DESIGN AND SIMULATION OF AN ON-BOARD ELECTIC VEHICLE CHARGER FOR WIDE RANGE OF BATTERY VOLTAGE

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***Abstract*—*Now a days, an interest in development of electric vehicle are more popular in order to reduce the pollutant in environment. The electric vehicles are derived as two types one is on-board battery charger and another one is motor drive. Based on the power flow,electric charger are classified as Unidirectional(From grid to battery) and Bidirectional(from gird to battery and viceversa). A 1KW prototype multi functional on board charger is designed and operation modes of converter is described. The designed charger has 0.999 power factor during full-load condition and THD is consider to be very less. Bidirectional DC-DC converter is designed, for regulation of the voltage and current of propulsion battery during charging period. Li-Ion battery is considered with nominal voltage of 360V and during fully charge condition voltage is depleted about 320V. In order to overcome the switching losess and EMC/EMI issues the review of soft switching technology is described. Soft switching technologies mainly refers to shape the switch current and voltages, at raising and falling edges.*

Keywords—On board charger(OBC); PFC Boost converter; Bi-directional DC-DC Converter; Electicvehicle(EV); Soft Switching.

I. INTRODUCTION

The sources used in conventional internal combustion engine vehicle are petrol, diesel, or LPG, for driving purpose of vehicle. The requirenment of fossil fuel is one of the most critical issue in world wide. The solution for this is adopting the electric vehicle (EV) or hybrid electric vehicle(HEV), the adoption of these electric vehicle are limited, Due to limited availability of electric vehicle battery charger. Elecrtic vehicle does not emit the pollutant which are harmfull to environment. An on board charger is used to charge the propulsion battery, During charging period it acts as a AC-DC converter i.e. controlled rectifier and during supplied back to grid it act as a Inverter i.e.DC-AC conversion.The first step isto design the Boost PFC converter. To charge the auxillary battery whose volatage is about 12V, during drivining condition on-board charger operates as a low DC-DC voltage converter.The battery can be charged, where cureent is consider to be constant, the battery constant current is 2.3A. An auxillary battery voltage is charged, when voltage is constant.The review of soft Switching technologies are described. Soft switching technologies maily refers to shape the switch current and voltages, at raising and falling edges.

II. TYPES OF ELECRTIC VEHICLE CHARGERS

Basaed on the enrgy transfer topic electric vehicle chargers are classified into two different types: Conductive and Inductive Chargers. These two methods uses a different power electronics structure and interfaces, based on their own advantages and limitations, these are particularly related to efficiency, Operating voltage range power ect.,

A) Conductive Chargers

The interfacing of these charger uses a hard wired connection in between source and converter, that is used for charging EV. Based on the location, conductive chargers are classified as on-board and off-board .The charger mounted on the vehicle are called as on-board charger where as the off board chargers are implemented off the vehicle

B) Inductive Chargers

In case of Inductive chargers there is no hard wired connection between surce and converter. These chargers useses a primary and secondary coils to transfer the power. The principle of Magnectic Induction is used to transfer the power in these type of charger.

The Inductive chargers are not more efficient compared to Conductive chargers, however the conductive Charger are most commonly used for different application.

The elecrtic chargers are again classified into “unidirectional” and “bi-directional” based on the Characterstics of power flow. Power transfer from grid to battery that performs a unidirectional charger and Power transfer in both the direction, i.e grid to Battery and viceversa.

III. DIFFERENT POWER LEVELS AND CHARNING PROFILE

The amount of power transferred, cost, charging/Discharning time, different location and external effect is impact on grid, These are some important considreations of charger. Basically chargers are described by using different power levels.

Level ‘ONE’ Charging: This charging system is one of the slowest method compare other two charging level. Level ONE charger is consider in US Standard, about the voltage and current rating of 120V/15A.

Level 'TWO' Charging: This Charging system is the semi charging system or semi-fast charging system. Level TWO charger is consider in US Standard, about the voltage and current rating of 240V/(12-80A).

Level 'THREE' Charging: This charging system is the fast DC charging or fast AC Charging and the time taken by level THREE charning system is with in one hour. The voltage and current rating are 400V AC/(32-63)A.

