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Two Stage on-Board Battery Charger for Plug –in Electric Vehicle Applications

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ABSTRACT

On board battery charger is an essential part of plug-in electric vehicle technology. In medium powered electric vehicles, level II battery chargers are preferred, which contains AC-DC power factor corrected converter and DC-DC converter in two stages. Bridgeless interleaved (BLIL) boost topology is a preferred PFC converter in level II battery charger with higher converter efficiency. The proposed work deals with cascading of BLIL boost topology with full bridge dc-dc converter in closed loop for battery charging. Analysis over problems associated with open loop operation and closed loop operation of BLIL, while it is cascaded with full bridge converter is carried out using MATLAB/Simulink computer simulation.

Keywords: BLIL topology, two stage converter, power factor correction, current reference control.

I. INTRODUCTION

Recently the evacuation of fossil fuel and increased emission of CO_2 from vehicles leads to an urge of innovation in electric vehicles. Electric Vehicle has the battery as a primary energy storage system. And the batteries are expected to have high charge density, longer life time, high performance and low cost. The extensive research work on battery technologies made the Nickel Metal Hydride (NiMH), Lithium ion (Li-ion) and lithium polymer batteries as a viable solution for electric vehicles and is preferred increasingly due to its compactness and longer life time [1]. The charging of battery is done by a front end AC-DC converter which includes the AC-DC rectifier with power factor correction and an isolated dc-dc converter [3].

The conventional PFC boost converter for the conversion of AC to DC supply has increased harmonics in input source current, and ultimately reduces the distortion factor and the rectifier input power factor. The Bridgeless interleaved (BLIL) boost topology is proposed to replace the conventional boost topology which has high converter efficiency and the least input ripple quantities [4]. Cascading of open loop BLIL boost topology with full bridge dc-dc converter introduce high switching stress in full bridge converter switches and also high ripple in output dc load voltage, which affects the stability of the two stage converter significantly.

The proposed work focuses on a BLIL boost topology cascaded with full bridge DC-DC converter with closed loop control. The cascading of BLIL topology and full bridge converter offers boost and buck operation, which gives the required output for varying input voltage. Section II reviews the BLIL boost topology, section III discusses the closed loop control of BLIL with current reference control. The cascading of BLIL with full bridge DC-DC converter with closed loop control is discussed in section IV. The simulation results of BLIL boost converter in open and closed loop, cascaded with full bridge converter is discussed with respect to switching stress on full bridge converter and its output voltage in section V.

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II. BRIDGELESS INTERLEAVED BOOST CONVERTER

The generalized architecture of a universal battery charger is shown in figure 1. A simulation study of the complete system is carried out MATLAB/Simulink environment and the performance in closed loop is compared with that obtained in open loop.

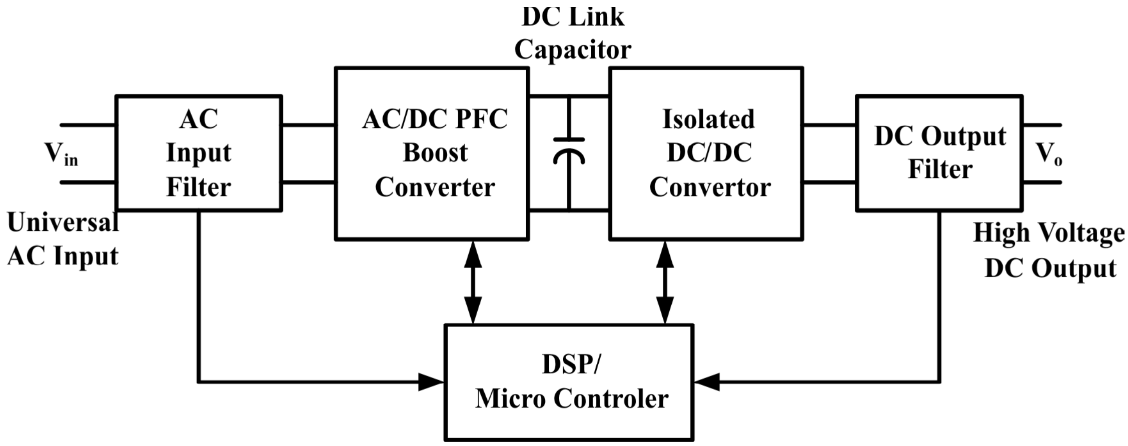

Figure 1: Generalized Architecture of Universal Battery Charger

The Bridgeless interleaved boost topology is integration of bridgeless and interleaved boost PFC converter, in which two bridgeless converter are operated in parallel. This incorporates the merits of bridgeless and interleaved PFC boost converters such as elimination of conventional AC-DC rectifier offers the reduction in EMI. The BLIL boost topology converter is shown in Figure 2.

