Improvement in Performance of Hybrid Electric Vehicle Charging Station by Using Single-Stage Boost DC-DC Converter

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ABSTRACT

Charging of Li-ion battery can be done which is used for providing propulsion torque and through various stages of charger voltage and current level is controlled and make them desired for charging. But, it requires dual-stage conversion system which utilizes dual DC-DC converters for voltage-power conversion which increases the cost and size of the system. Based on the summarized merits & demerits of dual-stage DC-DC converters, a single-stage high voltage gain converter is greatly suitable for EV-charging system due to high voltage gain, low switch stress, low current ripples, low EMI issues, and low complex design. The voltage 230V coming from AC source is converted into 324-329V by using proposed modified boost converter with a moderate duty cycle which reduces the switching losses and maximizing the efficiency. The main objective of this work is proposing a novel single stage high step-up DC-DC converter for EV charging system powered by AC utility grid with enhanced profiles. The well-recognition of proposed scheme is validated under dual-stage and single-stage DC-DC converters for EV charging is demonstrated through Matlab/Simulink tool and results are conferred with proper comparisons.

Keyword: *- Battery Energy Storage System, DC-DC Converter, EV Charging System, High-Voltage Gain Converter, Power-Factor Correction*

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1. INTRODUCTION

The need for a green and sustainable mode of transportation and the advancement of a battery technology has sparked interest in electric vehicles (EVs) as a viable mode of transportation. The battery pack of the EVs can be leveraged for this purpose making EVs more feasible than internal combustion engine (ICE) vehicles. As EVs or PHEVs are equipped with high voltage batteries to increase the driving range and improve the fuel efficiency, a universal input charging station for EVs is developed to deploy it commercially for the quicker appropriation of the electrified transportation framework in the country. Thus, in the last decade, numerous researchers have contributed toward the technological advancements and fruitful implementation of the grid-integrated EV charging station [1]. A concept of grid-integrated battery charging framework to enhance the system reliability is proposed by using on-board charging system.

This has led to an increased interest in vehicle electrification, foremost hybrid electric vehicles (HEVs) which can reduce fuel consumption compared to conventional vehicles, but also battery electric vehicles (BEVs). BEVs offer high powertrain efficiency and no tailpipe emissions, which is why they are so far considered CO2 neutral in the regulations [2]. If charged with electricity that is produced by fossil free and renewable sources, BEVs have the potential to offer an emission free. Today a large part of the major automotive manufacturers in the world have developed their own BEV model, and BEV sales have seen increased annual growth rates, as high as 54%-87% during 2025-2030.

The powertrain of a Battery Electric Vehicle (BEV) consists of an electric drive system with a battery serving as an energy buffer. Often there is only one electric machine, typically of three phase AC type, connected to the wheel shaft via a gearbox and a differential. However some applications may utilize several electric machines, e.g. hub wheel motors. The energy is stored chemically in a battery, which is electrically connected to the machine via a DC-DC and DC-AC power electronic converter accompanied by a control system [3]. The control system controls the frequency and magnitude of the three phase voltage that is applied to the electric machine, and these are depending on the driver's present request, which is communicated via the acceleration and/or brake pedal.

The electric propulsion system is the heart of EV. It consists of the motor drive, transmission device, and wheels. The transmission device sometimes is optional. In fact, the motor drive, comprising of the electric motor, power converter, and electronic controller, is the core of the EV propulsion system. Clearly, electric motors are a key component of an electric vehicle and the requirements for traction motors can be summarized as light weight, wide speed range, high efficiency, maximum torque and long life. Battery as a load has a variable profile [4]. The Battery can be modeled as an electrochemical model, Thevenin based electrical model and impedance based model.

The power converter should be capable of meeting the wide variations caused due to varying irradiance and providing dependable power. Buck, boost, buck-boost and fly back are the DC-DC converter topologies widely reported for extraction of maximum power [5]. Conventional buck based topologies have inductor performing the dual function of energy storage and filtering. The conventional boost converter has inductor on the source side and hence requires filters on the load side. It offers a maximum gain of twice the input for higher efficiency with a limitation of 50% duty cycle.

Efficient, cost-effective, and simple structure of battery charging for EV system by utilizing suitable power conditioning stages with assisted knowledge of control scheme. Based on the summarized merits & demerits of conventional boost DC-DC converters, a single-switch high voltage gain converter is greatly suitable for EV-charging system due to high voltage gain, low switch stress, low current ripples, low EMI issues, and low complex design [6]. The voltage 230V coming from the utility-grid system is converted into 450V by using proposed boost – buck converter with a moderate duty which reduces the switching losses and maximizing the efficiency.