IV. PFC CONVERTER OPERATION

Conside the limitations of PFC passive Technique and unity power factor is achieved at the conversion of first stage, and Total harmonic distrortion (THD) is less during the converter. The I/P current follows the the I/P voltage, to improve the power factor and reduce the harmonics. Tha main AC source is converted to DC perfoms a Controlled rectifier operation. The convereted DC voltage is given to either Isolated or Non-Isolated DC-DC converter depending on the applications, again the DC voltage is used to charge the battery, The battery source is consider as 300V.

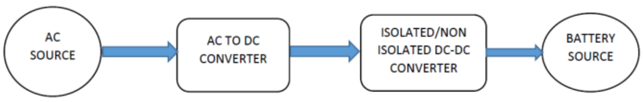


Figure 1: PFC Converter operation block diagram

The block diagram shown in figure1 is used for power factor correction and a basic AC-DC Converter is implemented. In this type of operation a basic diode bridge rectifier is implemented, to rectifies the voltage at input side. Active PFC device produce less ripple voltage and switching frequency is high. The reactive element size must be small.

The DC-DC Converter used at the conversion stage. The Converter is either, Boost, Buck, Buck-Boost, CUK, or SEPIC converters depending on the requirement of output voltage. The output voltage lesser than input voltage is termed as Buck converter. The output voltage greater than input voltage the converter operates in Boost mode. Where as Buck-Boost converter output voltage is either greater or smaller than input voltage. In CUK converter the output voltage magnitude can be either larger or smaller than that of input, There is a polarity revesal on the output side. A converter similar to cuk converter is the single ended primary inductance converter, it can produce an ouput either smaller or larger than input but no polarity revesal. The DC-DC converter stage is Isolated Converter. Galvanic Isolatation is provided in case of Isolated topologies and transformer is used, considering high frequency, and the connection between the source and load. In non-Isolated topologies there is no isolation provided between source and load. Isolated converter offers a wide range of voltage and provides a safety as well as EMC & EMI regulation. The function of 2nd stage DC-DC Converter is used to charge the battery during current is constant and as well as voltage is constant. The on-board Charger is design with PFC Boost converter at a 1st stage to obtain the power factor close to unity and less THD.

V. A) BOOST PFC CONVERTER OPERATIPON

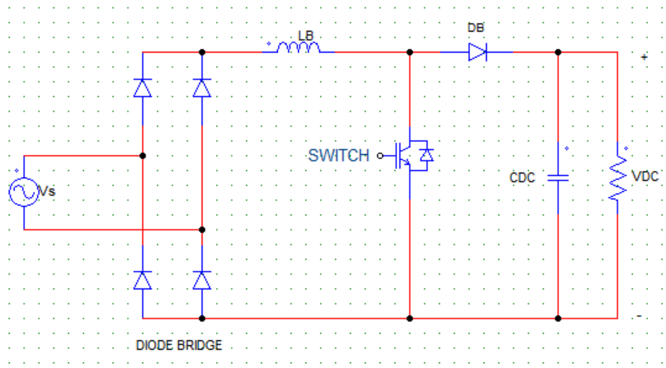
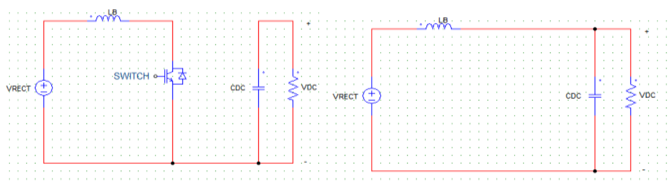


Figure 2: Boost PFC Converter

The figure shown above is used as a power stage conversion circuit. The input AC voltage is first rectified by using diode bridge rectifier and the rectified voltage is given to Boost converter. It performs Boost converter operation and make the supply current sinusoidal. Where I/P cureent follows the I/P Voltage, The average output voltage of the converter shown in figure 2 is about 400 to 450V for 230V input supply.

B) SWITCHING OPERATION OF BOOST CONVERTER

The input supply is converted into a DC rectified voltage by using diode bridge rectifier. After the diode bridge the circuit follows boost converter. The rectified voltage is used as a input to boost converter and this rectified voltage is varying from "0"(zero) to "311V"(peak value of the supply voltage). For the analysis pupose pulsating input DC voltage is assume to be constant DC voltage source. The operation of the boost converter can be explained by considering the ON and OFF period of cycles. The Boost Converter equivalent circuit during ON and OFF period is shown in figure 3(a) & 3(b).



