DESIGN AND SIMULATION STUDIES OF BUCK CONVERTER

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ABSTRACT

Power electronic circuits that transform a DC voltage into a different DC voltage level are called DC-DC converters. The DC-DC converters that are the most basic include buck, boost, buck-boost, cuk, and sepic respectively. The function of every DC-DC converter is distinct. In this paper, a buck converter is proposed for developing and verifying the design procedure. Buck converter is a simple step-down DC-DC converter. The duty cycle and voltage source are both important factors in determining the output voltage. All converters are derived based on two basic converters, such as the buck converter and boost converter. The objective of designing converters is to achieve high efficiency and high gain with quick response times. There are so many parameters involved in developing these converters. There is a lot of computer software that has been developed to design these converters. Pspice simulations make it easy to analyze the system's behavior without the need for harmful hardware. The function of the buck converter designed ensures a good efficiency in converting power from 6V to 2.8V and 24v to 9v (2.85A & 1.10A). Pspice simulation results confirmed the effectiveness of the designed buck converter through a simulation study.

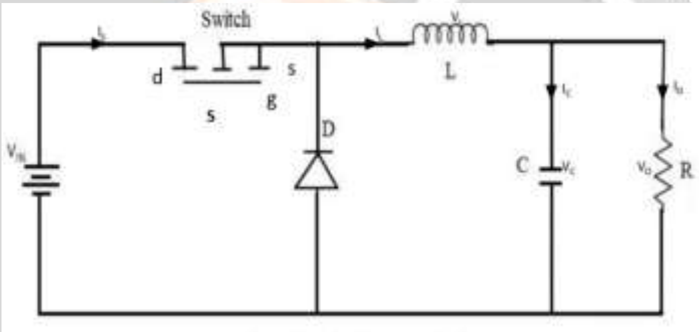
Keywords – *simulation, switching frequency, pulse width modulation, duty cycle, inductor voltage, ripple current.*

1.INTRODUCTION

The field of power electronics is concerned with the processing of electrical power using electronic devices. The key element is the switching converter[1]. Converter is power electronics device that can transform electric power from one form to another form. The dc-dc converter is converts the direct current of one voltage level to another level. The dc-dc converter is a dc power supply that is small, lightweight and highly efficient and uses a semiconductor switching element. A buck converter is a dc-dc converter which provides an output voltage which is always lower than the input voltage. Buck converter is also called step down voltage converter, stepping up current converter or buck regulator[2]. Buck converter are one of the most important components of the circuit which operates the voltage from the desired level to fixed level[3]. The dc-dc buck converter have been employed in various applications[4-6]. Any dc-dc converter has parasitic resistances in its storage elements (inductor, capacitor) and switching device (MOSFET, diode) etc. Moreover, diode also has forward conduction voltage drop, which is about 0.7-1.5v[7-8]. Dc-Dc converter consists of a simple structure formed by a few components, such as power switch, inductor, resistor, diode and capacitor. Computer based analysis/simulation tools have been used for power electronics circuit for many years, yet we are still far from being able to create routinely complete design without breadboarding. Challenges in the area of analysis or simulation tools for power electronics are described in literature[9]. The simulation package (PSPICE) is used to calculate the circuits wave forms, dynamic and steady state performance of the developed system[2]. The objectives of this study is to design and analysis of buck converter using Pspice software program. Using this Pspice aided design in dc-dc converter, it can reduce the time and cost. To accomplish this aim, verifying the operation of buck converter has been done by hardware implementation[10]. The 8W and 10W model of the buck converter have been analyzed to verify the effectiveness of the proposed converter [11].

2. OPERATION AND ANALYSIS OF DC-DC BUCK CONVERTER

The original concept of a Buck converter requires that the input voltage is chopped, in amplitude and develops the lower amplitude voltage at the output. A buck converter has switch mode dc-dc conversion with the advantages of simplicity and low cost. The Fig1 shows a simplified non-isolated buck converter, which allows a dc input and employs pulse-width modulation (PWM) of switching frequency to control the output of an internal power MOSFET. Apart, an external diode, external inductor and output capacitor, produce the regulated dc output. A buck or stepdown converters are designed to produce an average output voltage lower than the input source voltage[3]. The operation of buck converter is based on two modes.



