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Design of Buck and Boost DC-DC Converters for Auxiliary Components in Electric Vehicles Using MATLAB Simulink

V. Nandagopal[1], N. Sivakamasundari[2], S Meena[3], R. Thenmozhi[4]

[1]Professor, Department of Electrical & Electronics Engineering, Mohan Babu University (Erstwhile Sree Vidyanikethan Engineering College), Tirupati, Andhra Pradesh India.
[2]Assistant Professor, Department of Mechatronics, School of Engineering and Technology, Hindustan Institute Of Technology and Sciences, Kelambakkam, Chennai.
[3]Associate Professor, Department of Electronics and Instrumentation Engineering, St. Josephs's College of Engineering, Chennai, India.
[4]Associate professor, Department of Electrical & Electronics Engineering, Priyadarshini Engineering College Vaniyambadi, Tamilnadu, India.

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ABSTRACT:

The proliferation of Electric Vehicles (EVs) is rapidly growing, yet they face a persistent challenge known as range anxiety due to their limited single-charge range. Electric motorcycles typically necessitate a higher voltage system in evaluation to electric bicycles. While the precise voltage specifications vary across manufacturers and models, most electric motorcycles operate within the voltage range of 48V to 96V or even higher. In EVs, battery voltage varies based on the sort of battery used. Lead-acid batteries, commonly employed in electric two-wheelers, typically operate at 12V, whereas lithium-ion battery packs, predominant in electric four-wheelers, generally operate within the assortment of 400-800V. This study introduces the utilization of DC-DC boost converters for auxiliary functions in electric two-wheelers and DC-DC buck converters for auxiliary purposes in electric four-wheeler manufacturing. In the context of two-wheelers, where the indicting voltage typically stands around 50V and a 12V Lead Acid battery is employed, the proposed DC-DC boost converter is utilized to generate the requisite voltage. Conversely, in four-wheelers, the proposed DC-DC buck converter is deployed to regulate lower voltages for tasks such as dashboard lighting, indicators, and other components requiring reduced voltage in electric cars. A Simulink model of both the Buck and Boost converters is developed, and the simulation results and performance metrics are thoroughly discussed.

Keywords: Electric Vehicles, Buck Converter, Boost Converter, Battery

1. Introduction

A standard 12-volt motorcycle battery comprises six cells housed in a plastic housed enclosure, each containing + (positive) and – (negative) plates submerged in an electrolyte solution. When completely charged, all the cell typically holds a voltage level of approximately 2.1 volts, resulting in a combined battery voltage of around 12.6 volts. This battery supplies DC voltage to the motorcycle's electronic components once the engine is not running. Moreover, it provides the necessary current to initiate engine ignition when the electric start button on the switchgear is activated. Once the engine is running, the alternator begins generating electricity. Essentially, it utilizes the engine's crankshaft rotation to induce electromagnetism in the magnets, thereby producing electricity. However, the alternator generates Alternating Current (AC) which must be converted into Straight Current (DC). This adaptation is accomplished through a rectifier/regulator, which not only transforms AC to DC but also regulates the quantity of current distributed to all the electronic systems onboard the motorcycle. In motorcycles, the electrical current is directed to the electronic components via a wiring harness. This harness consists of wires, terminals, and connectors tailored for a specific two-wheeler model to distribute electric power effectively. It serves a crucial function by interconnecting various electronic elements on the motorcycle. Electric bikes commonly utilize either a 48-volt or 52-volt battery. The variance between the two lies in power and performance, with the 52V battery offering superior performance.

A higher-voltage battery offers improved efficiency, as it requires less electricity to deliver the same or even better power output for the motorcycle. Traditional motorcycle batteries mostly belong to the conventional lead-acid type. While commonly mentioned to as either 6 or 12 volts, this description is somewhat inaccurate as the actual voltages often differ from these values when battery is in optimum condition. The principal voltage of the battery is resolute by the chemistry of the Lead Acid cell. When completely charged and in excellent condition, each cell typically maintains a voltage level around 2.1 volts across its terminals. Motorcycle batteries are composed of multiple such cells interconnected in sequence to achieve the desired voltage level.

A "6v" battery consists of three cells, resulting in a total voltage diagonally its terminals of 3 multiplied by 2.1 volts, which equals 6.3 volts. Similarly, a "12v" battery comprises six individual cells, providing a total of 6 multiplied by 2.1 volts, which equals 12.6 volts. These voltages remain not fixed and will vary depending on both the battery's state of charge (or discharge) and the electrical load placed upon it. As the battery is used and loses its charge, its voltage gradually decreases. Likewise, connecting an electrical load to the battery also causes a drop in voltage.