(a) (b)

Figure 3: Equivalent circuit diagram of Boost converter during (a) ON Period (b) OFF Period.

Figure 3(a) & 3(b) describe the ON and OFF period circuit simplification of boost converter. Consider a time period, 0(zero) greater than or equal to"**t**" less than or equal to DTs (0< t < DTs) the boost converter switch is turned ON by triggering the gate pulses, Where D consider as a duty cycle and switch period is mention as Ts, which is always reciprocal of (fs) switching frequency i.e.(fs=1/Ts). During switch on period, the inductor (LB) is short circuited and diode is reverse biased.The Inuctor current flows through switch.

When switch is closed:

VLB = LB(diL/dt) = Vreact (1)

The rate of change of current is constant, so current increses linearly.

When switch is open:

diL/dt = (Vreact – Vo)/ LB (2)

The capacitor voltage (Vc) is given by

dVc/dt = -Idc = Vdc/R (3)

During the period DTs grater than or equal "t" less than or equal to Ts the switch is open. When switch is open, Inductor current can not change Instataneously and diode becomes a forward bias and it provide the path for Inductor current.

Assuming constant voltage, The voltage across the Inductor is given by,

VLB = LB(diL/dt) = 1/ (VREACT-Vdc) (4)

The voltage across the capacitor is given by,

dVc/dt = iL – Idc (5)

Both modes Repeated for every period of cycle Ts.

C) BOOST CONVERTER OPERATION MODES

Considering the inductor current waveform of boost converter, The modes of operation can be categorized into 3 types:

(1) Continuous conduction mode (CCM)

(2) Discontinuous conduction mode.(DCM)

(3) Critical conduction mode.(CRCM)

- In CCM, Inductor current is continuous ans it is non-zero. Inductor current is increases during ON peiod of cycle and it decreases during OFF Period of cycles.
- In DCM, Inductor current reaches to zero during OFF period of time, and it follows for every switching cycle. In DCM mode the voltage and current stress is ery high on power controlled devices. In this case there no separate current controller is required.
- In Boundary or Critical conduction mode, The inductor current is always discontinuous.

The PFC Boost converter is designed, when inductor current is continuous i.e. CCM. Consider the efficiency more than 90 to 95% for power stage conversion. In many cases it can be considered as above 95%.

D) AVERAGE CURRENT CONTROLLER FOR PFC BOOST CONVERTER

This the most common method for controlling the PFC converter is termed as average current control mode. The

Controller mainly consists of 2 different loops, The voltage control loop is the outer loop and at the output terminal it maintains the voltage , Hence it is called as voltage control loop and the current control loop, that shapes the input current waveforms and it manipulates the input current always follow the input voltage shapes. The supply frequency is lesser compared to switching frequency of the particular converter. i.e. supply frequency is 50Hz and switching frequency is 200KHz. The outer voltage loop is much lesser than inner current control loop. Comparision of the DC link voltage with reference voltage gives an output as error value, hence the output value is depends on the generated error value. The error value is multiplied with a reference value, In order to generate the current reference signal(Iref). The rectified current and actual reference current is compared, The resultant signals are given as a input to current controller block. The output of controller is always track the reference value of current and the voltage controller decides the amplitude of reference current. The diode bridge rectifier output voltage Vreact voltage is multiplied with the error amplifier value of output voltage and inductor current iL is compares with reference current value (Iref). Depending on the value of error obtained the control signals are generated and average current controlled is compares with sawtooth waveforms with switching frequency of 50Hz(same as switching frequency), and it produce the gate pulses to operate the switches during different intervals, hence it is called as a closed loop operation. Both Inner cuuerent control loop and outer voltage control loop is achieved in average current controller mode.

VI. SOFT SWITCHING TECHNIQUE FOR ELECTRIC VEHICLE CHARGERS

A soft switching technique in elecrtic vehicle is explained by using one-stage electric vehicle charger by considering the power factor correction as a main content. One-stage Electric vehicle charger with PF correction is shown in figure 4.

