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Design and Implementation of Charging Circuit for Electric Vehicles

Anbarasan.S[1], Pradeepkumar.S[1], Satheeshraj.S[1], Vijayakrishnan.K[1], Dr.R.Seyezhai[2], S.Harika[3]

UG Student, Department of Electrical and Electronics Engineering, Renewable Energy Conversion Laboratory, SSN College of Engineering, Chennai, India[1]

Associate Professor, Department of Electrical and Electronics Engineering, Renewable Energy Conversion Laboratory, SSN College of Engineering, Chennai, India[2]

Research Assistant, Department of Electrical and Electronics Engineering, Renewable Energy Conversion Laboratory, SSN College of Engineering, Chennai, India[3]

ABSTRACT: The battery plays a major role in electric vehicle (EV) and for that on-board battery charger is essential. Therefore, this paper focuses on the design of charging circuit for EV. The proposed charger circuit comprises of diode bridge rectifier, interleaved boost DC-DC converter and single phase DC-AC inverter. The design and operation of interleaved boost converter is discussed. Single phase DC-AC inverter is modeled and analyzed with different modulation techniques. From the comparison, the sinusoidal PWM (SPWM) is chosen for the proposed network. Inductive power transfer (IPT) technology is used for the charging of EV batteries. A simulation study of the proposed charger circuit is carried out in MATLAB/SIMULINK and a prototype model is built to validate the simulation results.

KEYWORDS: EV, Interleaved boost converter (IBC), IPT and SPWM.

I. INTRODUCTION

Nowadays, demand for electric vehicles has increased rapidly. Initially, EV uses simply plug-in charging methods which have the drawbacks of exposed plugs and cable damage. To overcome this, wireless charger is introduced for EV batteries. The proposed charging method uses a coupled inductor with both the primary and secondary sides fully isolated and without physical contact. Thus, the charger should be designed as versatile, automatic, safe and user convenient.

As the demand of charger for EV has increased, many studies on chargers have been carried out and found that inductive wireless power transfer system (IPT) is adoptable. The proposed IPT comprises two coil resonators for a short distance. With smaller air gap, a high efficiency in power transfer between the coils is achieved. But if the air gap distance exceeds, consequently the efficiency will decline as the magnetic coupling is weak. To enhance the magnetic coupling, many researchers suggested using the high permeability material such as ferrites [1]. Using high permeability material will increase the volume and weight which is unsuitable for EV application. Hence the design and placing the coils with suitable air gap plays a critical role in EV charging process. By increasing the air gap distance between 20 cm and 100 cm, a high efficiency at high frequency can be achieved but it is suitable only for low power application. This is because the transferred power is inversely proportional to frequency [2].

The contactless charging which is more suitable for low power transfer, is now possible in medium and high power applications due to development of semiconductor devices with lower conduction resistance, and frequency behaviour[3 & 4]. High operation frequency can provide efficiency improvement and higher power density. This paper involves the design and implementation of a contactless battery charger for electric vehicles, using a series-series (SS)

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inductive power transfer system. The contactless charging circuit is composed of ac-dc converter with an interleaved Power factor correction (PFC) converter, a series-series converter with an H-bridge and a secondary rectifier. The interleaved PFC converter reduces the Total harmonic distortion (THD) of the input current and controlling the primary side dc-link voltage. The H-bridge inverter is simulated with different modulation techniques and compared. The block diagram of proposed charger circuit for EV is shown in Fig.1.

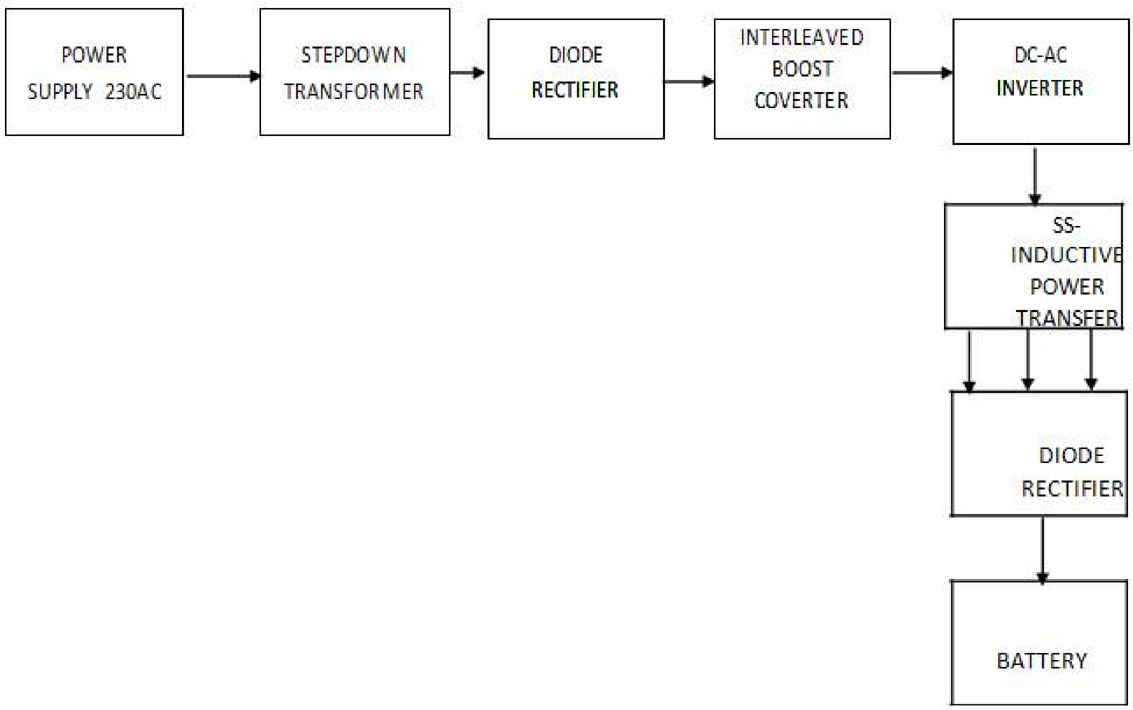

Fig.1. Block Diagram of Charger Circuit for EV

The circuit diagram of the proposed charger circuit is shown in Fig.2.

