Design and Performance Evaluation of a 750W Boost Converter for Two-Wheeler Electric Vehicle Charging

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Abstract – *This study focuses on the development and assessment of a 750 W boost converter designed to elevate a fixed DC input voltage, making it suitable for charging electric two-wheelers such as Ola, Ather, and iQube. The converter's behavior is initially examined through small-signal analysis, considering duty cycle and voltage as the control and output variables, respectively. The performance evaluation is conducted with the help of Matlab simulations using a supplied fixed DC power source. The feasibility of the underlying power electronics converter developed in the study is also researched for integration with solar PV arrays. Experimental results verify the ability to step up an input voltage of 24V to a 36V output with an efficient ratio. The proposed design is verified to achieve an efficiency of 93.31% with the aid of Simulink, which is an effective approach to energy conversion for electric vehicle charging and for solar energy utilization.*

Keywords – Boost Converter, DC-DC Conversion, Electric Vehicle (EV), Duty Cycle Control, Power Electronics

1. INTRODUCTION

DC-DC converters are electronic circuits or electro-mechanical devices through which the direct current (DC) voltage can be converted from one voltage level to another level in modern power electronic era [1]. Their versatility and high efficiency make them essential of a wide variety of applications from electric vehicle to marine hoists [2], [3] A DC-DC converter can change the voltage level and therefore can step up or step down a voltage level, which is one of its basic functionalities and makes it indispensable in every power managing application [4].

The most attention of this technology evolves around the Electric vehicles (EVs), especially in traction motor control. Block converters are used in EVs,trolley cars, marine hoists, forklifts, trucks, and mine haulers to manage and regulate voltage levels that power traction motors [5] This demanding application has many benefits, such as high operational efficiency, accurate control of the acceleration and fast dynamic response [6], [7]. In addition, the regenerative braking function of DC motors, in combination with DC converters, allows for the unique possibility of feeding energy back into the supply in the braking phase, leading to net energy savings for transport systems with frequent stopping segments [8].

DC converters are not limited to only electric cells; in fact, they have a wide range of applications beyond their use in electric vehicles. They are used in DC voltage regulators [9], where they help to stabilize voltage and regulate from various sources. Well, actually, they take on different characteristics (they are essentially a DC current source) when used in conjunction with an inductor, forming DC converters. This configuration is particularly relevant to the current source inverter [10].

DC converters aren't confined solely to the realm of electric vehicles; they also find their utility in various other domains. They are utilized in DC voltage regulators, contributing to voltage stabilization and regulation across different applications [9]. Moreover, when employed in conjunction with an inductor, DC converters assume a different role as they generate DC current sources. This configuration finds its significance in applications like the current source inverter [10].

This paper aligns with these developments and presents a comprehensive exploration of DC-DC converters, with a specific emphasis on voltage boosting, a critical component of numerous energy conversion systems [11], [12]. We commence by establishing the foundational mathematical principles that underpin our proposed approach [13]. Subsequently, we rigorously evaluate the effectiveness of our voltage-boosting converter topology through a combination of simulations and experimental results [14], [15]. To ensure result integrity, we discuss signal conditioning techniques that are commonly employed to maintain the purity of both input and output signals, minimizing undesired harmonics [16]. While our specific implementation does not incorporate a low-pass LC filter [17], these filters can be employed to effectively reduce harmonic content in other scenarios [18].

In the following sections of this paper, we conduct an in-depth examination of DC-DC converters, elucidating their control mechanisms and highlighting the adaptability of a fixed DC voltage source as the input [19], [20]. Additionally, we propose the potential extension of this converter design for use with Photovoltaic (PV) arrays as a renewable energy source, emphasizing its versatility in accommodating evolving energy generation technologies [21], [22]. Through

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discussion of simulation and experimental results, we illuminate the efficiency and practical feasibility of our voltage-boosting converter design. Finally, we reflect on the broader implications of this research on the landscape of electric vehicle power systems and beyond.

2. MATHEMATICAL MODEL

The DC-DC boost converter, a specialized iteration of the DC chopper, is often described as a high-speed semiconductor switch capable of swift on/off transitions. This electronic device plays a pivotal role in facilitating rapid connections and disconnections between a power source and a load. Figure 1 illustrates the designed DC boost converter for electric vehicles (EVs), visually depicting the fundamental process of elevating the output load voltage from a stable DC power supply obtained through a bridge rectifier.

