

IMPROVED ON-BOARD CHARGING ARCHITECTURE WITH LOW DC-LINK CAPACITANCE FOR ELECTRIC VEHICLES

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ABSTRACT:

With the rise of Electric Vehicles (EVs), there is a growing need for efficient, compact, and high-performance battery charging systems. Typically, conventional onboard chargers have high conduction loss, large DC-link capacitors, low power density and complicated converter structure which decreases the charging efficiency and system cost. This project aims to address these drawbacks by presenting a High-Efficiency On-Board Charger for Electric Vehicles (EV) based on a Bridgeless Power Factor Correction (PFC) converter with reduced DC-link capacitance. The proposed charger is aimed to improve the charging performance, power quality and reduce the component count without compromising reliable battery charging operation. The proposed architecture is a Bridgeless Zeta PFC converter followed by DC-DC buck converter. The Bridgeless Zeta converter is a novel converter that removes the traditional diode bridge rectifier resulting in lower conduction losses and higher conversion efficiency. The converter works in Discontinuous Conduction Mode (DCM) that simplifies control strategy and also number of sensing elements required. In addition, the system operates at a high DC-link voltage of about 400 V, allowing to reduce the capacitance of the DC-link and thus to reduce the size and weight of the charger. DC-DC Buck converter is used to control the battery charging under the CC and CV modes for safe and efficient charging. Modeling and analysis of the proposed system is done in MATLAB/Simulink for steady state and transient characteristics. Simulation results prove that the power factor, voltage stress of semiconductor devices, Total Harmonic Distortion (THD), DC voltage regulation and charging speed are also improved compared to the conventional charger topologies. The proposed onboard charger is a solution with high power density, low cost and energy efficiency for next generation applications to electric vehicle charging.

Keywords: Electric Vehicle (EV), On-Board Charger (OBC), Bridgeless Zeta Converter, Power Factor Correction (PFC), DC-Link Capacitance, DC-DC Buck Converter, Battery Charging, Discontinuous Conduction Mode (DCM), Charging Efficiency, Total Harmonic Distortion (THD), Power Quality, High Power Density, Electric Vehicle Charging System.

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I.INTRODUCTION

With the rise of Electric Vehicles (EVs), there has been a growing demand for efficient, compact, and reliable battery charging systems. Electric Vehicle (EV) technology has become a viable alternative to the internal

combustion engine vehicle as governments and industries around the world encourage the pursuit of sustainable transportation solutions to decrease the amount of fossil fuel consumption and greenhouse gas emissions. The onboard charger (OBC) is one of the most

important parts of an EV as this component converts AC power from the power grid to a regulated DC power source that can be used to charge the onboard battery. In general, the conventional onboard charger adopts diode bridge rectifiers with a power factor correction stage and DC-DC converter. While these systems offer good charging performance, they have disadvantages like conduction loss, heavy circuits structure, large size of the DC-link capacitors and less efficiency. Moreover, large electrolytic capacitors require a lot of space and are not very reliable due to their limited lifespan. Thus, the design of high efficiency, component reduced, small sized and power quality improved advanced onboard charging system has become an area of research. In this context, modern power electronic converter topologies are being investigated to obtain an improved power density and enhance the power quality of the system, allowing it to satisfy the international standards while increasing the speed of charging, meeting the battery charging requirements [1,2].

Power Factor Correction (PFC) Converter are playing a critical role in improving the performance of Electric Vehicle (EV) chargers to minimize the input current harmonics and ensure a power factor as close to unity as possible. Bridgeless converter is one of those PFC topologies which has gained much attention because it eliminates the traditional diode bridge rectifier and hence reduces the conduction losses and overall losses, which improves the overall efficiency of the PFC. The Bridgeless Zeta converter is one of the best topologies that can be used as it features a high voltage gain, low voltage stress on semiconductor devices, and has good power quality characteristics. In addition, the use of higher converter DC-link voltage will greatly decrease the required DC-link capacitance because capacitance is inversely proportional to the voltage. Such reduction enables to replace bulky electrolytic capacitors with smaller, more reliable capacitors and thus to achieve high power density and compactness of the charger. Besides, the converter is shown to be working in

Discontinuous Conduction Mode (DCM), thus simplifying the control strategy and decreasing the number of sensing components. All these features render the Bridgeless Zeta converter very attractive for next generation onboard charging applications to achieve high efficiency, lower costs, and better charging performance [3] [4].