Voltage levels of 12/24 volts remain prevalent for supplying power to most electric four-wheeler vehicles. An EVs are composed to dominate the transport and flexibility sector, surpassing traditional Internal Combustion Engine (ICE) vehicles in the near future. In the inner power demands of EVs expected to rise, exertions are focused towards achieving extended driving ranges and providing adequate power for low-voltage (LV) network auxiliary loads. This heightened demand stems from the incorporation of additional cameras, sensors, and small activating motors, particularly in anticipation of upcoming independent vehicles.

2. Literature Review

In their study, Md. Rezanul Haque and Md. Abdur Razzak (et al., 2021) emphasized the importance of controlling the harvest voltage overshoot and settling time of buck converters by implementing a altered PI controller. They conducted a comprehensive analysis comparing the recital of the conservative PI controller with the projected altered PI controller. This altered

PI controller created buck converter, characterized by condensed minimal overshoot and settling time, grips considerable potential for attractive the efficiency of EV battery charging systems [1].

Sanjeev P S, Arunkumar R, Naveen P, Sritha P (et al., 2023) have highlighted the increasing popularity of electric vehicles (EVs) as a sustainable means of transportation, playing a important part in fostering a greener future. The establishment of efficient and dependable charging infrastructure is paramount for facilitating the widespread acceptance of EVs. A crucial component within EV charging systems is the DC-DC converter, responsible for bridging the hole amongst the power source and the vehicle's battery. This paper introduces the plan and replication of a Buck-Boost converter tailored for EV charging applications, utilizing MOSFET technology within MATLAB Simulink. The proposed Buck-Boost converter is engineered to accommodate the fluctuating voltage levels encountered during EV charging scenarios, rendering it suitable for both rapid and gradual charging requirements. Through the optimization of the converter's design and control strategies, the objective is to contribute towards the advancement of efficient and reliable EV charging infrastructure, ultimately fostering the uptake of electric vehicles and mitigating carbon emissions.

This paper delves into a detailed investigation of designing and simulating a converter specifically tailored for EV charging. The range of MOSFET technology, well-known for its tall competence and precise control, highlights the commitment to achieving optimal performance in managing voltage fluctuations and load variations commonly encountered in EV charging scenarios. The principal aim of this study is to contribute to the progress of EV charging infrastructure, aligning with the mission of promoting technological innovation for societal improvement. Through refining the plan and controller strategies of the Buck-Boost converter, this research aims to enhance the effectiveness and dependability of EV charging systems. By offering valuable insights into the design and simulation of Buck-Boost converters for EV arraigning, this study strives to advance the realization of a cleaner and more sustainable transportation ecosystem [2].

R. D. Belekar,Shweta Subramanian, Pratik Vinay Panvalkar, Medha Desai , Ronit Patole, (et al 2017) implementation of modelling and testing for a battery electric motorcycle with a self-charging system aimed at optimizing energy utilization is described. The endeavour involved developing a regenerative system for a Battery Electric Vehicle (BEV), which harnesses the rotational liveliness of the wheels to replenish the batteries. This system maximizes the utilization of power generated by the electric motor. To accommodate the battery sizes and integrate the self-charging system, modifications were made to the chassis of a commercially available motorcycle. Mechanisms such as the alternator, motor, and DC-DC converter were strategically arranged to transfer rotational energy from the chain sprockets to the alternator. The alternator, capable of producing 14.4V DC, directs the power to the DC-DC messenger through a battery source. The DC-DC converter steps up the voltage to 54V, sufficient to charge the four batteries connected in series, yielding a 48V output. Consequently, the batteries, initially providing rotational energy to the shaft through a motor, receive a suitable voltage source for recharging. The effectiveness of the vehicle's power supply to the batteries was assessed using a multi-meter, while the distance travelled with and without the recharging circuit was also examined, demonstrating its efficacy [3].