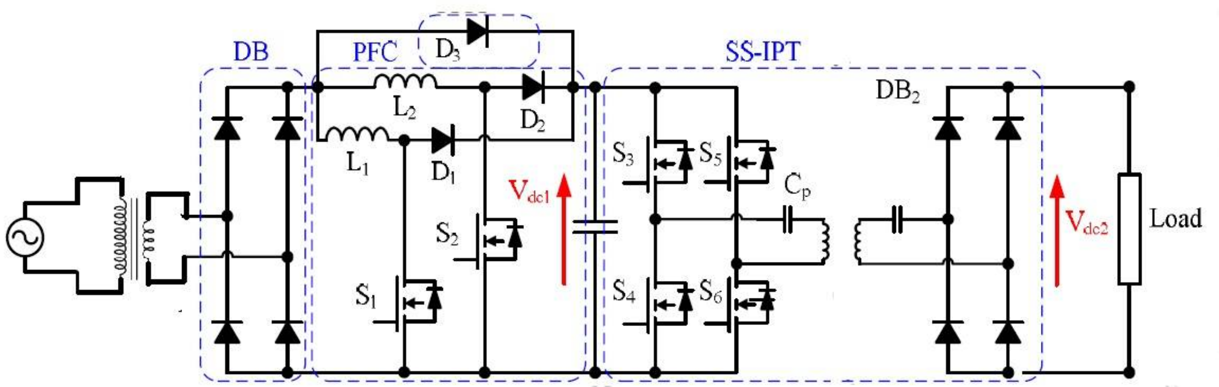

Fig.2. Circuit Diagram of Charger Circuit for EV

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II.RECTIFIER AND INTERLEAVED BOOST CONVERTER

In general, all the AC/DC converters comprises of a transformer following the input filtering, and then passes to rectifier in order to produce rectified DC. The AC-DC converters use multi-stage conversion topologies [5]. Diode bridge rectifiers conduct current in only one direction and even silicon controlled rectifiers (SCR) and triode for alternating current (TRIAC) are also used as rectifiers. During positive half cycle of the input voltage, the upper end of the transformer secondary winding is positive with respect to the lower end. Thus during the first half cycle diodes D1 and D3 are forward biased and current flows through the load resistance. During this negative half of each input cycle, the diodes D2 and D4 are reverse biased and current is not allowed to flow as shown in Fig.3.During second half cycle of the input voltage, the lower end of the transformer secondary winding is positive with respect to the upper end. Thus diodes D2 and D4 become forward biased and current flows through arm CB, enters the load resistance.

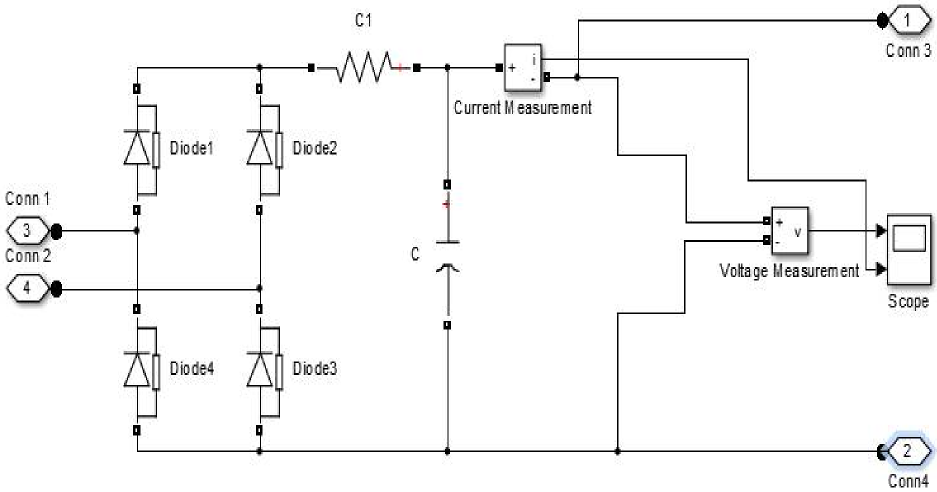

Fig.3. Circuit of diode rectifier at the primary side

Interleaving is to connect the N number of boost converters in parallel at same switching frequency but with 360/n phase shift. Interleaved boost converter has the benefits of low ripple content in input and output voltage, reduced peak current value and high ripple frequency [6]. This leads to high efficiency and high reliability. Since the proposed converter operates at high frequency, the size and losses of the magnetic components can be reduced. The two-phase interleaved boost converter is considered in this work where pulses to the MOSFET switches are displaced by 180 degrees. With this, the flow of current gets divided in two paths which leads to reduced conduction (I^2R) losses and increased overall efficiency compared to the conventional boost converter. The ripple frequency gets doubled because the two phases are combined at the output capacitor, which makes ripple voltage reduction much easier. Likewise, ripple requirements is reduced as the input capacitor are staggered. Thus the total harmonic distortion (THD) of the input current is reduced to meet the harmonic standards [7 &8]. The circuit diagram for interleaved boost converter is shown in Fig.4.