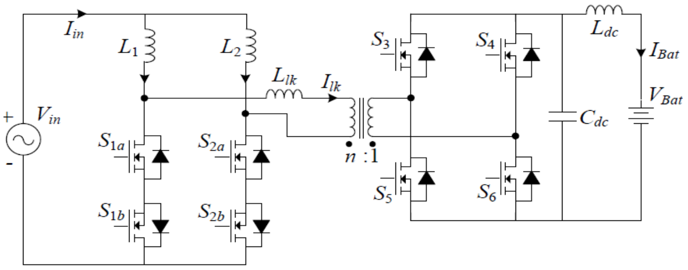


Figure 4: One-stage electric vehicle charger with PF correction

The circuit shown in figure 4 is operated in all 4 quadrant of voltage and current. At the primary side the circuit is bi-directional 1/2 bridge current-fed converter. At the Secondary side the circuit is known as full bridge conveter. This topology is interface with battery by considering the filter inductor (Idc). The transformer with high frequency is used for exchanging the power between primary side & secondary side and Equivalent series inductance (Llk) which is refered as a leakage inductance of transformer. The external series inductor is connected only when, leakage inductance smaller than the requirement.The converter acts as a 2-phase boost converter in charning mode and it is a full bridge converter and as well as current doubler during reverse power flow.

OPEARTION OF ELECTRIC VEHICLE CHARGER

There are 4 modes to explain the operation of the converter, and it depends on direction of I/P current and also depends on I/P voltage polarity. Mode-I and Mode-II is used transfer the power from AC grid to battery source.Where in case of Mode-III and mode-IV power is transfer between battery source to grid. Hence the regulation of active power and reactive power in both direction is possible.

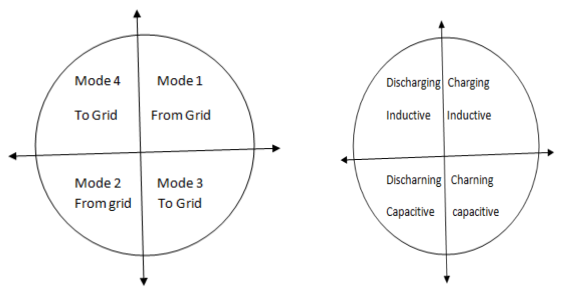


Figure 5: Modes of operation in different quadrants

VII. STATE SPACE REPRESENTATION OF THE CONVERTER

In order to understand the 'Dynamic' and 'Steady' state representation of the converter mathematical modeling is necessary and by using state space averaging method small-signaling model of the particular converter is designed. The operating states of converters is derived into following periods, that can be represented as :

d10, d9, d8, d7, d6, d5, d4, d3, d2, d1.

The state space equations for the converter is written by considering the voltage and current direction, for the above mention intervals(from ***d1*** to ***d10***). Considering the converter Mode 1 operation for the analysis pupose and Mode 1converter graph is shown in figure 6.

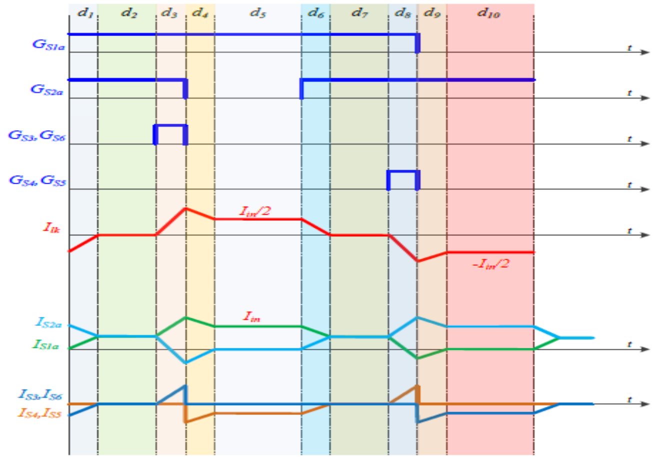


Figure 6: Mode-I converter operation graph

The Current and Voltage equations for different interval are written by considering the following assumptions:

L = L1= L2, C = Cdc, and Vo = Vbat = Vc.