Mode 1: Operation of buck converter ON state

When the switch is turned ON, diode become reverse biased and thus it will be in the non conducting state. The supply current starts flowing through filter components inductor, capacitor and through the load, as shown in Fig 1a. The inductor voltage during this period is the voltage difference between supplied voltage and output voltage. $V_L = V_{in} - V_o$

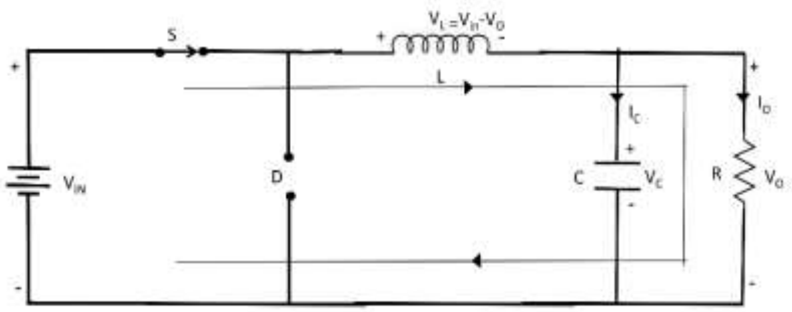


Fig 1a. Buck converter during switch ON state

Mode 2: Operation of buck converter OFF state

When the switch is turned OFF, the polarity of inductor reverses and it start acting as a source. The current in the mode flows due the stored energy in the inductor. The vin is disconnected during this period. Therefore, the current flows in the circuit till the inductor discharges. The voltage appears across the inductor is equal to the load voltage with negative polarity. $V_L = -V_o$, After turning OFF the switch, the polarity of inductor changes which makes the diode forward bias. The anode voltage become move positive then cathode during this period and hence starts conducting.(Fig.1b).

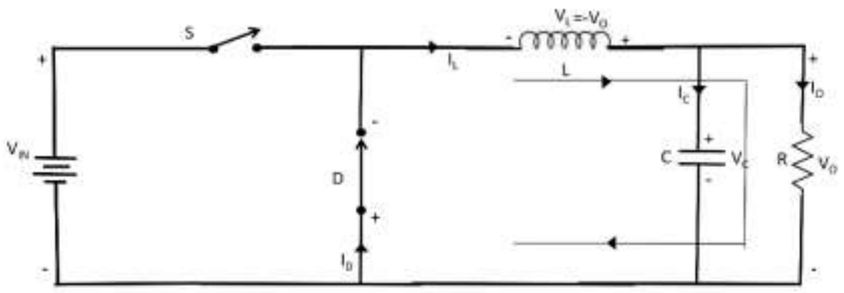


Fig 1b. Buck converter during switch OFF state

3. Design Methodology of Buck Converter

For designing the buck converter, under mentioned parameters have been utilized.

i) Duty cycle (D)

If the output and input voltages of buck converter are v_o and v_{in} , then the duty cycle, D is calculated as follows which is equal to conventional buck converter.

$$D = V_o/V_{in} \quad \text{--------(1)}$$

Duty cycle can be varied from 0 to 1 which is stated as percentage or ratio. In this paper, 46.6% and 37.5% duty cycle is used to design buck converter for different output voltages.

ii) Inductor (L)

The value for inductor is calculated by using this equation

$$L = (1-D) R / 2f_s \quad \text{--------(2)}$$

where, R is resistance(Ω), f_s is switching frequency(kHz)[13].

iii) Capacitor (C)

$$C = (1-D) / 16Lf_s^2 \quad \text{--------(3)}$$

iv) Resistor (R)

The value of resistor is calculated by using the following equation.

$$R = V_o^2 / P \quad \text{--------(4)}$$

where, P is power (W).

v) Output current (I_o)

$$I_o = P_o/V_o \quad \text{--------(5)}$$

Where, P_o is the output power.

vi) Ripple current (△I)

$$\Delta I = DV_S / f_s L \qquad \text{--------(6)}$$

vii) Ripple voltage (ΔV)

$$\Delta V = DI_o / f_s C \qquad \text{--------(7)}$$

viii) Efficiency (η)

$$\eta = \frac{\text{output power}}{\text{Input power}} \qquad \text{--------(8)}$$

The system simulation is carried out through Pspice. To obtain the Pspice simulation results the desire parameters of buck converters are listed in Tables 1- 2

Table 1. Design parameters of conventional buck converter for 6v to 2.8v.

Parameters	Symbols	Values	Units
Input voltage	V_{in}	6.0	V
Duty cycle	D	56.0	%
Pulse Width Modulation	T_{ON}	28.0	µs
Inductor	L	60.0	µH
Capacitor	C	70.0	µF
Resistor	R	1.0	Ω
Switching frequency	f_S	20.0	kHz
Power	P	8.0	W

Table2. Design parameters of conventional buck converter for 24v to 9v.