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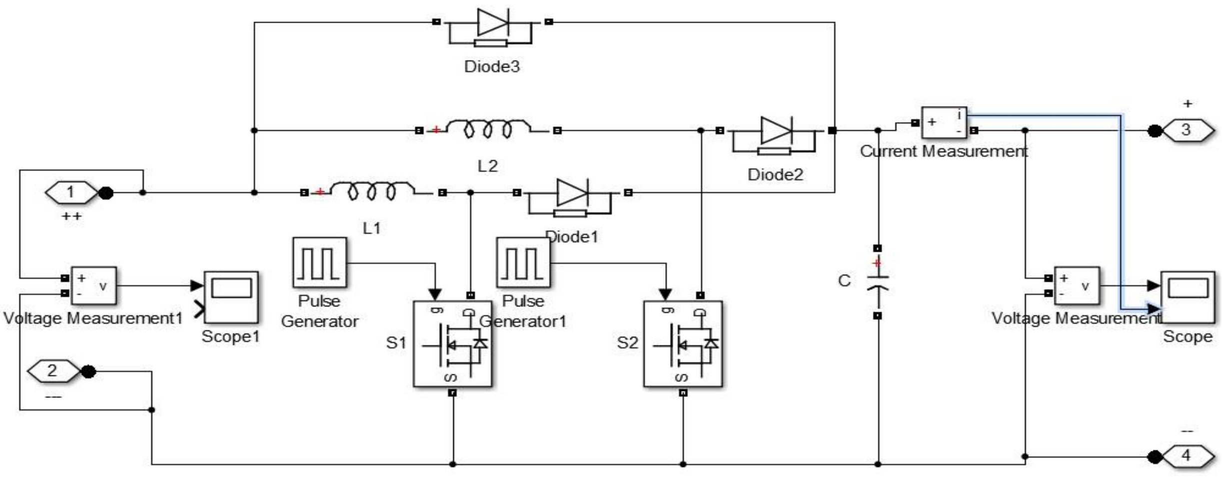

Fig.4. Simulink diagram of Interleaved Boost Converter

III. PWM VOLTAGE SOURCE INVERTER AND COIL DESIGN

Inverter plays a major role which does the conversion of fixed dc into variable ac [9]. Renewable energy sources can act as an input to the inverter or dc supply derived from an ac source can be used as input to the inverter. The single phase inverter has two arms with four semiconductor switches connected with anti parallel diode. During turn-off condition of the switches the reverse current flows through the anti parallel diode. The switches (are S_1, S_2, S_3 and S_4) are turned on alternatively so that no switch on the same leg can conduct which leads to 'shoot-through problem'. But at certain period of time called blanking time, both the switches turned off to avoid short circuiting [10]. The load is connected in between the two arms. The simulink diagram of proposed single-phase inverter is shown in Fig.5.

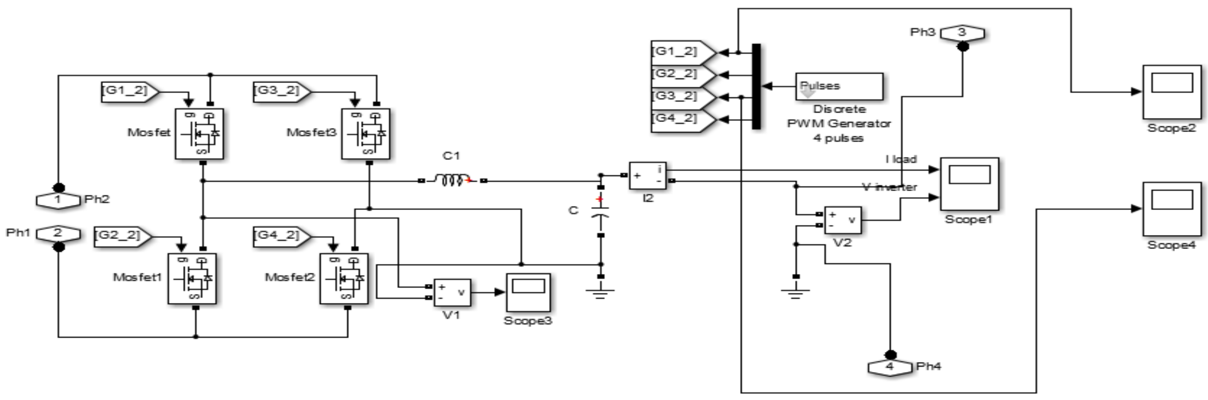

Fig.5. Single Phase Inverter

In SS (series-series) compensation, the power transfer depends on the values of bus voltages, the operation frequency and the mutual inductance between the two inductive pads. To achieve minimum commutation losses, the frequency is

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maintained as constant and equal to resonant frequency. And for maximum bus voltage and maximum mutual inductance, the maximum power will be obtained [11]. The alignment of two inductive coils plays a major role. If two coils are close to each other, maximum coupling will be reached and if two coils are separated, the bus voltage will get reduced. Thus the alignment characteristic of inductive power transfer system is limited by single-phase inverter characteristics. To maintain the proper alignment of inductive coils, an iterative design process has to be framed.

In the series-series compensation, the resonant frequency depends only on the self-inductance values of each inductive pad:

$$\omega = \frac{1}{L_1\ C_1} = \frac{1}{L_2\ C_2} \qquad (1)$$

where L_1 and L_2 are the self-inductance values of the primary and secondary, respectively, and C_1 and C_2 are the required capacitance values for a specific resonant frequency.

The main drawback of the SS compensation is the voltage gain varies with the load and the associated control difficulties. However, the transferred power depends directly on both bus voltages, as well as the mutual inductance of the coils and the angular frequency.

$$p = \frac{8 V_{dc1} V_{dc2}}{\Pi^2 \omega M} \qquad (2)$$

where V_{dc1} and V_{dc2}, are the primary and secondary bus voltages respectively, ω is the angular frequency and M the mutual inductance between the inductive coils.

IV. SIMULATION RESULTS

The simulation studies are carried out in MATLAB/SIMULINK with input voltage of 230 V. The simulation results are depicted below. The specifications are listed in TABLE.I.