The switching signals for BLIL boost converter are given through gate input G1 and G2 which are 180° phase shifted and the gates of the switches Q1 and Q2 are tied together, also the gates of switches Q3 and Q4. BLIL boost topology has duty ratio D<0.5 for input voltage more than half of its output and D>0.5 for input less than half of its output voltage[4].

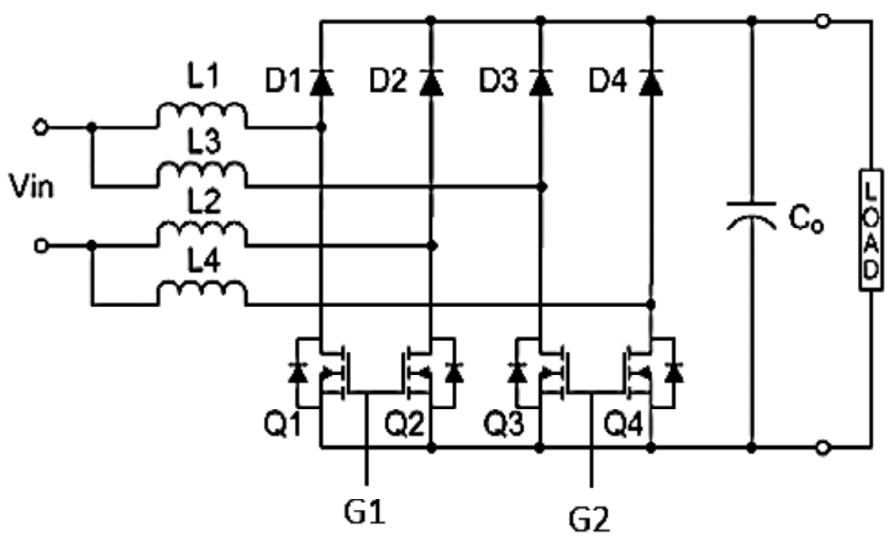

Figure 2: Bridgeless Interleaved Boost Converter

The BLIL boost topology have four switching modes of operation for duty ratio D<0.5, Table-1 gives the positive half cycle switch mode.

Table 1
Switch Mode Operation for D<0.5

(Positive half cycle)

Switch Mode	*Charge loop*	*Discharge loop*
Q1 Q2 - ON Q3 Q4 - OFF	+Vin - L1 -Q1 - Q2 - L2 - -Vin	+Vin - L3 - D3 - Load - Q4(BD) - L4 - -Vin
Q1 Q2 - OFF Q3 Q4 - OFF	-	+Vin - L1 - D1 - Load -Q2(BD) - L2 - -Vin +Vin - L3 - D3 - Load -Q4(BD) - L4 - -Vin
Q1 Q2 - OFF Q3 Q4 - ON	+Vin - L3 - Q3 - Q4 - L4 - -Vin	+Vin - L1 - D1 - Load - Q2(BD) - L2 - -Vin
Q1 Q2 - OFF Q3 Q4 - OFF	-	+Vin - L1 - D1 - Load - Q2(BD) - L2 - -Vin +Vin - L3 - D3 - Load - Q4(BD) - L4 - -Vin

BD – Body diode

Table 2, shows the negative half cycle switch mode operation of BLIL,

Table 2
Switch Mode Operation for D<0.5

(Negative half cycle)

