Buck-Boost Converter as Controller for Power Factor Correction Plug-In Electric Vehicles and SOC Battery Charging Application

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ABSTRACT
The operation of the buck-boost converter as a power factor correction controller useful for battery charging in electric car applications is covered in this study. Depending on the rectified voltage at the input side and the battery voltage at the load side, this design can operate in either the boost or buck modes. In order to achieve a power factor that is closer to unity, this work provides an informal and efficient line frequency current shaping control system. This goal is accomplished via an active power factor control circuit that uses a buck-boost converter in continuous conduction mode (SOC) with an adjustable duty cycle control approach. The control performs well and is quite simple. In the MATLAB/Simulink environment, the control scheme's performance is simulated for both open-loop and closed-loop control. [1]

Keywords
Buck-Boost Converter, Diode, Proportional Integral Controller (PI), Power factor correction (PFC), Pulse width modulation (PWM), State of charge (SOC), THD.

1. INTRODUCTION
Energy conservation is considered to be one of the most significant issues in modern science. Fuel costs are also rising daily as a result of declining fuel supplies and rising pollution rates. As a result, experts are offering an alternative method using battery-fed electric vehicles to safeguard the environment. To maximize battery life and productivity, batteries in battery-fed electric vehicles should be charged and discharged correctly. In order to accomplish this, State of Charge (SOC) conventional methods are utilized to charge and discharge the battery. In order for this Buck-Boost converter to function, we must use diode ground to convert the ac force into dc force. The goal of this research is to create a method that can be used in the PWM and SOC battery while using data from a power system model to determine corrective measures.

2. SOC WIRELESS CHARGING CIRCUIT

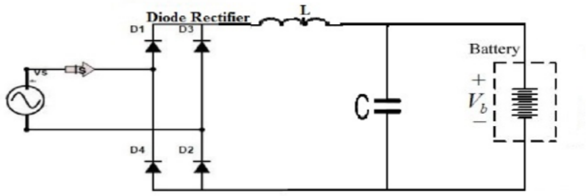


Fig. 1 Battery charging circuit diagram

Figure 1 displays the basic wireless circuit diagram for the battery charger powered by an AC source. For ac to dc conversion, the diode bridge rectifier receives the applied ac voltage. Batteries heat up when they are being charged because to fluctuations in the dc voltage or current. The dc voltage is smoothed and ripples are filtered using an L-C filter. Thus, the issues that come with it. The primary elements that require attention are power factor and source current/voltage distortion. Inadequate power factor on the source side raises system losses and degrades system performance.

3. IMPLEMENTATION

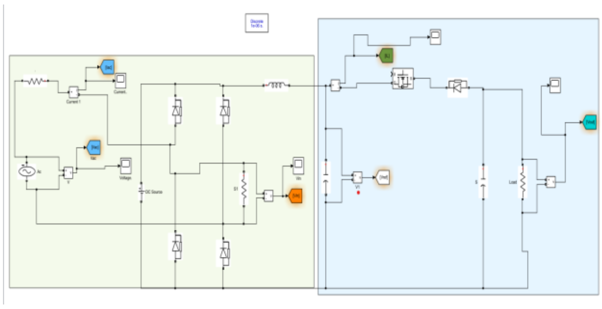


Fig -2: Using Battery charging Buck Boost converter

As seen in Fig. 2, the buck-boost converter is inserted before the load but after the rectifier circuit. The primary goal of using a buck-boost converter is to minimize source side THD losses and achieve precise battery loading. According to the equations link between %THD and power factor, a decrease in THD results in an increase in power factor. [2]

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

3.1 Design parameter of converter

The circuit parameters are used in the design of the buck-boost PFC converter.

Equation provides the rectifier's output voltage (Vin).

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

Equation represents the formula for the DC voltage buck-boost PFC converter conversion ratio.

Vdc = Output Voltage

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

Equation 4 expresses the buck-boost converter, in which the inductor critical (Lcric) is intended to function under continuous conduction mode.

