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Research Article

Simulation and Analysis of DC-DC Boost Converter using Pspice Software Program

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ABSTRACT

In many topologies and uses, the DC-DC converter has emerged as a crucial component. Electric cars, marine hoists, photovoltaic (PV) systems, uninterruptible power supply (UPS), and fuel cell systems have all seen a rise in the use of DC-DC converters in recent years. Focusing on both 9-24 V and 9-48 V applications, this study aims to showcase the design of a working DC-DC boost converter prototype. A direct-current-to-direct current (DC-DC) boost converter is essentially a step-up converter that produces a higher voltage at the output (Vo) than at the input (Vin). To get a greater voltage output, it boosts the input voltage. Because of its cheap price and great efficiency, the boost converter—also called a switch mode regulator—is quite common. The output voltage is highly dependent on the duty cycle and voltage source. A diode, capacitor, inductor, resistor, and metal oxide semiconductor (MOSFET) comprise the boost converter circuit. The operating principle of the boost converter relies on the inductor's capability to withstand variations in current. The boost converter is modeled and studied using the Pspice software application. The designed parameters were validated through simulation of the converter circuit model, which had an output power specification of 50W, an input voltage of 9V, and an operating frequency of 46kHz. A comparison is made between the theoretical and simulated outcomes of the boost converter.

1. Introduction

The tremendous benefits of power DC-DC converters (step up/step down) are driving their ever-increasing importance. A compatible power DC-DC converter has recently gained more attention as a means to achieve the needed power conversion in several domains, such as renewable energy, high and medium power applications, and so on1. In many ways, it functions similarly to an ac system's transformer. There is a growing need for switched mode power supplies and other DC-DC converters due to the proliferation of battery-operated portable electronics [1-5]. The current power landscape is characterized by rising consumption and relatively low utility. Renewable energy sources are crucial as a result of the increased need for their supply. You can't produce energy without first storing it, and that's where batteries come in. The DC-DC converter regulates the voltage derived from the batteries, which provide direct current. Power electronic switches and passive storage elements are used in DC-DC converters, which are constructed according to the application [6-10]. Vehicles utilizing high intensity discharge lights necessitate a DC voltage of 96V and a power rating of 40W. Although batteries can meet power needs, they take up a lot of room in cars. Therefore, a DC-DC boost converter is employed to increase the supply voltage to the necessary level. By carefully crafting the converter, this becomes a reality. High step up boost converters are utilized for huge DC voltage boosts, and each converter has its own set of advantages and disadvantages. Many studies have focused on this area in an effort to develop a converter that has better efficiency, faster response times, lower costs, and less redundant power processing.5. In general, when a large dc voltage is needed, boost converters are in high demand. The SPICE, which stands for a Simulation Program with an Emphasis on Integrated Circuits, was created at Berkeley, California, USA, University. Pspice is a version that Microsim Corporation7 created for commercial use. The designs of the step-up dc-dc converter have been verified by PSpice simulation [11-13].

The primary goal of this study is to propose a design for a direct current boost converter that has significantly lower losses, more efficiency, a simpler construction, and lower operational costs. It is also necessary to offer the steady-state analysis of the suggested converter operating in continuous conduction mode.In Section II of this study, the fundamental boost converter's topology is provided. Section III presents the modalities of operation. Section IV presents the process for designing the boost converter. The converter and its pspice simulation results are detailed in Section V. Section VI presents the results of the performance analysis of the proposed converter.

2. Topology

You can see the basic structure of a dc-dc boost converter in Fig.1. It has one inductor L, one diode D, one switch S, and one capacitor C. With a duty cycle of 66.3% and 83.7%, respectively, the suggested converter employs a MOSFET switch.

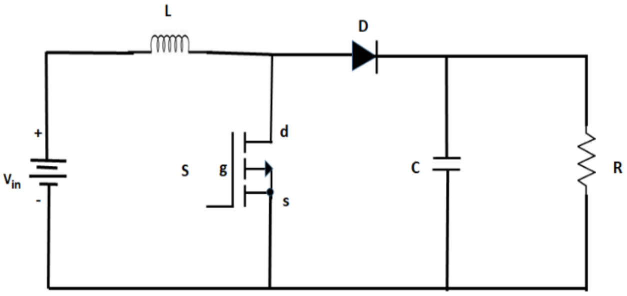

Figure 1. Basic dc-dc boost converter

3. Modes Of Operation

Boost converter operation based on two modes. They are

(1) Mode I: switch S is ON and diode D is reverse biased.
(2) Mode II: switch S is OFF and diode D is forward biased.