Switch Mode	*Charge loop*	*Discharge loop*
Q1 Q2 - ON Q3 Q4 - OFF	+Vin – L2 – Q2 – Q1 – L1 - -Vin	+Vin – L4 - D4 – Load – Q3(BD) – L3 - -Vin
Q1 Q2 – OFF Q3 Q4 - OFF	-	+Vin – L2 – D2 –Load – Q1(BD) – L1 - -Vin +Vin – L4 – D4 – Load – Q3(BD) – L3 - -Vin
Q1 Q2 - OFF Q3 Q4 - ON	+Vin – L4 – Q4 – Q3 – L3 - -Vin	+Vin – L2 – D2 – Load – Q1(BD) – L1 - -Vin
Q1 Q2 – OFF Q3 Q4 - OFF	-	+Vin – L4 – D4 – Load – Q3(BD) – L3 - -Vin +Vin – L2 – D2 – Load – Q1(BD) – L1 - -Vin

BD – Body diode

The BLIL boost topology operates with an AC input source and it holds the relation of input voltage and output voltage similar to boost converter, given in equation (1).

$$\frac{V_O}{V_{in}} = \frac{1}{1-D} \tag{1}$$

In addition, it holds good the inductor current ripple equation(2) similar to that in a boost converter.

$$\Delta i_{L1} = \frac{(V_o - V_{in})}{(L_1 + L_2)}\left(\frac{1}{2} - D\right)T_S \tag{2}$$

T_s = Switching Period;

The design of inductor in series with the power input and capacitor filter at the output holds good as boost converter, to improve the BLIL topology input power factor to 0.9997.

The BLIL topology was studied in open loop Simulink in MATLAB environment. The output voltage contains large ripple content with double the fundamental frequency as shown in figure 3.

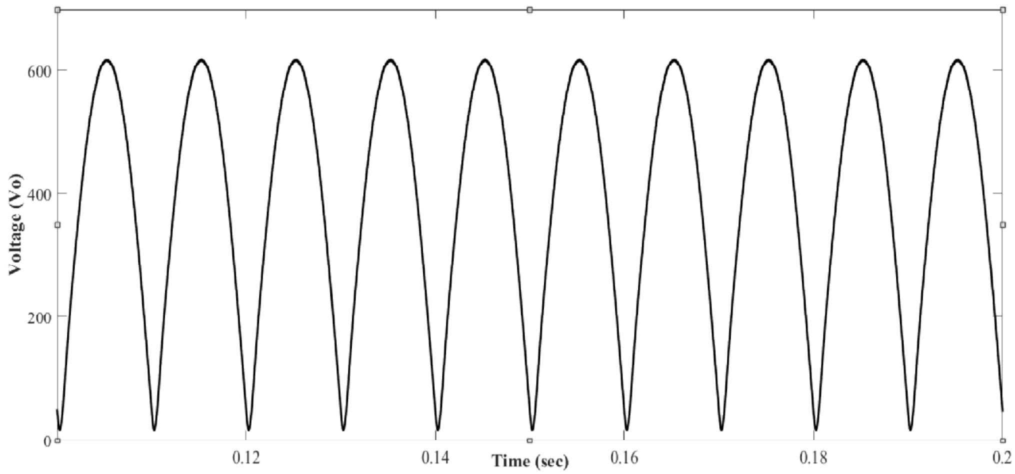

Figure 3: BLIL Boost topology output voltage in open loop

If BLIL topology is integrated with any DC-DC converter, it causes significant voltage stress on dc-dc converter and affecting it's the performance. Increase in the value of output capacitor filter reduces the ripple content in the output voltage, but at the cost of substantial reduction in power factor.

III. CLOSED LOOP CONTROL OF BLIL BOOST TOPOLOGY

More than a decade, various control techniques viz., constant duty ratio control, variable duty ratio control, current reference control, hysteresis control and many are in use[7], for power factor correction in converters. The proposed system, implements the current reference control using MATLAB/Simulink model in closed loop for BLIL boost topology, in which a filter capacitor is chosen to have an output ripple voltage less than 5% and the power factor improvement is carried out by current reference control techniques.

(A) Current Reference Control

The current reference control is a switching strategy with constant frequency and variable duty ratio shown in Figure 4.