Ramy Kotb, Sajib Chakraborty, Dai-Duong Tran, Ekaterina Abramushkina, Mohamed El Baghdadi, and Omar Hegazy (et.al 2023) emphasize be accomplished of converting the high-voltage (HV) adhesion battery voltage, ranging from 320–800 V DC, to normal LV levels while accommodating huge current ratings of 5 kW and more. This High Voltage to Low Voltage DC-DC converter, commonly referred to as an Auxiliary Power Module (APM) in literature, theatres a crucial role in the EV's electrical system. The usual LV rails in an EV consist of the 12 V/24 V rail, responsible for instantly powering the vehicle's lighting and the electronic

control units (ECUs), while the 48 V rail is essential for propellent loads such as air compressors and electric power steering systems.
Moreover, in certain claims, this converter assumes the responsibility of voltage boosting to facilitate hybrid vehicle starting or extra backup power management, necessitating bidirectional capability. Consequently, this paper presents potential Auxiliary Power Module (APM) topologies tailored for EV applications. It also outlines the primary values and safety necessities associated with APMs [4]. The DC-DC converter serves to adjust the output power after the battery to meet these requirements and facilitates charging of the auxiliary battery as needed.

Design of Buck and Boost Converter

Design of Buck Converter.

The Buck Converter, categorized as a type of chopper circuit, is specifically engineered for step-down conversion of the incoming DC input signal. In operation, the fixed DC input signal is transformed into another DC signal at the output, but with a reduced magnitude. Essentially, it is tailored to generate an output DC signal by a lower magnitude than the initial input. This converter is occasionally denoted to as a Step-down DC to DC Converter, Step-down Chopper, or Buck Regulator.

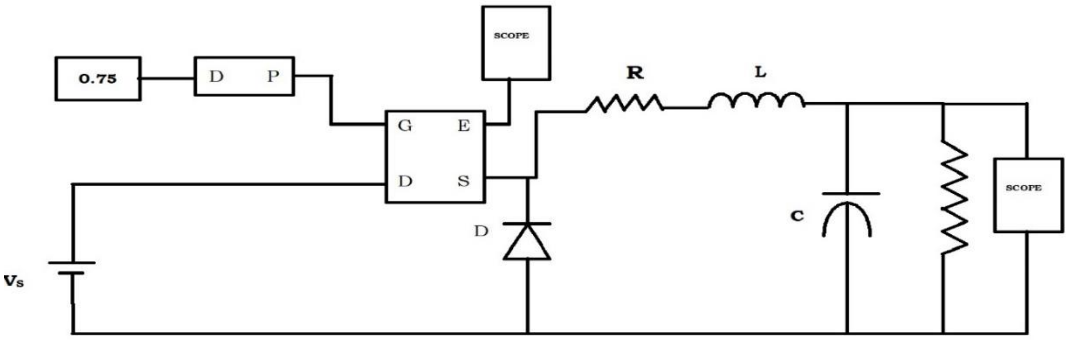

Figure.1 Simulink diagram of Buck Converter

The circuit layout clearly reveals the presence of two switches: one being the control electronics solid-state device serving as the primary switch, and the other being a freewheeling diode. These switches, in conjunction with a low-pass LC filter, form a connection aimed at mitigating current or voltage ripples, thereby facilitating the generation of a regulated DC output. Additionally, a pure resistor is combined into the arrangement to function as the circuit's load. The operation of the circuit unfolds in two distinct methods. The first mode occurs when the power MOSFET, also denoted to as switch S1, is closed. In this operational mode, switch S1 remains in a closed state, thereby enabling the flow of current through it.
When a fixed DC voltage is initially applied across the input terminal of the circuit, current flows through the circuit in the manner described above when switch S1 is closed. This current flow causes the inductor along the path to stock energy in the form of a magnetic field. Additionally, as current passes through the capacitor in the circuit, it also accumulates charge, resulting in the appearance of voltage across the load. However, in accordance with Lenz's law, the energy stowed within the inductor opposes the force that generated it, leading to the generation of an induced current and a reversal in polarity across the inductor. In this scenario, the total time period consists of a combination of Ton and Toff time. The parameters of buck converter as shown in table 1.

$$T = T_{on} + T_{off} \tag{1}$$

The duty cycle is written as

$D= T_{on} /T$ (2)

On applying KVL

$\Delta\, i_L = \frac{(V_s - V_{out})}{L} DT$ (3)

To find the Rate of Inductor,

$L = DV_S(1 - D)/\Delta i_L$ (4)

To find the Rate of Capacitor,

$C = V_0 (1\text{-}D) / 8\ (\Delta V_0) f^2\ L$ (5)

Assumption is $\Delta\, i_L$ $is\ 2\%\ of\ output\ Current\ and\ \Delta V_0$ is 0.5 % of Output Voltage.