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

R= Output resistance

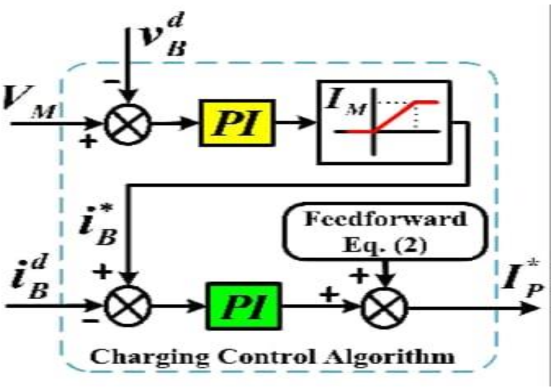
Fs = Switching frequency

Equations (4) and (5) can be used to design the critical inductor and capacitor of the buck-boost converter, where the output capacitance and inductor inductance should be selected to be larger than the critical value. The critical value of the output capacitor is given in equation 5.

3.2 Constant Voltage Control Mode

In the constant current mode, the battery voltage rises to the limit while the charging current is maintained at the rating. In actuality, although the voltage increase is not linear in time, it takes several minutes to charge in this mode.

It is therefore reasonable to assume that the battery voltage remains constant during one rectified grid period between the battery voltage and the battery current remains constant during one rectified grid period.



$$R_M = \frac{V_{M}(t)}{i_B(t)}$$

The converter model can be adjusted to manage current in terms of the squared charging current,

$$X_S = \frac{i_B^d I_P - 2P_S}{(R_B^2)S}$$

The PI controller utilized in CV mode can be applied to SOC by comparing the squared charging voltage. If the PI benefits are multiplied by times. Put another way, as seen in Fig. 6, the PI controller defined in CV mode can be utilized in SOC mode without impacting the performance of the charging system by multiplying the difference between the squared charging current and its reference by the coefficient. The average value of the battery voltage and charging current is obtained by using a second-order low-pass filter with a cut-off frequency lower than the double grid frequency in order to calculate.[3]

$$X = \frac{i_B^d\left(\frac{K_P}{R_M^2}S+\frac{K_1}{R_M^2}\right)}{\left(C_S^2+i_B^d\frac{K_P}{R_M^2}S+i_B^d\frac{K_1}{R_M^2}\right)S}\, x_0$$

3.3 SOC Battery Charging Control

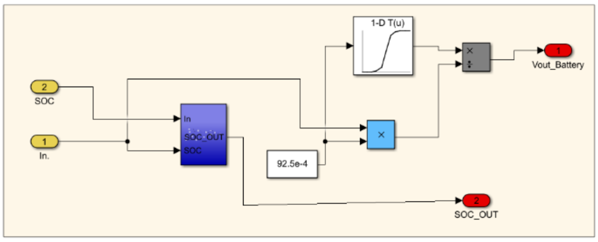


Fig -3: Using MATLAB Battery Charging Controller

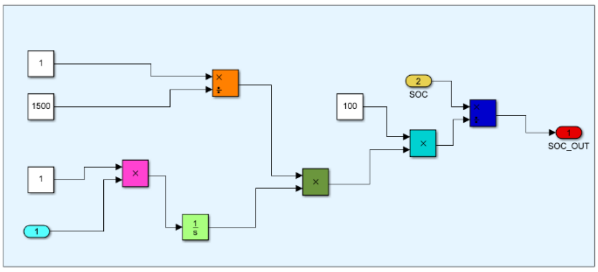


Fig -4: Using MATLAB Battery Charging Controller

A circuit is completed when a load is placed across the positive and negative terminals of a lead-acid battery. Electrons in the electrolyte's sulfuric acid solution.

3.3.1 Running of Battery

Whilst a load is applied throughout the lead-acid battery's superb and negative terminals, a circuit completes. Electrons in the sulfuric acid solution in the electrolyte.

