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Design and develop a boost converter by using matlab simulink simulation

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ABSTRACT

This paper presents the design and development of a boost converter by using a resistive load. A booster converter is the most popular application in the industry to step up the direct current (DC) input voltage. This study focuses on determining the suitable value of the inductor and capacitor for use in the circuit. Then, this design focuses on continuous mode operation, with different voltage inputs of 9V and 15V DC, where the switching frequency input is 25kHz using the MOSFET as a switching device. The evaluation of this circuit design is to control the input voltage to keep the output voltage maintained at 24VDC. This analysis also uses a ripple inductor current, not more than 25% of inductor current, and output voltage ripple is less than 1%. The parameters for design circuits based on the output voltage, inductor voltage, and inductor current waveform. The design of this circuit will be analyzed using MATLAB Simulink software to verify the results between simulation and theoretical. Based on the simulation results prove that the developed model can maintain the output voltage by using different voltage input values. Finally, a boost converter circuit can be developing by using these parameters.

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Introduction

In many applications in industry, it is required to convert a DC input voltage into variable DC output voltage. The conversion voltage supply directly from DC voltage to a different DC voltage is called a DC converter. This converter is used to step the input voltage to desired voltage (Boujelben et al., 2017) .DC converter widely used in industrial applications that include motor control for electric automobiles, trolleys cars, marine hoists, uninterruptible power supplies, and battery-operated equipment (Abdessamad, Salah-ddine, & Mohamed, 2013) (Fathah, 2013). Generally, to step up input DC supply from the power sources such as batteries, solar panels, the output of the rectifier, DC supply, or DC generator the boost converter is used. (Palanidoss & Vishnu, 2018)The controller of operation boost converter is based on the duration of the switching process. The ratio of ON duration to the switching time period is called the switching duty cycle D, (M.J, 2016). The study is focused on the continuous current mode operation, which the analysis is referring to the continuous positive cycle during the switching operation. In this paper, the continuous current mode operation is used to get the better regulation for the circuit.

Operation of Boost Converter Circuit

The basic circuit diagram of the operation boost converter shown in Figure 1. The inductor used to provide a smooth input current, and some ripple components are included in the input current but considered as small, which can be ignored when the switching action is repeated at high frequencies. The circuit operation can be divided into two modes. Mode 1 begins when the switch is closed and Mode 2 when the switch opens. The switch can be implemented by a MOSFET, IGBT, or BJT. In this study, MOSFET is used to react to a switching process in a Boost circuit. The MOSFET is used because this component has lower switching losses compare to other components. (Hossain et al., 2018). Mode 1 begins when the switch is on, as shown in Figure 1(b), the current will flow from DC source to inductor L and switch. At this time, the diode is reversed bias and blocking the path current through the load. The inductor current and the energy stored in the inductor rises until the switch is turned off.

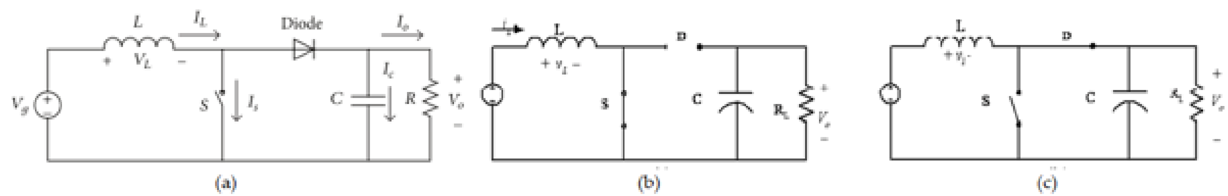

Figure #1 (a) The boost converter (Hajighorbani et al., 2014), (b) When switch is closed, (c) When switch is opened

Based on Kirchoff voltage law (KVL), the equation can be determined as **VL = Vs.** The voltage across the inductor is,

$$v_L = V_S = L\frac{di}{dt}, \qquad \frac{di}{dt} = \frac{Vs}{L} \quad \text{switched ON}$$