The main objective of this work is proposing a novel single stage high step-up DC-DC converter for EV charging system powered by AC utility grid with enhanced profiles [7]. The well-recognition of proposed scheme is validated under dual-stage and single-stage DC-DC converters for EV charging is demonstrated through Matlab/Simulink tool and results are conferred with proper comparisons.

2. DESIGN OF CONVENTIONAL ON-BOARD CHARGING SYSTEM

2.1 Design of Dual-Stage Power Factor Corrector

The Fig.1 shows Block diagram of the on-board charger which is used for charging the propulsion battery of electric vehicle. on- board charger consists of two stages that are power factor corrector (PFC) and DC-DC Converter. Power factor corrector consists of AC-DC rectifier and boost converter [8]. The main purpose of PFC is to improve the power factor so that total harmonic distortion will be reduced and to make current wave form sinusoidal. This can also help in improving the efficiency of the on-board charger and reduces losses during operation of the on-board EV charger for EV system [9]. Fig.2 shows Conventional Two-Stage DC-DC PFC Scheme of on-board charger.

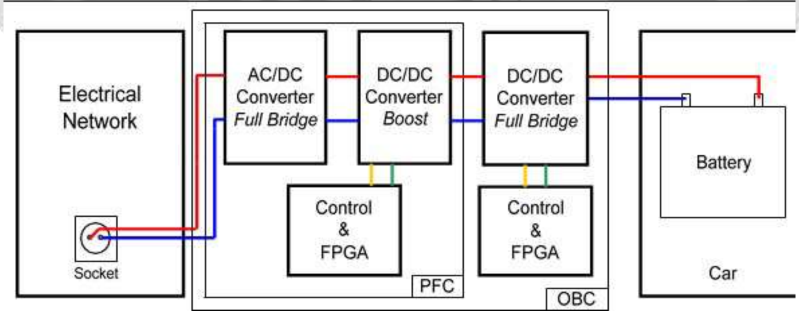


Fig.1 Block diagram of on board charger.

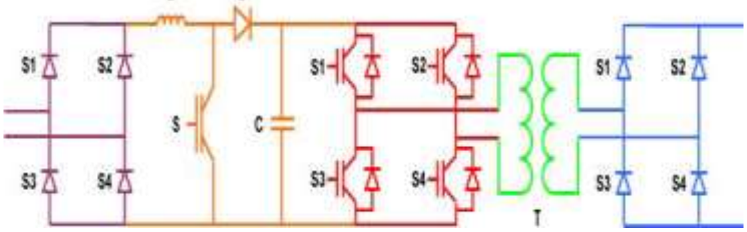


Fig.2 Conventional Two-Stage DC-DC PFC Scheme

2.2 Design of Conventional DC-DC Converter

The Fig.3 Shows the Matlab Simulink model of DC-DC Converter. The design of this converter depends on transmitted power and the requirement of step up or step down converter and whether the isolation required or not.it will supply desired value of voltage or current to the battery for charging.

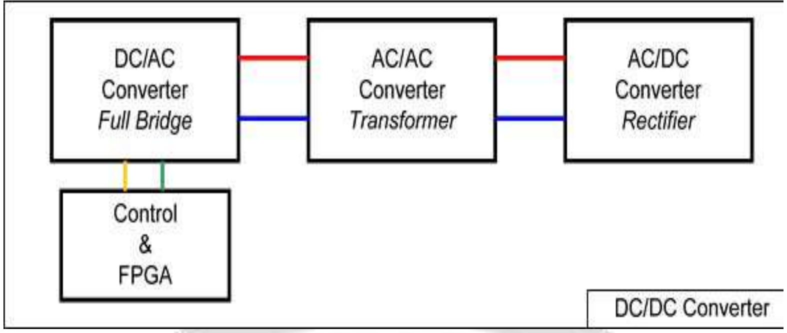


Fig.3 Block diagram of DC-DC Converter.

3.1 DESIGN OF PROPOSED ON-BOARD CHARGING SYSTEM

3.1.1 Design of Single-Stage Power Factor Corrector

The proposed converter employs a coupled inductor with same winding turns in the primary and secondary sides. In step-up mode, the primary and secondary windings of the coupled inductor are operated in parallel charge and series discharge to achieve high step-up voltage gain. Thus, the proposed converter has higher step-up voltage gains than the conventional dc–dc boost converter. Under same electric specifications for the proposed converter, the average value of the switch current in the proposed converter is less than the conventional boost converter. Based on this converter, a novel DC–DC converter is proposed, as shown in Fig.4. The proposed converter employs a coupled inductor with same winding turns in the primary and secondary sides. Comparing to the proposed converter and the conventional boost converter, the proposed converter has the following advantages: 1) Higher step-up and step-down voltage gains and 2) lower average value of the switch current under same electric specifications.