TABLE.I. Specifications of contactless charger for EV

Parameter	Rating
Step-down Transformer : Input Voltage	230V
Output Voltage	12 V
Primary side Rectifier: Input voltage	12 V
Output Voltage	12 V
Capacitor	1mF
Interleaved Boost Converter: Input Voltage	12 V
Inductor	500µH
Capacitor	220µF
Switching Frequency	25000 Hz
Duty ratio	50%
Output Voltage	23 V
Single Phase PWM Inverter: Modulation Index	0.7
Carrier Frequency	1050 Hz
Inductor	30mH
Capacitor	220µF

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Input Voltage	23 V
Output Voltage	22 V
Coupled Inductor : Primary side Voltage	22 V
Secondary side Voltage	12 V
Secondary side Rectifier: Output Voltage	12 V
Inductor	33mH
Capacitor	220μF

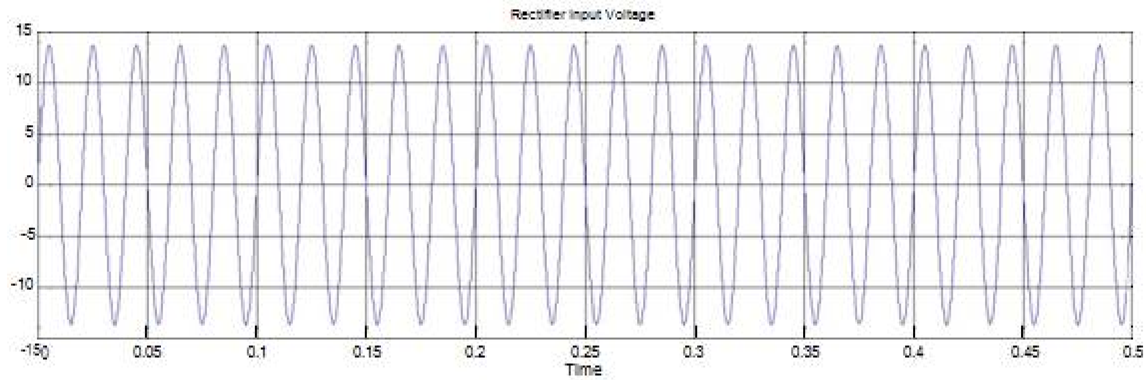

Fig.6. Input Rectifier Voltage

The output voltage from the step-down transformer is given as input for the rectifier shown in Fig.6. and the rectifier output is shown in Fig.7. The interleaved boost converter (IBC) boost the 12 V to 23V is shown in Fig.8.

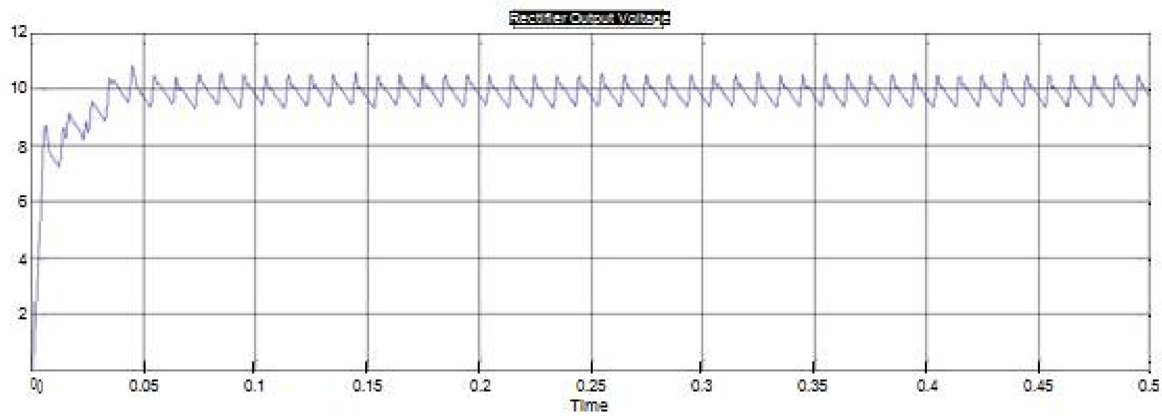

Fig.7. Rectifier output Voltage

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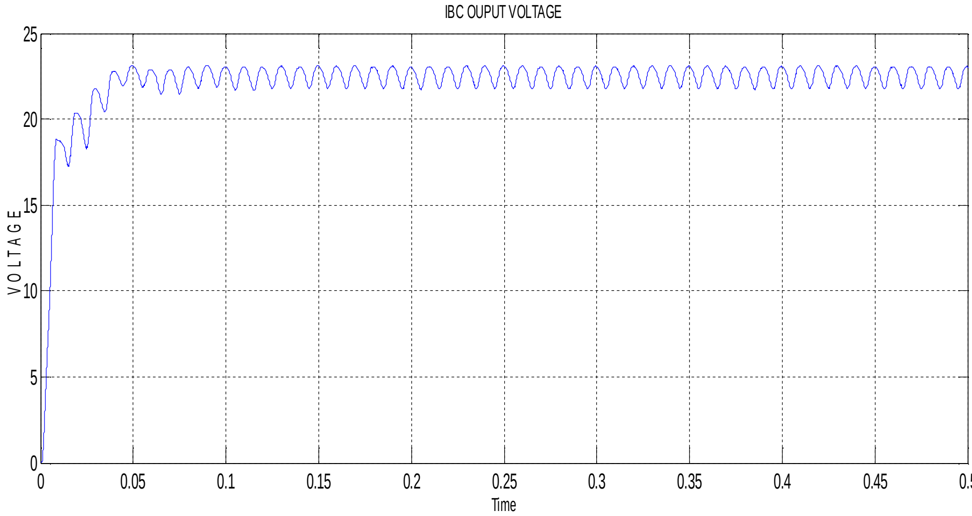

Fig.8. IBC output voltage

Fig.9 shows the output ripple voltage of IBC which is around 0.06% which is less compared to the conventional boost converter.

