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Electric Vehicle Charger with Interleaved Converter



Abstract: - The increasing adoption of electric vehicles (EVs) has been demanding advanced charging solutions that prioritize efficiency, reliability, and scalability. The EV charger is based on two-stage power converter which includes rectifier (AC – DC conversion) followed by DC-DC converter. EV chargers employ buck, boost or buck converters. Conventional boost converters, while widely used, face limitations in high-power EV charging due to higher current ripple and efficiency degradation. This paper presents an interleaved boost converter (IBC) topology for EV charging applications, with phase-shifted parallel operation to mitigate high current ripples and improve efficiency. By distributing current across multiple phases, the IBC significantly reduces input current ripple, minimizes inductor losses and enhances thermal management. Results demonstrate a peak efficiency of 96%, as well as reduction in current ripple compared to conventional designs. Furthermore, the IBC's modular structure supports scalability for higher power demands and seamless integration with renewable energy systems. These attributes underscore the converter's suitability for fast-charging infrastructure, offering reduced electromagnetic interference, extended component lifespan and robust grid compatibility.

Keywords: EV charging, boost converter, interleaved boost converter, ripples

I. INTRODUCTION

With deep penetration of EVs, the EV battery charging is being focused from power quality point of view. The EV charger essentially consists of a rectifier. The rectifier exhibits nonlinear voltage current relationship and hence serves to be a nonlinear load. Any nonlinear load deteriorates the power quality in first place by degrading the power factor and injecting harmonics into the system [1]. With increasing number of EVs these problems continue to accelerate. A distribution system may experience operational and service quality related challenges if these large number of EVs are inadequately addressed [2]. Various topologies of isolated and non-isolated power converters are developed by researchers and designers with power factor correction (PFC) capability for EV charging. These converters ensure near unity power factor at the source side [3]. The scalability of these converters is still questioned for handling power levels for suitability in type 1, type 2 and type 3 chargers. Multi-output converters are invented [4] for charging multiple EVs with single input. A review of DC – DC converters for EV charging [5] reveals the necessity for developing high efficiency, low cost, high power and reliable converter for EV charging.

The conventional DC-DC converters in this context, interleaved converters [6] are gaining popularity in EVs. The power converter requirements vary between on-board and off-board chargers [7]. An interleaved converter presents a class of converter wherein multiple paths for current flow exist from single input to single output via switching elements. These converters are developed for buck as well as boost operation in DC – DC converters. Almost all types of DC-DC converters can be configured to operate in interleaved manner. Interleaved converters are designed to enhance performance through parallel operation of multiple converter phases [8]. These systems are particularly noted for their ability to minimize current ripple and improve efficiency, making them suitable for high-power and precision applications. An interleaved converter typically consists of two or more identical power stages connected in parallel. Each phase operates with a controlled phase shift relative to the others. In a two-phase system, switching signals are displaced by 180 degrees, causing their current waveforms to overlap inversely. This phase-shifted operation leads to partial cancellation of ripple currents when the outputs are combined, effectively reducing the overall ripple amplitude. The result is a smoother output current with diminished high-frequency noise [9].

In EV chargers, these converters utilize multiple parallelized power stages with phase-shifted switching to distribute current across components, reducing individual phase stress and improving thermal management [10]. This distribution minimizes hotspots, enhances reliability, and enables faster charging by sustaining higher power levels without overheating. Additionally, interleaving significantly reduces input/output current ripple, a vital feature for preserving battery health and ensuring stable energy transfer [11]. The inherent ripple cancellation lowers electromagnetic interference (EMI), simplifying compliance with stringent automotive standards. For DC fast charging, interleaved topologies improve efficiency by lowering conduction losses and enabling compact

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designs through smaller passive components [12]. Advanced control algorithms ensure balanced current sharing between phases, preventing imbalances that could degrade performance. Their modular scalability also allows seamless adaptation to varying power requirements, making them ideal for both onboard chargers and stationary charging stations [13].

While interleaving offers numerous benefits, it introduces complexity in control systems. Ensuring uniform current sharing between phases is critical; imbalances can lead to uneven wear or failure. Advanced control strategies, such as digital signal processing with current-mode feedback or predictive algorithms, are often employed to synchronize phases and maintain balance [14]. Additionally, the need for multiple gate drivers and sensors increases design complexity and cost. Interleaved converters provide a robust solution for modern power challenges, leveraging phase-shifted parallelism to achieve superior performance. Their adoption continues to grow in sectors where efficiency, thermal management, and noise reduction are paramount, despite the intricacies involved in their control and implementation. This balance of advantages and challenges underscores their importance in advancing power electronics technology [15].