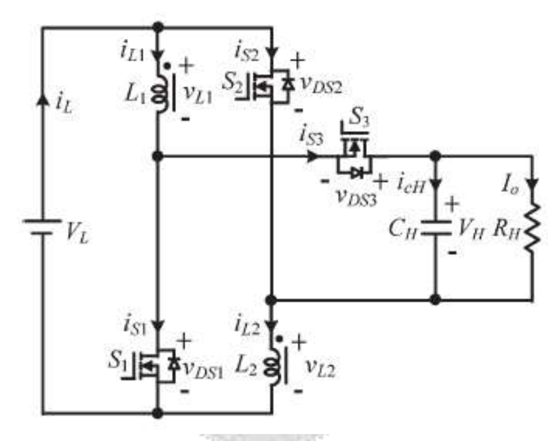
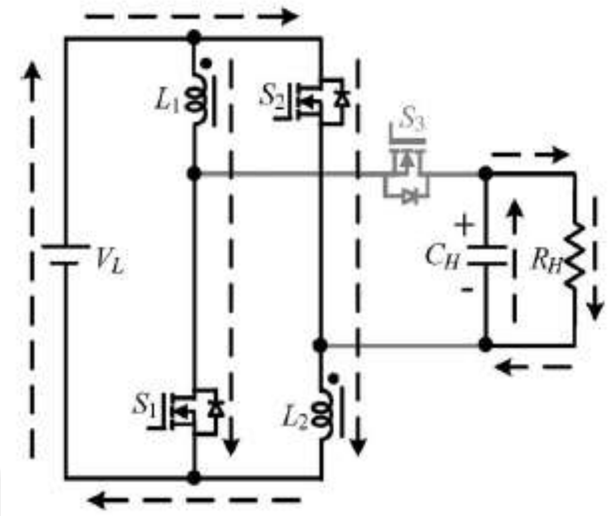
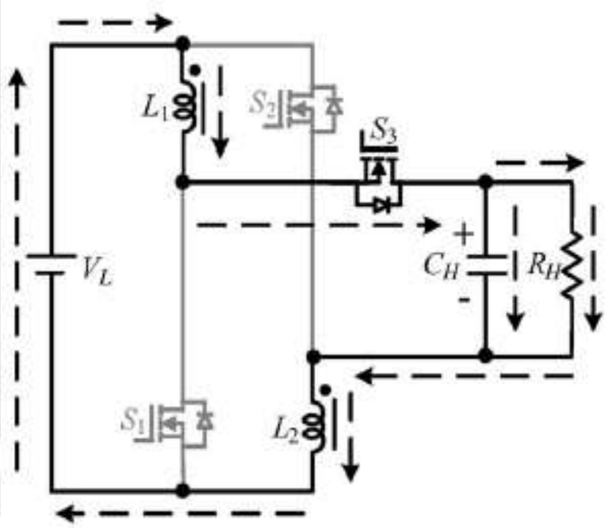


Fig.4 Proposed High-Gain DC–DC converter



(a) Parallel Charging Mode

Mode 1: During this time S1 and S2 are turned on and S3 is turned off. The current flow path is shown in Fig. 5(a). The energy of the low-voltage side VL is transferred to the coupled inductor. Meanwhile, the primary and secondary windings of the coupled inductor are in parallel. The energy stored in the capacitor CH is discharged to the load.



(b) Series Discharge Mode

Fig.5 Operating Modes of Proposed High-Voltage Gain DC-DC Converter

Mode 2: During this time interval S1 and S2 are turned off and S3 is turned on. The current flow path is shown in Fig. 5(b). The low-voltage side VL and the coupled inductor are in series to transfer their energies to the capacitor CH and the load. Meanwhile, the primary and secondary windings of the coupled inductor are in series.

