International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-6, April 2020

Direct Power Conversion Battery Charger for Low Electric Vehicles

P.K Banushya, C Govindaraju

Abstract: This paper presents a new battery charger for low power electric vehicles with high power factor and Efficiency. The main objective of the proposed design is to reduce the conduction losses and Reverse Recovery Problem in power diodes. To eliminate both the issues, the diode rectifier is present in primary and secondary side of the transformer an series resonance circuit added. By using the series resonance circuit, Zero Current Switching (ZCS) possible and also alleviates the reverse recovery problem. Thus the proposed new battery charger operates with high power factor and high efficiency. Additionally, by using the present single power conversion, it is easy to install the on-board charger in the EVs. After the theoretical analysis, Simulation Results are obtained on MATLAB/Simulink environment and Hardware results are from the proposed model.

***Keywords* : AC–DC converters, DC-DC power converter, Series Resonance Circuit, Electric Vehicle, power factor correction (PFC), on board charger (OBC), Battery.**

I. INTRODUCTION

In recent years most of them are preferring both the Electric Vehicles(EV) and plug-in hybrid EVs. Because EVs are eco-friendly and also to reduce the environmental pollution. Battery has an very important role, while choosing the battery for EVs consider the lifetime of the battery, charging time, power density, cost and the Energy density. The batteries are charged from the source by using an on-board charger, which makes an very important role in an EVs. Additionally the charger has been installed in the EVs, it decides the weight, size, and life of the battery. Conventional on-board charger includes both the controlled semi converter and uncontrolled semi converter and also it has a two stage structure of Power Factor Correction stage (PFC) and DC-DC power conversion stage. The DC-DC power conversion stage is a high frequency isolated DC-DC converter and it provides a galvanic isolation. The PFC stage is like a boost converter, it convert the AC supply into DC link voltage with an unity power factor. By using this method, there are many advantages higher output power and power factor. But using this method having some disadvantages, such as the circuit is very complex because two power processing stages and it gives very low Efficiency. The main drawback is an bulky intermediate DC link capacitor is used to filter the power fluctuations. Fig 1.1 shows the block diagram for the ON-Board Battery Charger. Due to high current flows through the intermediate DC link capacitor and also it provide power losses due to this condition, the capacitor lifetime has been reduced finally the capacitor gets failed. To solve this problem reduce the PFC stage, and also the DC link capacitor, now single stage power conversion has been introduced. In this method, the controllable switch can merge both the PFC stage and DC –DC conversion stage.

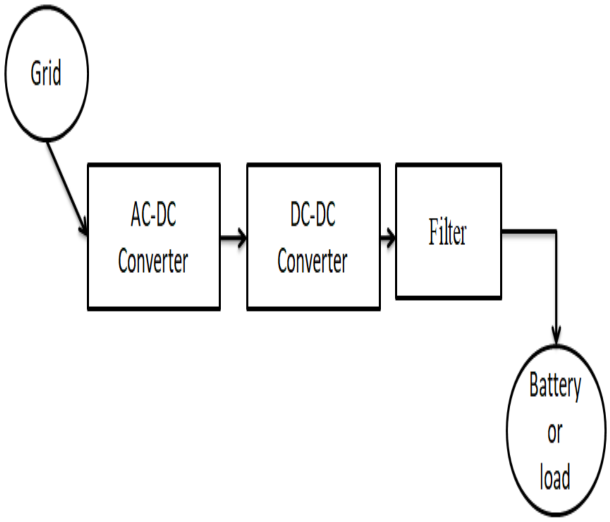


Fig 1.1 Block diagram for the ON-Board Battery charger

The DC link voltage is not controlled, because the grid voltage is more than twice and also it contain high switching losses, and conduction losses. To get a high power factor without a DC link capacitor and the power factor correction stage, initiate an single stage resonance converters by means of inherent PFC and current fed full bridge converter. By using a single stage power converters, it contain many components and also in input side diode that cause a high conduction losses also it require an additional heat Sink management.