Within this diagram, key components come to light: Vs representing the supply voltage; Vo denoting the output load voltage; Is signifying the source current; L representing the inductor; D symbolizing the diode; and VL the voltage across the inductor.

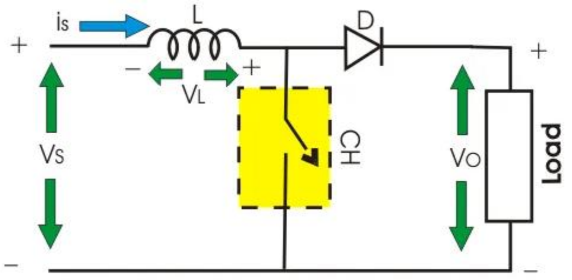

Fig. 1. Designed EV boost converter.

In this configuration, the key component responsible for the rapid switching action is the chopper, symbolized as 'CH' and enclosed within a dashed square. The chopper can be precisely controlled, enabling it to be turned on or off as needed to modulate the electrical output.
To gain a deeper understanding of the voltage-boosting mechanism in the DC-DC converter, let's examine two distinct states: the 'On' state and the 'Off' state of the switch (chopper). This is further elucidated below, with Figure 2 illustrating the corresponding waveforms during these two states.

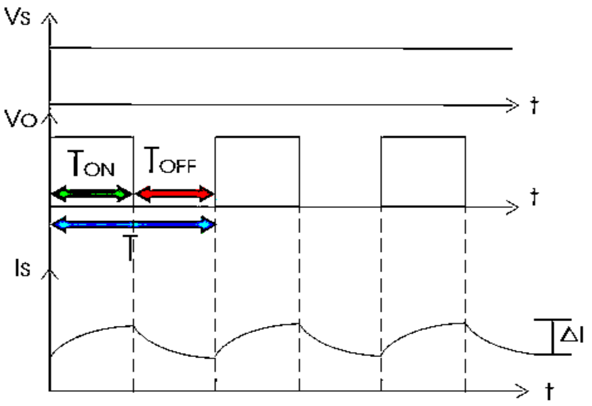

Fig. 2. Waveform of designed EV boost converter.

Where T_{on} and T_{off} are the 'On' and 'Off' duration of the chopper and $T = T_{on} + T_{off}$.

Another term used here is duty cycle (D) which is formulated as below:

$$D = \frac{Ton}{T} \tag{1}$$

Also, switching frequency of chopper is defined as

$$F_s = \frac{1}{T} \tag{2}$$

ON State: When CH is in the 'On' state, as shown in Figure 3, it essentially forms a short circuit across the load. As a result, the output voltage becomes zero for the duration of the 'On' period. Concurrently, the inductor initiates the process of energy accumulation. These conditions lead to the following outcomes:

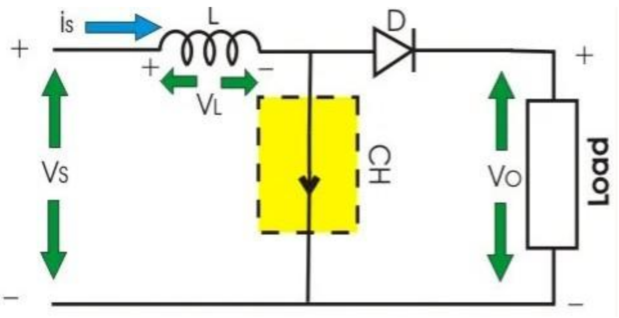

Fig. 3. Designed EV boost converter in 'On' state.

$$V_L = V_s$$

$$\Rightarrow \qquad L\frac{di}{dt} = V_s$$

$$\Rightarrow \qquad \frac{\Delta \mathrm{I}}{T_{on}} = \frac{V_s}{\mathrm{L}}$$

$$\Rightarrow \qquad \Delta \mathrm{I} = \frac{V_s}{\mathrm{L}} T_{on} \tag{3}$$

Where ΔI is the peak to peak inductor current.

OFF State: When CH is in the 'Off' state, the inductor L discharges through the load as shown in Figure 4. Consequently, we obtain the summation of both the source voltage V_S and the voltage across the inductor V_L as the output voltage, i.e.