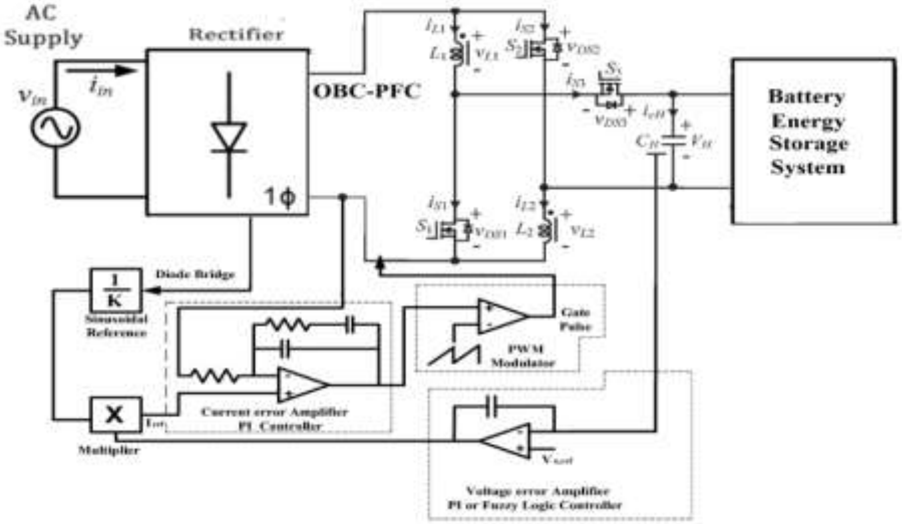


Fig.6 Schematic Diagram of Proposed Single-Stage PFC Fed High-Voltage Gain DC-DC Boost Converter for Battery-EV Charging System

4. MATLAB/SIMULINK RESULTS & ANALYSIS

The Matlab/Simulink modelling is carried based on various cases and the proposed models are developed by using described system specifications illustrated in Table.1.

Table.1 System Specifications

S.NO	System Specifications	Values
1	Input Source Voltage	Vrms-230V, Fs-50Hz
2	Conventional Two-Stage Converter	L1-0.2mH, C-2000µF, L2-1mH, C-1000µF
3	Proposed Single-Stage DC-DC Converter	L2=L1-15.5mH, C-330 µF
4	DC-Link Voltage	Vdc-450V
5	Switching Frequency	Fs-50KHz
6	Battery	V-329, P-0.5Ah, SOC-95%
6	PI Controller	Kp-0.5, Ki-0.01

4.1 The Performance of On-Board Charging System for HEV System by using Conventional Two-Stage DC-DC Conversion System

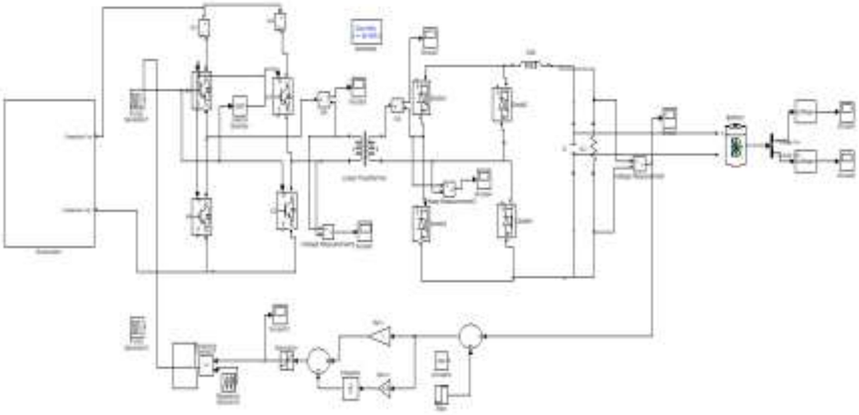
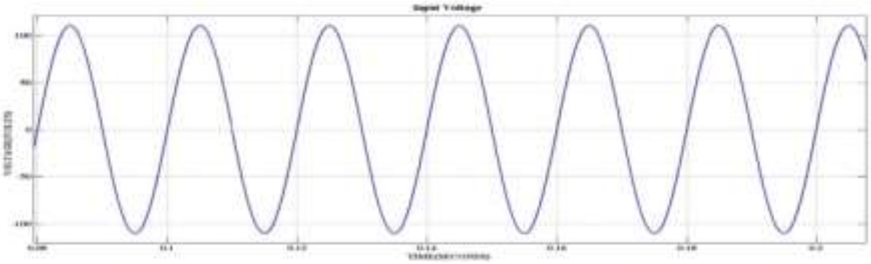
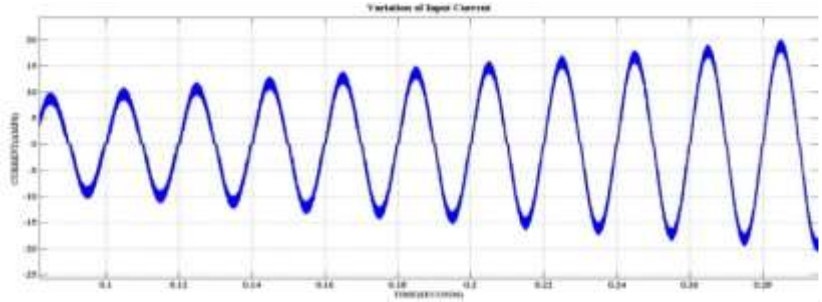