3.1 Mode I: Switch S is ON and Diode D is Reverse Biased

Diode D is open and reverse biased in this mode of operation, while switch S is closed and in the ON state. Therefore, current can pass through switch S. The entire current will travel via the inductor L, switch S, and then return to the dc input source via the closed channel. Fig. 2 shows the circuit diagram for this mode.

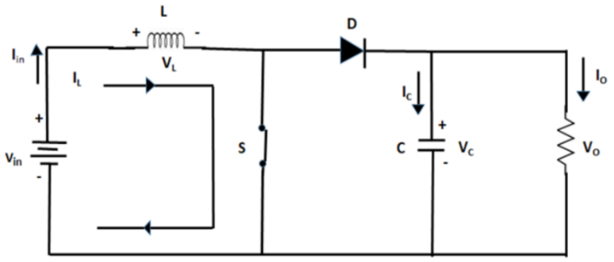

Figure 2. Boost converter circuit when switch S is closed

What this means is that the inductor's polarity will change depending on which way the current is flowing. By putting diode D into a reverse biased state, this mode isolates the output stage from the input by blocking current passage through the load. The input voltage VL=Vin and the voltage across the inductor IC=-Io are identical.

3.2 Mode II: Switch S is OFF and Diode D is Forward Biased

In this mode of operation, diode D is closed (forward biased) and switch S is open (OFF state). As a result, current can flow via switch diode D but cannot through switching S. See Fig. 3 for the circuit diagram of this mode.

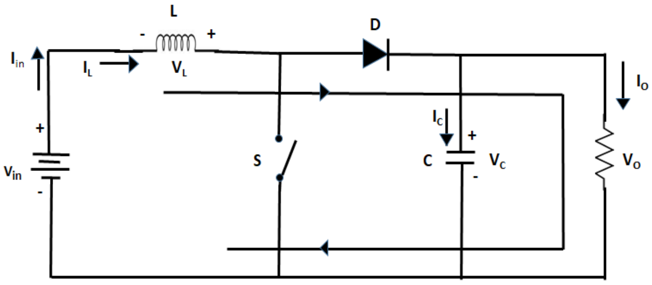

Figure 3. Boost converter circuit when switch S is open

When switch S is open, the inductor acts as a source of energy, storing it in the form of a magnetic field. Because of this, diode D is negatively biased. With switch S closed, the inductor stores energy for the next mode of operation, which is energy release. As the inductor's stored energy is released, the diode D is put into a forward biased state due to the reversal of the inductor's polarity. Therefore, it permits current to flow towards the load. To keep the current flowing in a straight line through the load and to increase the output voltage VL=Vin-Vo and IC=IL-Io, the dissipated energy is eventually dissipated in the load resistance.

4. Design Of The Proposed Boost Converter

The power rating for the load is 50W and the output voltages are 24V and 48V respectively. Thus, the input voltage is taken as 9V[9].

Resistance: (R)

$$R = \frac{V_o^2}{p} \tag{1}$$

where V_o is the output voltage

Duty cycle: (D)

$$D = 1 - \frac{V_{in}}{V_o} \tag{2}$$

where V_{in} is the input voltage. Using the value of D, the values of inductance and capacitance can be calculated.

Inductance: (L)

$$L = \frac{D(1-D)}{2f} \times R \tag{3}$$

where f is the switching frequency.

Capacitance: (C)

$$C = \frac{D}{2fR} \tag{4}$$

Output current (Io)

$$I_o = \frac{P_o}{V_o} \tag{5}$$

where P_o is the output power

Ripple voltage: (ΔV)

$$\Delta V = \frac{DI_o}{f \times C} \tag{6}$$

Ripple current: (ΔI)

$$\Delta I = \frac{DV_S}{fL} \tag{7}$$

Efficiency: (η)

$$\eta = \frac{output\ power}{input\ power} \tag{8}$$

To obtain the pspice simulation results, the parameters of the non-ideal boost converter under consideration are given in Tables 1-2.