$Pb + PbO_2 + 4H + 2SO_4^2 = 2PbSO4 + 2H_2O$

Anode oxidation occurs:

$Pb = Pb^{2+}$

$Pb + SO_4^{2-} = PbSO_4 + 2e^-$

Cathode reduction occurs:

$PbO_2 = Pb^{2+}$

$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- = PbSO_4 + 2H_2O$

The State of Charge (SOC) of a battery is its current charge level relative to its full capacity, expressed as a percentage. State of charge (SOC) monitoring is essential to provide optimal performance, extended battery life, economical energy use, safety, and user awareness. Voltage, current, and temperature are measured to determine state of charge (SOC), often with the aid of sophisticated battery management algorithms and systems. To sum up, SOC provides an essential metric for understanding and optimizing battery energy utilization in many applications.

$$\textbf{SOC}\ (\%) = \frac{CurrentCharge}{TotalCapacity}\ \text{X}\ 100$$

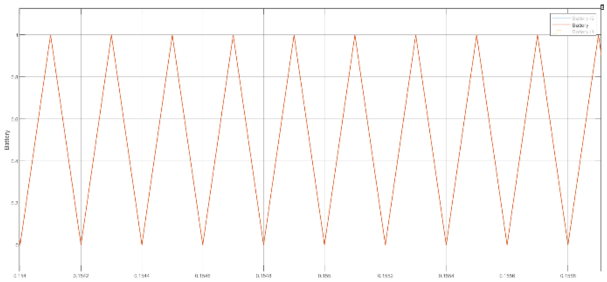


Fig -5: Using Matlab Charging Battery Output

3.4 Buck-boost PFC Converter

Fig. 6 displays the block diagram for the buck-boost PFC converter's line frequency current shaping control. The external voltage control loop of the suggested PFC controller is utilized to control the battery voltage. In order to get unity power factor, it additionally has an internal current control loop that regulates the reference input current and modifies the converter's input current.

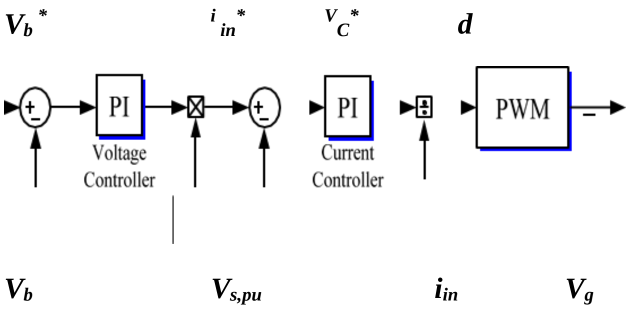


Fig-6:.Block diagram of the buck-boost PFC converter

$$V_g = \frac{2\sqrt{2}dV}{(1-d)\pi}$$

The suggested buck-boost PFC converter's circuit specifications for an off-line battery charger are described in this section. There are two control loops in this controller. Voltage control is done in the outer loop and current control is done in the inner loop. The buck-boost converter receives a PWM pulse with the proper duty cycle when the controller operation is executed.

Now that the source current is coming from the supply, it seems to be sinusoidal and is in phase with the source voltage. [4]