Fig1.2 shows the circuit configuration for the proposed battery charger. To overcome all these drawback, the single stage isolated Semi converter topology is derived from boost flyback converter PFC converter has been investigated. By this configuration, the conduction losses and the heat management problem reduced related to the secondary side bridge diode.

In secondary side of the transformer, an Series Resonance circuit will provide a ZCS to reduce the reverse recovery problem. At the end a high power factor and conversion Efficiency is achieved.

Revised Manuscript Received on April 30, 2020.

***** Correspondence Author

P.K Banushya*, Department Of Electrical And Electronics Engineering, Government College Of Engineering, Salem, India, banuciya04@gmail.com

Dr. C Govindaraju , Department Of Electrical And Electronics Engineering, Government College Of Engineering, Salem, India,drcgovindaraju @gmail.com

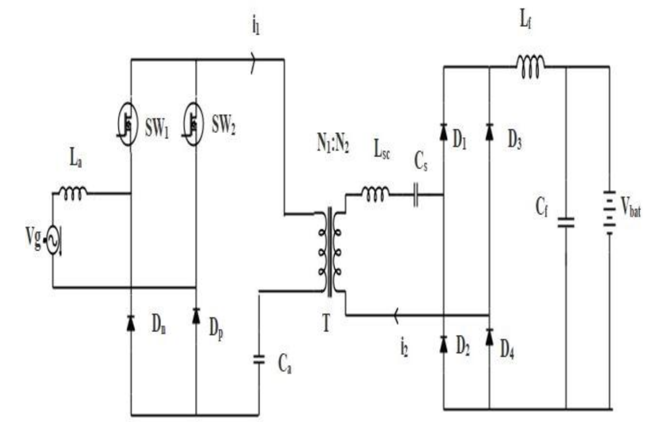


FIG 1.2 Proposed New Single Power Conversion Battery Charger Topology

II.ANALYSIS OF PROPOSED SINGLE POWER CONVERSION TOPOLOGY

A. Circuit Configuration for proposed ON- Board charger

In proposed charger, two diode and two switches are present in primary side of the transformer. When the switch SW_1 is at high frequency the switch SW_2 is in on during the positive half cycle, same as when the switch SW_2 is driven at high frequency the switch SW_1 is in on during the negative half cycle. Therefore, the switching losses gets reduced, it occurs in only one switch.

Both the diodes D_p and D_n conducts alternately during each half cycle of the grid period. In the secondary side of the transformer, contains diode, bridge and the series resonance circuit consists of an leakage inductance L_{sc} and a resonant capacitor C_s. By using the series resonance circuit, it will provide the ZCS and solves the diode reverse recovery problem. The proposed charger transfers power to the battery based on the switching states of SW_1 and SW_2.

When SW_1 is on condition, the energy get stored in the primary side of the transformer, transmit the energy to the secondary through the resonance circuit.

When SW_1 is in off, the primary inductor L_a and L_m inject the energy to secondary. Also, a HFT is used to protect the isolation between the grid and battery for the safety purpose.

B. Operating Principle for the proposed converter battery charger

The steady state analysis of the new proposed charger has some statement:

- Ideal switches SW_1 and SW_2 not include the body diodes.
- During the switching period the grid voltage (V_g) is regard as constant is much smaller than the grid period T_g.
- The filter capacitor sufficiently big so the battery voltage V_{bat} is consider as an constant
- The HFT is considered with Magnetizing inductance L_m and the inductance L_{sc}.

In steady state condition, there are three operating modes in the switching period T_s

Mode1 [t_0-t_1] Switch SW_1 ON: At time t_0 condition, the switch SW_1 is in ON condition, the primary inductor L_a gets charged by the grid voltage V_g .

$$V_{Ca}=V_g \tag{1}$$

The switching period T_s it reduce linearly the Magnetizing current i_m because the voltage V_{C1} is in constant. And the secondary capacitance C_s is in resonance, with the series resonance circuit. The angular frequency ωr and the impedance Z_r of the series resonant circuit are,

$$\omega r = \frac{1}{\sqrt{(L_{sc}C_{eq})}} \tag{2}$$

$$Z_r = \sqrt{\frac{L_{sc}}{C_{eq}}} \tag{3}$$

$$C_{eq} = \frac{C_s C_a}{n^2 C_s + C_a} \tag{4}$$

At At the end of this mode, the power gets transferred from primary side to the secondary side of the transformer ending with the secondary current i_2 becomes zero.