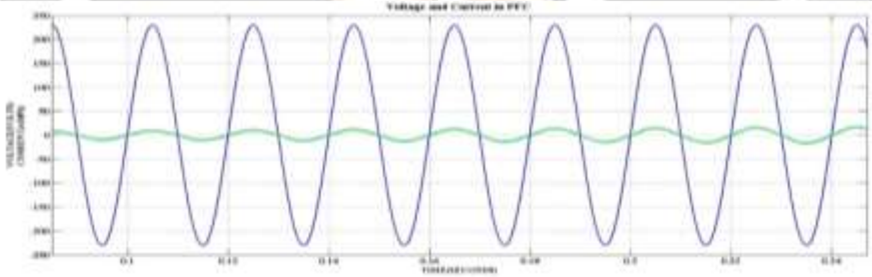
Fig.7 Matlab/Simulink Model of On-Board Charging System for HEV System by using Conventional Two-Stage DC-DC Conversion System



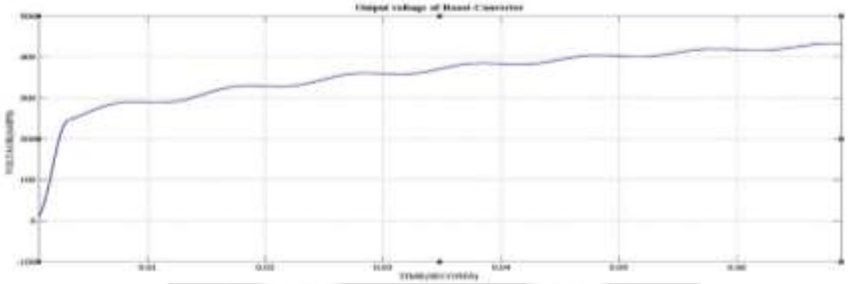
(a) Input Voltage



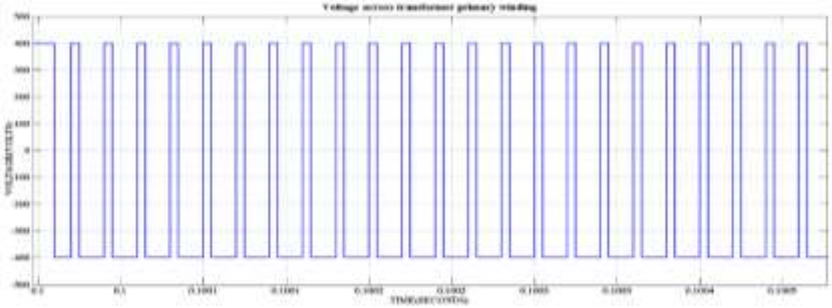
(b) Input Current



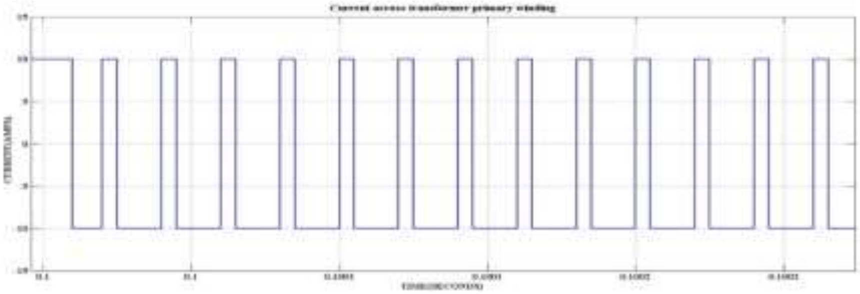
(c) Source Voltage & Current (In-Phase)