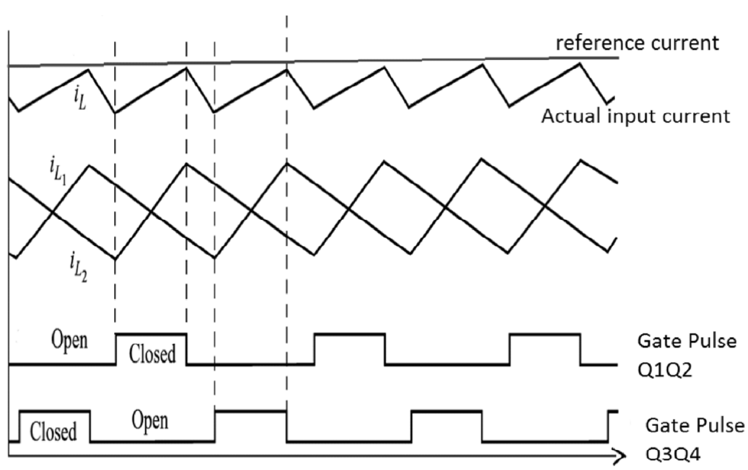

Figure 4 : Switching pulse generation technique

In this, the inductor input current is compared with reference current, which is a derivative of the difference in output voltage and reference voltage. If the inductor input current i_{L1} is less than reference current i_{ref}, the switches Q1 and Q2 are turned ON, till inductor input current equals the reference current. The switches Q1 and Q2 remain OFF, during the rest of the switching period. The switches Q3 and Q4 are turned ON and OFF with a phase shift of 180°. The MOSFET switches will be turned ON and OFF accordingly with PWM switching pulses generated by current reference control technique. The schematic diagram of closed loop current reference control technique is shown in figure 5.

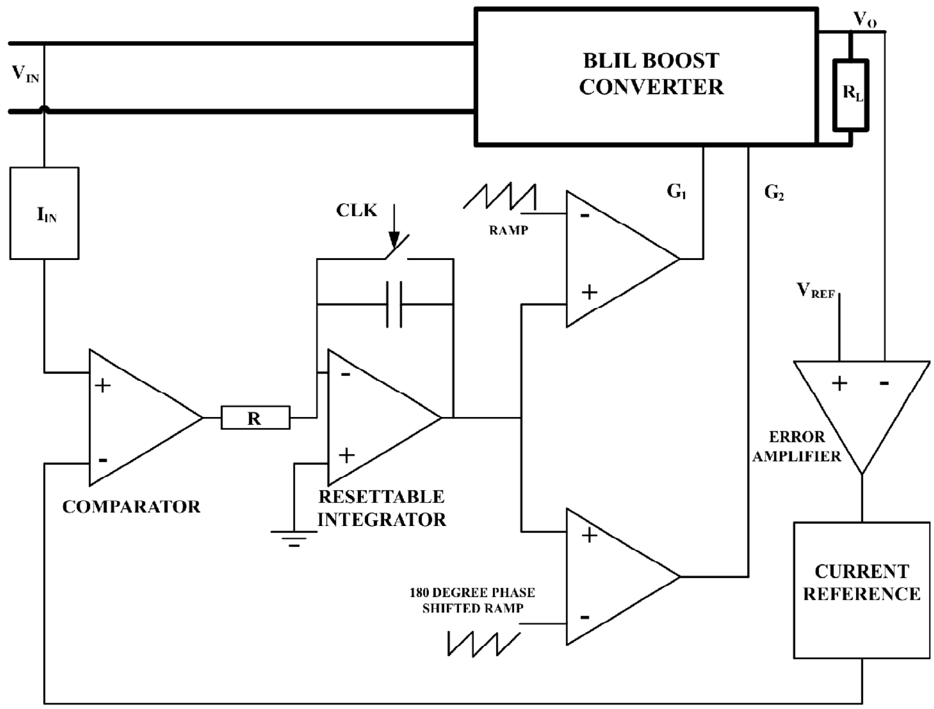

Figure 5: Closed loop current reference control – Schematic representation

The implementation of current reference control in BLIL topology improves the maximum input power factor to 0.9997. Figure 6, show the output voltage of BLIL boosts with closed loop current reference control.

In closed loop current reference control of BLIL boost topology the input THD is found to be less than 5% as per IEC standards, and the output ripple voltage is also maintained less than 5%. Further increase in output capacitor may decrease the ripple voltage, but reduce the input power factor.