Mode 2 [t_1-t_2] High frequency Transformer OFF:

The switch SW_1 is remain on, the inductor L_a getting charged. The primary current i_1 is same as the magnetizing current i_m, linearly decreases so as no current flow on the secondary. The power transfer from primary to secondary is zero.

Diode D_3 and D_2 are turned off and get blocking condition. By using the series resonance circuit, ZCS possible and reduce the reverse recovery problem for the output side diodes.

$$V_{bat} = \frac{nDvg}{1-D} - V_{cs} \tag{5}$$

To eliminate the V_{cs}, the relation between the grid voltage and battery voltage can be represented as,

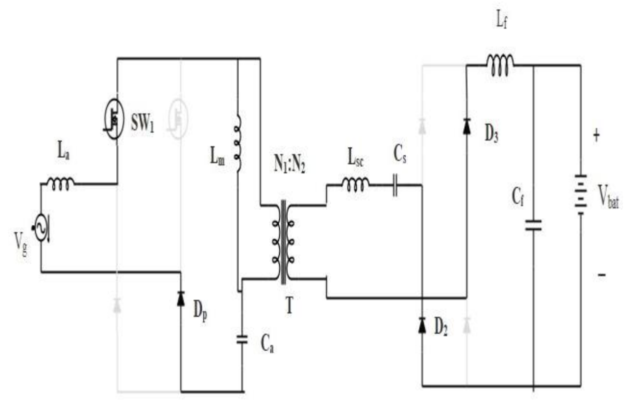
$$\frac{Vbat}{Vg} = \frac{n}{2(1-D)} \tag{6}$$

Mode 3 [t_2-t_3] Both Switches SW_1 and SW_2 OFF:

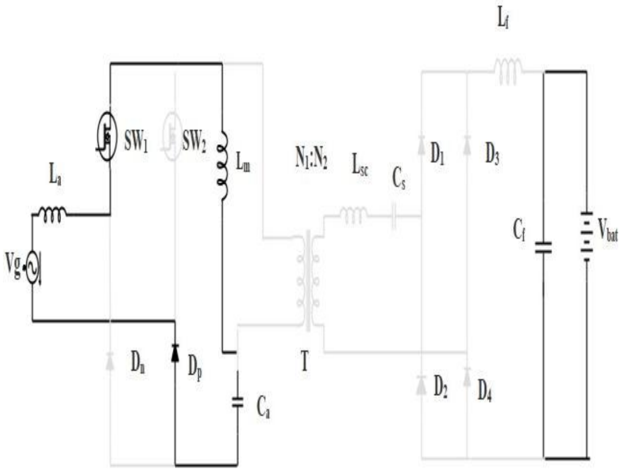
Switch SW_1 is switched OFF, so that the magnetizing current i_m starts to increase and the source current i_g starts to decrease linearly.

The energy stored in inductor L_a and L_m is transferred to the battery through the diodes D_1 and D_4, due to this condition the secondary current i_2 combines the grid current i_g and magnetizing current i_m.

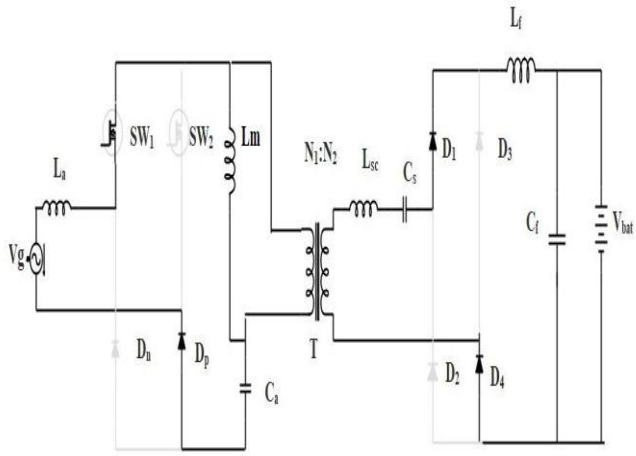
Mode 4-6 [t_4-t_6]: These three modes operates in the negative half cycle of the grid voltage. All the operating modes are standard are similar to the positive half cycle. The operating mode 1-3 is for positive half cycle and the operating mode 4-6 for negative half cycle.