Table.1 Design parameters of conventional boost converter for 9-24V

Parameters	Symbols	Values	Units
Input Voltage	V_{in}	9	V
Inductor	L	60	µh
Capacitor	C	50	µf
Resistor	R	11.52	Ω
Duty Cycle	D	66.3	%
Pulse Width Modulation	T_{on}	14.4	µs
Switch Frequency	F	46	Khz
Power	P	50	W

Table.2 Design parameters of conventional boost converter for 9-48 V.

Parameters	Symbols	Values	Units
Input Voltage	V_{in}	9	V

Inductor	L	152	µh
Capacitor	C	80	µf
Resistor	R	46.08	Ω
Duty Cycle	D	83.68	%
Pulse Width Modulation	T_{on}	18.19	µs
Switch Frequency	F	46	Khz
Power	P	50	W

5. Result and discussion

In order to anticipate how well a circuit will work before implementing hardware, simulation is utilized. Figures 4 and 5 display the DC-DC boost converter simulation model, which includes the less-than-ideal component effects.The VIn=9v, L=60µH, 152µH, C=50µF, 80µF, R=11.52 **Ω**, 46.08 **Ω**, and MOSFET (IRF540) with a switching frequency of 46kHz are used to model these circuits in PSpice. Efficiency needs are the primary factor in deciding the switching frequency. Switching pulses for 9V-24V and 9V-48V boost converters at 66.3% and 83.6% duty cycles, respectively, are shown in Figs. 6-7. To activate the MOSFET switch, a gate pulse of 5 volts was applied. Using the simulated outcomes, we may evaluate the system's performance. In Table 3, you can see the results of the boost converters' performance simulations. A boost converter's output voltage is proportional to its input voltage and duty cycle. We can change the output voltage by adjusting the duty cycle, while the input voltage remains constant. You can adjust the duty cycle by adjusting the pulse width modulation (PWM) of the switching pulse. The pulse's charging time (TON) has a direct correlation to the output voltage.

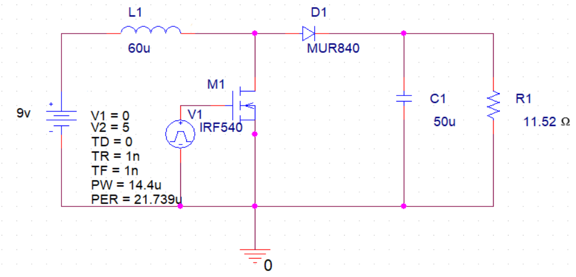

Figure 4. Simulation circuit of proposed boost converter (9-24V) using pspice

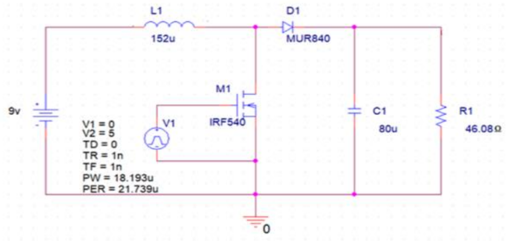

Figure 5 Simulation circuit of proposed boost converter (9-48V) using pspice

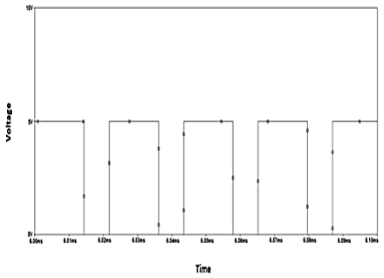

Figure 6. Switching pulses of boost converter using pspice (9-24V)

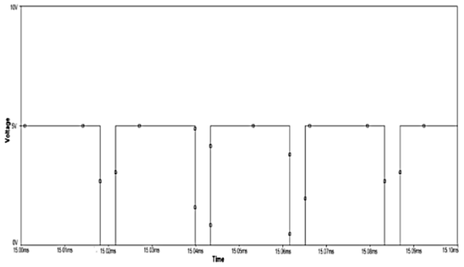

Figure 7. Switching pulses of boost converter using pspice (9-48V)

Figs 8-13 display the simulation outcomes for voltage, current, and power waveforms of boost converters. Fig 8 shows the waveforms of Vin, VL, VS, VD, VC and VO of the designed boost converter for 9V to 24V.