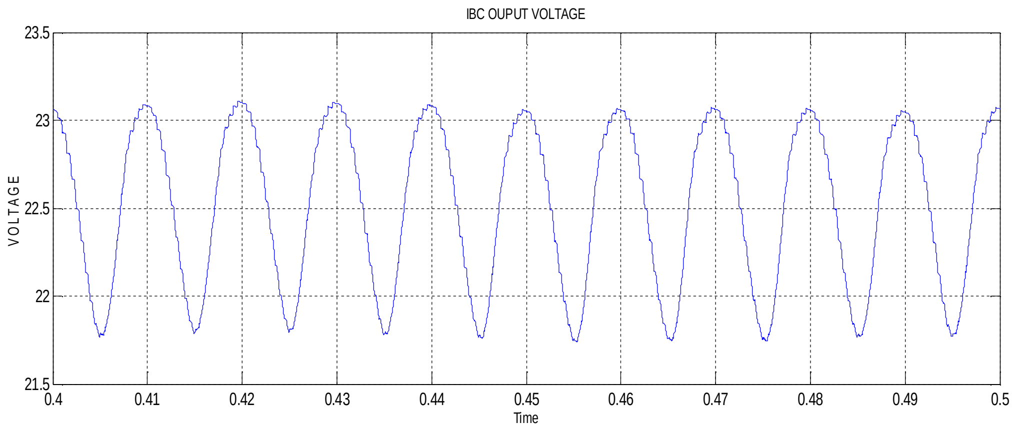

Fig.9. Output voltage ripple of IBC

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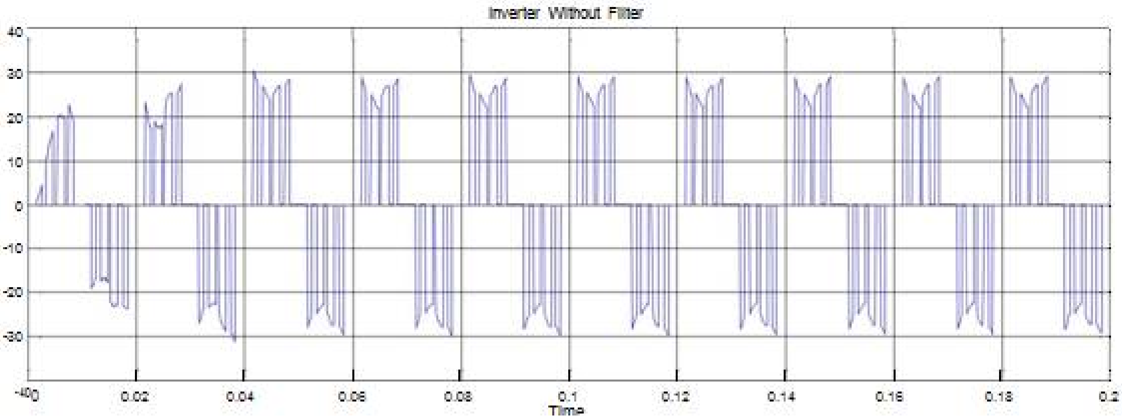

Fig.10. Single- phase inverter output without filter

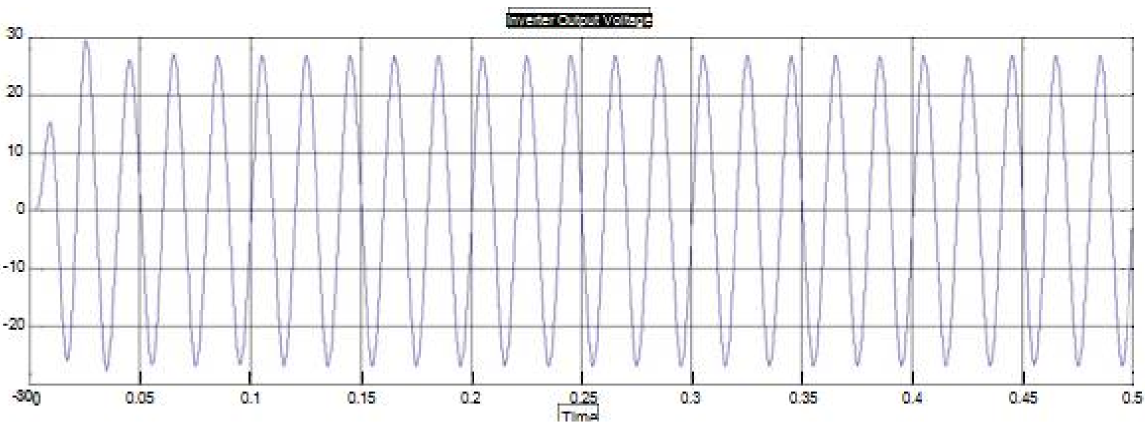

Fig.11. Single phase inverter output with filter

The single-phase inverter with sine PWM is simulated and it is output voltage without filter and with filter is shown in Figs 10 & Fig.11. Fig.12 depicts the total harmonic distortion of inverter output voltage of about 2.68%.

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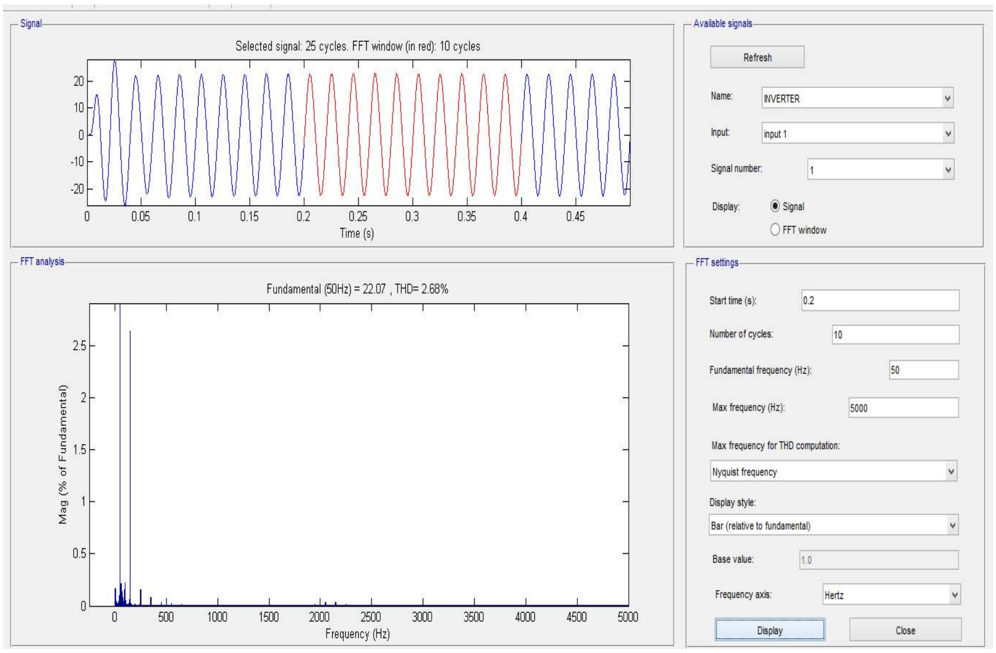

Fig.12. THD analysis of inverter output voltage

The output voltage of both primary and secondary of inductive coil is shown in Figs.13 & Fig.14.