So, the duration of the process is called as on-time, $\mathbf{t_{ON} = DT}$. Recall that, $\mathbf{D = t_{ON} / T}$. The change in inductor current when the switch is closed is computing from

$$\Delta iL_{ON} = \frac{Vs}{L}DT = \frac{VsDT}{L} \qquad \text{---- Equation 1}$$

Mode 2 begins when the switch is off, as shown in Figure 1(c). The current that was flowing through the inductor, capacitor, resistor load, and diode so it produces **VL = Vs – Vo**. The inductor current falls until the switch is turned on again in the next cycle. The energy stored in the inductor is transferred to the load. In this design circuit, the output voltage Vo is assuming as constant, the voltage across the inductor is

$$v_L = Vs - Vo = L\frac{di}{dt}, \qquad \frac{di}{dt} = \frac{Vs - Vo}{L} \quad \text{switched OFF}$$

At this condition, the duration of off time is t_{OFF} = (1- D) T. Recall that, t_{OFF} = T - t_{ON} = T – D. So, the changing in inductor current can be computed from,

$$\Delta iL_{OFF} = \frac{Vs - Vo}{L}(1 - D)T \qquad \text{---- Equation 2}$$

Figure 2 shows the inductor voltage, inductor current and output voltage waveforms for the continuous current operation. It assumed that the current rises and falls linearly.

Southeast Asian Journal of technology and Science
Vol. 1, No. 2, 2020, pp. 48-53

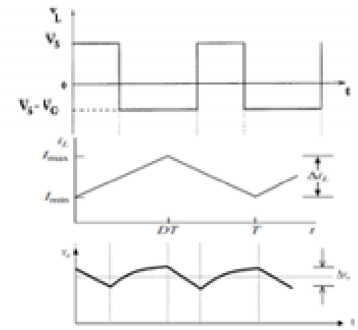

Figure 2 Step up converter waveform Inductor voltage (V_L) (Saharia & Talukdar, 2016), Inductor current (I_L) and Output Voltage (Vo)

Using equation 1 and *2*, the voltage output Vo is, $\Delta iL_{ON}+\Delta iL_{OFF}=0$

$$Vo = \frac{Vs}{1-D}$$

By resolving the average inductor current and making various substitutions, I_L expressed as

$$I_L = \frac{Vs}{(1-D)^2 R}$$

From the waveform we also can determined the value of maximum and minimum inductor currents by using the average value and the change in current

$$I_{max} = I_L + \frac{\Delta iL}{2} \quad \text{and} \quad I_{min} = I_L - \frac{\Delta iL}{2}$$

On the other hands, by a design perspective, it is useful to express L in terms of a desired*,* ΔiL , and also an equation to express required capacitance C, in term of specified voltage ripple can be calculated by

$$L = \frac{VsDT}{\Delta iL} = \frac{VsD}{\Delta iLf} \quad \text{and} \quad C = \frac{D}{R(\Delta Vo/Vo)f}$$

Design the Boost Converter

In this study, we need to consider the value of peak to peak inductor current and the output voltage ripple to design the Boost converter circuit. In the first stage of design, the calculation of parameters of boost converter circuit need to be done for two different input voltages of $9V_{DC}$ and $15V_{DC}$. After the value of the inductor (L) and capacitor (C) is already known, the simulation of the circuit is designed by using MATLAB Simulink software as shown in Figure 3. Based on the simulation reading, the comparison between calculation and simulation has been discussed.

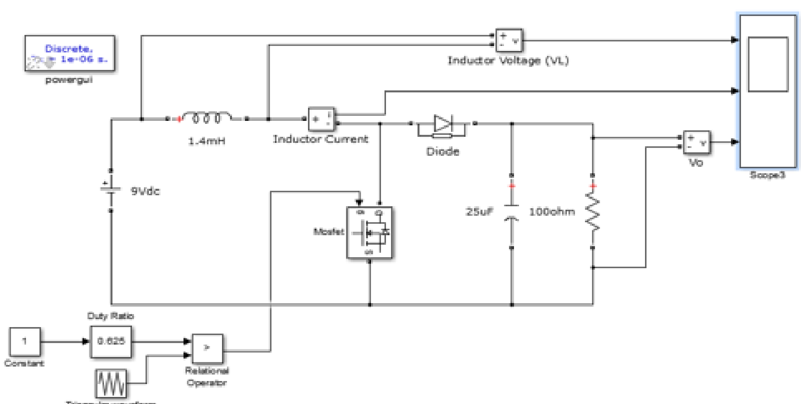

Figure 3 Boost Converter Circuit design using MATLAB Simulink

In this analysis use a ripple inductor current not more than 25% of inductor current, and output voltage ripple is less than 1%. The calculation below shows the first steps on designing Boost circuits by using a switching frequency value of 25kHz is shown in Table 1.