Parameters	Symbols	Values	Units
Input voltage	V_{in}	24.0	V
Duty cycle	D	40.0	%
Pulse Width Modulation	T_{ON}	20.0	µs
Inductor	L	220.0	µH
Capacitor	C	80.0	µF
Resistor	R	8.10	Ω
Switching frequency	f_S	20.0	kHz
Power	P	10.0	W

4. RESULT AND DISCUSSION

Simulation is employed to predict the circuit's performance before its implementation in hardware. The simulation model of a DC-DC buck converter with non-ideal effects of the components is shown in Figures 2 and 3. These circuits were simulated in PSpice with V_{in}=6v and 24v, L= 60µH and 220µH, C= 70µF and 80µF, R= 1 Ω and 8.1 Ω and MOSFET(IRF540) with a switching frequency of 20KHz. Switching frequency selection is usually determined by efficiency requirements. The switching pulse for 6V-2.8V and 24V-9V buck converters is depicted in Figs. 4-5 with a duty cycle of 56% and 40%, respectively. The MOSFET switch was subjected to a 5-volt gate pulse. The simulated results are utilized to evaluate how well the system performs. In Table 3, the simulation results for the performance of buck converters can be found. The duty cycle and input voltage are the two factors that influence the output voltage of the buck converter. The output voltage can be controlled by changing the duty cycle because the input voltage is constant. The duty cycle can be varied by changing the PWM of the switching pulse. The charging time (TON) of the given pulse has a direct impact on the output voltage.

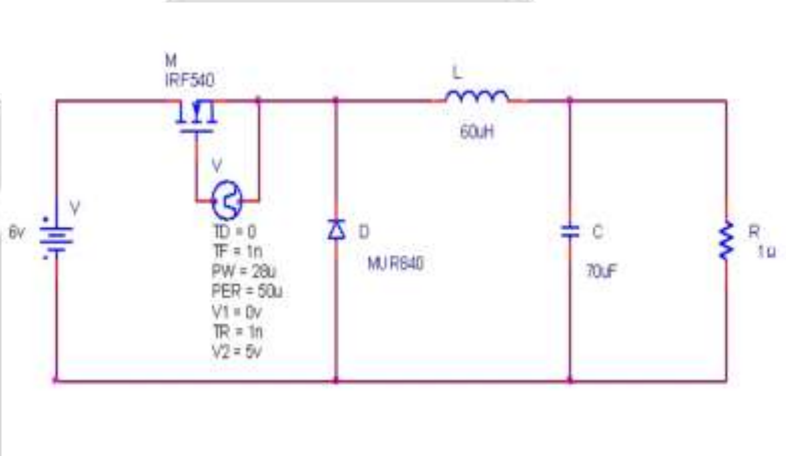


Fig.2 Simulation circuit of proposed buck converter (6v-2.8v) using Pspice

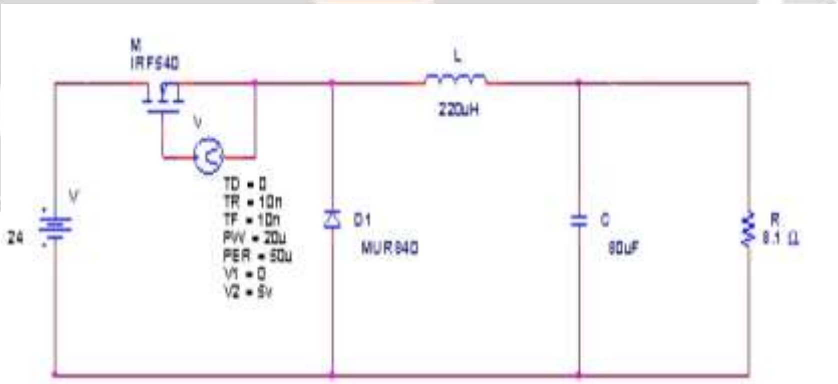


Fig.3 Simulation circuit of proposed buck converter (24v-9v) using Pspice

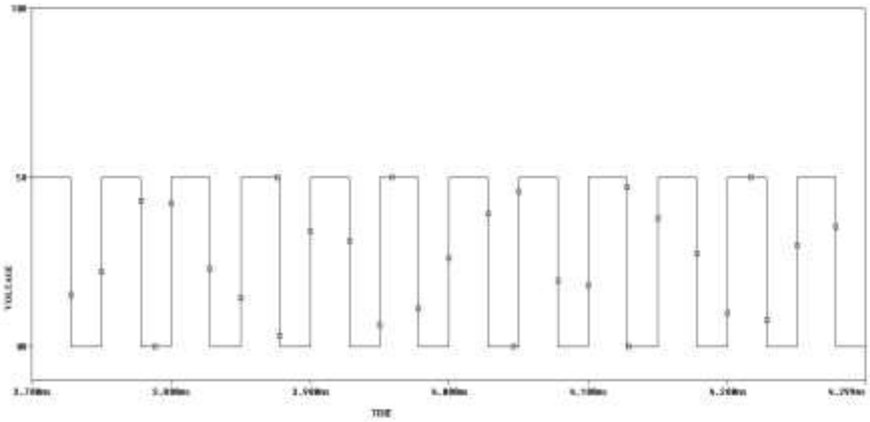


Fig.4 Switching pulses of buck converter using Pspice (6v-2.8v)