(a) Mode 1

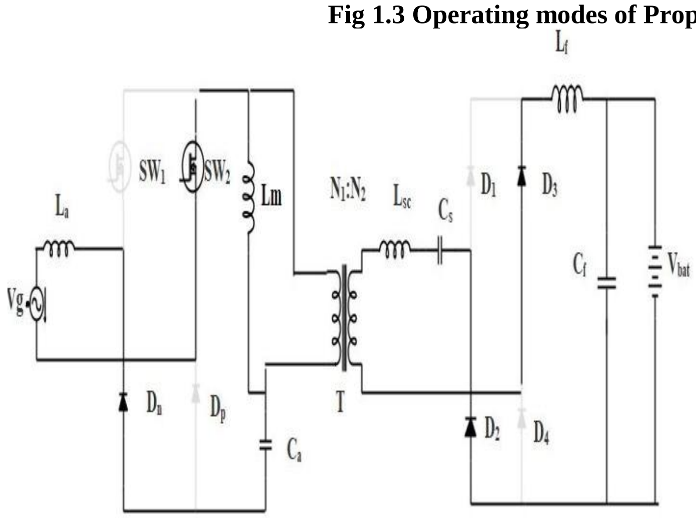


(b) Mode 2

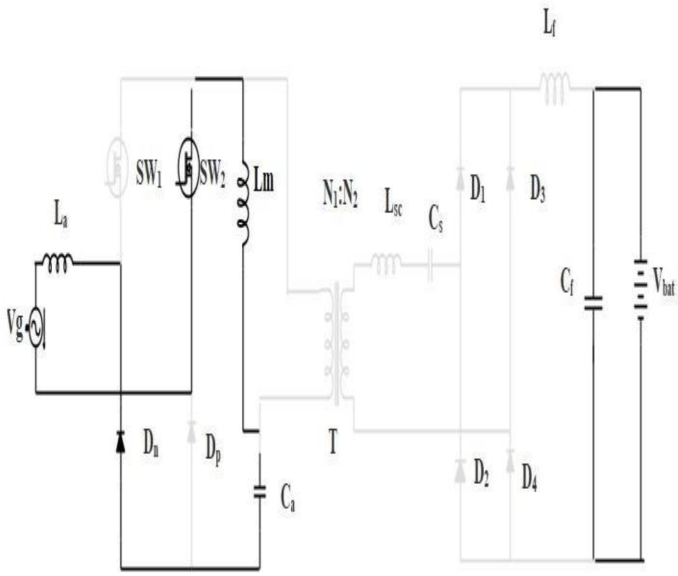


(c) Mode 3

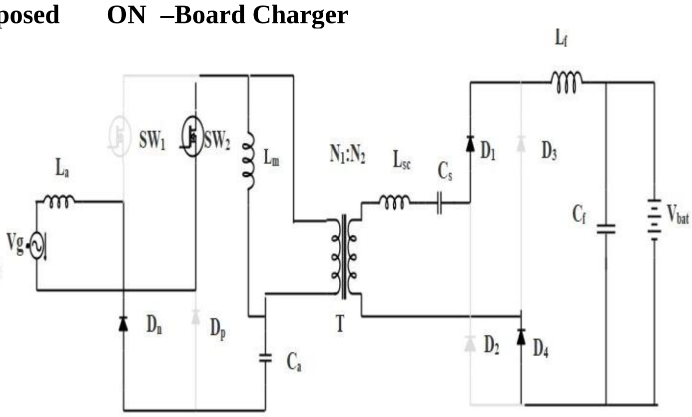
Fig 1.3 Operating modes of Proposed ON –Board Charger