In this project, a novel high-efficiency on-board charger for EV is proposed to address the drawbacks of conventional EV charging systems by using a bridgeless PFC converter with reduced dc-link capacitance. The suggested architecture is comprised of a bridgeless zeta PFC converter and a DC-DC buck converter to regulate the charging current of the battery. The PFC stage delivers a near unity power factor, low Total Harmonic Distortion (THD) and regulates the AC supply into a stable high voltage DC output. Ensuring safe and efficient charging, the DC-DC buck converter controls the battery charging function, both Constant Current (CC) and Constant Voltage (CV). The proposed charger is designed to use a higher DC link voltage, about 400V, which leads to a remarkably smaller capacitor of the DC link, and faster charging speed and higher power density. The analysis of MATLAB/Simulink shows that the proposed charger has advantages such as higher charging speed, lower voltage stress of switching devices, lower component count, better power quality and higher charging efficiency as compared to the conventional bridgeless charger topologies. Hence, the proposed system is practical, cost effective and high-performance system for future EV charging stations [5, 6].

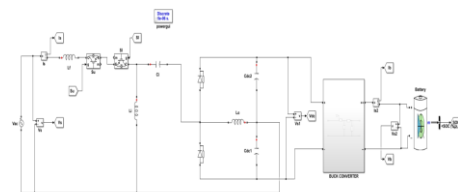


Fig. 1. MATLAB/SIMULINK circuit of the Proposed BL Zeta converter based on-board charger with reduced number of components.

The MATLAB/Simulink simulation model of the proposed EV onboard charger with Bridgeless Zeta converter and DC-DC Buck converter is shown in Fig. 1. The Bridgeless Zeta converter is a converter that converts AC power to DC power without the use of a conventional diode bridge rectifier, and also provides Power Factor Correction (PFC) and reduces conduction loss. A high DC-link voltage (400 V) is maintained in the converter to keep the needed DC-link capacitance to a minimum and to obtain high power density. In the CC (Constant Current) and CV (Constant Voltage) charging modes, the battery charging is regulated by the DC-DC buck converter. To keep the DC-link voltage and charging current stable, PWM signals are generated by the control system. The proposed charger achieves high efficiency, better power quality, less component, low switch stress, and fast battery charging compared with the conventional onboard chargers.