The graph shown in figure 6, The different intervals summation is equal to one, Therefore

d10+d9+d8+d7+d6+d5+d4+d3+d2+d1= ONE

Consider ***D' = d9 + d4***

(1-D)' = d10 + d9 = d5 + d4

Combining the equatios from different intervals & averaging, The small signal modeling can be represented as follows:

$$\begin{pmatrix} iL{\cdot}1 \\ iL{\cdot}2 \\ iL{\cdot}3 \end{pmatrix} = n^* \begin{pmatrix} 0 & 0 & -(1-D)'/L \\ 0 & 0 & -(1-D)'/L \\ (1-D)'/C & (1-D)'/C & -1/nCR \end{pmatrix} \begin{pmatrix} iL1 \\ iL2 \\ Vc \end{pmatrix} + \begin{pmatrix} (Vc^*n)/L \\ (n^*Vc)/L \\ (-n^*Iin)/C \end{pmatrix}$$

$$d\hat{}+ \begin{pmatrix} 1/L \\ 1/L \\ 0 \end{pmatrix} Vin$$

The output equations of the converter described below:

$$Vo = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} iL1 \\ iL2 \\ Vc \end{pmatrix}$$

The mathematical model can be derived by using non-liner and linear equations and state space representation of the converter as well as samall signal model can be described by using various differential equations.

VIII. SIMULATION CIRCUIT AND RESULTS

Proposed converter topology was simulated by using MATLAB software. It was verified for different operating modes. The bidirectional non-isolated DC-DC converter is designed and A 1 KW prototype multi-functional on-board charger is designed and simulation is also done. The expected power factor is 0.999 during full load condition and total harmonic distrortion (THD) is 3.6%. Battery is fully charged when current is constant, (320V to 420V) maintaining battery constant current 2.3A and when, voltage is constant battery current falls to 0.242A.

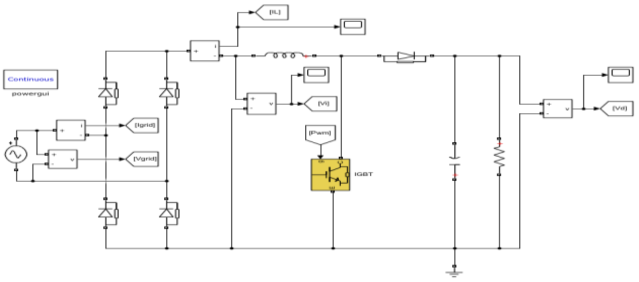


Figure 7: Simulated PFC Boost converter circuit

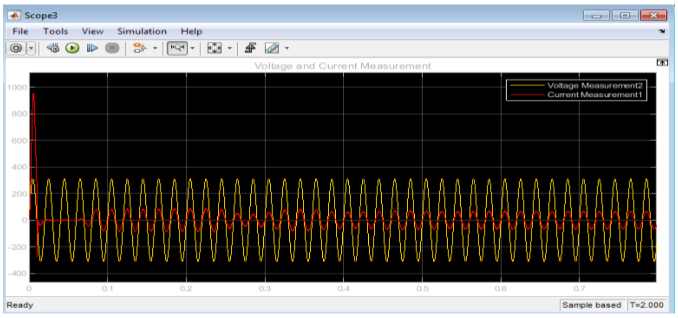


Figure 8: I/P Voltage and I/P current waveforms

The above figure:8 shows I/P voltage and I/P current waveforms, which are in same phase , then it conclude that the power factor is close to unity and THD is small.

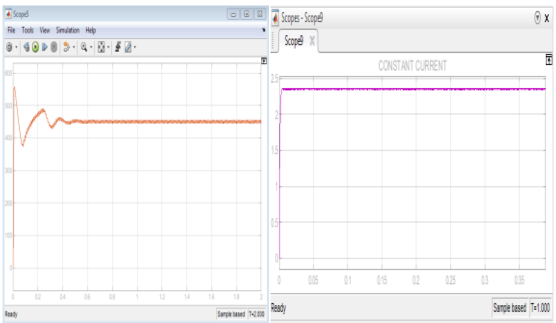


Figure 9: Constant battery current (2.38A) and expected boost PF Conveter output voltage waveform(450V).