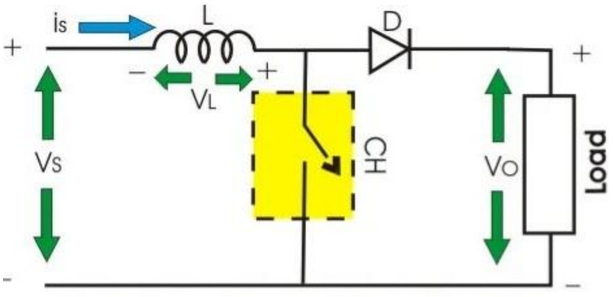

Fig. 4. Designed EV boost converter in 'Off' state.

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$$V_o = V_s + V_L$$

$$\Rightarrow \quad V_L = V_o - V_S$$

$$\Rightarrow \quad L\frac{di}{dt} = V_o - V_S$$

$$\Rightarrow \quad L\frac{\Delta I}{T_{off}} = V_o - V_S$$

$$\Rightarrow \quad \Delta I = \frac{V_o - V_S}{L}T_{off} \qquad (4)$$

Now by equating Equations (3) and (4)

$$\frac{V_s}{L}T_{on} = \frac{V_o - V_S}{L}T_{off}$$

$$\Rightarrow \quad V_s\left(T_{on} + T_{off}\right) = V_o T_{off}$$

$$\Rightarrow \quad V_o = \frac{T}{T_{off}}V_s$$

$$\Rightarrow \quad V_o = \frac{1}{(1-D)}V_s \qquad (5)$$

Where V_O represents the desired output voltage and can be adjusted within the range from V_S to infinity when $0 \leq D \leq 1$.

3. SIMULATION MODEL

We are designing a boost converter of 750 Watts for electric two-wheelers. Based on the proposed electric vehicle system, specific parameter values have been carefully chosen/calculated to guide the design of the DC-DC converter. These values encompass various aspects of the converter's operation and performance.

- **Input and Output Values of DC-DC Converter:**

  Input Voltage (V_S): 24V, reflecting the typical output of solar panels.
  Output voltage (V_o): 36V, in line with the expected input voltage for two-wheeler charging.
  Switching frequency (f_s): 25 kHz.
  Load resistance: 1.728 ohms, calculated to deliver 750 watts at 36 volts.

- **Duty Cycle:**

  Using Equation (1) the value of duty cycle [$D = 1 - (V_S / V_O)$] is calculated as = 0.3333

- **Inductor Design:**

  To achieve 100% efficiency in the DC-DC converter, we can use the power equation $P = V_s \times I_s = V_o \times I_o$. Therefore, the inductor current (I_L), which is also equivalent to the input current (I_s), can be expressed as $I_L = 31.25$. Now, considering a 30% ripple in the inductor current (within the broad range of 20% to 40%), we can calculate the value of the inductor as follows:

$$L = \frac{D \times V_s}{f_s \times \Delta I_L}$$

$$= \frac{0.3333 \times 36}{25 \times 10^3 \times (0.30 \times 31.25)}$$

$$= 34\ mH$$

- **Capacitor Design:**

  As discussed in the previous section, the output current (Io) is calculated to be 20.8333 A, assuming ripples in the capacitor voltage at 1% (within a broad range of 1% to 5%). We can determine the value of the capacitor as follows:

$$C = \frac{D \times I_o}{f_s \times \Delta V_o}$$

$$= \frac{0.3333 \times 20.8333}{25 \times 10^3 \times (0.01 \times 36)}$$

$$= 772\ \mu F$$

Considering tolerances and assuming slightly higher values for the inductor and capacitor as 50 mH and 900 μF, respectively, we also assume a duty cycle of 38% instead of 33% to get the desired output. These parameter choices and design considerations form the basis for the subsequent analysis and performance evaluation of the proposed DC-DC converter system for electric vehicle applications.

With these defined parameters, we conducted a simulation of the Boost Converter using a 24V DC input source, a duty cycle of 38%, and a frequency of 25 kHz in MATLAB. You can reference the Simulink diagram illustrating this simulation in Figure 5.