II SURVEY OF RESEARCH

1. Considering minimization of conduction losses and enhancement of the overall converter performance, J. M. Kwon and B. H. Kwon have proposed a high-efficiency bridgeless converter for battery charging applications. In the proposed topology, the conventional diode bridge rectifier was removed and less semiconductor devices were used in the current conduction path. This helped to minimize the power losses and improve the energy conversion efficiency. The study showed that the structures of bridgeless converter make it possible to obtain higher efficiency and lower thermal stress than the structures based on rectifiers. These experimental results demonstrated that the power factor, harmonic distortion and reliability were improved under various operating conditions. Power density was improved with the converter because of the fewer number of components. Bridgeless topologies are found to be very suitable for electric vehicle charging systems which are dominated by the criteria of efficiency and size reduction, the authors concluded. The results of this research serve as the basis for designing high power factor correction and battery charging onboard chargers in a simplified converter structure.
2. The complete survey of single-phase power factor correction converters for Electric vehicles charging system was presented by B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari. The study involved analysis of the different types of converter topology such as boost, buck-boost, SEPIC, Cuk, and Zeta converter. The authors rated the performance of the respective converter with regard to efficiency, power factor, harmonic distortion, number of components and complexity of control. They showed that Power Factor correction plays a vital role as part of their research on reducing Power Quality issues and Grid side current Harmonics. It was found that the energy utilization can be increased considerably by using advanced PFC converters and it meets the international standard. In addition, the authors stressed the need to design a small converter structure that not only has high conversion efficiency but also lowers the switching loss. The book provides valuable reference material for the development of modern electric vehicle onboard chargers that can be designed to be energy efficient and have high power quality.
3. B. Singh and S. Sharma studied different bridgeless power factor correction converter topologies for Electric Vehicle Battery Charging. Their research area was to minimize conduction losses, increase power density and boost the efficiency of the charger. Various converter configurations such as Bridgeless Boost, Bridgeless SEPIC, Bridgeless Cuk and Bridgeless Zeta converter were analysed and compared. The study proved that the bridgeless converter structures are more efficient than the conventional PFC converter since the diode bridge rectifier is not used in the current path. Also briefly discussed are control strategies, harmonic reduction methods and converter design aspects as related to electric vehicle charging applications. Experimental results have been shown to validate the higher efficiency, lower EMI and better thermal performance of the bridgeless topologies. As a result, the research showed that bridgeless PFC (power factor correction) converters can be a good

solution for future high-performance onboard charging systems.

4. A compact multifunctional power electronic interfaces for plug-in electric vehicles was proposed by S. Dusmez and A. Khaligh, where both charging and propulsion functions are combined into a single converter structure. The goal of the research was to decrease complexity, number of components, and manufacturing costs and to increase efficiency. The proposed converter architecture could be used to charge the battery, control the propulsion and manage the energy with common power electronic devices. Results showed high efficiency and power density improvement both in simulation and experimentation. The integrated approach was able to reduce the size of the system and improve the reliability of the system by reducing the amount of redundant components. Power flow control, converter optimization, and battery charging management in diverse operating conditions were also taken care of in the study. This work pointed out the merits of multifunctional converter design schemes and gave insightful inputs for compact and efficient EV charging system design.

5. A high efficiency power factor correction rectifier topology for battery charging application was proposed by Y. Jang and M. M. Jovanovic. The aim of the proposed charger was to maximize the utilization of the magnetic components while minimizing the switching losses and conduction losses using advanced converter design techniques. The study was based on how to make the chargers more efficient and how to make the converter smaller using the magnetic design and how to manage power flow. The power factor correction performance and harmonic distortion were achieved under different load conditions and obtained by experimental results were excellent. The charger had a higher conversion efficiency than conventional PFC converter architectures. The authors described the need for efficient power conversion in charging systems for EVs and

discussed approaches to enhance the reliability and performance of the power converter. The study is significant for the advancement of small, efficient and affordable EV charging technologies.

6. A detailed study of conductive charging technologies for electric vehicle battery charging systems were presented by S. Li and C. C. Mi. Various charging architectures, power electronic converter topologies, charging standards and battery management techniques were analyzed. This study examined the effect of charging efficiency, power quality, converter design, and charging speed on the overall vehicle performance. The study underscored the critical need for high-efficiency charging systems for fast and reliable battery charging, while ensuring grid compatibility. Key technologies for improving the performance of chargers, such as advanced power factor correction techniques and intelligent control strategies of the converter, were discussed. This study also investigated the future trends in charging infrastructure and pointed out the requirement of small size with high power density on board chargers. This work offers useful information for the design of new generation EVC systems for electric vehicles that are more efficient and require fewer components.