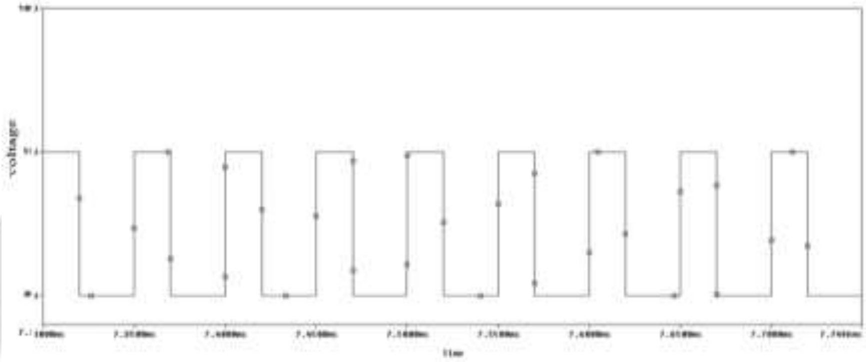


Fig.5 Switching pulses of buck converter using Pspice (24v-9v)

The simulation results for voltage, current, and power waveforms of proposed buck converters are depicted in Figs. 6-11. Fig.6 shows the waveforms of V_{in}, V_s, V_D,V_L,V_C and V_o of the designed buck converter for 6v to 2.8v.

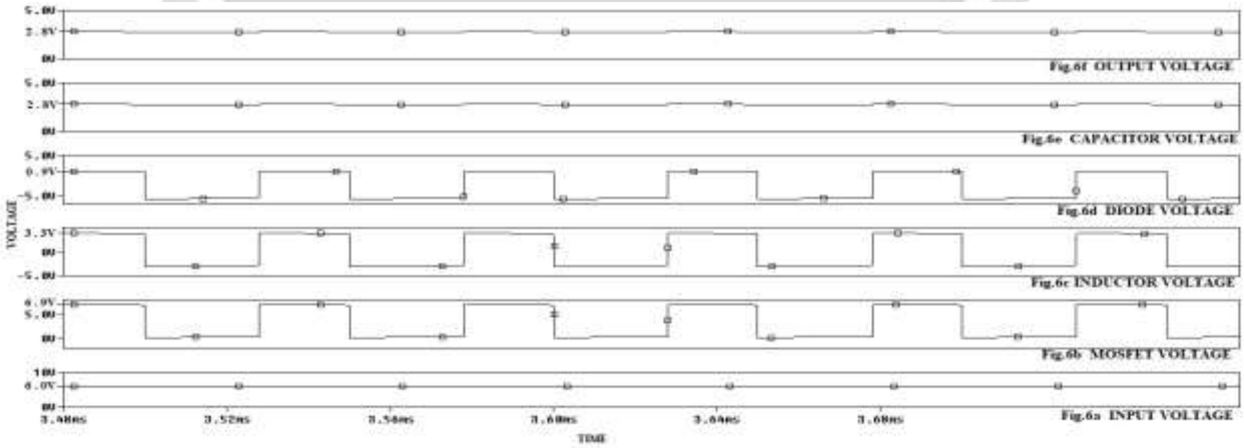


Fig.6 Voltage waveforms of buck converter using Pspice (6v-2.8v)

As shown in fig.6a, the waveforms of the input voltage at 6V correspond to the proposed buck converter. The voltage across the MOSFET and diode is depicted in Fig 6b and 6d. These waveforms indicate that the voltage across the MOSFET and diode during ON state fluctuates between 6.9V and 0.9V. The MOSFET and diode experience a voltage of 0.2V and -5.6V while in the OFF state. Fig. 6c illustrates the voltage across the inductor. In ON and OFF state of the switch, the polarity of the voltage is opposite. Therefore, during the ON state, the voltage across the inductor is 3.3V, while in the OFF state, it is -2.9V. The proposed buck converter's voltage across the capacitor and load is depicted in Figs 6e and 6f, and we obtained a regulated output voltage of 2.8v without any ripples.

