Design of Power Factor Correction Controller using Buck-Boost Converter in Wireless Charging System for Electric Vehicle

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Abstract - Nowadays, the grid interference is increasing. To overcome this problem, a power factor correction (PFC) controller circuit is used for electric vehicle (EV) wireless charging system. The working of PFC controller is based on buck-boost converter topology. This converter work either in buck mode or boost mode based on the rectified DC voltage at the input side and load voltage at the output side. This paper describes how the power factor close to unity can be obtained with line frequency current control arrangement. The goal is achieved through the power factor controller circuit working in continuous conduction mode of converter. The process is modeled using the MATLAB Simulink model of closed-loop operation.

Key Words: Wireless charging system, Buck-Boost Converter, Proportional-Integral controller (PI), Power factor correction (PFC).

1. INTRODUCTION

The conservation of energy is necessary and also fuel cost is getting increased day by day due to reduction in availability of fuel and pollution ratio is increasing in daily basis. To overcome these issues, an electric vehicle is introduced. The main component of electric car includes rechargeable battery, controller and the electric motor. First, the electric car battery is charged by using a supply voltage. Then the converter converts the current from DC-AC so that it can be easily drive the motor. The conversion of electrical energy to mechanical energy is done by the motor. The power electronic circuits consist of rectifier and choppers are the integral part of modern day electric vehicle. The battery plays an important role in electric vehicle. Thus the selection and implementation of battery charger using DC-DC converter has play a major role in electric vehicle. Apart from this, the existing battery chargers have power factor correction which affects the life and performance of the battery. So, to overcome these problems this paper presents a charging circuit of battery used in electric vehicle with the concept of power factor correction controller circuit.

2. WIRELESS CHARGING SYSTEM

The wireless charging system working principle is same as transformer. It consists of transmitter and receiver, the AC supply is converted into high frequency alternating current, which is supplied to transmitter coil. Then it produces an alternating magnetic field which cuts the receiver coil and the receiver coil generates AC power output. The important thing in the wireless charging system is to maintain the resonance frequency between transmitter and receiver in order to make it effective. To retain the resonant frequency, the compensation networks are added on both sides. The receiver side is then AC power, which is rectified to DC and fed to the battery via the Battery Management System (BMS). Classification of wireless charging system for EV into two categories based on the application.

- Static Wireless Charging
- Dynamic Wireless Charging

3. BUCK-BOOST CONVERTER

Buck-Boost converter is a type of DC-DC converter (chopper) with a constant output voltage. It may be more or less than equal to the input voltage magnitude which depends on the mode of operation. The buck-boost converter is identical to the fly-back circuit, but instead of the transformer, the only difference is the single inductor is used. There are two types of converters in buck-boost converter based on the operations that are buck converter and the boost converter. These converters can produce the range of output voltage than the input voltage with the change in duty cycle. The Fig.1 represents the basic buck-boost converter topology.

The DC-DC converter working operation is based on the input resistance inductor which causes unpredictable variance in the input current. If switch is ON, the supply power is fed by the inductor and stored in the form of magnetic energy. This dissipates energy to the load if switch is OFF. The capacitor values of output circuit are assumed to be high. The objective is to maintain the constant voltage at the load terminal.

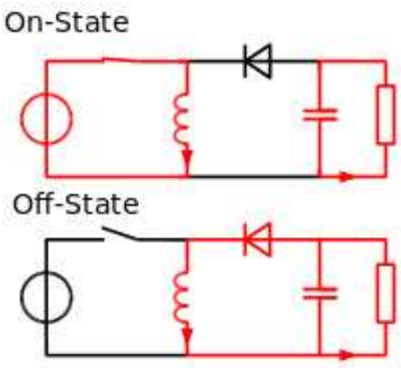

Fig -1: Buck-Boost Converter

A. Mode of buck-boost converter

In the conduction mode of converter, there are two operating modes.

- Continuous conduction mode.
- Discontinuous conduction mode.

B. Continuous conduction mode

The current from the inductor never goes to zero in this mode. Before the switching cycle, the inductor partially releases energy.

C. Discontinuous conduction mode

The current through the inductor goes to zero in discontinuous conduction mode. At the end of switching cycle, the inductor will discharge total energy.