Table 1 Calculation of Boost circuit

Switching frequency value is 25kHZ, input voltage is 9V$_{DC}$ and output voltage is 24V$_{DC}$	**Switching frequency value is 25kHZ, input voltage is 15V$_{DC}$ and output voltage is 24V$_{DC}$**
$VL_{ON} = V_S = \underline{\underline{9V}}$	$VL_{ON} = V_S = \underline{\underline{15V}}$
$VL_{OFF} = Vs - Vo = 9V - 24V = \underline{\underline{-15V}}$	$VL_{OFF} = Vs - Vo = 15V - 24V = \underline{\underline{-9V}}$
$D = 1 - \frac{9}{24} = \underline{\underline{0.625}}$	$D = 1 - \frac{15}{24} = \underline{\underline{0.375}}$
$I_L = \frac{9}{(1-0.625)^2 \times 100} = \underline{\underline{0.64A}}$	$I_L = \frac{15}{(1-0.375)^2 \times 100} = \underline{\underline{0.384A}}$
$\Delta iL = \frac{25}{100} \times 0.64A = \underline{\underline{0.16A}}$	$\Delta iL = \frac{25}{100} \times 0.64A = \underline{\underline{0.096A}}$
$I_{max} = 0.64\text{A} + \frac{0.16\text{A}}{2} = \underline{\underline{0.72A}}$	$I_{max} = 0.384\text{A} + \frac{0.096\text{A}}{2} = \underline{\underline{0.43A}}$
$I_{min} = 0.64\text{A} - \frac{0.16\text{A}}{2} = \underline{\underline{0.56A}}$	$I_{min} = 0.384\text{A} - \frac{0.096\text{A}}{2} = \underline{\underline{0.34A}}$
$L = \frac{9 \times 0.625}{0.16 \times 25000} = \underline{\underline{1.4mH}}$	$L = \frac{15 \times 0.375}{0.096 \times 25000} = \underline{\underline{2.34mH}}$
$C = \frac{0.625}{100 \times 0.01 \times 25000} = \underline{\underline{25\mu F}}$	$C = \frac{0.375}{100 \times 0.01 \times 25000} = \underline{\underline{15\mu F}}$

Result and Discussion

In the first step, the buck converter is designed using MOSFET with switching frequency of 25kHZ, the input voltage is 9 V$_{DC,}$ and the duty cycle is 0.625. From the calculation, the value of the inductor is 1.4mH and the capacitor is 25uF. The design circuit is using MATLAB Simulink to obtain the result.

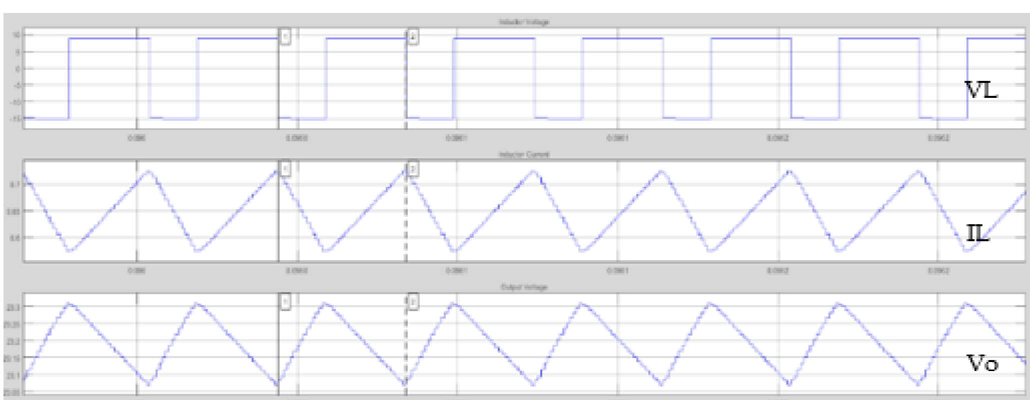

Figure 4 Boost converter waveform for Inductor voltage (VL), Inductor current (IL) and Output Voltage (Vo)