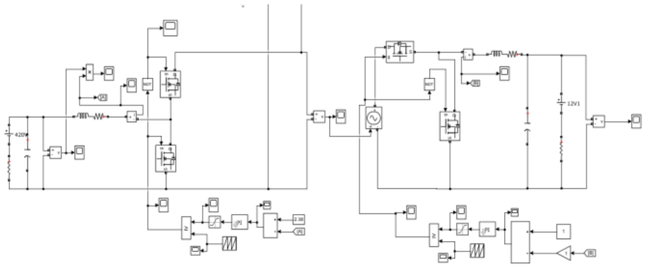


Figure 10: A 1KW PFC Electric charger simulation circuit

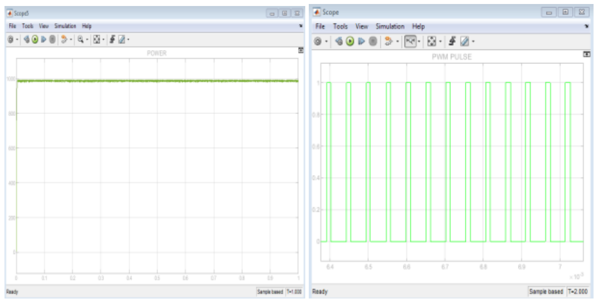


Figure 11: 1 KW Power and Gate Pulse Generated

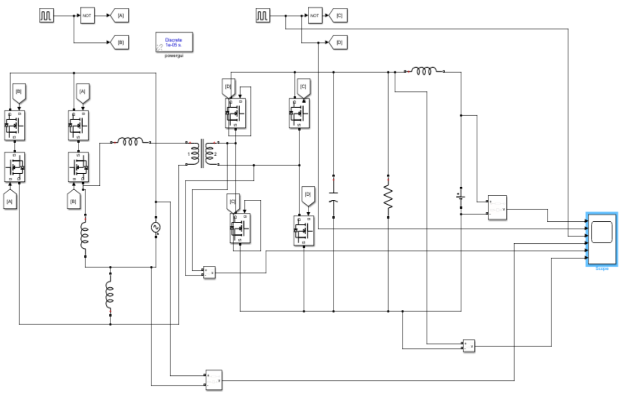


Figure 12: Soft-Switching technique for one-Stage electric vehicle charger with PF correction simulated circuit diagram.

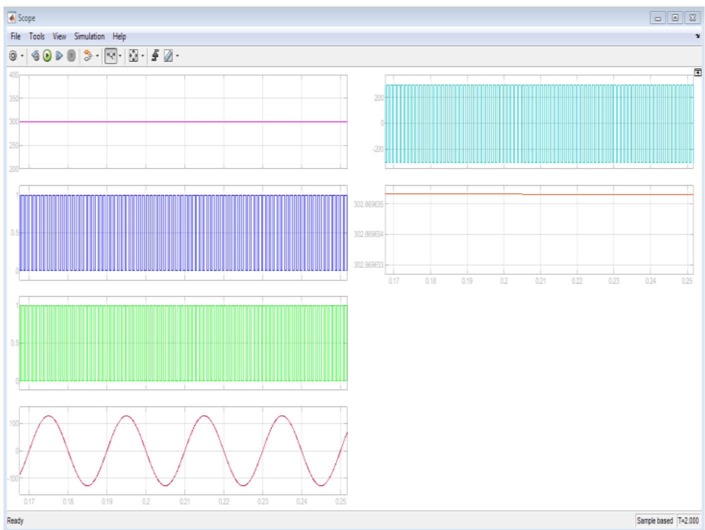


Figure13: Simulation results for Soft-switching one-stage charger with PF correction results.

IX. CONCLUSION

The 2nd stage of on-board charger i.e. DC-DC Converter is used for regulation of the battery voltage and battery current. The familiar method for Li-ion batteries charging is Constant current/Constant voltage method , it is obtained by designing a DC-DC converter. The battery can be charged from 320V to upto 420V when current is constant i.e. constant current mode, with 2.3A constant current and In constant voltage (CV) mode battery voltage is fixed 420V. The designed DC-DC converter supports bidirectional power flow. Different Types of electric vehicle chargers are discussed and the soft switching technique one-stage electric vehicle charger is designed and simulated, to overcome the disadvantages from hard switching. A soft switching techonologies is presented without considering an additional passive or active elements in the in order to reduce the heat sink requirenment. A 1 KW multi-fuction EV charger is designed and simulated using MATLAB simulation software.