Finally Output Voltage

$V_0 = D * V_{in}$ (6)

Table 1 Parameters of Buck Converter

S. No	Parameters	Value
1.	Resistor	0.02 Ohm
2.	Inductance	3milli Hendry
3.	Load Resistor	10 Ohm
4.	Capacitor	30 micro-Farad
5.	PWM	10KHz

Design of Boost Converter

Boost Converters, also referred to as step-up choppers, are a type of chopper circuit capable of generating an output voltage greater than the supplied input voltage. Unlike other chopper circuits, such as buck converters, where the output voltage is lower than the input voltage, boost converters operate in a manner that results in an increased magnitude of output voltage associated to the input. The term "boost" is aptly applied to these converters because they elevate the output voltage beyond the input voltage level.

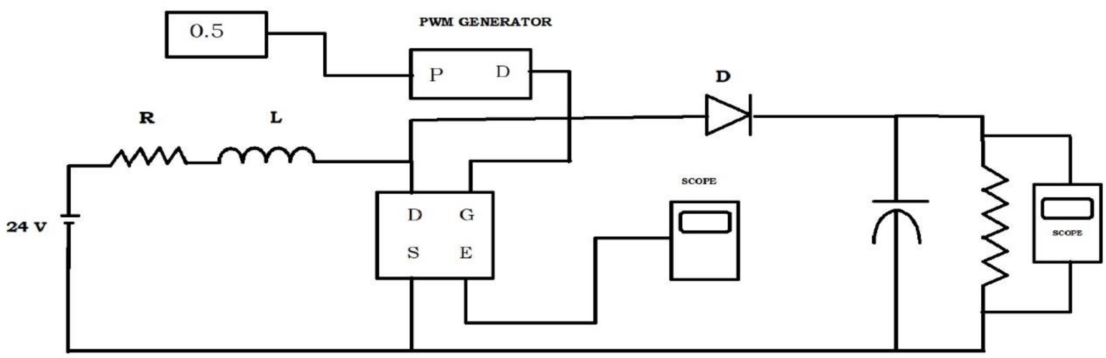

Figure.2 Simulink diagram of Boost Converter

The inductor, by storing energy in the method of a magnetic field, ensures that the current through it does not dissipate instantly. According to Lenz's law, a reverse current is induced to counteract the action that caused it. Consequently, the induced current leads to a reversal in polarity across the inductor. This reversed polarity forward biases the diode within the circuit, creating a pathway aimed at current flow through the diode and subsequently through the load during the off state of the chopper, denoted as Toff. It is important to recognize the current through the inductor decreases over time and eventually dissipates. The parameters of boost converter as shown in table 2.

Thus, the total voltage across the load resistor will be given a

Thus, the total voltage across the load resistor will be given a

$V_{out} = V_{in} + V_L$ (7)

$$\Delta\, i_L = \frac{DV_s}{L * f} \quad (8)$$

$$\Delta\, V_C = \frac{DI_0}{C * f} \quad (9)$$

The output Voltage is defined by

$V_0 = V_{in} / 1\text{-}D$ (10)

Table 2 Parameters of Boost Converter

S.No	Parameters	Value
1.	Resistor	0.001 Ohm
2.	Inductance	250 Micro Hendry
3.	Load Resistor	3 Ohm
4.	Capacitor	200 micro-Farad
5.	PWM	20 KHz

3. Results and Discussion

Simulation Results of Buck Converter

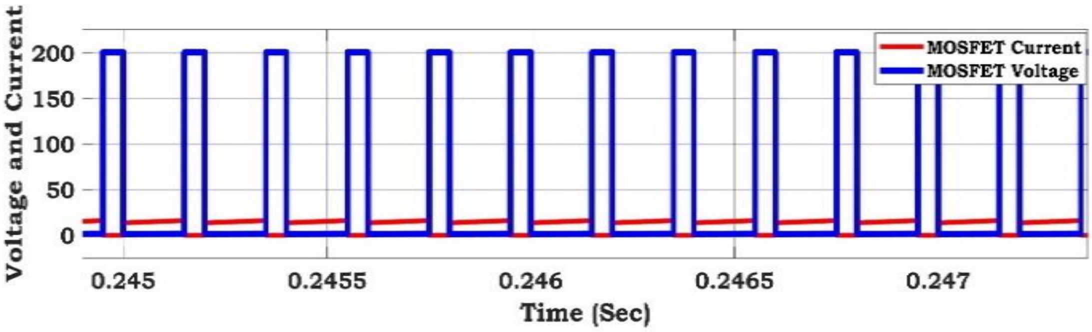

Figure.3 Simulation result of Input Voltage in Buck Converter

The input voltage of buck converter is 200V as shown in figure 3 and the output voltage is 150V by means of output voltage of buck converter is multiplication of Duty Cycle and input Voltage as shown in figure 4. A Buck converter reduces a DC voltage from its input to its output. Its functionality relies on the conduction status of the MOSFET: During the on-state, the current passing through the inductor rises while the diode prevents reverse current flow.