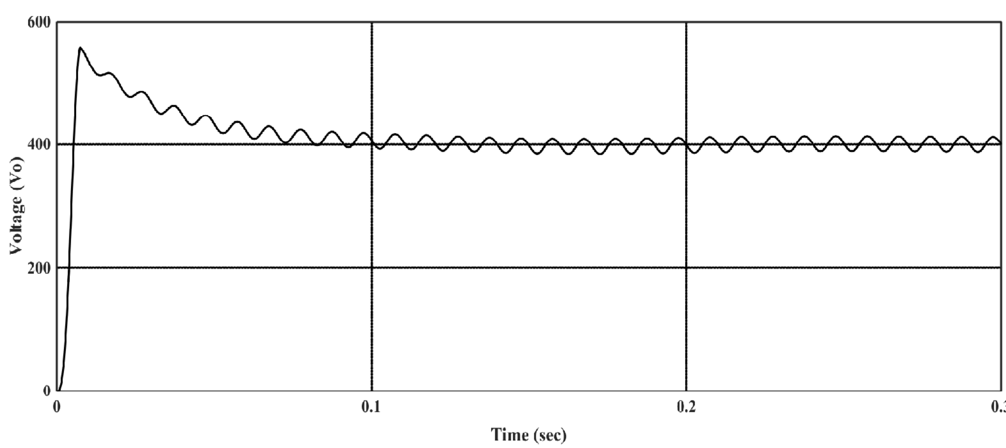

Figure 6: BLIL Boost topology output voltage with current reference closed loop control

IV. BLIL BOOST TOPOLOGY CASCADED WITH FULL BRIDGE DC-DC CONVERTER

The cascading of BLIL boost topology with full bridge dc-dc converter is designed to have the constant voltage and constant current in the output, by restricting the BLIL boost topology input voltage to 230 V_{rms}, and 15A of input current.

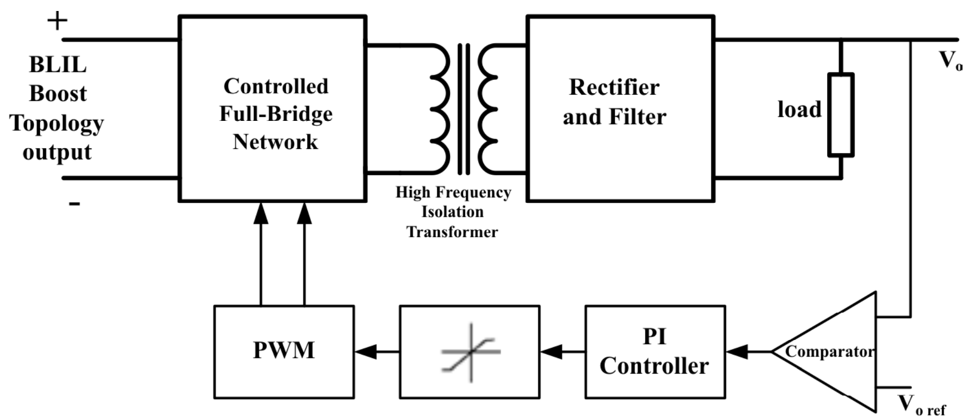

Figure 7: Full Bridge dc-dc converter cascaded with BLIL boost topology with closed loop voltage control

The full bridge dc-dc converter is cascaded with BLIL topology with closed loop voltage control is shown in figure 7. The full bridge dc-dc converter offers isolation between power circuit and load circuit, which eliminates stability issue in closed loop operation [10]. The design of inductor and capacitor of full bridge converter is same as that of buck converter.

V. SIMULATION RESULTS AND DISCUSSION

In this section, output voltage of full bridge converter and voltage stress on full bridge converter switches is discussed, both in open and closed loop current reference control of BLIL boost topology cascaded with full bridge dc-dc converter. Introducing open loop BLIL boost topology with full bridge converter provides increased output ripple voltage greater than 5% of BLIL boost due to full bridge converter switching. Also, the isolation transformer and full bridge converter circuit gives the loading effect on open loop BLIL boost topology which decreases the input power factor to 0.7809 as seen in figure 8, giving an increased THD.