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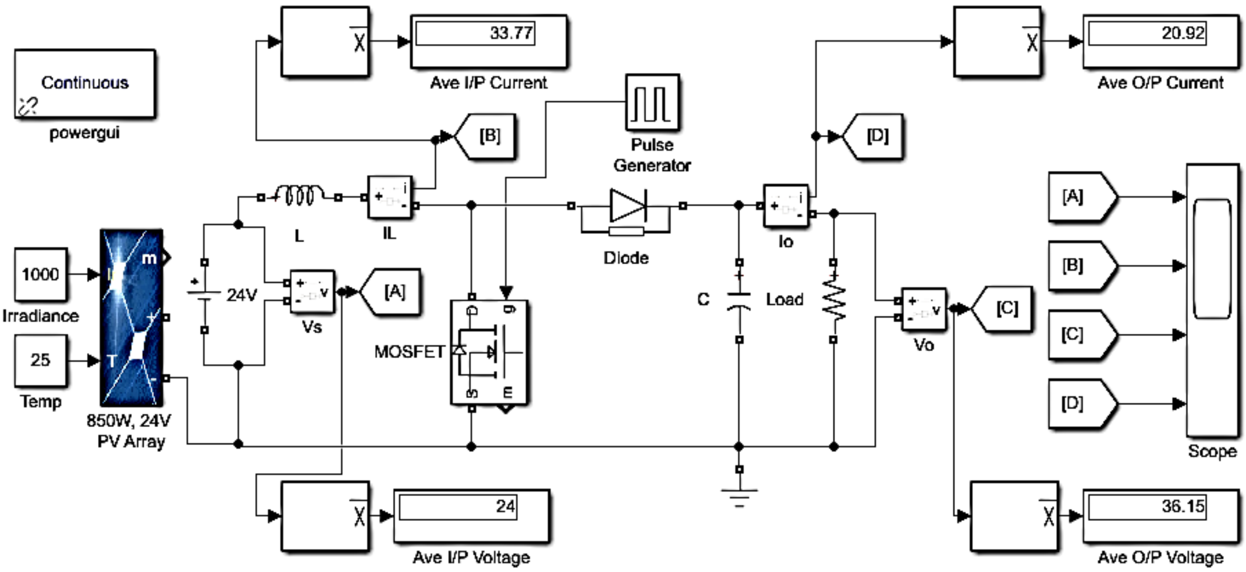

Fig 5. Simulation Model of Proposed Boost Converter

4. RESULTS AND DISCUSSIONS

We have performed a comprehensive analysis of key metrics including input voltage, input current, output voltage, and output current for the proposed converter. The results of these analyses are presented in Table 1 and Figures. 6 and 7. As indicated in the table, the input voltage is boosted to 36.15 volts, while the output current decreases to 20.92 amps at the output of the boost converter.

Figures. 6a and 6b depict the input voltage and current applied to the boost converter. The inductor current mirrors the input current since it is in series with the input supply. In these figures, the input voltage remains constant at 24 volts with a brief minor spike in input current, ultimately stabilizing at 33.77 amps. This results in an input power of 810.48 watts.

Table 1. Different voltage, current and power values.

S. No	Quantity	Voltage (Volts)	Current (Amp)	Power (Watt)
1.	Input	24.00	33.77	810.48
2.	Output	36.15	20.92	756.26

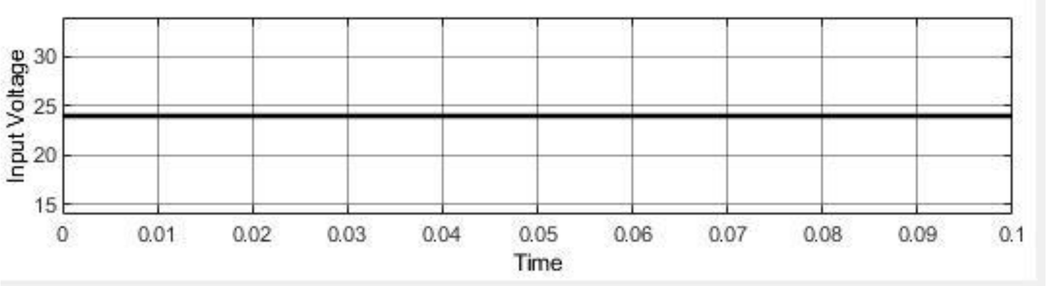

Fig. 6a. Simulated response of input voltage.