(d) Mode 4



(e) Mode 5



(f) Mode 6

C. Design the parameters for the resonant capacitor C_s and the filter capacitor C_f

At resonance condition,

$$X_L = X_C$$

The series resonance circuit capacitor C_r and the filter capacitor C_f are as follows,

$$\omega_r = \frac{1}{2\Pi\sqrt{LC}}$$

$$\mathbf{Cr = 3.230\mu F}$$

$$Z_\rho = \sqrt{Lsc/Ceq}$$

$$Zr^2 = \frac{Lsc}{Ceq}$$

$$C_{eq} = \frac{1.6*e-6}{6069811*e12}$$

$$\mathbf{C_{eq} = 2.635*e\text{-}19F}$$

$$\mathbf{C_a = 1.17155*e\text{-}19F}$$

Inductor, L= 1.6μH

The voltage gain expression for the proposed charger is defined as,

$$\frac{Vbat}{Vg} = \frac{n}{2(1-D)}$$

To calculate the filter capacitor C_f ,

$Vc = I_c X_c$

$$C_f = 2.9824e\text{-}8F$$

D)Calculation for the charging time and charging current for batteries

Charging time of battery is the ratio of battery rating Ah to charging current

$$T = Ah / A$$

T = Time hrs.

Ah= Ampere hour rating of battery.

A= Current in Amperes.

For 100Ah battery,

The charging current is consider as 10% of Ah

=100Ah*(10/100)

= 10Amperes.

TABLE I

Design Parameters And Components Used In The Proposed Converter

S.NO	PARAMETERS	SYMBOL	VALUE
1	Grid Voltage	V_g	230V
2	Grid Frequency	F_g	50HZ
3	Nominal Battery Voltage	V_{bat}	360V
4	Switching Frequency	F_s	20kHz
5	Primary Capacitance	C_a	1.171e-19F
6	Resonant Capacitance	C_s	3.230μF
7	Magnetizing inductance	L_m	450μH
8	Filter Inductor	L_f	40μH
9	Filter Capacitor	C_f	2.982e-8F
10	Secondary leakage Inductance	L_{sc}	1.6μH

III. SIMULATION MODEL AND RESULTS

The Simulink model consists of Pulse Generator, Controlled Semi converter, Controller module System, Output Bridge Diode Module, and Transformer subsystem Block. By Using the Controlled Semi converter block it convert the AC into pulsating DC. Using the Uncontrolled Semi converter it will convert DC-DC. Using the pulse generator block pulse has generated for switches of the converter. The controller block gets the control for over all system, closed loop of the converter is shown in Fig (c). Here PI controller is used to control output voltage of the converter. The battery pack is designed to store the energy. The powergui block is a Graphical User Interface (GUI) that shows the steady state values of measured current and voltage. The powergui block allows to modify the initial states in order to start the simulation from initial conditions. The input voltage 230V is given to the controlled Semi converter at 20kHz frequency by using logical operators to generate the pulse for both the switches. The ripples are reduced by using specified filter circuit.

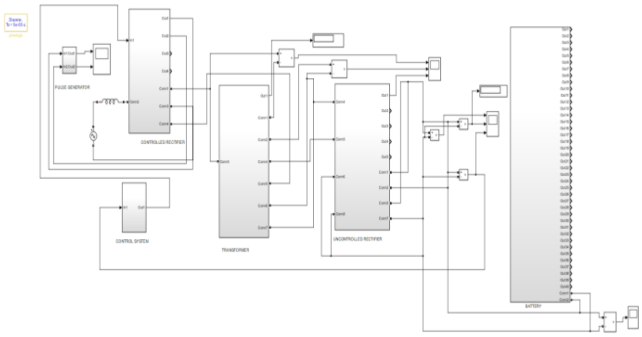
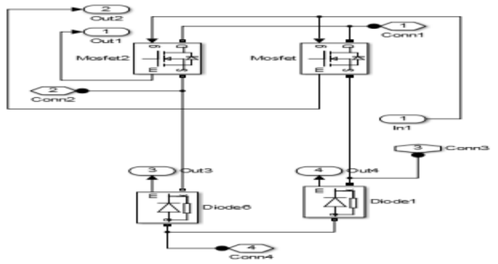
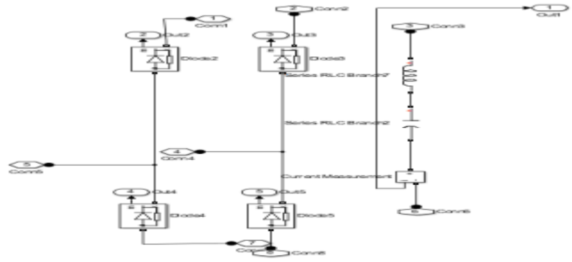