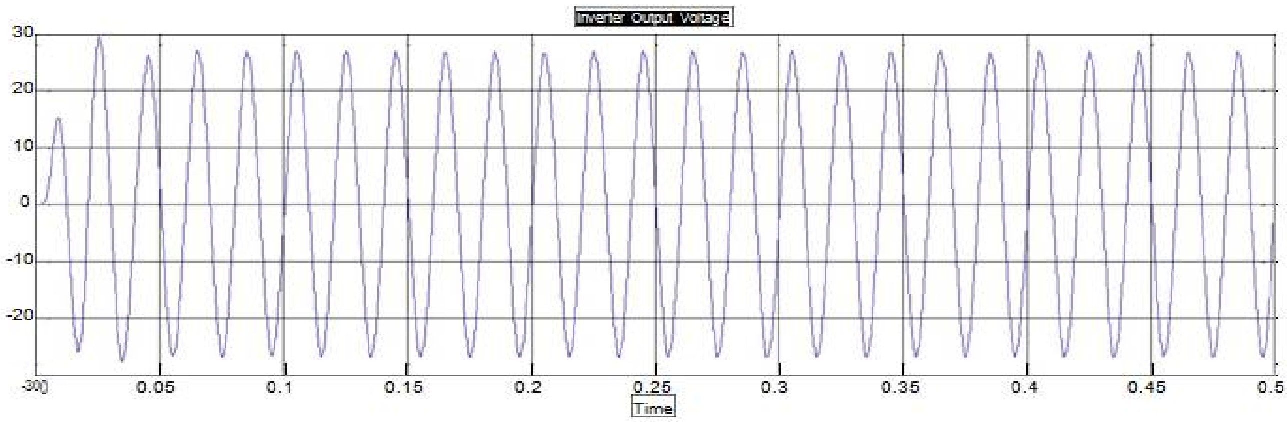

Fig.13. Inductive coil primary side voltage

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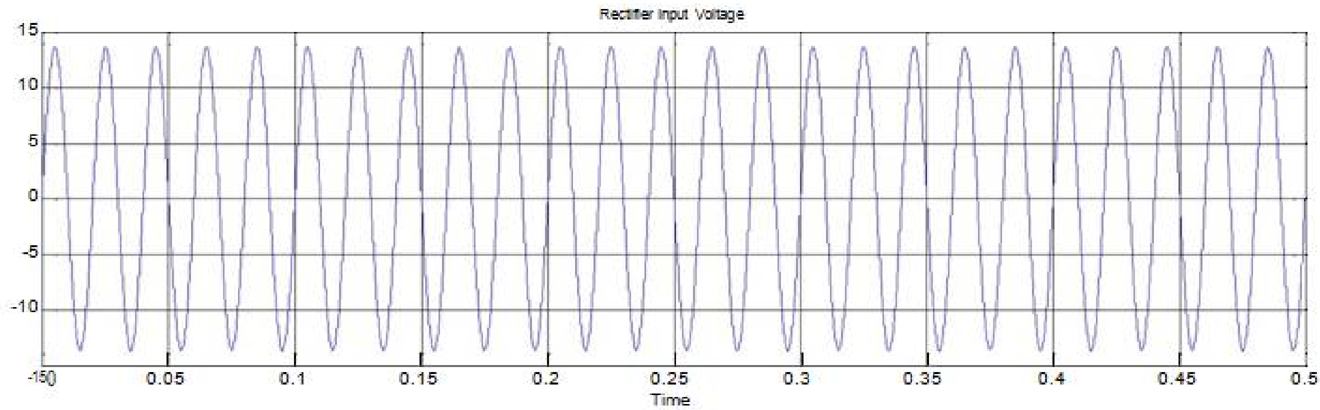

