig :2 simulation circuit.

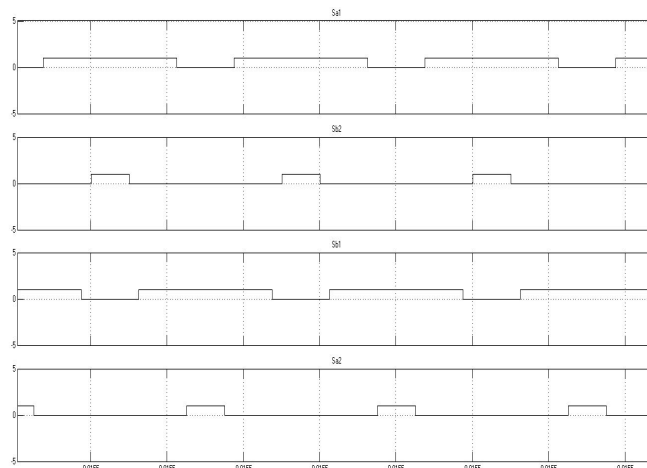


Fig : 3 pulse generated for 4 switches.

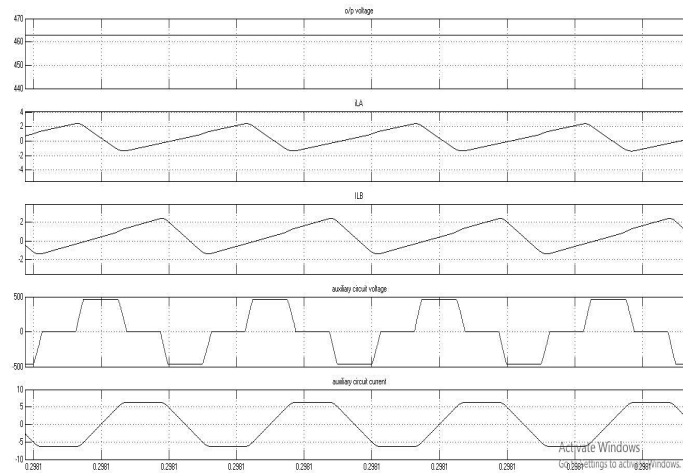


Fig :4 simulated waveforms.

IV. CONCLUSION

In this project, an interleaved boost PFC converter is presented, which provides soft switching for the power MOSFETs through an auxiliary circuit. This auxiliary circuit provides reactive current during the transition times of the MOSFETs

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to charge and discharge the output capacitors of the MOSFETs. By simple direct switching strategy the zero voltage switching of converter switches is achieved. The study and analysis of presented boost converter is done. Also the converter is simulated using matlab/Simulink.

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