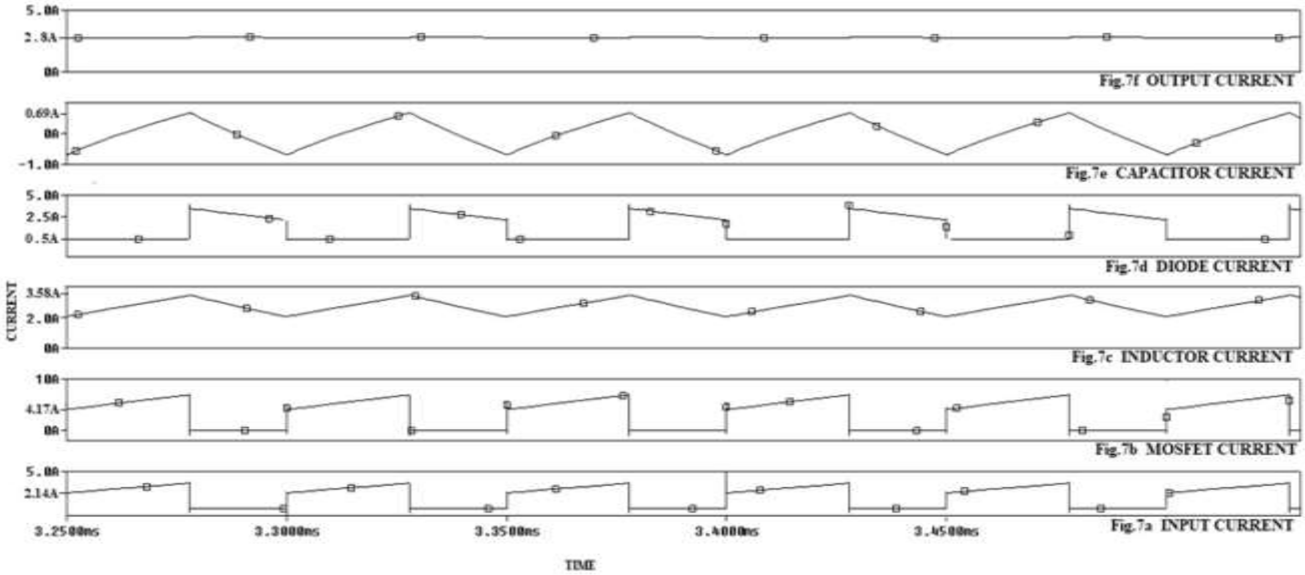


Fig 7. Current waveforms of buck converter using Pspice (6v-2.8v)

Fig.7 shows the current waveforms of the input, MOSFET, inductor,diode, capacitor, and load of a buck converter with a voltage range of 6V to 2.8V. The current waveforms of the input supply and MOSFET can be seen in Figs 7a and 7b. According to these waveforms, the input current and MOSFET current values increase by 2.14A and 4.17A while the system is in ON state. It was observed from Figs 7c and 7d that the diode and inductor currents are 0.5A and 3.58A. Furthermore, from Figs. 7e and 7f, it can be observed that the capacitor and output current value are 0.69A and 2.85A, respectively.

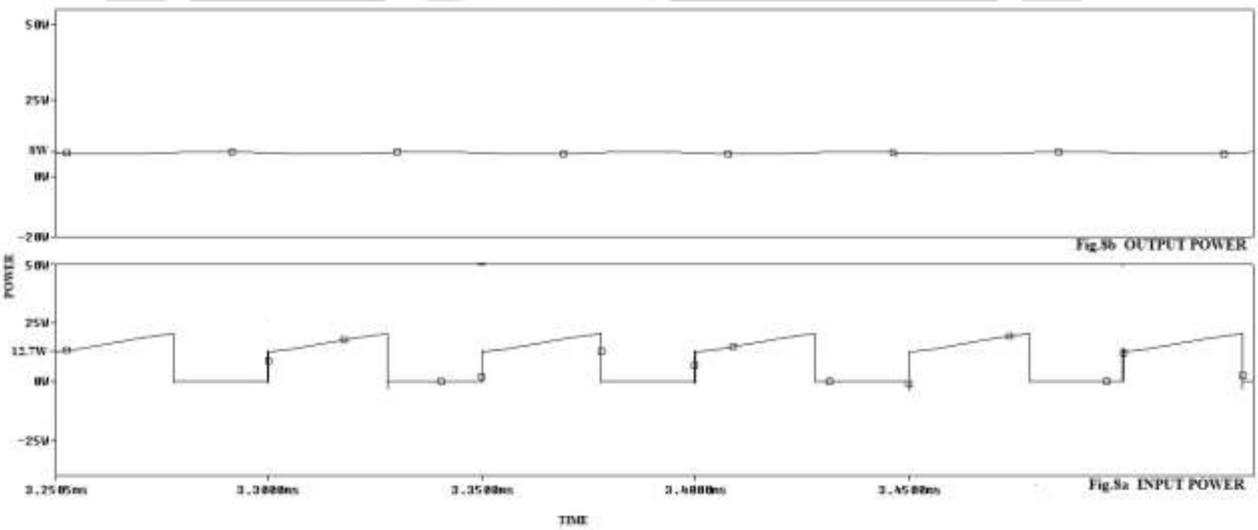


Fig.8 Power waveforms of buck converter using Pspice(6v-2.8v)

Fig.8 shows the power waveforms of a buck converter for 6V-2.8V. The waveforms of input and output power of the buck converter design are represented by Fig 8a and 8b. It was established that the input power and output power are 12.7W and 8W, respectively, based on these waveforms.

Table 3. Simulation results of conventional buck converters performance.