Fig.14. Inductive coil secondary side voltage

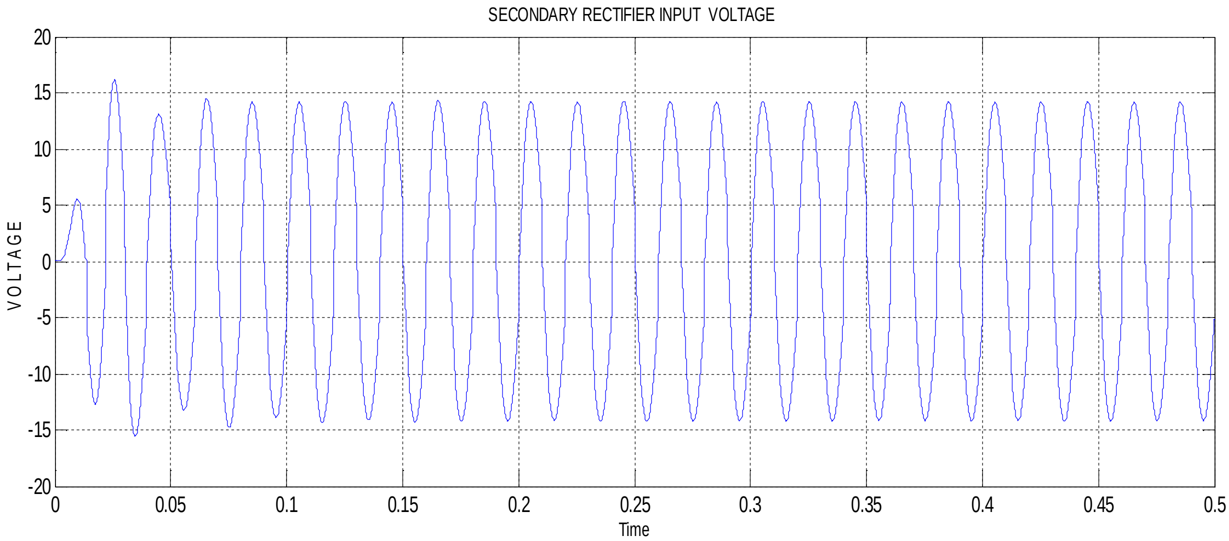

Fig.15 Input voltage of secondary side rectifier

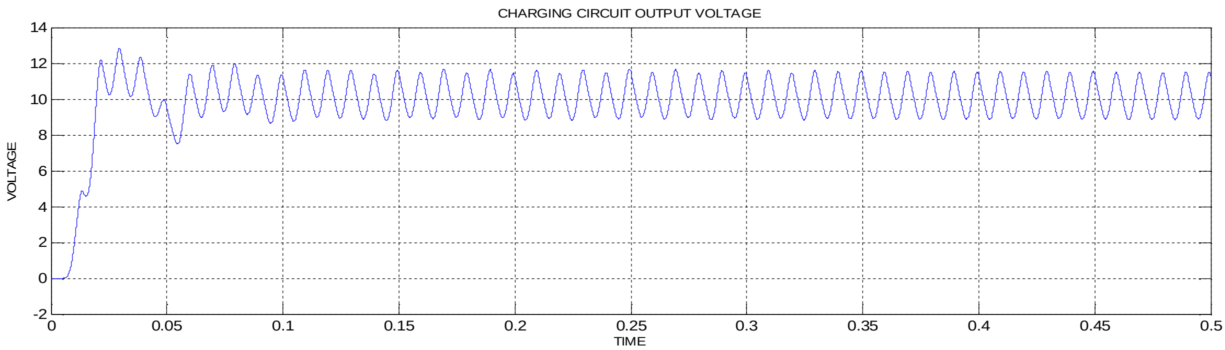

Fig.16. Output voltage of secondary side rectifier

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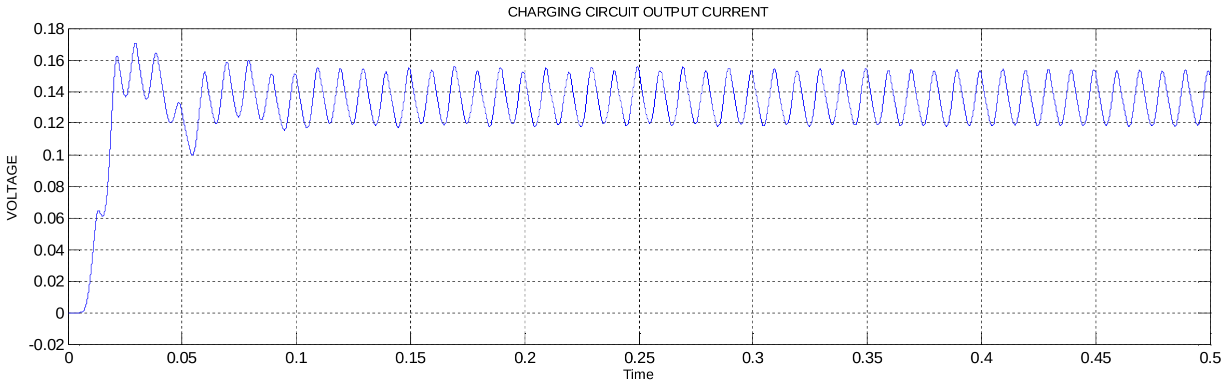

Fig.17. Output current of the charger circuit (secondary side)

Fig.15 shows the input voltage waveform to the rectifier and the magnitude is equal to 12V and Fig.16 & 17 illustrates the output voltage and output current of the charger circuit.

V. HARDWARE RESULTS

A prototype of the charging circuit is developed with power MOSFETS and the pulses are generated using arduino. The rectified output is given to the interleaved boost converter in order to reduce the ripple content and supply current THD. The rectified DC is given to the single-phase PWM inverter through inductive power transfer coil. The rectifier output is shown in Fig.18. The output of rectifier is 10.3V.

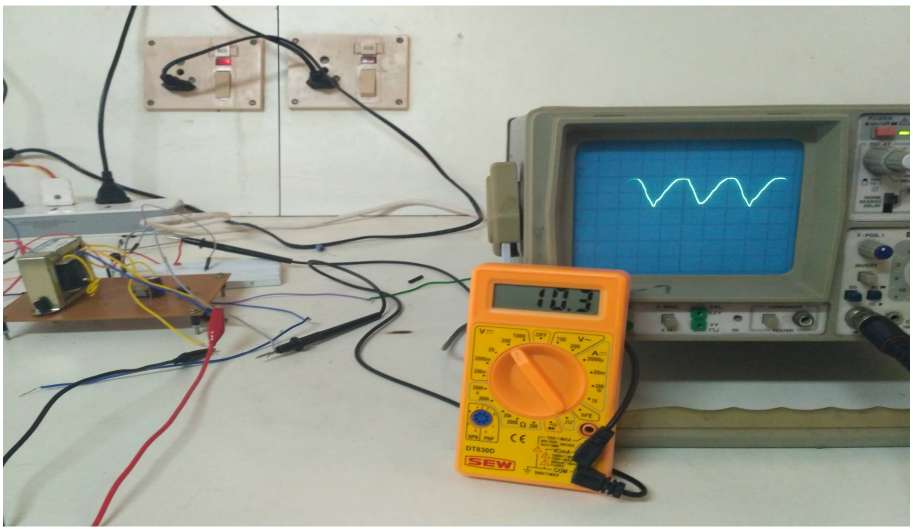

Fig.18. Hardware for the rectifier output of the charging circuit

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Fig.19. Hardware for the Interleaved Boost Converter output of the charging circuit

Fig.19 shows the output of the interleaved boost converter.