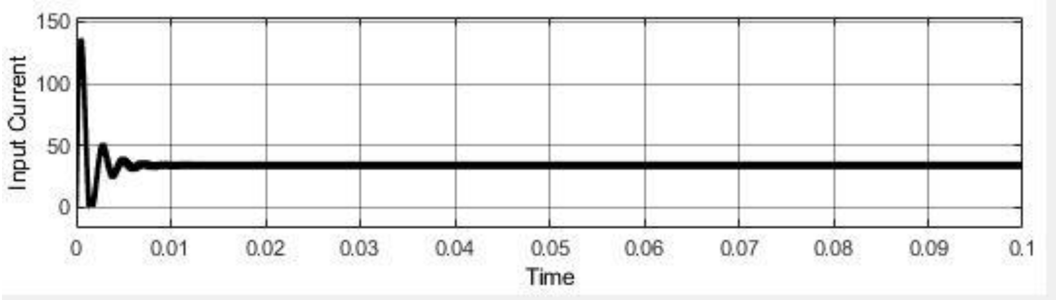

Fig. 6b. Simulated response of input current.

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The boosted output voltage is illustrated in Figure 7a, showing a slight short-duration overshoot before settling around 36 volts. Likewise, Figure 7b displays the output current with a minor overshoot of very brief duration, stabilizing at 20.92 amps. This results in an output power of 756.26 watts.

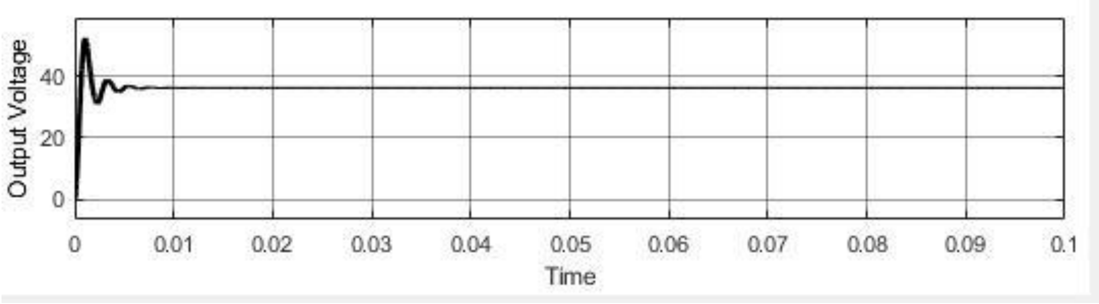

Fig. 7a. Simulated response of output voltage.

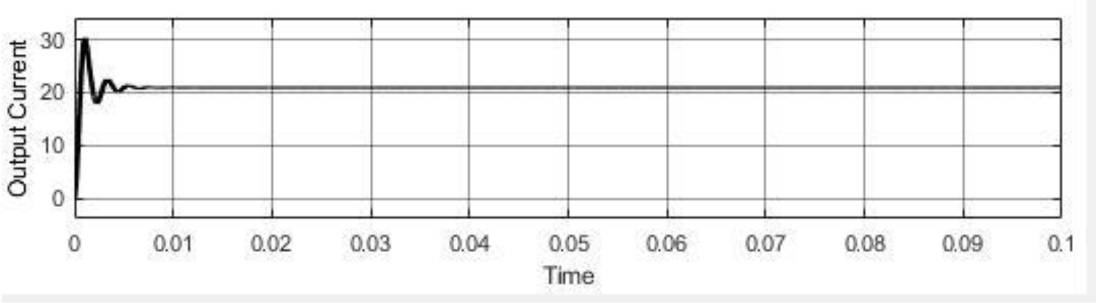

Fig. 7b. Simulated response of output current.

In the final stage of our analysis, we calculated the efficiency of the Boost Converter using the formula: efficiency = Pout / Pin, where Pout is 756.26 watts and Pin is 810.48 watts. The obtained efficiency is 93.31%, which demonstrates the effectiveness of the designed controller.

5. CONCLUSION

This study demonstrates a detailed design analysis and optimization process for a boost converter intended specifically for two-wheeler electric vehicle power systems. Through meticulous planning based on predefined requirements researchers evaluated this converter design both through simulation and analysis methods. MATLAB simulations with calculated parameters enabled us to understand how the converter operates and performs. The boost converter proves itself essential in DC-to-DC power conversion by showing it can raise voltage while maintaining effective current levels which is crucial for power management systems. Our design when put into practice showed a great outcome. The converter achieved an elevated 36.15V output voltage from a 24V input while demonstrating impressive efficiency of 93.31% during operation. The study also reveals how duty cycle changes affect output voltage stability to evaluate the converter's dynamic performance. Our research successfully implements the proposed boost converter design both theoretically and experimentally for EV systems. Our study finds relevance in developing efficient energy conversion solutions which will enhance DC-DC converter technology to operate in systems such as solar power. This study provides essential information to enhance power delivery while promoting sustainable technology integration.

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