$$V_g = \frac{2\sqrt{2}dV}{(1-d)\pi}$$

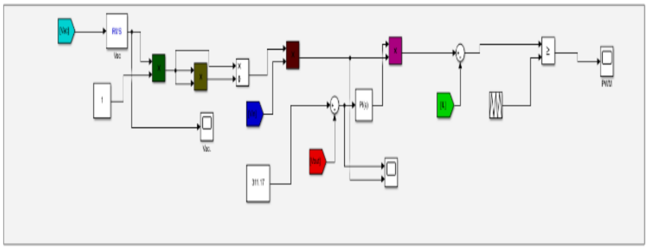


Fig -7: Using Matlab PFC Converter

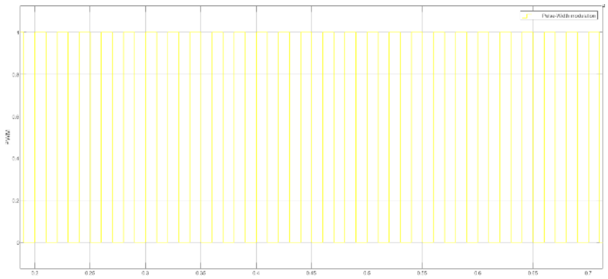


Fig -8: Using Matlab PWM pulse

3.5 Power Factor Correction in Battery Charging

The purpose of power factor correction (PFC) schemes is to guarantee the highest possible level of system efficiency. PFC Circuits lower operating costs, enhance performance, and facilitate the effective use of power. There are two control modes available for this PFC controller: voltage control mode and current control mode. To precisely charge the battery and bring the input power factor as near to unity as possible. This is done to extend the battery's life and enhance performance. An IGBT diode bridge rectifier, which transforms AC voltage into DC voltage, receives the first AC supply. The battery is connected to the load side of the buck-boost converter and receives the generated DC output voltage. In order to control the duty cycle and output voltage of the converter with power factor correction at the input AC side, the switch receives feedback signals from the PFC controller in the form of pulses that are produced when the output voltage of the battery and the rectifier's input current are sensed.[5]

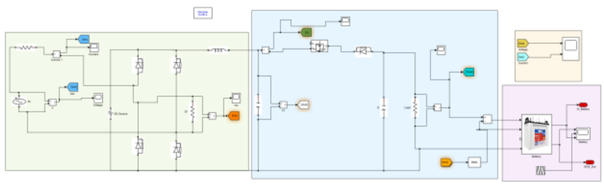


Fig -9: Power Factor Charging with buck-boost converter

3.6 Buck-Boost Converter

One kind of DC-DC converter (chopper) with a steady output voltage is the buck-boost converter. Based on the mode of operation, it could be greater or less than the input voltage magnitude. The only distinction between the buck-boost converter and the fly-back circuit is the use of a single inductor in place of a transformer. Based on the activities, there are two sorts of converters in a buck-boost converter: a buck converter and a boost converter. With a change in duty cycle, these converters can generate a wider variety of output voltages than input voltages. The input resistance inductor, which generates an unpredictable fluctuation in the input current, is the foundation of the DC-DC converter's working mechanism. When the switch is turned on, the inductor feeds and stores magnetic energy on behalf of the supply power. If the switch is turned off, this releases energy to the load. It is expected that the output circuit's capacitor values are high. The goal is to keep the voltage at the load terminal constant. [6]

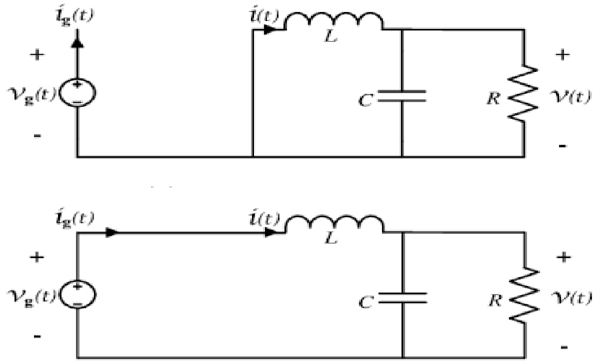


Fig -10: Buck-Boost Converter

4. MATLAB Simulation

Table -1 Simulation parameters

S.No	PARAMETERS	VALUES
1	Supply Voltage	220 V_{rms}
2	Supply Frequency	50 Hz
3	Switching Frequency	20 kHz
4	Inductance (H)	50H
5	Capacitance (F)	700F
6	Output Capacitor	1400µF
7	Output Voltage	40volts

4.1 MATLAB Simulink Advantages and Challenges

Since that they can manage a wide range of input voltages, buck-boost converters are therefore well-suited for applications needing battery charging and electric cars, which frequently meet fluctuating voltage circumstances. The overall efficiency of the system might be increased with their help in modifying the power factor. There are possible integration, cost, and complexity-related challenges when putting power factor correction and control systems in place for electric car charging. A fluctuating load during charging is one of the variables that the design needs to take into account. [7]

A. Solar SOC battery used benefits

Excess energy is stored in solar batteries, which make them a dependable power source at night or during times of low sunlight. Ensures the continued operation of critical appliances and systems by providing backup power during grid disruptions. By keeping an eye on SOC, one may optimize energy flows, increase system efficiency, and prolong battery life. Reducing dependency on fossil fuels and lowering carbon emissions are two benefits of combining solar energy with storage to mitigate climate change.