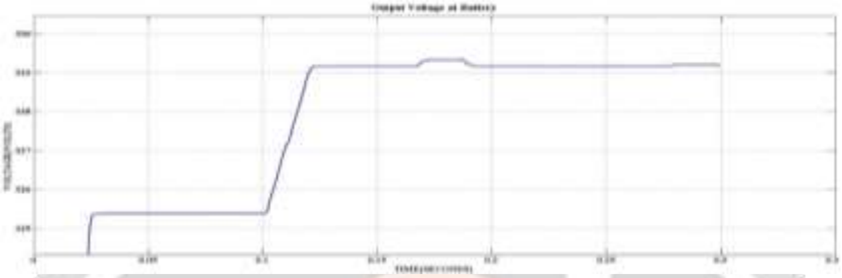
(d) DC-Link Voltage



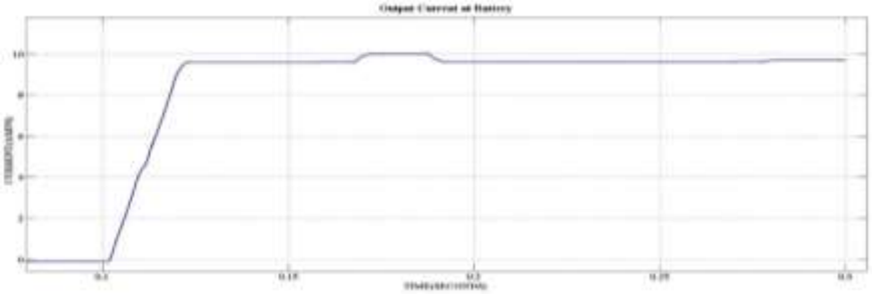
(e) Voltage across transformer primary winding



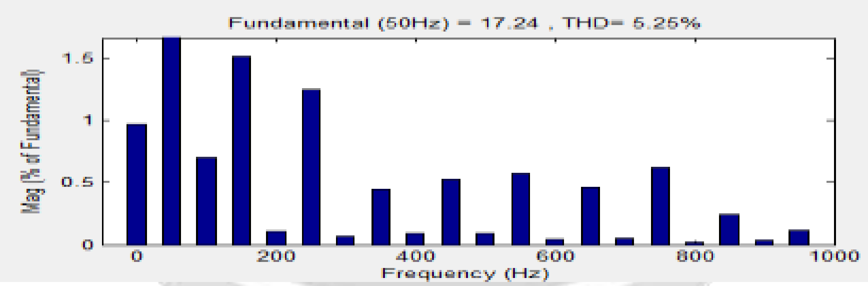
(f) Current in transformer primary winding



(g) Voltage across Lithium-ion battery



(h) Current in Lithium-ion battery



(i) THD of Source Current

Fig.8 Simulation Results of On-Board Charging System for HEV System by using Conventional Two-Stage DC-DC Conversion System

The Matlab/Simulink Model of On-Board Charging System for HEV System by using Conventional Two-Stage DC-DC Conversion System is depicted in Fig.7. The Simulation Results of On-Board Charging System for HEV System by using Conventional Two-Stage DC-DC Conversion System is depicted in Fig.8. Fig.8 (a) shows the sinusoidal input voltage which is applied to input of PFC for converting ac in to dc by using rectifier circuit. In Fig.8 (b) spikes of inrush current is observed at the input side of supply which can reduces the spikes of inrush current and sinusoidal wave form of input current is obtained. Fig.8 (c) shows the voltage & current in phase condition represents the unity-power factor. Fig.8 (d) shows the output voltage of boost converter which is approximately 450 volts. Fig.8 (e) and Fig.8 (f) variation in primary voltage and primary current of the transformer is shown in which it is observed that frequency is low as 10 HZ this is due to insufficient or low value of inductive reactance which can be improved by selecting proper reactance value. According to Fig.8 (g) and Fig.8 (h) the voltage and current required for charging Li-ion battery is determined. Fig. 8 (i) shows the THD value of source current is measured as 5.25%, it is un-comply with IEEE standards.

4.2 The Performance of On-Board Charging System for HEV System by using Proposed Single-Stage High-Gain DC-DC Conversion System

