



CHARGING OF ELECTRIC VEHICLE FOR LOW-POWER APPLICATIONS WITH IMPROVED POWER FACTOR CORRECTION

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Abstract – This paper presents a cohesive power electronics system for charging the battery in low-power EV applications with improved power factor correction. The system employs a diode bridge rectifier (DBR) to convert AC to DC efficiently. An interleaved boost converter (IBC) is utilized, incorporating a dual loop control technique to effectively manage the DC link voltage and ensure power factor correction. Small signal modeling is conducted, leading to the development of transfer functions that streamline controller design, ensuring robust and stable operation. The interleaved boost converter is linked to a buck converter for battery charging, operating in constant current and constant voltage (CC-CV) modes to govern the charging process. MATLAB simulations are carried out to validate the proposed model. The results confirm that the proposed charging system successfully achieves its objectives, including power factor correction, reduction of Total Harmonic Distortion (THD) in input current, and Constant Current Constant Voltage (CC-CV) charging of the battery.

Key Words: Electric Vehicle (EV) Charging, Interleaved Boost Converter, Total Harmonic Distortion (THD), Low-Power Applications, CC-CV algorithm

1. INTRODUCTION

Switching to electric vehicles (EVs) offers a range of benefits, encompassing environmental, economic, and societal advantages. As EV technology advances and infrastructure improves, the move to electric mobility is projected to be critical in developing a more sustainable and resilient transportation system. To ease this shift, the availability of convenient and widespread charging infrastructure is key to encouraging users to switch to electric vehicles. The battery chargers used to charge the battery must satisfy the IEEE grid standards for input current harmonics to keep the grid stable and safe [1]. Multiple power factor correction (PFC) techniques are used to ensure that the input current waveform closely resembles a sine wave [2]. The majority of charging topologies include two stages: a

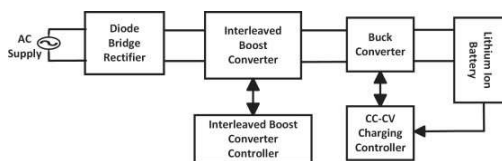
DC-DC converter that uses a control algorithm to charge the battery after a front-end AC-DC converter with PFC [3]. Classification of types of electric vehicle battery charger (EVBC) can also be done on the basis of output power levels

[4] and power supply [5]. Commonly used Lithium-ion (Li-ion) battery technologies encompass a variety of chemistries tailored for specific applications. Lithium Cobalt Oxide (LiCoO₂) batteries, known for their high energy density, are prevalent in consumer electronics like smartphones and laptops. Lithium Iron Phosphate (LiFePO₄) batteries are prized for their safety, stability, and long cycle life. Lithium Manganese Oxide (LiMn₂O₄) offers improved thermal stability and discharge rates. Lithium Titanate (Li₄Ti₅O₁₂) batteries excel in rapid charging, longevity, and safety, making them ideal for high-power applications like electric buses [6]. Electric vehicles commonly use lithium-ion batteries due to its high energy density, compact size, long lifespan, and low discharge rates. The CC-CV charging algorithm is chosen over other charging techniques to extend the life span of lithium ion batteries because it more closely resembles the chemistry of the battery. When charging the battery in CC algorithm alone, it may effect the battery due to rising temperature. When charging using CC-CV, the battery enters CV mode when its voltage hits a particular threshold, mitigating the temperature issue. The authors of [7] evaluated a number of charging methods, including pulse charging, multistage CC charging, varying current charging method and CC-CV on the basis of complexity, effect on the battery life and temperature effect on the battery. In [8], the authors have designed and implemented a single phase EVBC using a Cuk converter with PFC control and LLC resonant converter to charge the battery in CC-CV mode for a small two wheeler. In [9], the authors have compared the AC DC converter topologies on the basis of THD, power losses, total number of devices, etc. Authors in

[10] have compared various machine learning techniques on an ANN model for estimating the output current ripple from an interleaved boost converter. The dataset has been trained to regulate the grid current harmonics and enable dependable battery charging. In [11], the authors have presented an on-board single phase single switch Vienna Rectifier with PFC to charge a battery at 400V, simultaneously ensuring a unity power factor. This paper does not charge the battery using any specific charging algorithm. The design and simulation of a Vienna Rectifier with PFC using a dual loop control followed by an LLC resonant converter to charge the 280V/112Ah battery in CC-CV charging mode is presented in [12].