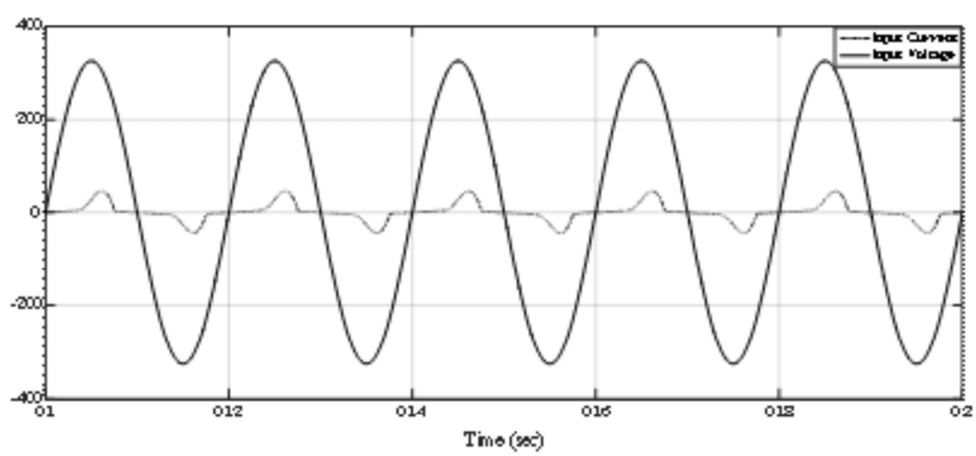

Figure 8: Input voltage and current waveform of open loop BLIL cascaded with full bridge converter

The loading effect of full bridge dc-dc converter over BLIL boost, increases ripple output of BLIL boost and introduces voltage stress on full bridge converter switches as shown in figure 9.

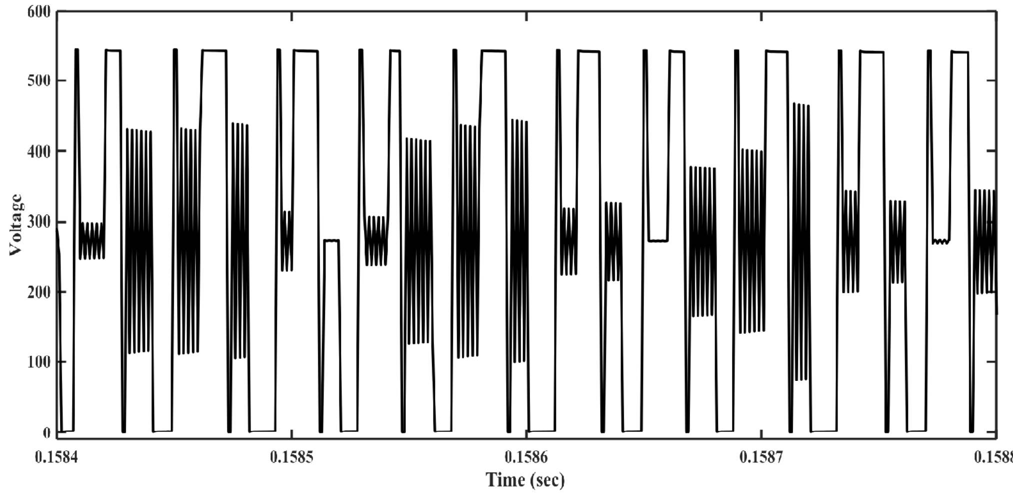

Figure 9: Voltage stress on full bridge converter switches (BLIL Boost Topology – Open Loop)

It is meaningless, in introducing BLIL boost topology to have low power factor under cascaded condition. The closed loop current reference controlled BLIL boost topology gives lower switch stress as seen in Figure 10, and provides the output voltage in stage two of cascaded converter.