III. WORKING METHODOLOGY

In this paper, a new design named High-Efficiency On-Board Charger for Electric Vehicles Using a Bridgeless PFC Converter with Reduced DC-Link Capacitance is proposed to achieve fast charging of the battery, high power factor operation, low harmonic distortion and high power conversion efficiency. The charger is made up of a Bridgeless Zeta Power Factor Correction (PFC) converter followed by a DC-DC Buck converter. The Bridgeless PFC stage transforms the AC electricity supply into a stable high voltage DC output with near unity power factor. DC-DC buck converter provides a control to the charging current and voltage to the battery. This overall system reduces conduction losses, decreases the size of the DC-link capacitors, and increases the power density of the chargers.

This is the AC Input and EMI Filtering Stage.

When the onboard charger is plugged into a single-phase AC power source, the charging process starts. The electrical energy is supplied to the charger from the AC source, via an Electromagnetic Interference (EMI) filter. The EMI filter is used to remove the high frequency switching noise and harmonics generated by the converter, which will avoid the interference to the utility grid and surrounding electronic devices. The filtered AC voltage is then fed to the Bridgeless Zeta PFC converter.

The RMS input power is:

$$[P_{in}] = V_{in} I_{in} \cos\phi$$

Where:

(P_{in}) = Input Power (W)

(V_{in}) = Input Voltage (V)

(I_{in}) = Input Current (A)

$(\cos\phi)$ = Power Factor

Bridgeless Zeta PFC Converter Operation to achieve high efficiency and reduced weight. :Bridgeless Zeta converter as the main AC-DC conversion stage. The proposed converter is different from the conventional rectifiers as it does not contain a diode bridge rectifier which reduces the conduction losses and increases the efficiency. The converter operates in Discontinuous Conduction Mode (DCM) that makes the implementation of the control easier and reduces the number of required sensors.

The output DC-link voltage produced by the converter is kept at around 400 V.

The ratio of the voltage transformation of Zeta converter is given by:

$$[\frac{V_o}{V_{in}}] = \frac{D}{1-D}$$

Where:

Output Voltage (V)

(V_{in}) = Input Voltage (V)

(D) = Duty Cycle

DC-Link Voltage Regulation : The regulated DC-link voltage is an intermediate energy storage stage between PFC converter and battery charging converter. The proposed charger achieves high DC-link voltage (around 400 V) that can greatly reduce the capacitance value.

Charger Efficiency Evaluation

Efficiency of On Board charger is based on the ratio of the output power supplied to the battery to the input power from the AC source.

$$[\eta] = \frac{P_{out}}{P_{in}} \times 100$$

Where:

(η) = Charger Efficiency (%)

(P_{out}) = Output Power (W)

(P_{in}) = Input Power (W)

The more efficient it is, the less energy will be lost and the more efficient the charger will be.

MATLAB/Simulink Validation : The entire onboard charger system is modeled and simulated in MATLAB/Simulink to assess the steady and transient performance of the system. Analysis of various parameters including input voltage, input current, DC-link voltage, battery charging current, battery charging voltage, power factor, THD and efficiency is done. The simulation results show that the power factor is close to unity, the harmonic distortion is reduced, the DC-link voltage is regulated and the charging speed is increased, the voltage stress on the switches is reduced, and the DC-link capacitance is reduced. The proposed methodology is able to offer an effective, miniaturised, efficient and cost-effective on board charging solution for modern EV applications.