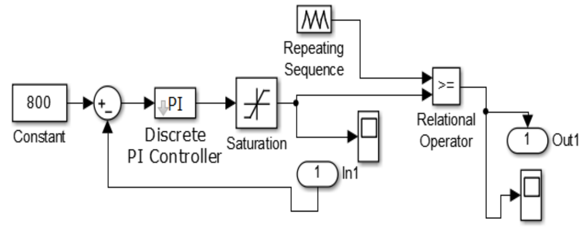
Fig 1.4 Simulink Model for the Proposed Converter ON-Board Charger



(a) Controlled Semi converter



(b) Output Bridge Diode model



(c) Controller Model

Fig 1.5 SubSystem Blocks for the proposed ON-Board Charger

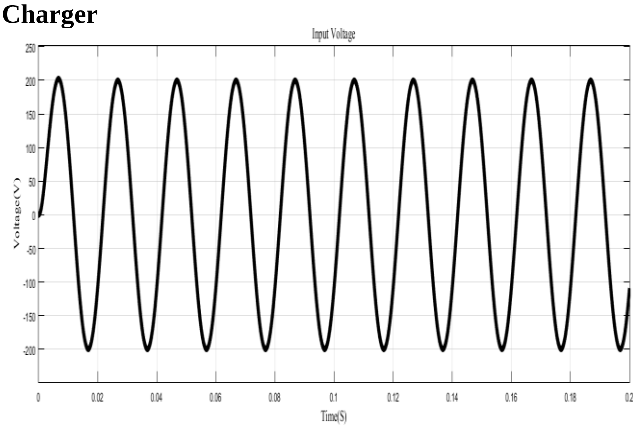


Fig 1.6 Input Voltage for the converter

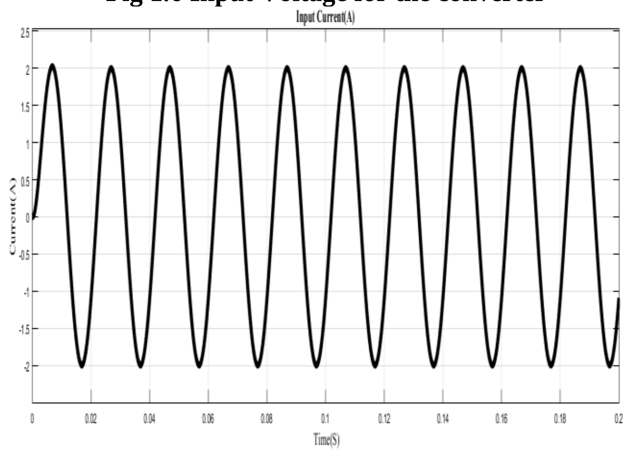


Fig 1.7 Input Current for the converter

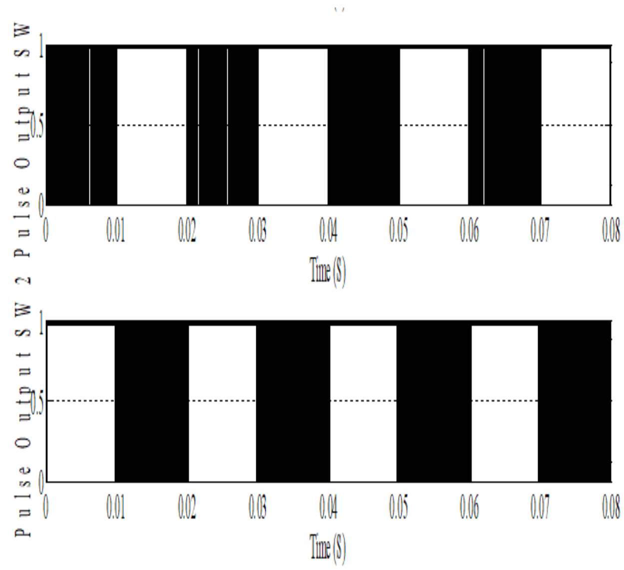


Fig 1.8 Waveform for Pulse Generator

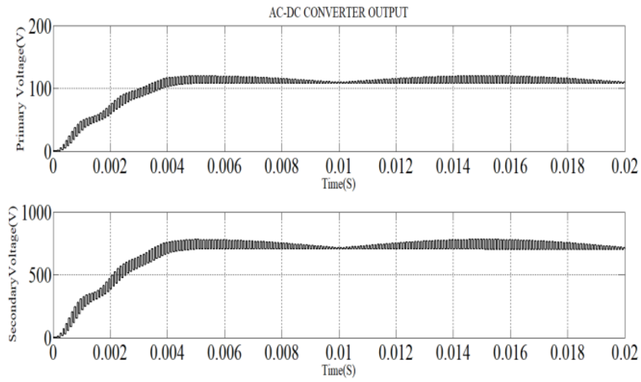


Fig 1.9 Output Voltage for both the Primary and Secondary Voltage

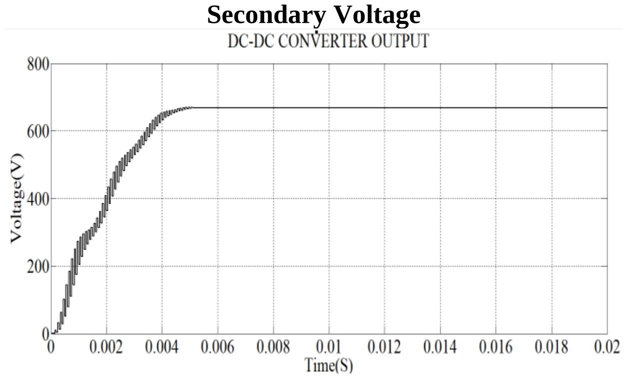


Fig 1.10 Output Voltage for DC-DC Converter

The primary inductor gets energised directly through diodes D_1 and D_4 into battery during switch SW_1 or SW_2 is in off state and also it decreases linearly. The circuit has only two diodes and two switches so it is called as Controlled Semi converter. During positive half cycle switch SW_1 and diode D_p gets turn ON and during negative half cycle switch SW_2 and diode D_n gets turn ON. In secondary side of the transformer series resonance circuit is placed. Using the series resonance circuit it will reduce the Reverse Recovery Problem and provide an Zero Current Switching. The output rectifier circuit has only four power, it operate two in positive and two power diodes in negative half cycle. Using the LC filter, the voltage ripple gets reduced. The PI controller is used to perform the closed loop operation. The closed loop operation is to maintain the Battery voltage constant when it's charges. By varying the Switching Frequency is follow the same method used in the variable frequency method.