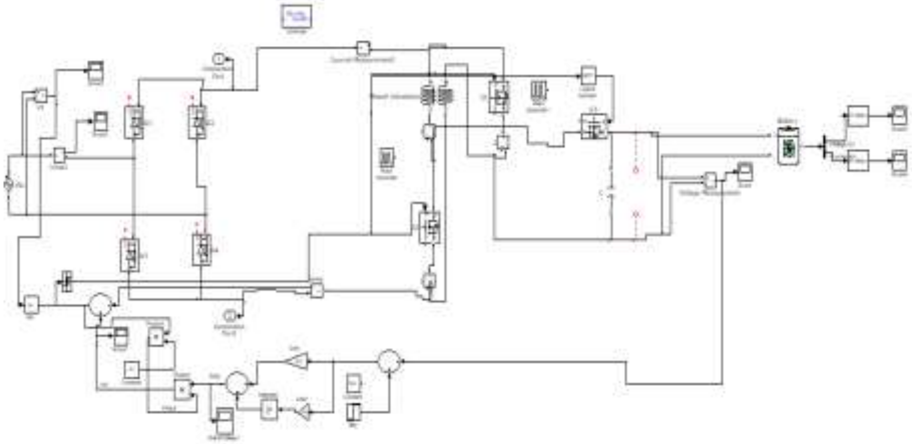
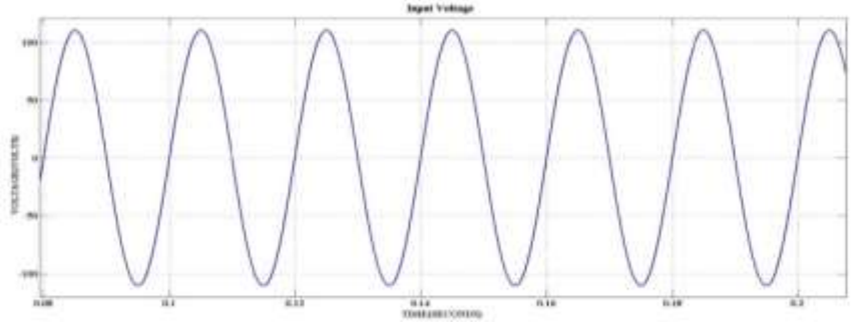
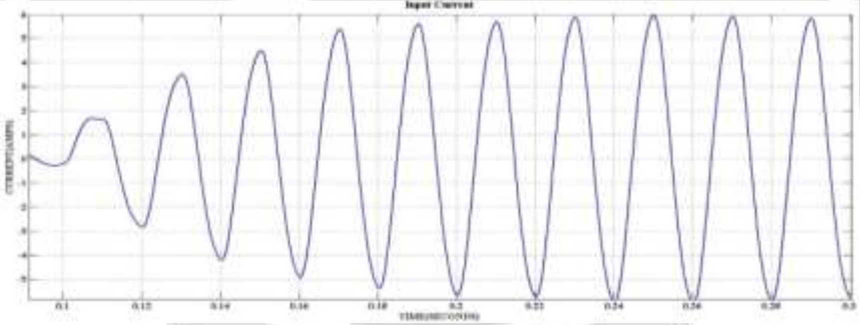


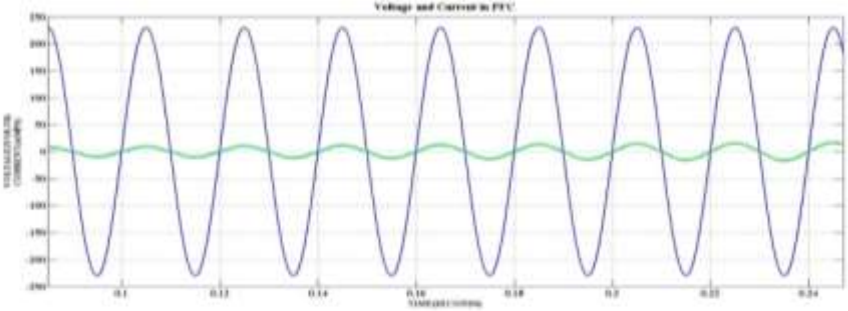
Fig.9 Matlab/Simulink Model of On-Board Charging System for HEV System by using Proposed Single-Stage High-Gain DC-DC Conversion System