PARAMETERS	SYMBOLS	SIMULATION RESULTS				UNITS
		FOR 6-2.8V		FOR 24-9V		
		ON	OFF	ON	OFF	
Input voltage	V_{in}	6		24		v
Switch frequency	f_S	20		20		kHz
Gate voltage	V_g	5	0	5	0	v
Mosfet voltage	V_{ds}	6.9	0.2	24.89	0.1	v
Inductor voltage	V_L	3.3	-2.9	14.7	-9.9	v
Diode voltage	V_d	0.9	-5.6	0.8	-23.8	v
Capacitor voltage	V_c	2.8	2.74	9.0	8.96	v
Output voltage	V_0	2.8	2.74	9.0	8.96	v
Ripple voltage	V_r	0.11	-	0.12	-	v
Input current	I_{in}	2.14	0.11	0.56	0.52	A
Mosfet current	I_{ds}	4.17	0.2	1.06	0.1	A
Inductor current	I_L	3.58	2.1	1.76	0.4	A
Diode current	I_d	0.5	2.82	0.5	1.77	A
Capacitor current	I_c	0.69	-0.65	0.67	-0.67	A
Output current	I_o	2.85	2.74	1.10	1.09	A
Ripple current	I_r	1.48	-	1.36	-	A
Input power	P_{in}	12.7	0.69	11.9	1.27	W
Output power	P_o	8	7.3	10	9.9	W
Efficiency	η	63.0		84.0		%

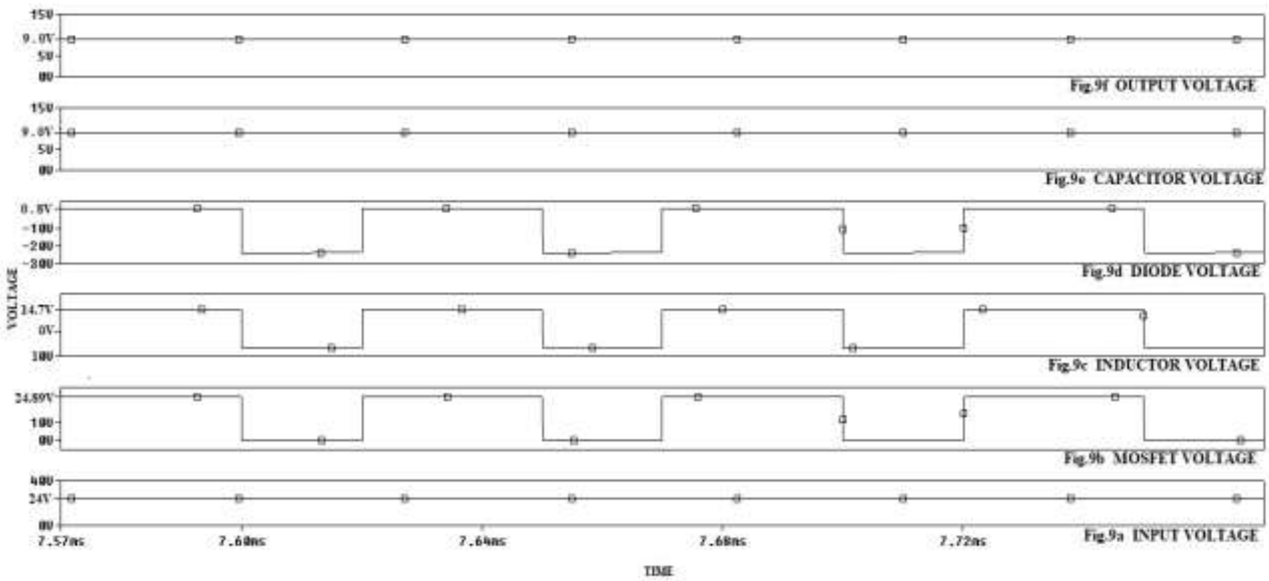


Fig.9 voltage waveforms of buck converter using Pspice (24v-9v)

Fig 9 shows the waveforms of Vin, Vs, V_D, V_L, V_C and V_O of the designed buck converter for 24v to9v. As shown in fig.9a, the waveforms of the input voltage at 24V correspond to the proposed buck converter. The voltage across the MOSFET and diode is depicted in Fig 9b and 9d. These waveforms indicate that the voltage across the MOSFET and diode during ON state fluctuates between 24.89V and 0.8V. The MOSFET and diode experience a voltage of 0.1V and -23.8V while in the OFF state. Fig.9c illustrates the voltage across the inductor. In ON and OFF state of the switch, the polarity of the voltage is opposite. Therefore, during the ON state, the voltage across the inductor is 14.7V, while in the OFF state, it is -9.9V. The proposed buck converter's voltage across the capacitor and load is depicted in Figs 6e and 6f, and we obtained a regulated output voltage of 9V without any ripples.