4. BATTERY CHARGING CIRCUIT

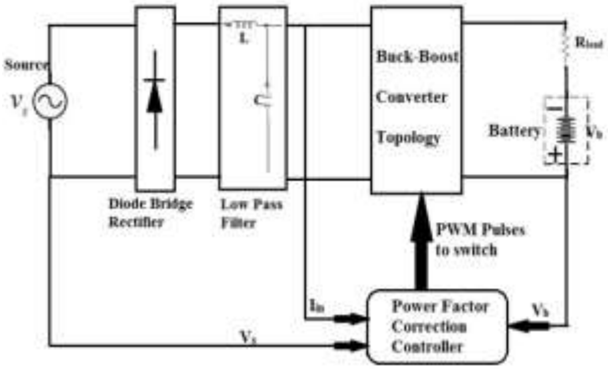

Fig -2: Closed loop battery charging circuit

Fig.2 represents the closed loop battery charging circuit. The charging and discharge cycle is done in battery-operated vehicle to improve productivity and battery life. This process is to be obtained by the buck-boost converter operated in CCM mode to charge and discharge the battery. The converter works on DC supply, but the supply voltage is AC to convert AC to DC supply, diode bridge rectifier (DBR) is used and while converting the more distortion occurs at the input side of supply current and power factor is reduced. The control circuit for the correction of the power factor is used. It is known as the power factor enhancement line frequency current shaping control scheme. The constant voltage control scheme and constant current control scheme applied to improve the charging of battery and also maintains the power factor nearer to unity. The output voltage of buck boost converter is sensed and rectified DC current of buck boost converter which is given to PI controller to create a PWM pulse. The PWM pulse is given to the MOSFET switch to control the duty cycle and produces a required output voltage to charge the battery with respect to input voltage. The advantage of this topology is very simple and it is used for high power rating applications.

5. IMPLEMENTATION

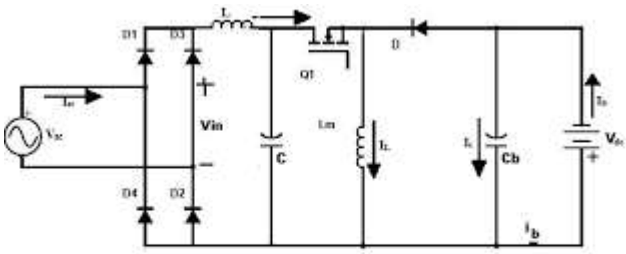

Fig -3: Battery charging circuit using Buck-Boost converter

The buck-boost converter is added after the rectifier circuit but before the load as shown in Fig.3. The main purpose of incorporating the buck-boost converter is to make accurate battery loading as well as to reduce the source side THD losses. Because of reduction in THD, the power factor gets increased as per the relationship of %THD and power factor given in equation.1

$$\cos \emptyset = P.F = \sqrt{\frac{1}{1+THD^2}} \qquad (1)$$

A. Design parameter of converter.

The buck-boost PFC converter is designed with the circuit parameters.

The output voltage from rectifier (V_{in}) is given in equation.2

$$V_{in} = 2 * \sqrt{2} * V_{rms} \qquad (2)$$

V_{rms} is the RMS AC voltage at the source side.

The DC voltage buck-boost PFC converter conversion ratio formula can be represented in equation.3.

$$\frac{V_{dc}}{V_{in}} = -\frac{D}{1-D} \qquad (3)$$

V_{dc} is the output voltage

D is the Duty cycle

The inductor critical (Lcric) is designed to operate in the buck-boost converter, which is expressed in equation.4, under continuous conduction mode.

$$L_{cric} = \frac{(1-D)R}{2f_s} \quad (4)$$

R= Output resistance

f_s = Switching frequency

The critical value of output capacitor is expressed in equation.5

$$C_{cric} = \frac{D}{2f_s R} \quad (5)$$

Therefore, the critical inductor and capacitor of the buck-boost converter can be designed according to equation (4) and (5) where the inductance of inductor and output capacitance should be chosen higher than the critical value.