In this paper an interleaved boost converter is deployed for charging of EV battery from a single phase AC source. The interleaved converter operations for EV battery charging are validated with MATLAB simulations and results are presented for state of charge (SOC) monitoring, power factor of the source and harmonics.

II. INTERLEAVED BOOST CONVERTER

An interleaved boost is designed to increase the voltage from its input to its output. In an interleaved boost converter, multiple boost converter circuits are connected in parallel as shown in figure 1, with each phase operating 180° out of phase with its neighbours. The key components of each phase include an inductor, a switch, a diode, and a capacitor. The phases share the same input and output but operate in a staggered manner to achieve interleaving.

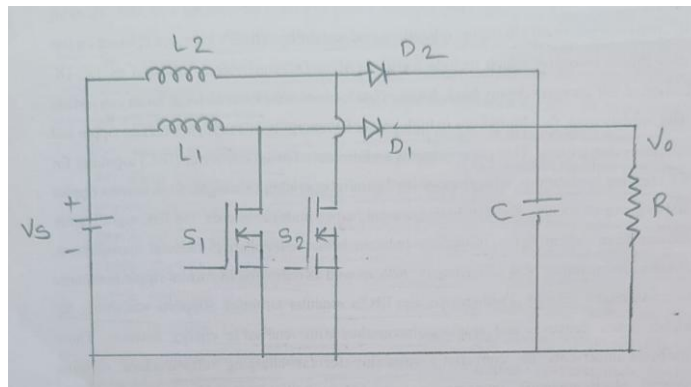


Figure 1: Circuit scheme of interleaved boost converter

The output voltage (V_O) equation of a conventional boost converter is given as,

$$V_O = \frac{1}{1-D} V_S \quad \dots (1)$$

When two boost converters are parallel connected to form interleaved converter, the equation of output voltage hence becomes,

$$V_O = \frac{2}{1-D} V_S \quad \dots (2)$$

From equation (2), it is evident that the output voltage of interleaved boost converter is function of duty cycle. However, it is to be noted that the two converters switching is displaced in phase by an angle of 180°. Hence in interleaved boost converter that maximum limit on duty cycle stands for 50%.

III. LITERATURE REVIEW

Reference	Topology	Advantages	Applications	Efficiency
Li et al. [26]	GaN-based 4-Phase IBC	Ultra-high efficiency, reduced EMI, minimized reverse recovery losses	EV fast-chargers, server PSUs	98.2%
Zhang et al. [17]	SiC 3-Phase IBC	High-temperature operation, low input ripple, MPPT integration	Solar microinverters	97.5%
Park & Lee [18]	Hybrid Switched-Capacitor IBC	Reduced voltage stress (50%), compact size, high step-up ratio	DC microgrids, UAV power systems	96.8%
Zhao et al. [19]	DAB with Interleaving	Bidirectional power flow, wide ZVS range, low transformer losses	Battery energy storage, solid-state transformers	97%
Chen et al. [20]	Interleaved Buck-Boost with AI Control	Robust current sharing ($\pm 2\%$), fast transient response, adaptive to load changes	PV-wind hybrid systems	96.3%
Wang et al. [21]	Integrated Modular IBC	scalable power, N+1 redundancy, plug-and-play phase expansion	Data centers, marine propulsion	97.6%

IV. SIMULATION AND RESULTS OF EV CHARGING IN INTERLEAVED CONVERTER

The EV charging system with interleaved boost converter is developed with MATLAB Simulink model. The system parameters are mentioned in table 1. The system consists of a 230V, 50Hz AC source on which a 600V, 10Ah lithium ion battery is to be charged. The initial state of the charge of the battery is kept at 20%. A closed loop PI controller is tuned to regulate the output voltage of interleaved boost converter. For charging of 600V battery, a 650V DC link voltage is desired. The MATLAB Simulink Model of the system is shown in figure 2.