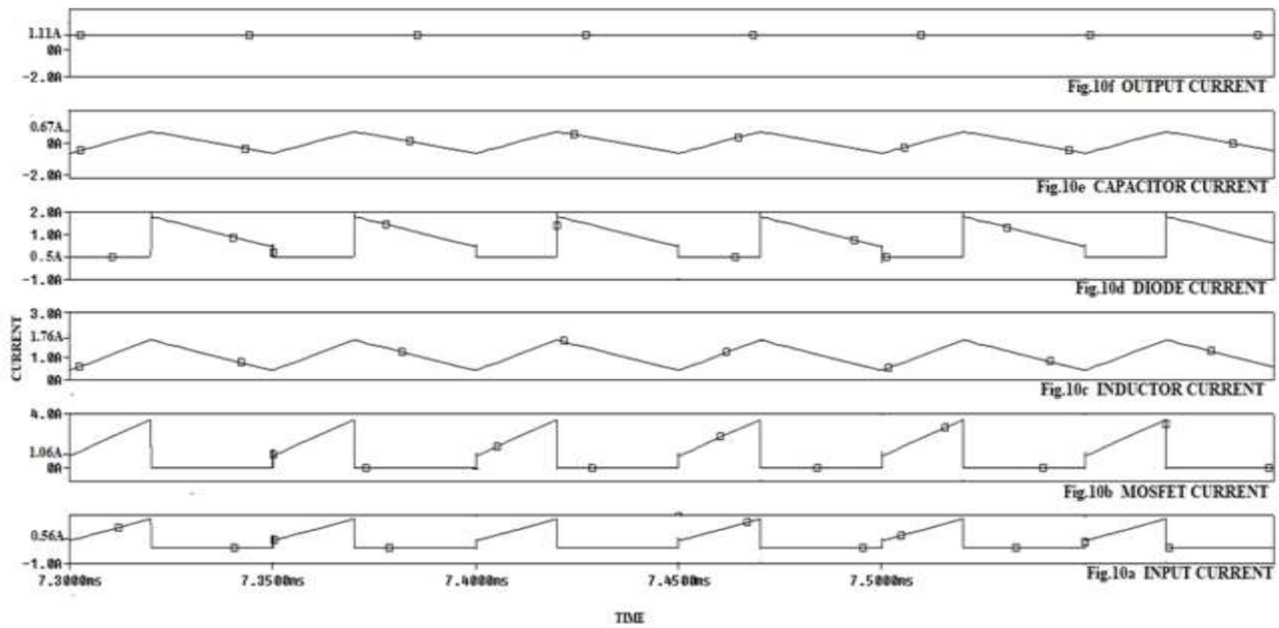


Fig.10 Current waveforms of buck converter using Pspice (24v-9v)

Fig.10 shows the current waveforms of the input, MOSFET, diode, inductor, capacitor, and load of a buck converter with a voltage range of 24V to 9V. The current waveforms of the input supply and MOSFET can be seen in Figs 10a and 10b. According to these waveforms, the input current and MOSFET current values increase by 0.56A and 1.06A while the system is in ON state. It was observed from Figs 10c and 10d that the diode and inductor currents are 0.5A and 1.76A. Furthermore, from Figs.10e and 10f, it can be observed that the capacitor and output current value are 0.67A and 1.10 A, respectively.