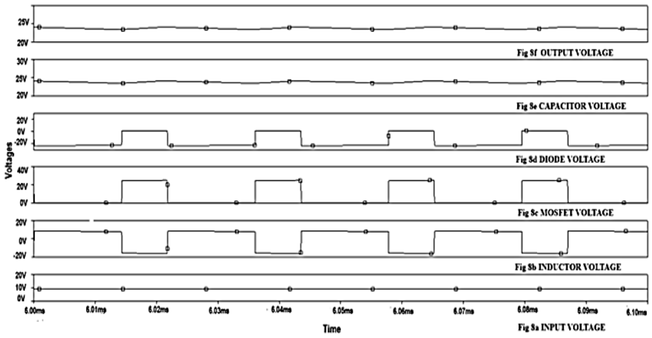

Figure 8 Voltage waveforms of boost converter for 9V-24V

Fig.8 shows the waveforms of the input voltage at 9V for the proposed boost converter. The voltage across the inductor is shown in Fig 8b. In the ON and OFF states of the switch, the voltage polarity is opposite. The switch voltage is +8.4V when the inductor is on and -16.1V when it's off. The above voltage is observed when the input source is connected to a 9V supply. Further, Fig. 8c and 8d represent the voltage across the MOSFET and diode. When the MOSFET and diode are on, the voltage across them reaches 0.6V. Figures 8e and 8f demonstrate the voltage across the capacitor and load of the proposed boost converter. From the waveform, we achieved a constant regulated output voltage of 24V without any ripples during both the ON and OFF states.

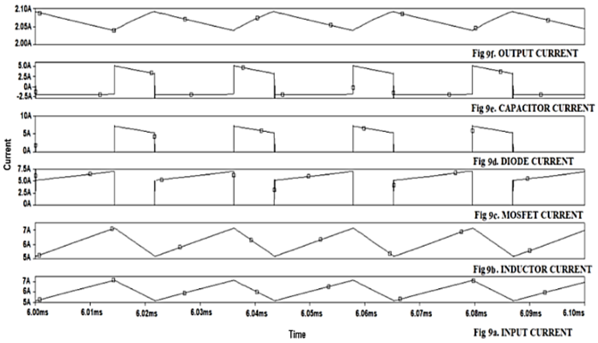

Figure 9. Current waveforms of boost converter for 9v-24v

Fig.9 shows the current waveforms of the input, inductor, MOSFET, diode, capacitor, and load of the boost converter with a voltage range of 9V-24V. Figs. 9a and 9b show the current waveforms of an input supply and an inductor. From these waveforms, we observed that the value of input current and inductor current is identical at 7.15A. Moreover, as shown in Figs 9c and 9d, the MOSFET and diode currents were 7.15A and 7.31A.. Fig 9e represents the capacitor current waveform. During the ON state, the current across the capacitor becomes -2.09A, and during the OFF state, it becomes 5.27A. As seen in Figure 9f, the output current value is 2.09A.

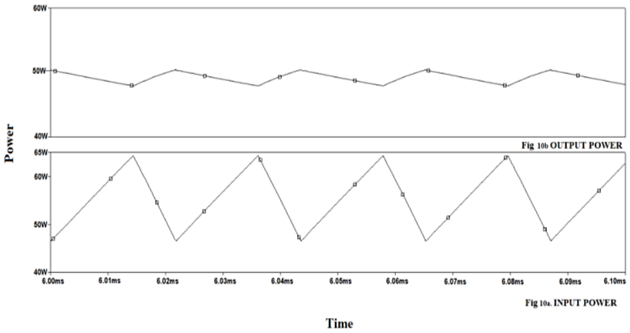

Figure 10. Power waveforms of boost converter for 9v-24v

Fig.10. Provides a visual representation of the power waveforms for the boost converter for 9V-24V. The waveforms of input and output power of the designed boost converter are depicted in Figs. 10a and 10b. The input and output power of 64.3W and 50W were confirmed by analyzing these waveforms.