IV RESULTS EXPLANATIONS

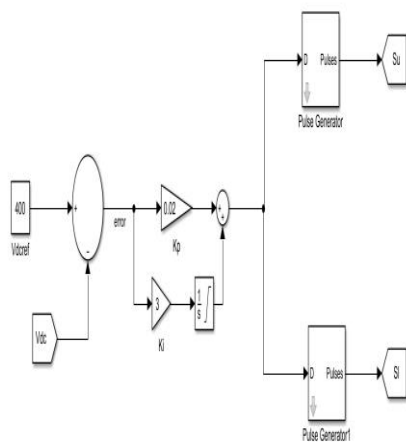


Fig.2 Control system for AC_DC Converter

The control strategy used for the proposed onboard charger AC – DC converter stage is shown in Fig. 2. The main goal of this control system is to keep the regulated DC-link voltage and operate the system near unity power factor. The sensed AC voltage is fed into a control algorithm which determines the appropriate switching pulses to the Bridgeless PFC converter. The controller continuously compares the real DC link voltage to the reference voltage and adjusts the duty cycle of the converter switches as per the comparison. This process enables to maintain stable voltage regulation on the DC-link despite changes in the supply and in load. Furthermore, the controller controls the input current waveform in such a way that it follows the input voltage waveform, thus reducing the harmonic distortion and power quality. Therefore, the converter is capable of converting energy efficiently, with lower conduction losses and improved charger performance.

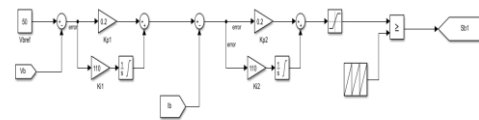
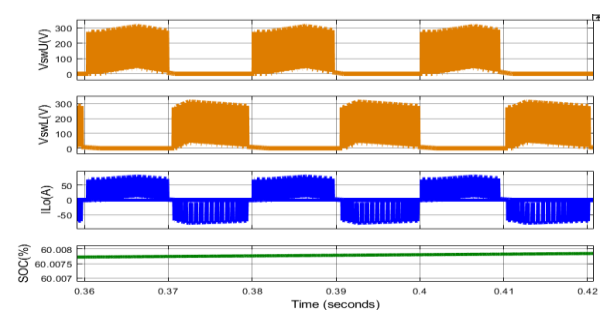


Fig.3 Control system for DC_DC Buck Converter

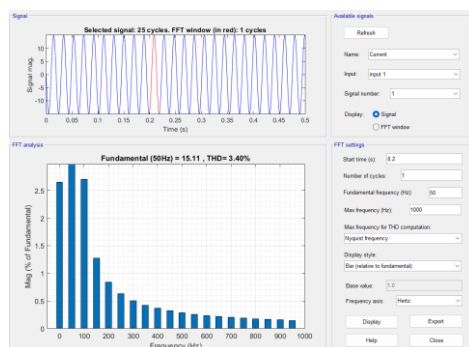
The control system adopted for the DC–DC buck converter in the battery charging stage is shown in Fig. 3. This controller is mainly used to control the charging current and voltage of the battery in accordance with the battery charging requirements. The Constant Current (CC) charging mode applies a constant charging current to charge the battery quickly. The controller automatically switches into Constant Voltage (CV) state when the battery voltage reaches the specified threshold, preventing any battery over charging. The voltage of the battery and the current flow are monitored constantly and are compared with reference values. The controller then produces the Pulse Width Modulation (PWM) switching signals for the buck converter based on the error signal. This control strategy is designed to ensure safe, efficient and reliable battery charging, to prolong battery life and to guarantee charging stability.



(a)

The steady state performance waveforms of the proposed onboard charger at rated input voltage of

110 V AC are shown in Fig. 4(a). The waveforms generally contain input voltage, input current, the DC link voltage, the battery charging current and the battery charging voltage. It is noticeable that the input current waveform is close to the input voltage, which shows good power factor correction working. The Bridgeless PFC converter maintains the DC-link voltage at the desired value, showing the efficiency of the PFC converter. In addition, the charging current and the charging voltage of the battery are within the target operating range range, thus battery charging performance is stable. The steady-state results confirm the potential of the proposed charger for efficient power conversion and good quality of power transfer during normal operation.

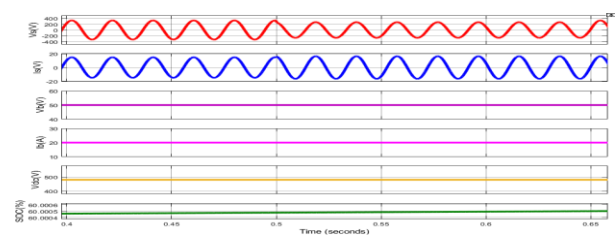


(b)

Fig. 4. Operation of proposed on-board charger at rated line voltage:(a)steady state waveforms, and (b) improved PQ indices.