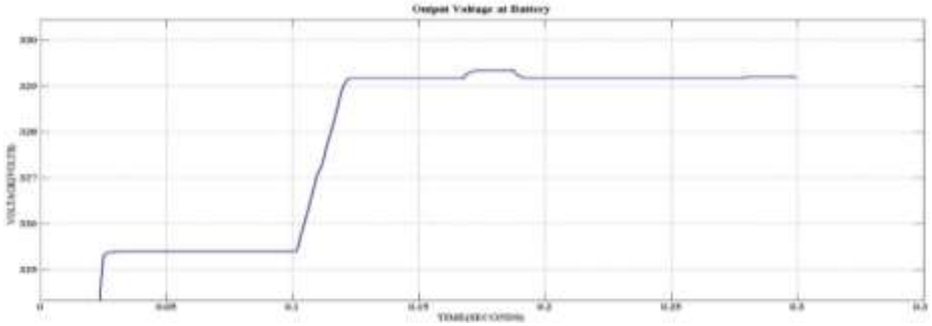
(a) Input Voltage



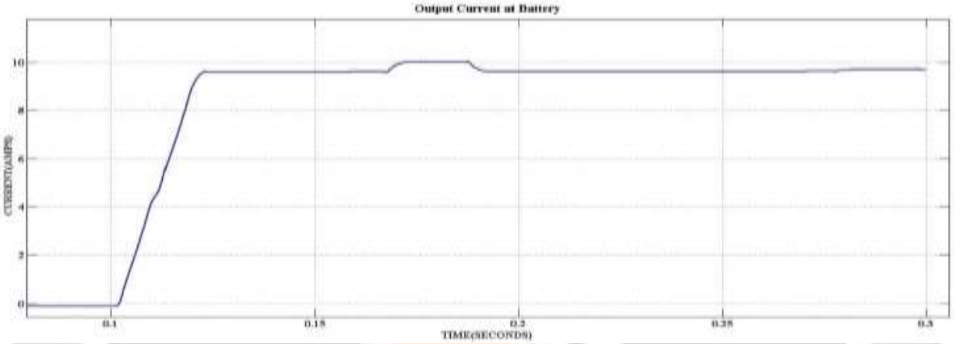
(b) Input Current



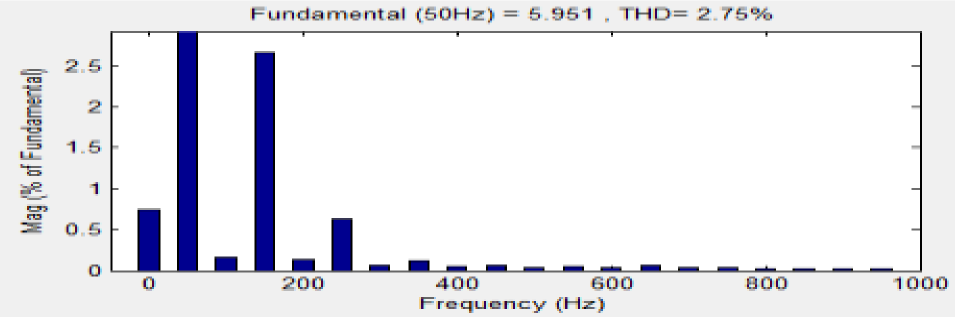
(c) Source Voltage & Current (In-Phase)



(d) Voltage across Lithium-ion battery



(e) Current in Lithium-ion battery



(f) THD of Source Current

Fig.10 Simulation Results of On-Board Charging System for HEV System by using Proposed Single-Stage High-Gain DC-DC Conversion System

The Matlab/Simulink Model of On-Board Charging System for HEV System by using Proposed Single-Stage High-Gain DC-DC Conversion System is depicted in Fig.9. The Simulation Results of On-Board Charging System for HEV System by using Proposed Single-Stage High-Gain DC-DC Conversion System is depicted in Fig.10. Fig.10 (a) shows the sinusoidal input voltage which is applied to input of PFC for converting ac in to dc by using rectifier circuit. In Fig.10 (b) the spikes of inrush current is decreased at the input side of supply and sinusoidal wave form of input current is obtained. Fig.10 (c) shows the voltage & current in phase condition represents the unity-power factor. According to high-gain DC-DC converter Fig.10 (d) and Fig.10 (e) the voltage and current required for charging Li-ion battery is determined. Fig. 10 (f) shows the THD value of source current is measured as 2.75%, it is comply with IEEE standards.

5. CONCLUSION

Prominent features of less environmental pollution & cheapest mode of transportation makes EV market more attractive to the consumers. As maximum EVs are charged at residential connection due to the lack of charging stations, the power sector has been failed to earn the profit from this sector. However, due to some reasons EVs penetration makes power system more vulnerable and hampers power quality. The work presents a conductive AC charging protocols for charging the plug in hybrid electric vehicles. In this work theory of conductive charging is investigated and complete analysis of the on-board charger is done due to which one should able to verify the valid states for the start of charging and the range of maximum current limit is determined by the duty cycle. The proposed high-voltage gain DC-DC converter has been developed for getting high voltage at output terminals over the conventional two-stage DC-DC converters which are used in on-board charging and PFC schemes. The proposed single-stage DC-DC converter requires less switching circuits over the conventional converters which reduce the switching loss, low cost, low size, low space and maximum efficiency, etc, are the key advantages.

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