6. PFC WITH BATTERY CHARGING CIRCUIT

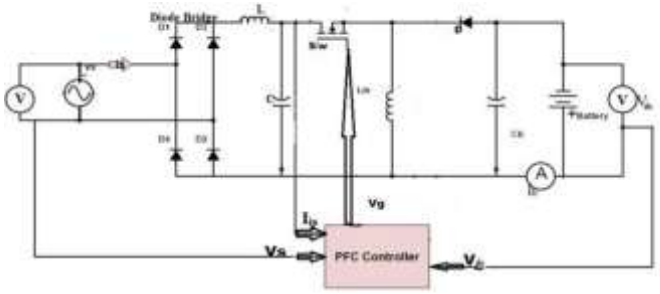

Fig -4: Circuit of PFC charging circuit

As shown in Fig.4 the first ac supply is given to a diode bridge rectifier (DBR) that converts AC voltage into DC voltage. The produced DC output voltage is given to buck-boost converter and to the battery is linked at the load side. The output voltage of battery and input current of rectifier is sensed which is given to PFC controller as feedback signal and produces output of PFC controller as pulses which is given to the switch to control the duty cycle and output voltage of converter with power factor correction at input AC side.

7. POWER FACTOR CORRECTION IN BATTERY CHARGING

Power factor correction (PFC) schemes are to ensure that these systems can operate at their maximum efficiency. PFC circuits help to use of power in efficient way, decrease operating costs and improve performance.

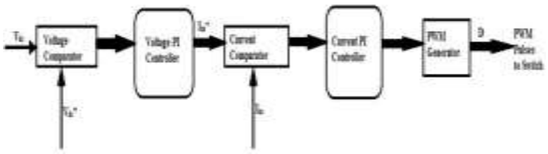

Fig -5: Block diagram of PFC controller circuit

The block diagram represents the line frequency current shaping control arrangement for power factor correction is presented in Fig.5. This PFC controller consists of two control modes, voltage control mode and current control mode. To make the input power factor close to the unity and to accurately charge the battery. This is done to improve the performance of the battery and also the life cycle.

A. Voltage controller

The PFC controller outer loop as shown in Fig.5. Comparing the battery output voltage (V_{dc}) with the reference voltage (V_{dc}*) which produces the error signal and provides the error signal as the current reference value (I_{in}*) to the PI controller.

B. Current controller

In inner current control loop has double the frequency of supply which is 100Hz and it is designed such a way that it can track the rectified supply voltage to make current in phase with the voltage waveform. As shown in Fig.5, the output voltage given to the current PI controller compares the reference current signal (I_{in}*) produced by outer voltage loop control with the output DC current (I_{in}) of the rectifier. This controller reduces the error and produces a signal that is added to the PWM generator. PWM generator will generate pulses for the switch to produce the necessary output voltage, as well as the converter to unify the power factor, according to the requirement of the duty cycle.

8. SIMULATION OF BATTERY CHARGING CIRCUIT

Table -1 Simulation parameters

S.No	PARAMETERS	VALUES
1.	Supply Voltage	$315V_{rms}$
2.	Supply Frequency	50Hz
3.	Switching Frequency	20KHz
4.	Filter Inductor	5mH
5.	Filter Capacitor	440μF
6.	Output Capacitor	1500μF
7.	Output Voltage	40volts

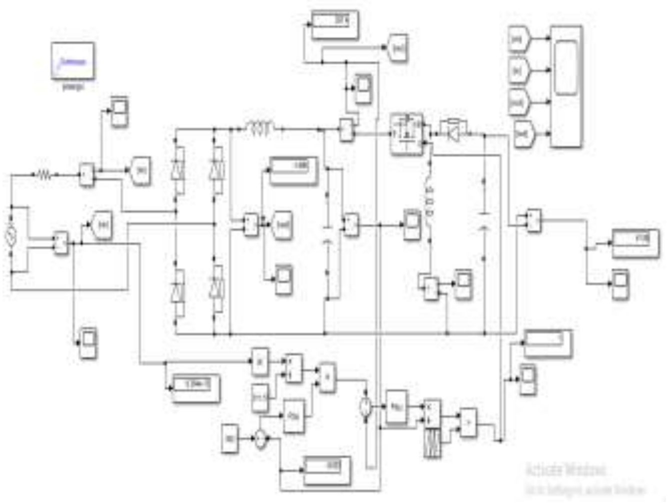

Fig -6: MATLAB Simulink model

The buck-boost PFC converter closed loop implementation is shown in Fig.6. To regulate the voltage and current, a proportional integral (PI) controller is used to improve the power factor.