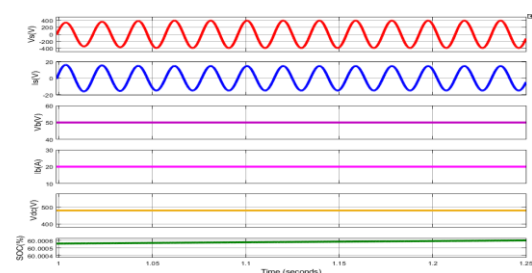
The results obtained by proposed onboard charger for power quality parameters are shown in Fig. 4(b). Typically these indices involve Power Factor (PF), Total Harmonic Distortion (THD), input current distortion, and conversion efficiency. The results show that the power factor of the charger is close to unity with very small harmonic distortion

of input current. There is a significant improvement in power quality, which also helps to prevent stress on the power line and complies with international power quality standards. The result of the input current THD and PF improvement is the efficiency of the Bridgeless PFC converter in improving input current characteristics. The charger, therefore, ensures high efficiency in energy use and excellent compatibility with the grid.



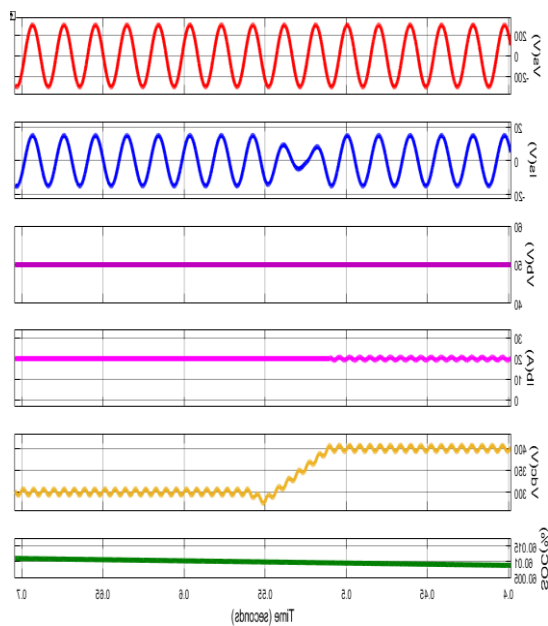
(a)

The transient response of the proposed charger is shown in Fig. 5(a) in the case of drop in the input voltage from 110 V AC to 90 V AC. In this example of a voltage sag, the controller rapidly responds to the lower input voltage and changes the duty cycle of the converter. Thus, the DC-link voltage and charging parameters for the battery are stable and hardly affected. The prompt response of the control system demonstrates the charger's capability to operate in low voltage conditions and also guarantees continuous battery charging process.



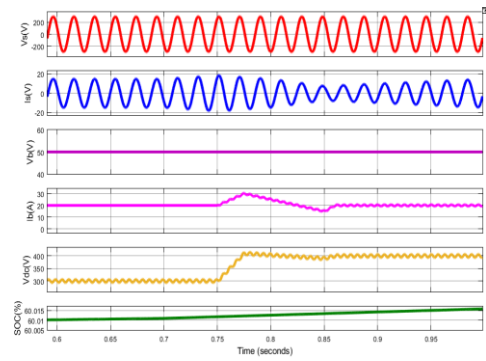
(b)

Fig. 5(b) shows the charger response to the input voltage being raised between 110 V AC and 130 V AC. The controller senses the voltage increase and quickly adjusts the switching action of the converter to keep the desired DC-link voltage. The transient results show that the system is able to suppress the voltage fluctuation and avoid excessive charging current to the battery. This shows that the proposed control strategy works well under the over voltage situation.



