DESIGN AND IMPLEMENTATION OF INDUCTIVE POWER TRANSFER FOR EV BATTERY CHARGING

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Abstract -- **Leading to an increased consideration of clean and renewable alternatives to traditional technologies, the automotive industry has shown a growing interest in electric and hybrid electric vehicle (EV). However, the transition to all-electric transportation is now limited by the high cost of the vehicles, the limited range and the long charging time. Inductive Power Transfer (IPT) systems can be the solution to the range restrictions of EVs by charging the vehicle while driving and reducing required battery size as well as overall cost of the vehicle. These systems transfer electric energy from source to a load without any wired connection and it is achieved through the affordable inductive coupling between two coils termed as transmitter and receiver coil. This paper proposes a bridgeless Interleaved Boost Converter (IBC) as the front end converter for the IPT system. The compensation network and the Inductive coil is designed and simulation studies are carried out in MATLAB/SIMULINK. The functional parameters of bridgeless topology is compared with the conventional bridged configuration. The hardware of the Bridgeless IBC, Inverter and Compensation network is implemented and the results are verified.**

Keywords: EV, IPT, IBC.

I. INTRODUCTION

With the rapid depletion in conventional sources of energy and the dramatic increase in the pollution level due to burning of fossil fuels, there is a need to adopt alternative energy sources. The conventional petrol and diesel vehicles are one of the major sources of air pollution, as burning fossil fuel releases a lot of toxic fumes. Electric Vehicle and Hybrid Electric Vehicle is an attractive solution to this problem. The EV is powered exclusively by electricity which uses energy stored in its rechargeable batteries [1]. Electrical energy has the advantage of the ease of transmission and is also a clean form of energy. One of the challenges in using EVs is refuelling. A battery-powered car would need to charge for several hours, usually overnight and yet the range would still be less than a petrol fuelled car.

WPT technology can be used to charge EVs without the use of wires, which has a number of advantages as opposed to wired charging [2]. The charging process can be automated more easily as there is no wire to move and no connection to be made. It could be safer as users do not handle high power cables. It could be less prone to wear as there is no connector to plug and unplug. It could also be less prone to damage from weather conditions and vandalism due to all components being embedded / concealed. These characteristics makes wireless charging more robust and easier to deploy in dirty and wet environments, compared to wired charging [3].

Due to these advantages, WPT also offers the possibility to charge an EV on the road, during both stopped or moving condition, by embedding the charger transmitter under the road surface [4]. IPT is a type of wireless power transfer that employs the induction of electricity by a changing magnetic field. In a typical setup, a transmitter coil is placed on/in the ground, powered by a high frequency inverter to generate an alternating magnetic field [5]. A receiver coil, mounted on the bottom of the vehicle, is then positioned above the transmitter coil such that the alternating magnetic field induces electricity in the receiver coil. Power is then transferred through a rectifier to the battery charger to charge the battery of the vehicle.

II. ANALYSIS OF DIFFERENT CONVERTER TOPOLOGIES FOR IPT

Boost converter is a popular option for most of the power electronic systems by serving as a pre-regulator due to its simplicity in design and high performance. There are different types of DC-DC boost converters that can be used for EV battery charging application. In this paper, the comparative analysis of traditional boost converter, bridged and bridgeless IBC converter is carried out [6]. A simple boost converter or a step-up converter is a DC- DC power converter where the output voltage is greater than the input voltage. It belongs to a class of Switched Mode Power Supply (SMPS) comprising of semiconductor elements; diode and transistor and an energy storage element such as inductor or capacitor or a combination of the two. Filters consisting of capacitors or inductors are added at the output of the converter in order to lessen the output voltage ripple.

However, as the power rating increases, it is necessary to connect converters in series or parallel [7]. In high power rating application, interleaving of boost converters is usually employed to improve the converter performance and also to partially reduce the input current, output voltage and inductor current ripple and step down the converter size effectively. As interleaving doubles the switching frequency and effectively reduce the ripple at the input current and output voltage, the size of energy storage elements also significantly reduces [8]. Additionally, it improves the transient response and increases the voltage gain of the converter. From the analysis, it is observed that there are different types of interleaved boost converter topologies such as conventional bridged IBC, bridgeless IBC.

In bridged IBC, the two phase interleaved boost converter consists of two identical boost converters connected in parallel. The two switches are alternatively switched with both the switches having the same frequency. In bridgeless IBC, additional two switches and inductors are required compared to bridged topology. A bridgeless interleaved boost converter eliminates the bridge rectifier employed in the conventional topology. This reduces the losses due to the presence of the diodes in the bridge rectifier [9]. Although it introduces some new losses due to the presence of additional switches and inductors, the efficiency of the bridgeless topology is better, as the losses due to the bridge rectifier is very large. Also, the THD of the current is reduced and the power factor is improved.