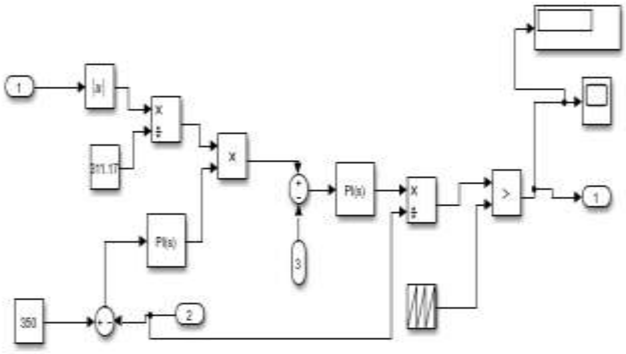

Fig -7: PFC control circuit diagram.

The line frequency current shaping control scheme is used to improve power factor nearer to unity is shown in Fig.7. This controller consists of two control loops. The inner loop is current control and the outer loop is voltage control. By varying PI controller voltage gain (Kpv and Kiv) and current gain (Kpc and Kic), the resulting source current waveform is almost sinusoidal and increasing the power factor near to unity. The controller action is implemented to generate a PWM pulse with appropriate duty cycle for the buck-boost converter. As shown in Fig.9, the resulting source current from the supply is now appeared as sinusoid and also has an in-phase relationship with the source voltage.

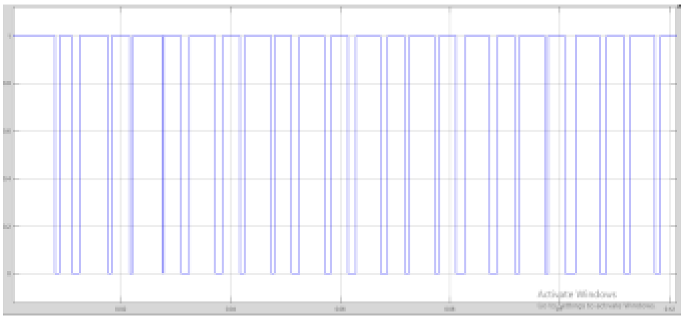

Chart -1: PWM pulse

The chart-1 shows the PWM pulse from the PI controller which is given to the switch to control the duty cycle to produce the required output voltage.

Chart -2: Source voltage and source current waveform

The source voltage and source current plot are shown in chart-2. It describes the performance control strategy implemented to shape the source current to sinusoidal. The conclusion from the graph is that the source current is in phase with the source voltage is being almost on the AC side with unity power factor.

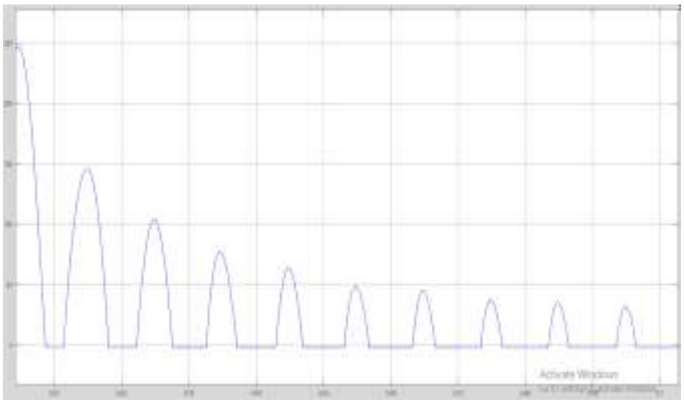

Chart -3: Rectifier voltage

The chart-3 shows the rectifier voltage is measured after the diode bridge rectifier.

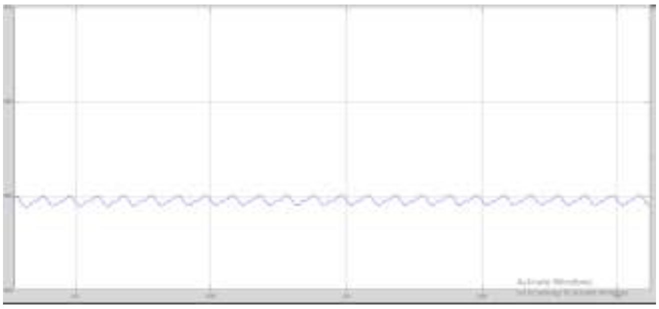

Chart -4: Series Inductor current

Chart-4 shows the inductor current which is presented in buck-boost converter. The charging and discharging status of inductor is represented.