Results

For 0.1 sec, run the simulation. We use a scope with vdc to view the output voltage of the BOOST converter, and we use another scope with Vabc and Iabc to view the final output voltage and current.

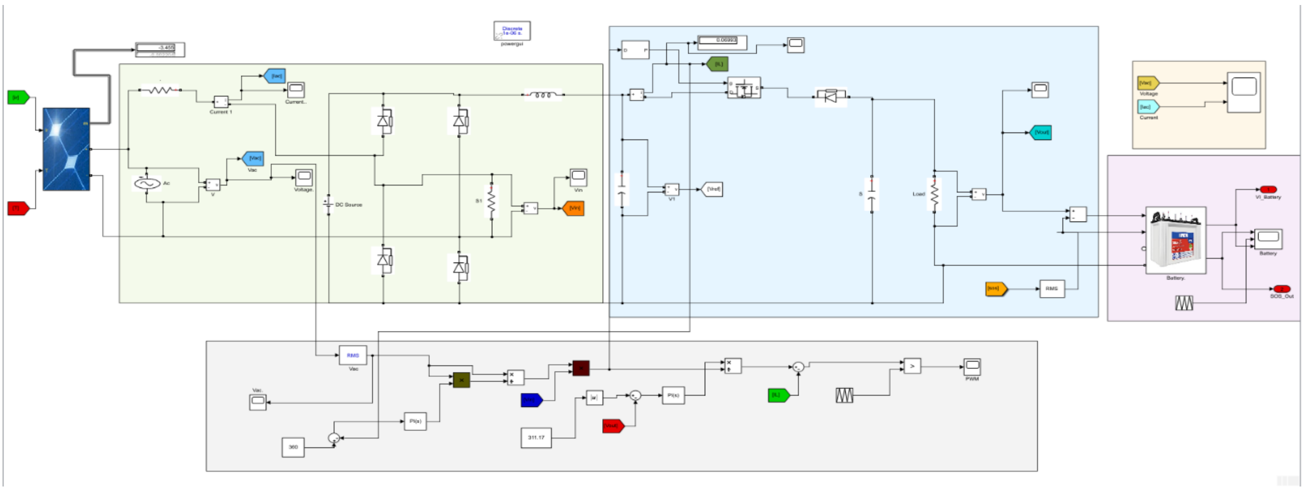


Fig-11: Overall, MATLAB Simulation

5. SIMULATION RESULTS

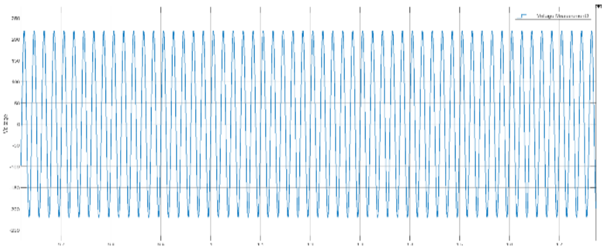


Fig -12: Inductor Voltage Input

It is clear from Fig. 12 that the buck-boost converter is operating in continuous conduction mode since` Inductor voltage wave forms

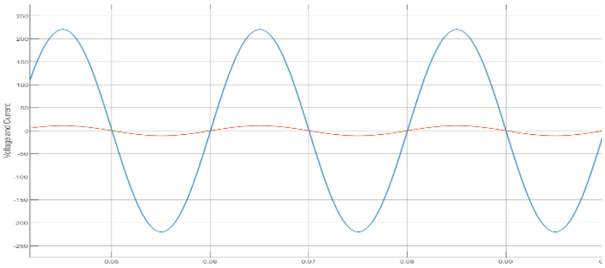


Fig -13: Supply voltage and current

As seen in Fig 13, there are some fluctuations in the supply current side as well as a growing phase alignment between the supply current (Ratio 1:2) and supply voltage. The performance applied control technique for source current shaping is displayed in Fig. 14 as a plot of source voltage (in actual scale) and source current (elevated scale of 1:2). Additionally, it is evident that the source current and source voltage are in phase, resulting in an almost unity power factor on the ac side. Additionally, there is a significant reduction in the influence of harmonic distortion, which can further lower the system's losses and voltage distortion.