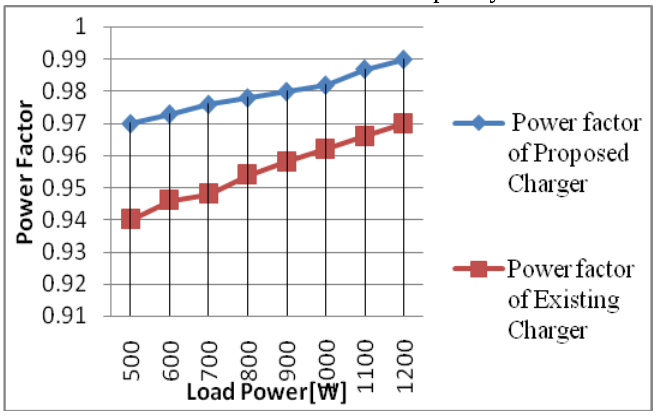


Fig 1.11 Measured Power Factor and Load Power

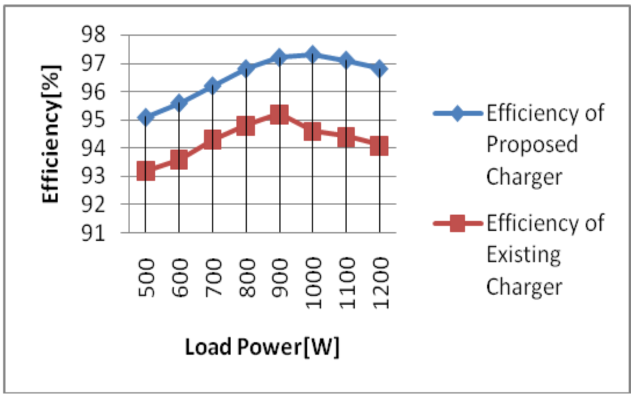


Fig 1.12 Measured Efficiency and Load Power

IV. CONCLUSION

This paper provides a single power conversion battery charger for low EVs, and analyzes its performance in Simulation using MATLAB/SIMULINK. To reduce the conduction losses from the input side elimination the input side bridge diode, and also to reduce the reverse recovery problem from the output side diodes an Series Resonance Circuit has been presented it will provide an ZCR to eliminate the Reverse Recovery Problem. Since the proposed charger has been applied the electrolytic capacitor less system with a sinusoidal DC current on the battery side of the transformer, the input side AC power is directly transferred to the secondary side of the battery and finally the efficiency gets improved. With all these advantages, the proposed charger gives a high efficiency and high power quality.

REFERENCES

1. A. Emadi, Y. J. Lee, and K. Rajashekara, "Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles," IEEE Trans. Ind. Electron., vol. 55, no. 6, Jun. 2008, pp. 2237–2245.
2. A. Y. Saber and G. K. Venayagamoorthy, "One million plug-in electric vehicles on the road by 2015," in Proc. IEEE Intell. Trans. Syst. Conf., Oct. 2009, pp. 141–147.
3. M. Yilmaz and P. T. Krein, "Review of charging power levels and infrastructure for plug-in electric and hybrid vehicles," in Proc. IEEE Elect. Veh. Conf., Greenville, SC, Mar. 2012, pp. 1–8.
4. A. Khaligh and S. Dusmez, "Comprehensive topological analysis of conductive and inductive charging solutions for plug-in electric vehicles," IEEE Trans. Veh. Technol., vol. 61, no. 8, Oct. 2012, pp. 3475–3489.

5. S.Haghbin, S. Lundmark, M. Alakula, and O. Carlson,"Grid-connected integrated battery chargers in vehicle applications: Review and new solution," IEEE Transactions on Industrial Electronics, vol. 60, no. 2, 2013, pp. 459–473.
6. S.G.Wirasingha, N.Schofield, and A.Emadi,"Plug-in hybrid electric vehicle developments in the US: Trends, barriers, and economic feasibility," in Proc. IEEE Vehicle Power Propulsion Conf., Sep. 3–5, 2008, pp. 1–8.

AUTHORS PROFILE

P.K Banushya completed B.E degree in Electrical and Electronics Engineering from Panimalar Engineering College, Chennai, India, in 2018 and pursuing M.E degree in Power Electronics and Drives in Government College of Engineering, Salem, India, in 2020. Her field of interests are Power Converters and Electric Vehicle.

C. Govindaraju received his B.E degree in Electrical and Electronics Engineering from Government College of Engineering, Salem, India, in 1999; and his M.E. degree in Power Electronics and Drives from College of Engineering, Anna University, Chennai, India, in 2003 and his Ph.D. degree in the field of Energy Efficient Multilevel Inverters from Anna University, Chennai, India, in 2011. He is presently an Assistant Professor in the department of Electrical and Electronics Engineering, Government College of Engineering, Salem, India. His current research interest includes multilevel inverters, power electronic interfaces for renewable energy systems, and smart grids.