III. SIMULATION RESULTS

The three topologies of boost converter, namely the conventional boost converter, interleaved boost converter and bridgeless interleaved boost converter were simulated in MATLAB/Simulink. The performance parameters such as the output voltage and current ripple, supply current THD and power factor of the three converters are analysed and compared. The power loss and efficiency analysis of the IBC and bridgeless IBC are also analysed. The ripple analysis between boost and conventional IBC is shown in Figs 1-Figs 2.

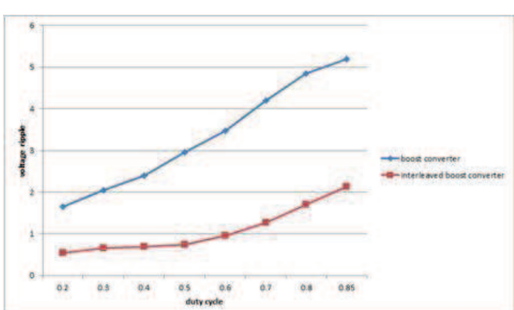

Fig.1 Output Voltage Ripple

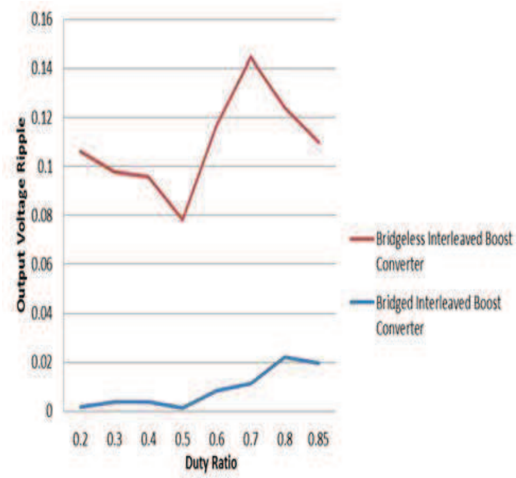

Fig.2 Output Current Ripple

The comparison shows that the ripple is reduced in the case of an IBC and that ripple reduction is maximised at a duty ratio of 50%. Then the conventional bridged IBC is compared with the bridgeless IBC. The ripple analysis between conventional IBC and proposed bridged IBC is shown in Figs 3-Figs 4.

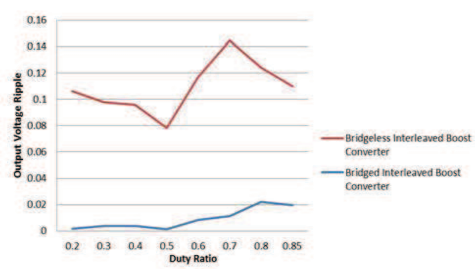

Fig.3 Output Voltage Ripple

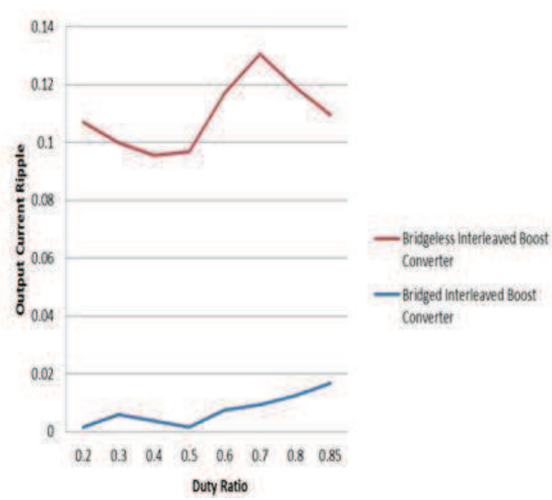

Fig.4 Output Current Ripple

From the results, it is observed that the proposed bridgeless interleaved boost converter has reduced output voltage and output current ripple compared to existing topologies. The performance parameter such as THD, distortion factor, displacement factor and power factor is evaluated and compared between bridged and bridgeless converter and the results are depicted in Table I.

TABLE. I POWER FACTOR AND THD COMPARISON BETWEEN BRIDGED AND BRIDGELESS IBC

Topology	THD (%)	Distortion Factor	Displacement Factor	Power Factor
Bridged Interleaved Boost Converter	99.19	0.7100	0.9900	0.7029
Bridgeless Interleaved Boost Converter	31.33	0.9542	0.9998	0.9541

From Table I, it is observed that the proposed bridgeless IBC has low THD and high power factor. Thus the proposed topology is best candidate for IPT system. The Simulink diagram of the IPT system incorporating proposed IBC is shown in Fig.5. The output voltage and output current waveform of the proposed IBC and FFT analysis of the supply current is shown in Figs. 6-Figs.8.