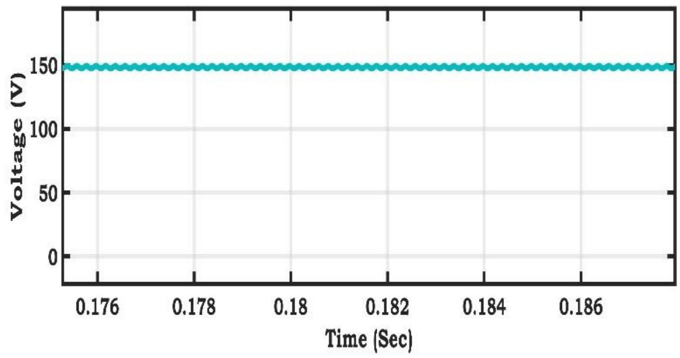

Figure.4 Simulation result of Output Voltage in Buck Converter

Simulation Results of Boost Converter

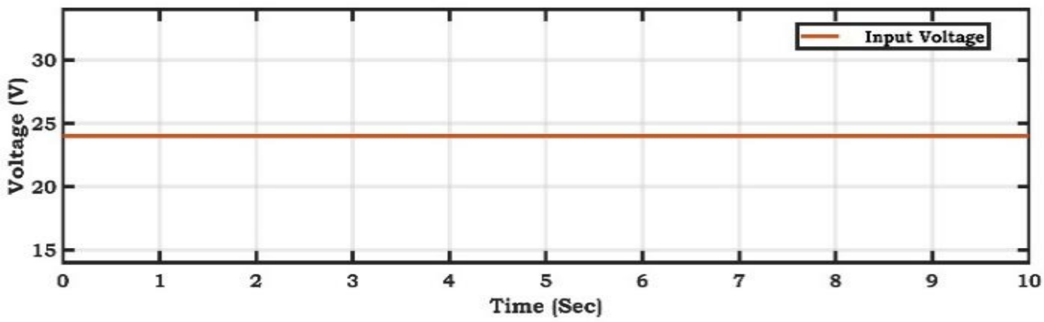

Figure.5 Simulation result of Input Voltage in MOSFET

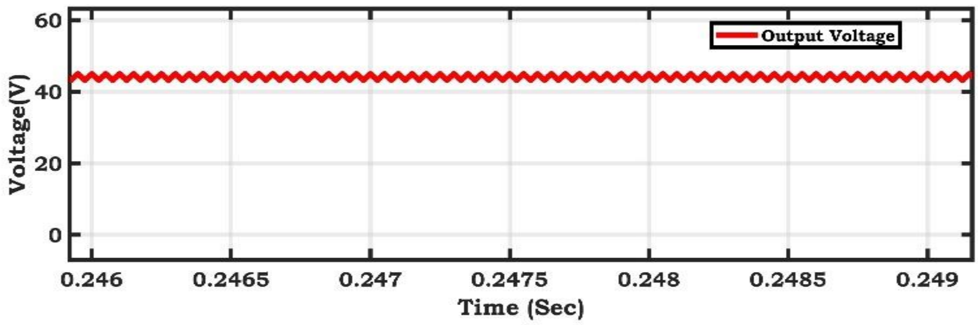

Figure.6 Simulation result of Output Voltage in Boost Converter

The input voltage of boost converter is 24V as shown in figure 5 and the MOSFET voltage is 48V by means of output voltage of boost converter is division of input Voltage by one minus duty cycle as shown in figure 6. The boost converter serves the purpose of elevating an input voltage to meet the higher level demanded by a load.

This procedure includes storing energy in an inductor and subsequently delivering it to the load at an increased voltage. Here, we discuss some prevalent challenges encountered when employing boost regulators.

4. Conclusion

The ongoing progress within the electric vehicle (EV) sector alongside the anticipated rise of independent vehicles is poised to drive increased demands on system functionality. One critical component, the HV-LV isolated DC-DC converter, faces the task of powering several LV networks such as 12 V, 24 V, and 48 V from the HV traction battery, typically operating at 400–800 V. With the automotive industry transitioning from traditional 12 V LV systems to higher voltages like 150 V using Buck Converters and the 48 V via Boost converters, there arises a necessity for new design criteria and safety protocols to enhance efficiency, power density, and overall reliability.

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