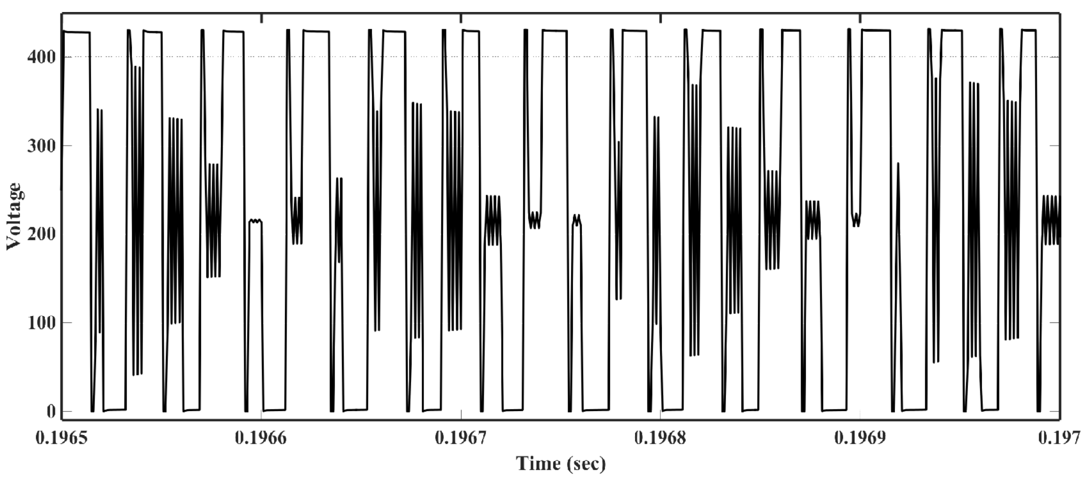

Figure 10: Voltage stress on full bridge converter switches (BLIL Boost Topology – Closed Loop)

The cascading of full bridge converter with BLIL boost topology has increased voltage ripple in BLIL boost output, which is the cause of oscillation in converter switch voltage stress waveform. However the input power factor is improved to 0.9995. The output voltage of full bridge converter is given in figure 11.

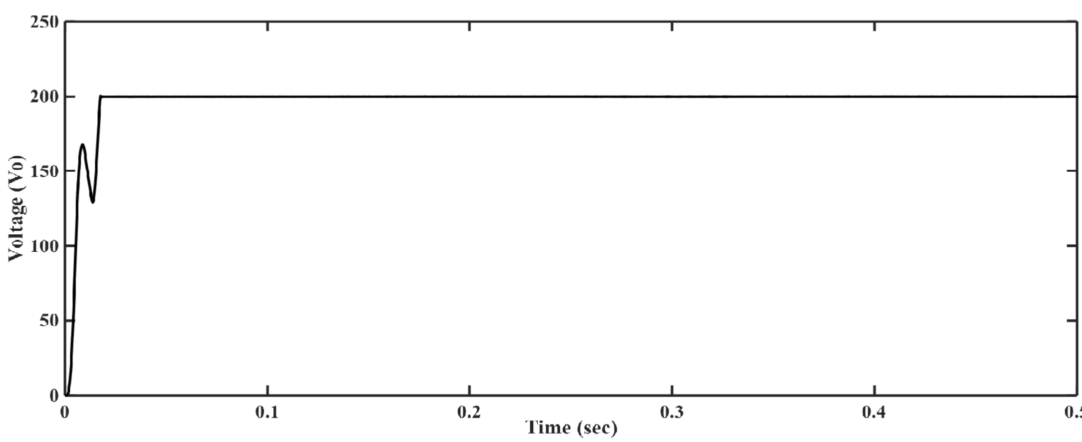

Figure 11: Output Voltage of full bridge converter cascaded with BLIL boost topology

The BLIL boost converter is designed to have constant output of 400V dc and load current of 7.5A from a 230Vrms AC source. The full bridge dc-dc converter is designed to have output of 200V dc and load current of 12.5A constant from the BLIL boost output.

VI. CONCLUSION

Cascading of BLIL boost topology with full bridge dc-dc converter provides the level II battery charger for automotive industires. This two stage converters are capable of stepping up and stepping down the output voltage based on input and output supply requirements. It is found that BLIL boost topology provides reduced output ripple voltage and better input power factor, low THD in closed loop current reference control. This closed loop control provides reduced full bridge converter switch stress during cascaded operation. The future scope of this work can be associated with closed loop system stability.

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