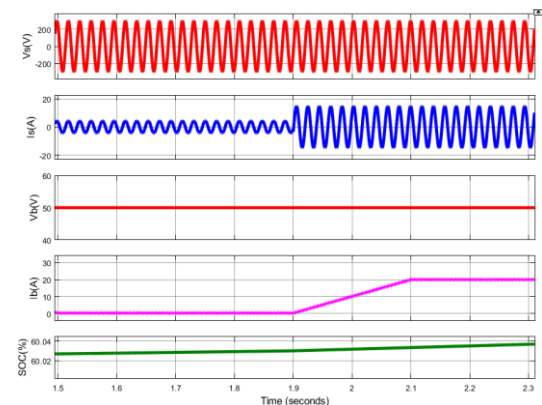
(c)

The behavior of the system is shown in Fig. 5(c) for a decrease of the DC-link voltage reference from 400 V to 300 V. The controller constantly checks the DC-link voltage and will carefully adjust the performance of the converter to realize the new voltage. The transient response shows no appreciable overshoot or oscillations, suggesting good dynamic characteristics. During the transition period of the voltage, the charger can ensure the normal working of the battery charging.



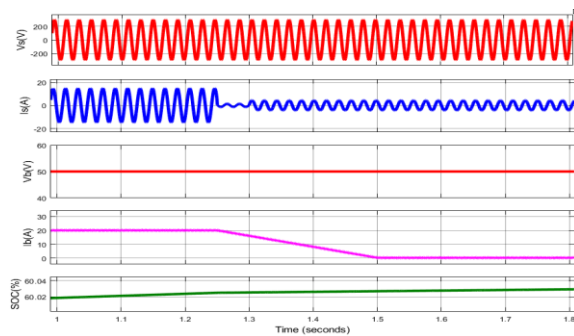
(d)

Fig. 5. Transient Performance of proposed on-board charger: (a) the variations in line voltage from 110 V-90 V, and (b) from 110 V-130 V, (c) during change in Vdc from 400 V-300 V DC-link voltage, and (d) from 300 V-400 V.



(a)

The start-up performance of the proposed on board charger is shown in Fig. 6(a). The converter starts from zero DC-link voltage and charging current, and ramps these up to their rated values gradually. Control system: to avoid excess inrush current and for smooth charging. This waveform shows a voltage build up in the system and good operation of the converter during system initialization. This soft start enhances the safety of the system and helps to prevent electrical stress on power electronic components.



(b)

Fig. 6. Transient Performance of charger. (a) during startup, and (b) shutdown process.

V.CONCLUSION

In this study, a new bridgeless Zeta converter is proposed that can potentially improve the charging performance of an electric car by utilizing less DC-link capacitance, less number of components and less switch voltage stress. The proposed bridgeless Zeta converter is a result of the sharing of the components, during both the positive and negative half-cycle operations, consisting of just 2 inductors and 2 diodes. The simpler construction of the converter throughout the battery charging process decreases the number of components, thereby increasing the efficiency, complexity reduction and power density of the converter. The proposed architecture has an advantage over the conventional slower EV charger since it can provide a significant reduction of the size of the DC-link capacitor at a higher DC-link voltage by using the bridgeless converter. The proposed charger reduces the size and reliability of the charger since the needed DC-link capacitance decreases with the rise of the DC-link voltage, which consequently reduces the size of the capacitors to be used and their uncertainty. The proposed charging structure is simulated and the result shows that the charging speed can be significantly improved by the proposed charging structure. It can charge the batteries about 8 times quicker than the conventional controller using a bridgeless Zeta converter while maintaining the parameters of the batteries. Further, the charger has a Unity Power Factor (UPF) and a low input

supply current distortion, which complies with the power quality requirements. All these attributes can be regarded as the high quality of this proposed OBC solution and its potential as a future-proof, space saving, high performance solution for EV charging.

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