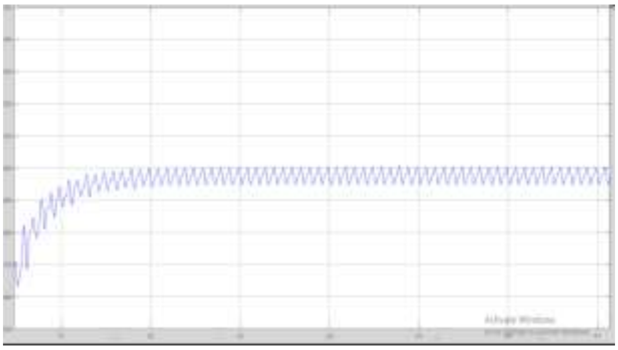

Chart -5: Filter inductor current

The buck-boost converter closed loop operation in CCM mode and the inductor current waveform are shown in chart-5.

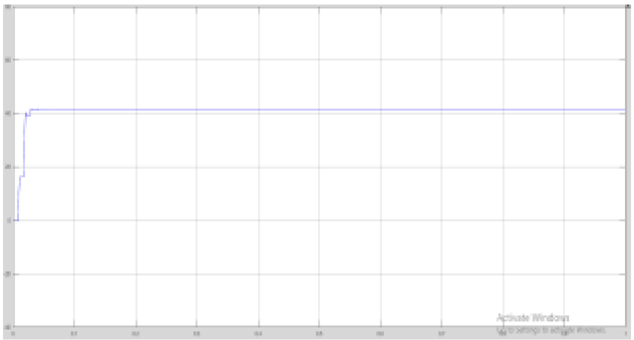

Chart -6: Output voltage

The output voltage (Battery voltage) waveforms are shown in chart-6. The average value of the battery voltage is around 40 volts. The output voltage represents the battery charging status, during charging battery voltage gets increased periodically and battery voltage is getting constant.

9. CONCLUSION

In this paper, the PFC circuit model is used for EV wireless charging system is represented. Based on the model, the PFC circuit is studied under different condition of charging powers and load inductances. The simulation result is shown that the load resistance affects the output voltage control performance. When the load resistance increases, the ripple at the output voltage becomes smaller, but it will not impact the input current control performance. The load inductance will not affect the input current and output voltage in the designed PFC circuit. The result in this paper are obtained for the application on electric vehicle, this also can be used where the high power factor is required.

REFERENCES

[1] Chirag P.Mehta., and Balamurugan P. "Buck-Boost Converter as Power Factor Correction Controller for Plug-In Electric Vehicles and Battery Charging Applications." IEEE, 2016 International Conference on, pp. 1-6.

[2] Chongyi Lu., and Zilong Guo. "Design of PFC in Wireless Charging System for Electric Vehicle." IEEE, 2018 International Conference on, pp. 1-5.

[3] Premkoumar, T., M. R. Rashmi, and A. Suresh. "Power Factor Correction Circuit Using Digital PI Controller." POWER 1, no. 6 (2013): 1049-1053.

[4] Jayahar, D., and D. R. Ranihemamalini. "Inductor Average Current Mode Control for single phase Power Factor Correction Buck-Boost Converter." In Emerging Trends in Electrical and Computer Technology (ICETECT), 2011 International Conference on, pp. 274-279.

[5] Tse, C. K. "Circuit Theory Of Power Factor Correction In Switching Converters." International journal of circuit theory and applications 31,no. 2 (2003): 157-198.

[6] Ketsingsoi, Supasit, and Yuttana Kumsuwan. "An Off-Line Battery Charger based on Buck-Boost Power Factor Correction Converter for Plug-In Electric Vehicles." Energy Procedia 56 (2014): 659-666.

[7] S. R. Khutwad, S. "Gaur.Wireless charging system for electric vehicle." International conference on signal processing, communication, Power and embedded system. IEEE, 2017: 441-445.

[8] X. Wu., X. Zhang., S. Jiang, Z. Yuan. "Research progress of wireless charging technology of electric vehicles. "Journal of power supply, 2014, 3: 27-32.

[9] J. Li. "Design of Automatic Charging Mode Alteration at Secondary Side in Electric Vehicle Wireless Charging System. "Dianli xitong zidonghua/automation of electric power systems, 2017.

[10] X. Liu, X. Zhang. "Research on topology and control strategy of electric vehicle wireless charging system. "Electronic technology application, 2017, 43(5): 155-158.