2. System Block diagram

Fig. 1. Block diagram of intended EV charger



II. DESIGN AND CONTROL OF A DC-DC POWER STAGE

A. Brief Description of Complete Circuit

The charger as depicted in Fig. 2, shows DBR followed by an IBC and a DC Link capacitor (Cdc). IBC consists of two boosting inductors L1 and L2. By utilizing a dual loop control algorithm, the DC link voltage is maintained at a set reference voltage, and the inductor currents are controlled in a way that they track the input voltage, thus resulting in unity power factor. The IBC is followed by a buck converter, which eventually charges the battery in CC-CV mode. The buck converter is used to step down the output DC link voltage from the IBC and converts it into the battery charging voltage.

B. Interleaved PFC Boost converter

Fig. 2 depicts the single-phase IBC. The converter functions in an interleaved manner and is composed of two traditional boost converters linked parallelly. The first converter leg consists of inductor L1, switch S1, and Diode D5, while the second converter leg is made up of L2, S2, and D6. At the output, the filter capacitor Cdc is shared by the two IBC legs. The converter parameters are assumed to be the same. This topology has the advantage of having less input current ripple since the gating pulses to the switches are 180° phase shifted, leading to inductor currents cancelling each other. The interleaved operation reduces output capacitor current ripple,

which helps optimize the design components. In comparison to a single boost converter, interleaved inductors handle lesser current, while DC-bus capacitors, MOSFETs, and diodes account for lesser current ripple. These benefits result in increased power density per watt [14]. IBC consists of two switches, which makes it possible to work in four modes during a given duty cycle. In Table 1, all possible modes of action are stated. The authors in [15] have given a very detailed account of working and modeling of IBC.

C. Design of Parameters

The IBC design parameters can be calculated using [16]. The calculated parameters are boost inductors (L1 and L2) and DC Link capacitor (Cdc). The boosting inductor is calculated using

$$(1). L = D \cdot V_{in} / (\Delta I_L \cdot f_{sw})$$

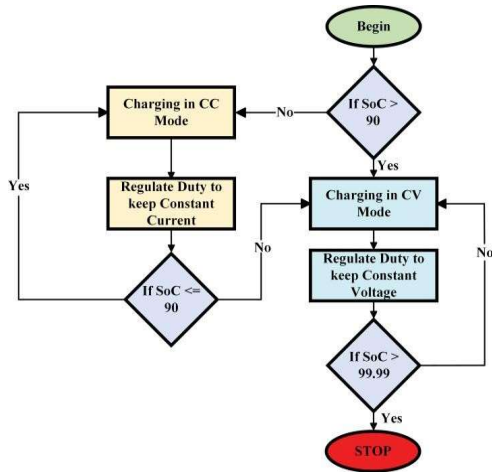
where the switching frequency is represented by f_{sw} , duty ratio is represented by D , V_{in} is the input voltage, ΔI_L is the desired inductor current ripple. The output filter capacitor can be calculated using (2)

$$C_{dc} = D \times I_{out} / (f_{line} \times \Delta V_{OUT})$$

Where the desired output voltage is represented by V_{out} , output current is represented by I_{out} , f_{line} is the line frequency of the system

D. Dual Loop Control

The IBC is controlled using a dual-loop control algorithm. It is a control strategy commonly employed in power electronics to regulate the input current and output voltage. This strategy finds its application in power factor correction (PFC) systems. It involves a one-within-one type control loop [17], as shown in Fig. 2. In this dual loop control, the voltage control loop is a slow-acting loop, whereas the current loop is fast-acting. The current control loop must be fast-acting as it must track the input voltage waveform. The faster and more precise the tracking, the lower the THD will be. Voltage controller is used



III. DESIGN AND CONTROL OF DC-DC POWER STAGE

A. Buck Converter

A buck converter is utilized to reduce the voltage level. It can efficiently regulate the output voltage while minimizing power losses and is easy to design, making it suitable for implementing the CC-CV charging algorithm. Fig.2 shows the buck converter circuit diagram, consisting of a DC power supply V_{dc} , a switch S_3 (MOSFET), a diode D_7 , an inductor L_3 , and an output filter capacitor C_{out} . The average output voltage may be adjusted by utilising a PWM technique. The output capacitance (C_{out}) and the filter inductance (L) of the buck converter are calculated using the equations given in [18] and are presented in (7) and (8) respectively.

$$C_{out} = \Delta I_L \cdot f_{sw} \cdot \Delta V_{out} \quad (7)$$

where ΔI_L represents ripple in inductor current, ΔV_{out} is the ripple in output voltage, and f_{sw} is the switching frequency.

$$L = V_{out} \cdot (V_{in} - V_{out}) \quad (8)$$

$\Delta I_L \cdot f_{sw} \cdot V_{in}$ Where V_{in} , V_{out} are the input voltage and desired output voltage respectively.