Battery under consideration	Type: Lithium ion 600V, 10Ah
Charging current	5A
Source	Single Phase, 230V, 50Hz
Primary converter	Diode bridge rectifier
Carriers	Two Triangular wave phase shifted by 180 ° Amplitude: 1 Frequency: 1kHz
Controller	PI controller

Table 1: System Parameters

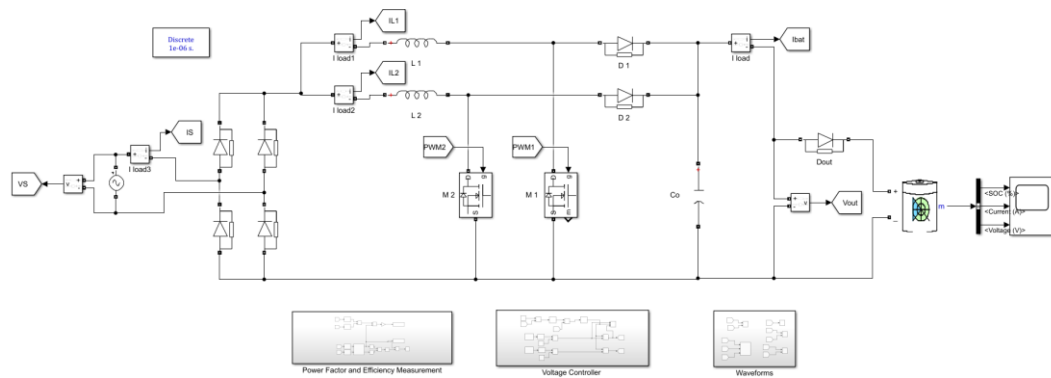


Figure 2: MATLAB Simulink model of interleaved boost converter based EV charger

The simulation model is executed for a period of 1 second and the readings for output voltage, gate pulses of MOSFETs S1 and S2, battery parameters, input voltage and current waveforms, harmonics, power factor and efficiency are recorded. As seen in figure 3, the PI controller regulates the DC output voltage to a level of 640V as required for battery charging. The voltage ripple in the output is observed to be 1V. The converter takes 0.05 second time to reach the desired output voltage level. A zoomed view of gate pulses of MOSFETs is seen in figure 4. These waveforms indicates that the converter is operating at duty cycle of 45% with phase shift of 180°.