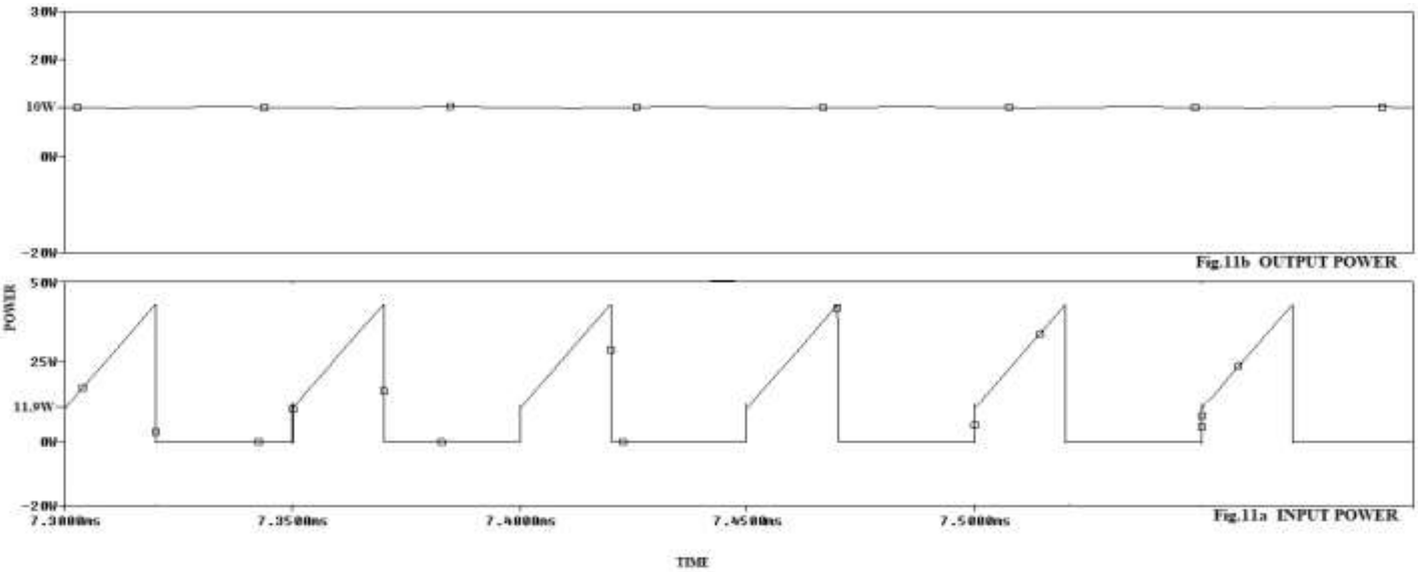


Fig.11 Power waveforms for buck converter using Pspice (24v-9v)

Fig.11 shows the power waveforms of a buck converter for 24V-9V. The waveforms of input and output power of the buck converter design are represented by Fig 11a and 11b. It was established that the input power and output power are 11.9W and 10W, respectively, based on these waveforms.

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

Parameters	**Theoretical results**		**Simulation results**		**Units**
	6v-2.8v	**24v-9v**	**6v-2.8v**	**24v-9v**	
Duty cycle	46.6	37.5	56.0	40.0	%
Capacitor voltage	2.80	9.0	2.80	9.0	v
Output voltage	2.80	9.0	2.80	9.0	v
Ripple voltage	1.14	0.27	0.11	0.12	v
Output current	2.80	1.11	2.85	1.10	A
Ripple current	0.08	0.09	1.24	1.27	A
Efficiency	-	-	63.0	84.0	%

Table 4 shows the comparison between the simulation results and the theoretical results of the desired buck converter. It is evident from the table above that the simulation results are closely aligned with the theoretical results.

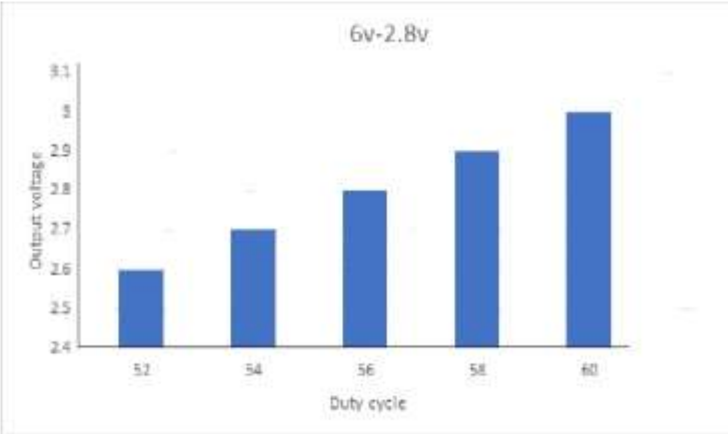


Fig.12 Output

voltage versus duty cycle of 6v-2.8v buck converter

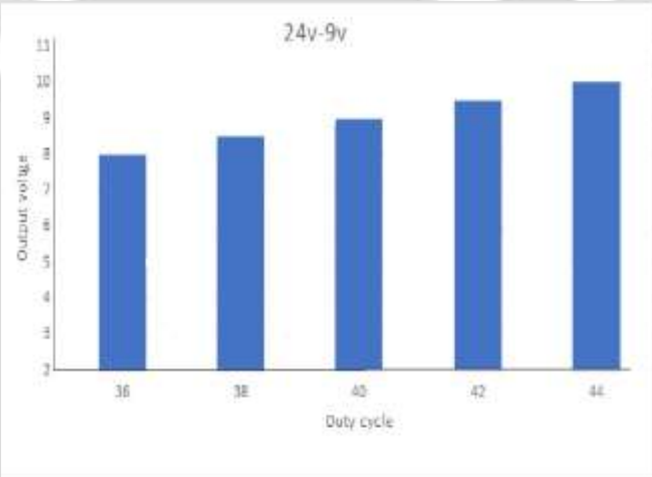


Fig.13 Output voltage versus duty cycle of 24v-9v buck converter

Figs 12 and 13 show the output voltage versus duty cycle for 8W and 10W prototype buck converters for 6v-2.8v and 24v-9v. The duty cycle's value has an effect on the output voltage of the buck converter. The buck converter's output voltage is determined by the specific duty cycle.

CONCLUSION

The focus of this study is on the analysis of a buck converter that is designed to handle low output voltage ripples (1.14V, 0.27V) with output voltages of 2.8V and 9V, and maximum currents of 2.8A and 1.11A. PSPICE software has been used to simulate the circuit, and it is confirmed that the desired output voltage is stable and the performance is satisfactory. There is a close agreement between the simulation results and theoretical results. The proposed buck converter is adaptable to both low voltage and high current applications.

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