B. CC-CV charging algorithm

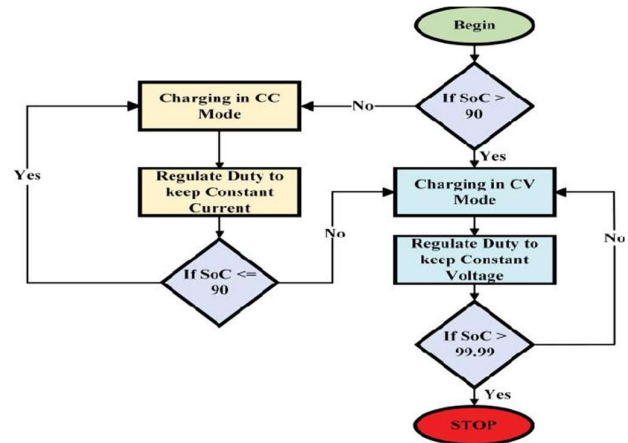
presented in (9).

$$i_L(s) \hat{d}(s) = V_{in} L s^2 + 1 RC s + 1 LC \quad (9)$$

2) Constant Voltage (CV) Mode Control: The control for the CV mode is implemented using a PID compensation technique.

The transfer function of duty ratio to output voltage is presented in (10) ^

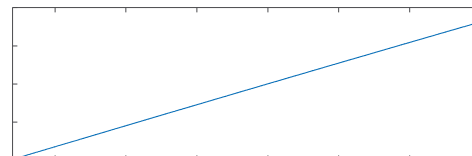
$$V_o(s) \hat{d}(s) = 22 V_{in} LCs^2 + Ls/R + 1 \quad (10)$$



Results and Discussion

A two-stage on-board EV charger is designed to charge a 200V/50Ah Li-ion battery at 0.8 C rate and the results are validated in MATLAB/Simulink. The design parameters, as shown in Table II, are for an input AC rms Voltage of 184 V to 276 V, to give a DC link voltage of 400V at the output of the IBC, charge the battery at 40A during CC mode and 224.65 V in the CV mode. Using (1) and (2) the IBC inductors (L_1 and L_2) and DC link capacitor (C_{dc}) are calculated to provide an output current ripple of 5% and output voltage ripple of 2%.

Using (7) and (8) the buck converter components (C_{out} and L_3) are calculated. The components are highly rated to cater to the low current ripple (0.1%) and low voltage ripple (0.1%) input criteria of the battery. This leads to better battery life and fewer heating issues. All the components have been rated 1.5-2 times the desired rating while performing the simulation. The PID controller values K_{p1} , K_{i1} , K_{d1} , K_{p2} , K_{i2} and K_{d2} have been designed using transfer function based PID Tuning in MATLAB. The stability of the two stages has been validated separately. The phase margin for the current and voltage loop are obtained as 62.4 degrees and 87.7 degrees, respectively, thereby confirming the stability



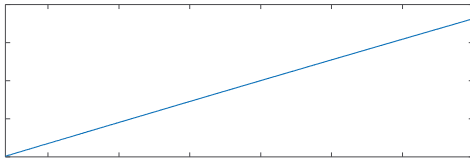


Fig. 12. Battery Voltage, Battery Current and SoC of the intended EV Charger

Conclusions and Recommendations

This paper proposes a comprehensive approach to low-power applications in electric vehicle (EV) charging through the implementation of an integrated power electronics system. The system employs a diode bridge rectifier for AC to DC conversion and an interleaved boost converter to address power factor correction and minimize harmonic distortion, ensuring adherence to grid regulations while improving overall performance. The utilization of a dual-loop control technique in the interleaved boost converter enables precise control of the DC link voltage and regulation of input current, thereby maintaining harmonic distortion within acceptable limits. Small signal modeling and transfer function development aid in optimizing controller design, ensuring the stable and robust operation of the power electronics system. Additionally, the integration of a buck converter into the battery charging system, operating in constant current and constant voltage modes, enhances the efficiency and reliability of the charging process. Extensive MATLAB simulations validate the proposed charging system, demonstrating its ability to achieve unity power factor, reduce total harmonic distortion, meet grid standards, and maintain a constant DC link voltage. This renders it a practical and cost-effective solution for low-power electric vehicle charging scenarios.

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