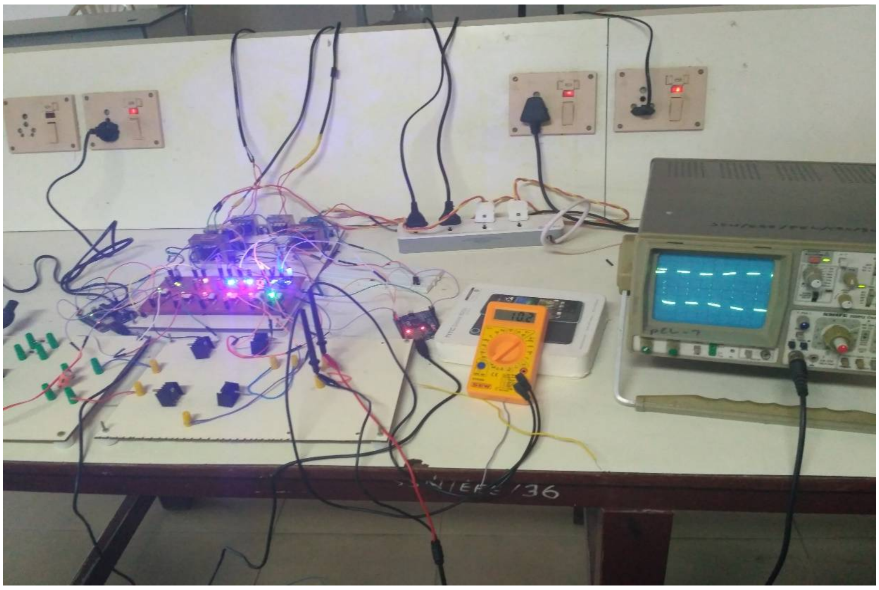

Fig.20 Hardware circuit for the single-phase inverter

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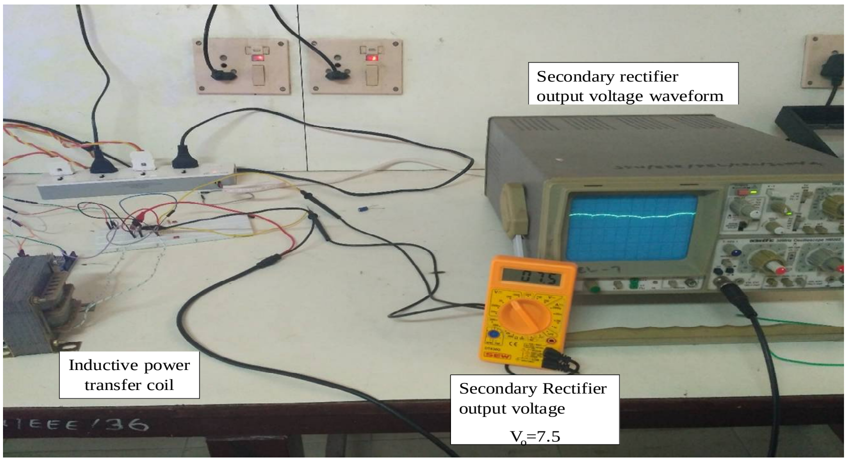

Fig.21 Hardware circuit for the secondary side rectifier

Fig.20 depicts the single-phase inverter output and Fig.21 shows the secondary side rectifier output equal to 7.5V.

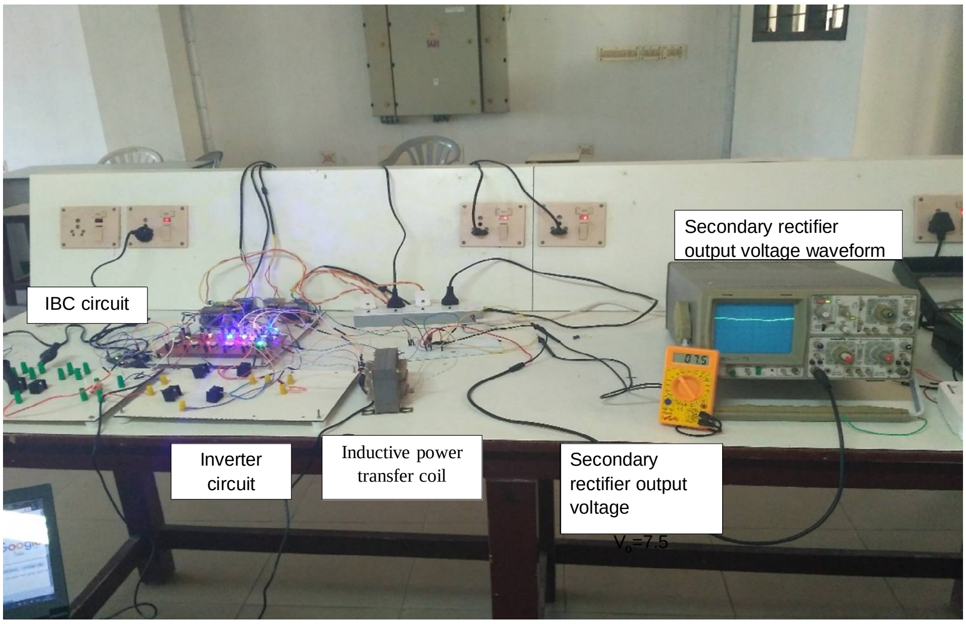

Fig.22. A prototype model of IPT based charger circuit for EV

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Fig.22 illustrates the prototype of the entire charger circuit for electric vehicle. Hence, from the results, it is concluded that the proposed power electronic converter topology is well suited for inductive power transfer for EV and the simulation results are validated.

VI. CONCLUSION

This paper has explored the significance of chargers for electric vehicle. The simulink model of IPT based contactless charger circuit is built and the results are discussed. The proposed topology has reduced total harmonic distortion, low ripple content and high efficiency. Further, a hardware prototype has been built and pulses have been generated using ARUDINO. Thus, the developed charger circuit is the best candidate for EV to enhance the life cycle of the batteries.

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