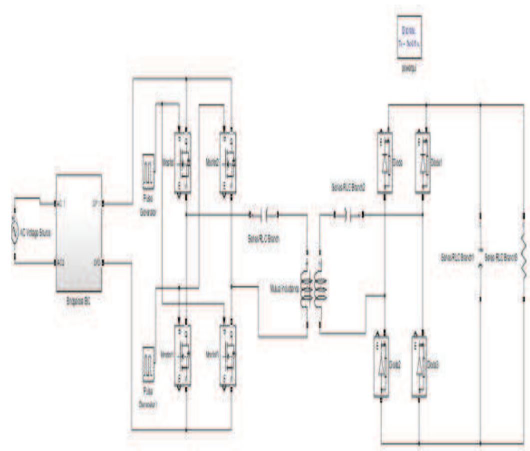

Fig.5 IPT system for battery charging

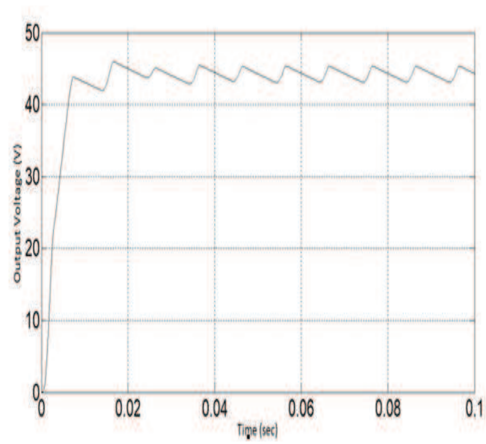

Fig.6. Output Voltage of Bridged IBC

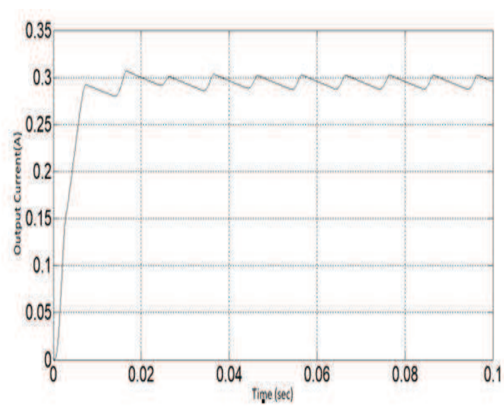

Fig.7. Output Current of Bridged IBC

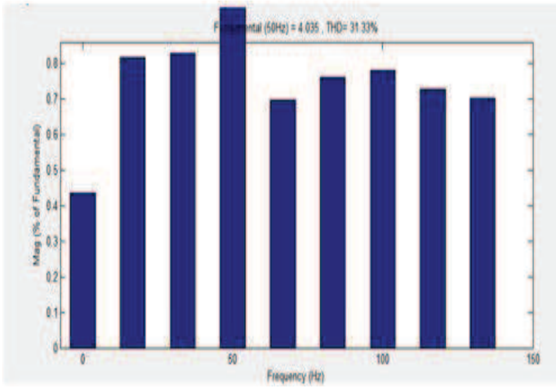

Fig.8 FFT Analysis of Supply Current

The input voltage of 24V is boosted to 48 V and output current of 0.3A is achieved as depicted in Figs.6 - Figs.7. From Fig.8, it is observed that the THD of supply current is reduced to 31.33%.

I. HARDWARE RESULTS

The experimental setup of wireless charger incorporating proposed bridgeless IBC is built and shown in Fig.9. The input of 6.3 V dc is converted to 4.76V ac voltage and transformed to the secondary side of wireless charger . The output voltage waveform of the secondary side is shown in Fig.10.

Fig.9 Hardware implementation of inductive power transfer

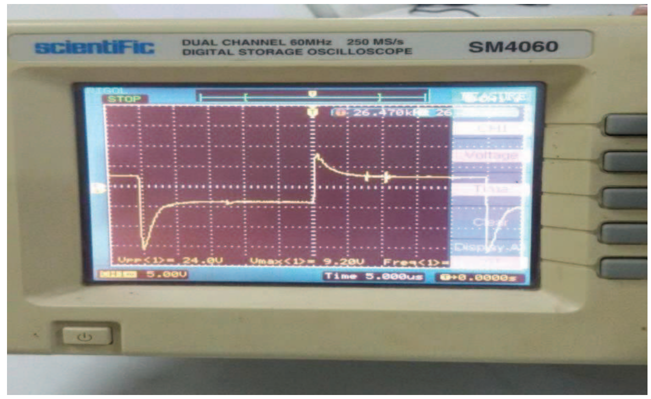

Fig.10 Secondary Output Waveform

II. CONCLUSION

The three boost converter topologies, namely, the Conventional Boost converter, Bridged Interleaved Boost Converter and Bridgeless Interleaved Boost Converter were simulated using MATLAB. Various performance parameters of the topologies such as output voltage and current ripple, THD, input current power factor and efficiency were analysed and compared. Comparison graphs were plotted for these parameters. It was observed that the Bridgeless interleaved boost converter offered better performance in terms of higher power factor, lower THD, better efficiency, improved RMS value of current for inductor, MOSFET and the fast diode. The efficiency was found to be increasing with load. Also the RMS value of current for inductor, MOSFET and the fast diode was found to be decreasing with increase in load. Hence, the bridgeless interleaved boost converter is widely preferred for applications which require higher power factor and increased efficiency.

The compensation network and the Inductive coil was designed for Wireless Power Transfer. The hardware of the Bridgeless IBC, Inverter and Compensation network was implemented and the results were verified.

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