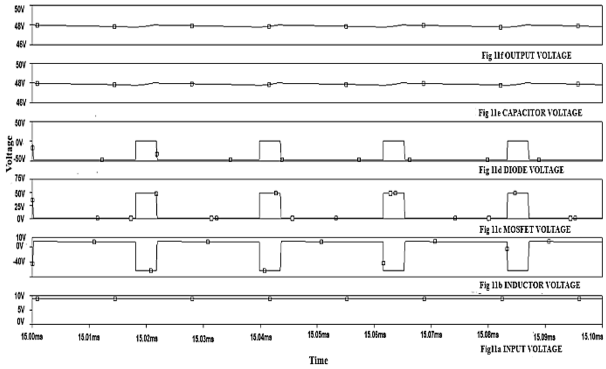

Figure 11. Voltage waveforms of boost converter for 9v-48v

Fig.11a shows the waveforms of the input voltage at 9V for the proposed boost converter. The voltage across the inductor is shown in Fig 11b. In the ON and OFF states of the switch, the voltage polarity is opposite. The switch voltage is +8.3V when the inductor is on and -40.1V when it's off. The above voltage is observed when the input source is connected to a 9V supply. Further, Fig. 11c and 11d represent the voltage across the MOSFET and diode. When the MOSFET and diode are on, the voltage across them reaches 0.6V. Figures 11e and 11f demonstrate the voltage across the capacitor and load of the proposed boost converter. From the waveform, we achieved a constant regulated output voltage of 48V without any ripples during both the ON and OFF states.

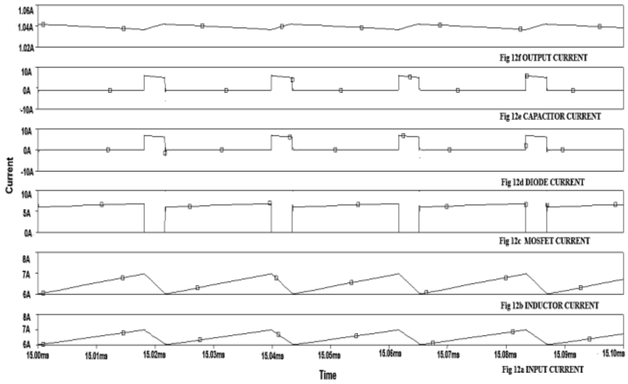

Figure 12. Current waveforms of boost converter for 9v-48v

Fig.12 shows the current waveforms of the input, inductor, MOSFET, diode, capacitor, and load of the boost converter with a voltage range of 9V-48V. Figs. 12a and 12b show the current waveforms of an input supply and an inductor. From these waveforms, we observed that the value of input current and inductor current is identical at 6.99A. Moreover, as shown in Figs 12c and 12d, the MOSFET and diode currents were 6.87A and 7.27A. Fig 12e represents the capacitor current waveform. During the ON state, the current across the capacitor becomes -1.04A, and during the OFF state, it becomes 6.23A. As seen in Figure 12f, the output current value is 1.04A.

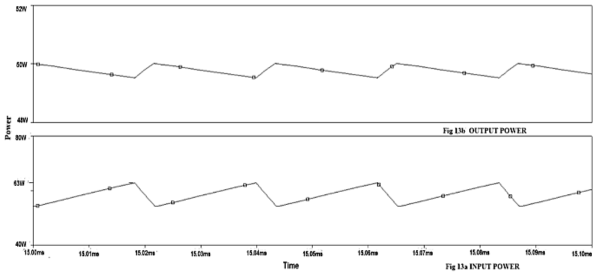

Figure 13. Power waveforms of boost converter for 9v-48v

Fig.13 Provides a visual representation of the power waveforms for the boost converter for 9V-48V. The waveforms of input and output power of the designed boost converter are depicted in Figs. 13a and 13b. The input and output power of 62.9W and 50W were confirmed by analyzing these waveforms.