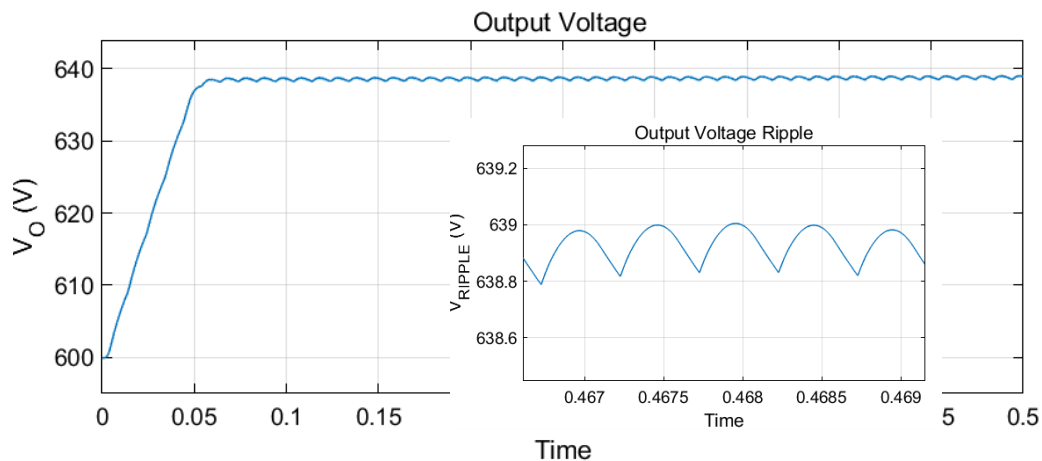


Figure 3: Output voltage of interleaved boost converter

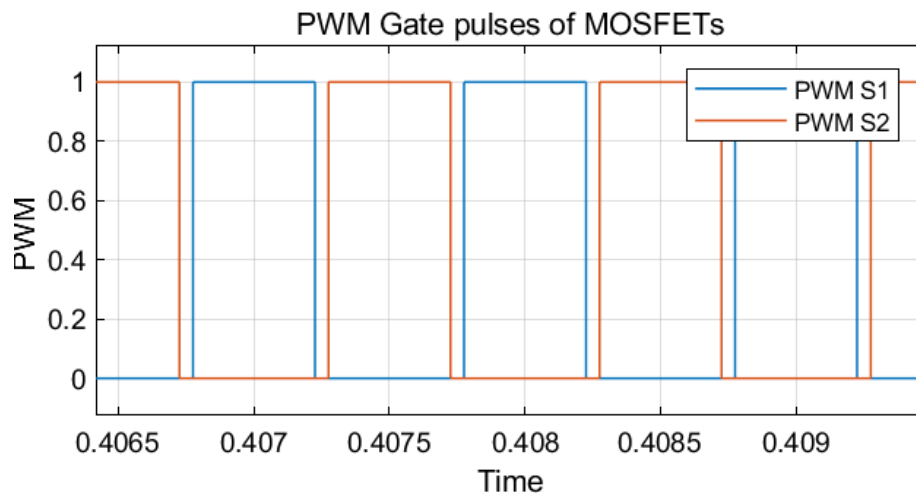


Figure 4: PWM Gate pulses of MOSFETs

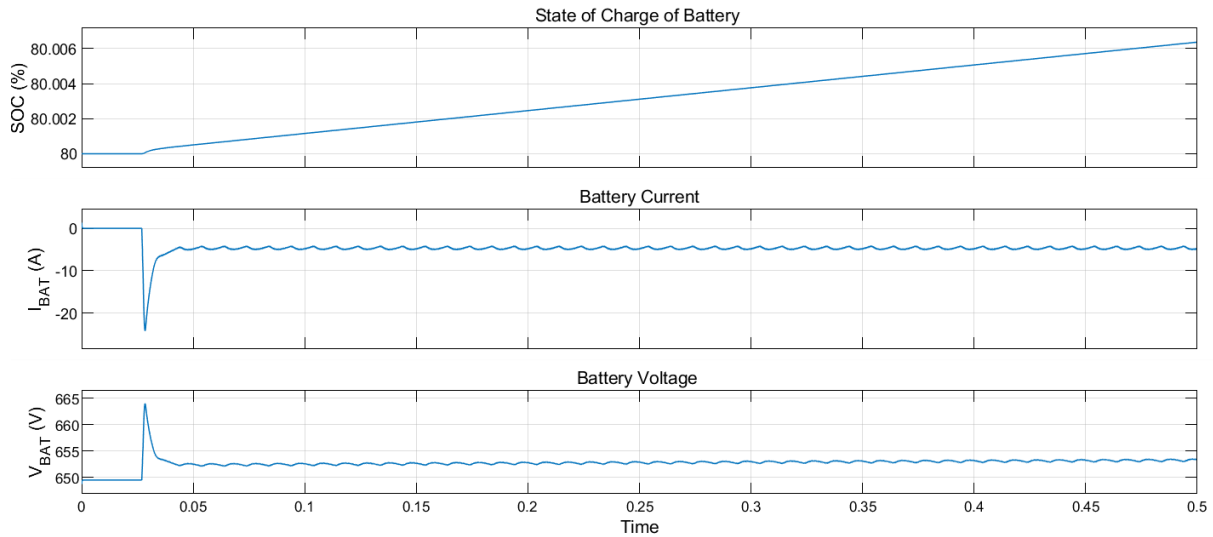


Figure 5: Battery state of charge, current and voltage

The graph of state of charge of battery, charging current and voltage are shown in figure 5. The increasing value of SOC indicates charging of the battery. The charging current of the battery is recorded to be 5A. The negative value of current indicates that current is flowing into the battery and hence battery charging is in progression. From figure 3 and figure 5, it is to be noted that the battery charging starts once the output voltage of the converter crosses the battery nominal voltage of 600V. This crossover occurs at time instance of 0.03 second.