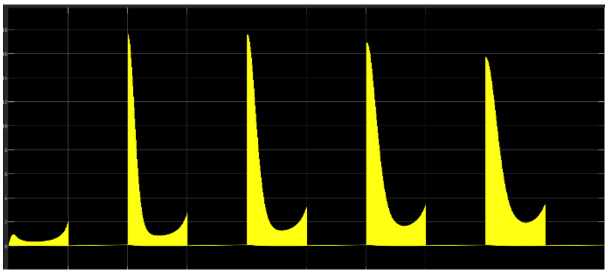


Fig -14: Inductor Current Simulink

It is clear from Fig. 14 that the buck-boost converter is operating in continuous conduction mode since the inductor current is not zero.

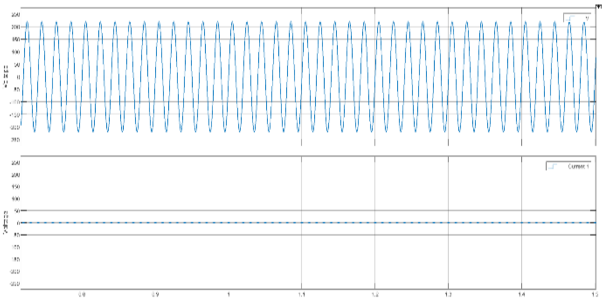


Fig -15: Output Voltage and Current

Figure 15 displays the output voltage and current of the converter under open loop conditions. Because it depends on the modes of operation, the voltage and current have a negative polarity. The average current is 5 amps, and the average voltage is 60 volts.

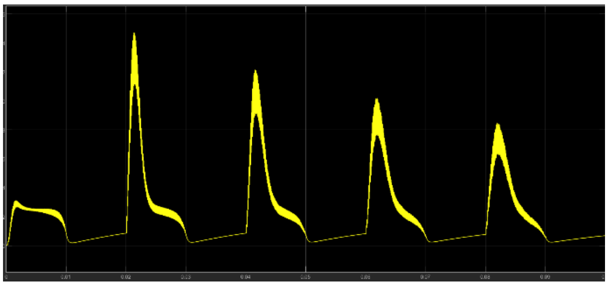


Fig -16: Output Simulink

Figure 16 displays the load voltage additionally, it is evident that the source current and source voltage are in phase, resulting in an almost unity power factor on the ac side. Additionally, there is a significant reduction in the influence of harmonic distortion, which can further lower the system's losses and voltage distortion.

6. CONCLUSION

This article represents a wireless charging system using the PFC circuit model. The PFC circuit is examined under various charging power and load inductance conditions using the model as a basis. Matlab/Simulink is used to the Buck-boost converter's power factor correction converter performance for battery charging applications. The implementation of a PI controller control approach resulted in a significant improvement in the source current's wave form. Filter capacitors at the diode bridge rectifier's output have a mitigating impact on source current. The control method in place also achieves a power factor at the source side that is almost equal to unity. By preventing deep draining and overcharging, monitoring SOC extends the life of the battery. Sustaining an ideal state of charge guarantees a steady flow of electricity, particularly in times of diminished solar radiation. SOC control prevents pointless cycles of charging and discharging, which increases the efficiency of energy storage devices. Understanding the SOC enables improved integration with solar inverters, enhancing the solar power system's overall performance. Off-grid solar installations, which offer a dependable energy source independent of the grid, are supported by SOC management. When grid electricity is unavailable, a solar battery with precise state of charge (SOC) data can effectively supply backup power. Overall, solar battery systems' longevity and efficacy are greatly enhanced by SOC monitoring and regulation.

7. ACKNOWLEDGMENTS

SOC assists in controlling the timing of charging and discharging, optimizing energy use according to demand and sun availability.

8. REFERENCES

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