Table.3 Simulation results of boost converters performance

PARAMETERS	SYMBOLS	SIMULATION RESULTS				UNITS
		FOR 9-24V		FOR 9-48V		
		ON	OFF	ON	OFF	
Input Voltage	V_{in}	9		9		V
Switch Frequency	F	46		46		Khz
Gate Voltage	V_g	5	0	5	0	V
Inductor Voltage	V_l	8.4	-16.1	8.3	-40.1	V
Mosfet Voltage	V_{ds}	0.6	25.1	0.6	48.5	V
Diode Voltage	V_d	-23.5	1.15	-47.3	0.53	V
Capacitor Voltage	V_c	23.5	24.1	48.0	47.7	V
Output Voltage	V_0	23.5	24.1	48.0	47.7	V
Ripple Voltage	V_r	0.60		0.23		V
Input Current	I_{in}	7.15	5.17	6.99	6.03	A
Inductor Current	I_l	7.15	5.17	6.99	6.03	A
Mosfet Current	I_{ds}	7.15	-0.16	6.87	-0.27	A
Diode Current	I_d	7.31	0	7.27	0	A
Capacitor Current	I_c	-2.09	5.27	-1.04	6.23	A
Output Current	I_o	2.09	2.04	1.04	1.03	A
Ripple Current	I_r	2.15		1.07		A
Input Power	P_{in}	64.3	47.9	62.9	54.2	W
Output Power	P_o	50.4	46.6	50.0	49.5	W
Efficiency	H	78	97	79	91	%

Table.4 Comparison of simulation results and theoretical results of boost converter

PARAMETERS	THEORETICAL RESULT		SIMULATION RESULT	
	9-24V	9-48V	9-24V	9-48V
Duty Cycle(%)	62.5	81.25	66.3	83.68
Inductor Voltage(V)	9	9	8.4	8.3
Capacitor Voltage(V)	24	48	24	48
Output Voltage(V)	24	48	24	48
Ripple Voltage(V)	0.60	0.23	0.61	0.25
Capacitor Current(A)	-2.08	-1.04	-2.09	-1.04
Output Current(A)	2.08	1.04	2.09	1.04
Ripple Current (A)	2.15	1.07	1.95	0.97
Efficiency(%)	80	80	80	80

Table.4. Compares the simulation results with the theoretical results of the designed boost converter. The simulation results are closely related to the theoretical results, as shown in the table above.

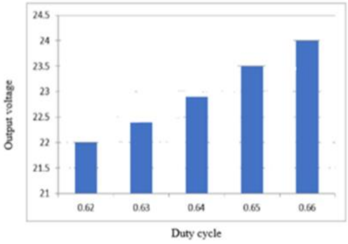

Figure 14. Output voltage versus duty cycle of 9V-24V boost converter

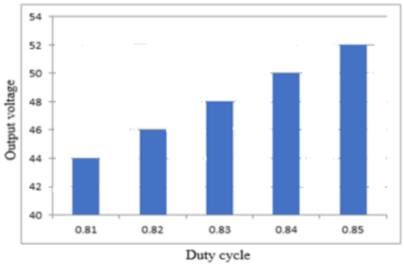

Figure 15. Output voltage versus duty cycle of 9V-48V boost converter

Figs 14 and 15 show the output voltage versus duty cycle for 50W prototype boost converters for 9V-24V and 9V-48V. An increase in duty cycle value leads to an increase in the output voltage of the boost converter. The boost converter's output voltage is influenced by the specific duty cycle.

6. Conclusions

In this paper, we examine the effective design and development of a DC-DC boost converter that utilizes low source voltage. The converter's design was done with an LT Spice XVII simulation tool and PSpice provided by the suppliers. The converter utilizes a simple circuit with a single switch and requires a minimal quantity of components. The simulation results indicate that the switching converter enhances the voltage by boosting from 9V to 24V and 9V to 48V, featuring low voltage and current ripple, and an efficiency of 80%. Theoretical results and simulation results are nearly identical. The simulation results that were obtained using PSpice give a comprehensive overview of the hardware's function and prepare us for the expected outcomes. Thus, the converter design's efficiency is improved and errors are minimized.

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Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study

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