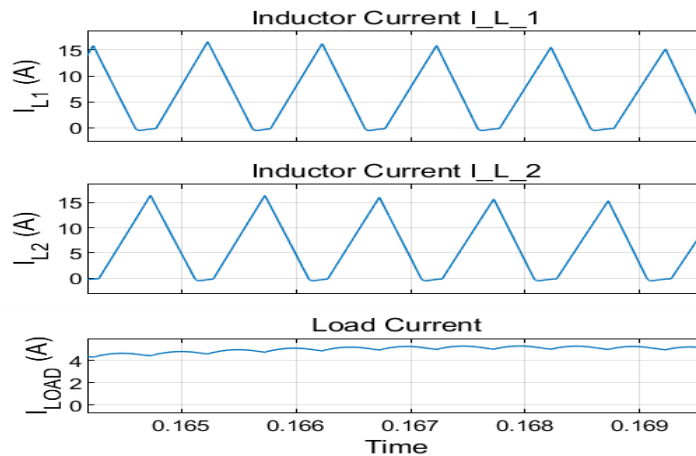


Figure 6: inductor currents and load current of the converter

The inductor current and load current waveforms (zoomed view) of the converter are shown in figure 6. When individual inductor current are observed, high ripple contents are observed. Whereas, these two inductor currents are combined before delivering to the load. At the load side, current ripples are observed to very less. As compared to the conventional boost converter, the output current ripple is observed to be 20% whereas conventional boost converter shows 40% to 60% current ripples [3], [5]. The efficiency of the charging system is computed as the ratio of DC power output to the battery vs. input AC power. The efficiency in steady state is recorded to be 92% The power factor is also computed at the source side which stands at unity as seen in figure 8

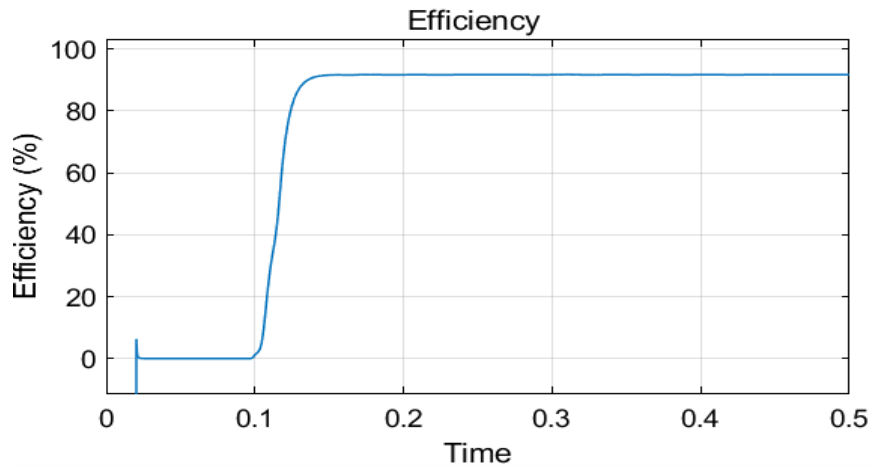


Figure 7 efficiency graph

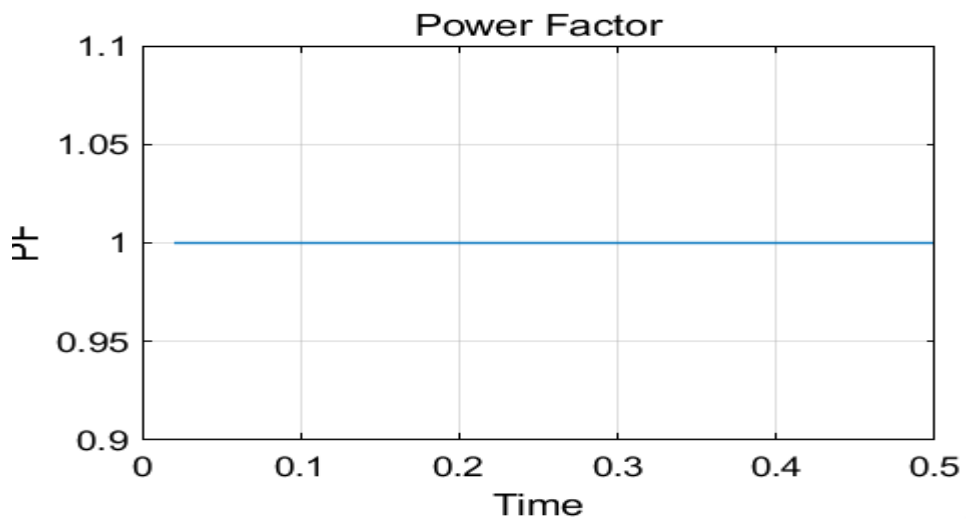


Figure 8: Power factor at the source side

Sr. no.	Parameter	Result
1	Output voltage	640V
2	State of charge	80.006%
3	Power factor	Unity
4	Efficiency	92%

Table 2: Analysis Table

V. CONCLUSION

The interleaved boost converter provides a feasible solution for EV battery charging. The simulation results shows that system works at 92% efficiency and near unity power factor. The current ripples are also minimized as compared with conventional boost converter. The output voltage of the converter is regulated with PI controller on the basis of duty cycle control. The modular design of interleaved converters allows for easy scaling and enables them to adjust to different power demands across the charging scenarios without compromising their compact form or high power density.

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