Based on the Table 2, the theoretical and simulation result for the boost converter circuit design shown the similar reading and all the accuracy is appropriate with 1. So, the suitable value of inductor and capacitor are influence to the result from simulation. On the other hand, when the duty cycle increases the value of ripple current or losses decrease. (Rai et al., 2016)

Table 2 <Comparison of the Parameter between Calculation and Simulation>

Parameter	Calculation	Simulation	Relative Error	Accuracy
VL_{ON}	9V	9V	0.00	1
VL_{OFF}	-15V	-15.11V	0.007	0.993
IL	0.64A	0.647A	0.011	0.989
ΔIL	0.16A	0.152A	0.05	0.95
I_{max}	0.72A	0.726A	0.008	0.992
I_{min}	0.56A	0.574A	0.025	0.975
Vo	24V	23.2V	0.033	0.967
ΔVo/Vo	0.01	0.01	0.00	1

In second analysis, the boost converter designed using a different input voltage is 15 $V_{DC,}$ and the duty cycle is 0.375. From the calculation, the value of the inductor is 2.34mH, and the capacitor is 15uF.

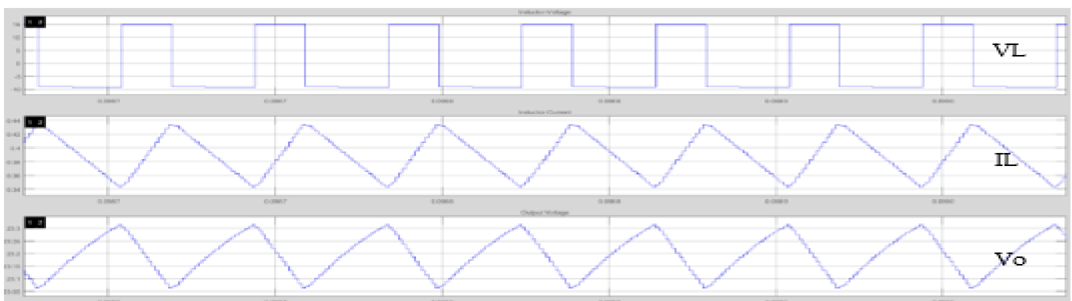

Figure 5 Boost converter waveform for Inductor voltage (VL), Inductor current (IL) and Output Voltage (Vo)

Table 3 <Comparison of the Parameter between Calculation and Simulation>

Parameter	Calculation	Simulation	Relative Error	Accuracy error
VL_{ON}	15V	15V	0.00	1
VL_{OFF}	-9V	-9.11V	0.012	0.988
IL	0.384A	0.389A	0.013	0.987
ΔIL	0.096A	0.091A	0.052	0.948
I_{max}	0.43A	0.434A	0.01	0.99
I_{min}	0.34A	0.343A	0.009	0.991
Vo	24V	23.194V	0.011	0.989
ΔVo/Vo	0.01	0.01	0.00	1

By referring on the result at Table 3, the accuracy is also closed to 1. It means that although the input supply is difference from previous design, but the accuracy can be maintaining as long the suitable value of inductor and capacitor can be determined.

Conclusions

Based on the boost converter circuit design, the setting of input switching frequency, percent of ripple inductor current from average value and output voltage ripple can be determining the suitable value of capacitor and inductor (Rashid, 2017). The simulation and theoretical results were compare based on the suitable value of inductor and capacitor. From the result shown although the input supply was changing, the output voltage can be maintaining as long the consideration of designing parameter is make. Both designing circuit shown the accuracy closed to 1. It means both circuits are successful design and develop.

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