DESIGN AND SIMULATION OF A DC – DC BOOST CONVERTER

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Abstract:
In this paper, a 300W DC – DC boost converter was designed by using electric circuit principles in obtaining the required circuit elements for the desired power, voltage and frequency specifications of the converter circuit. The values of the circuit elements obtained from the design were inputted in a model of the circuit in open and close loop configuration in MATLAB Simulink environment. On simulation testing, a 12V input to the open loop converter produced 20.4V, when a PI close loop controller was added, the boost converter produced the desired output voltage of 24.24V.

Keywords: DC- DC**,** Converters, Boost, Voltage, Simulation

1.0. INTRODUCTION

In our contemporary society, electrical and electronic devices are becoming more and more complex, because of the need to improve their quality, reduce their weight and increase efficiency. A power electronic circuit usually provides the power that drives electronic devices. A power circuit consist basically of a rectifier that converts the AC voltage to DC voltage, a filter to remove the ripples and a voltage regulator to maintain constant voltage output irrespective of changes in the load in the circuit (Zhimwang, et al, 2017). In certain application, A DC – DC rectifier is required to convert the input DC voltage to a different output voltage level (Laplante, 2018), just as a transformer changes an AC voltage input to another level of voltage output.

There are several types of DC – DC converters (Dokić and Blanuša, 2015), but the three basic types are; the buck, boost and buck-boost converters. The output voltage of a boost converter is always greater than the input voltage i.e. it is a step-up converter, the output voltage of a buck converter is always lesser than the input voltage i.e. it is a step-down converter while the output voltage of a buck–boost converter is either greater than or lesser than the input voltage (Rashid, 2004). Three basic types of DC-DC converters circuit are illustrated in Figure 1.

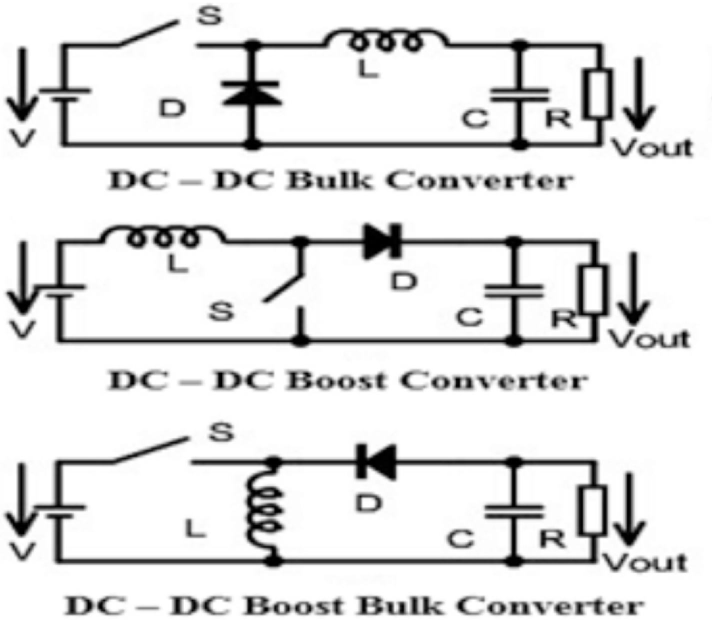


Figure 1. Circuit configuration of three basic DC –DC converter
Source: IEEE Xplore, DOI: 10.1109/ISCAS.2006.1692714

A DC – DC converter consist of two parts, the circuit element and the regulator or control (Dokić and Blanuša, 2015). As seen in Figure 1, the circuit elements in a DC –DC converters are an inductor, a capacitor, a diode and a switch. A power device is used as a switch. The switching power device can be a thyristor, gate turn-off thyristor (GTO), bipolar junction transistor (BJT) or Insulated Gate Bi-polar Transistors (IGBT). The trend however is that when DC – DC converter are required for high current applications, MOSFET is the preferred switching device and when a high voltage is desired, Insulated Gate Bi-polar Transistors (IGBT) are preferred (Wang et al, 2014).

The pulse-width modulation (PWM) technique is widely used to produce the ON and OFF signal to the switch (MOSFET or IBGTs) at the appropriate duty cycle and the two main methods of generating the PWM signal are: the Voltage-mode control and current-mode control. (Keeping, 2014). To achieve a stable output voltage, a close loop control system compares the output voltage with the desired set voltage and produce an error voltage (signal) by means of a feedback loop. The control system acts in such a way that the error is eliminated and a stable output voltage is maintained. Some close loop techniques includes PID, Fuzzy Logic and Artificial Neural Network. The PID controller is a basic close loop technique and involves three main algorithms. They are proportional (P) which is dependent on the present error, integral (I) which is the accumulation of past error and derivatives (D) which is the predictive of the future error (Bakar et al., 2015).

The DC – DC converters are applied in switch mode power supply, electrical vehicle, electric drives, electric brakes, solar and wind power system micro grid (Momoh, 2018).

Boost converter Operating Principle.

The operational principle of the boost

converter is as follows: As illustrated in the circuit configuration of the boost circuit in figure 2, when the transistor switch (MOSFET) is ON, the diode is OFF and the input current increases and flows through the inductor (L) and transistor (S). When the switch is OFF, the diode (D) is ON and the energy stored in the inductor flow through the diode, the capacitor and the load. When the inductor current falls to zero, the switch is ON and the process is repeated. The capacitor (C) in the output circuit is large enough to provide the output dc current to the load when the diode D is OFF and limit the output voltage ripple (Rashid, 2004; Czarkowski, 2001). The circuit configuration of the boost circuit is shown in Figure 2.

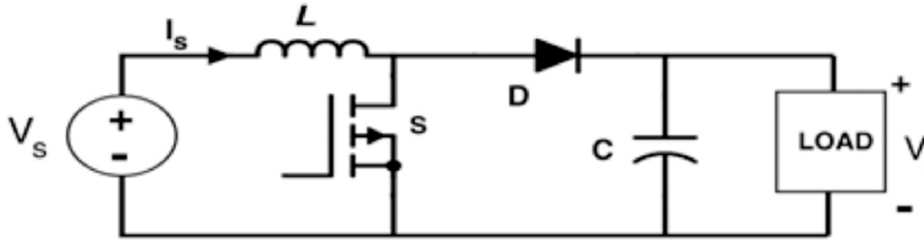


Figure 2: Schematic Diagram of Boost converter

Considering Figure 2, the relationship between the out and input voltage is expressed in (1) (Czarkowski, 2001).

$$\frac{V_o}{V_s} = \frac{1}{1-D} \tag{1}$$

where,
V_o is the output voltage,
V_s is the input or supply voltage
D is the switch duty cycle.
The circuit inductance (L) can be evaluated from (2) (Fathah, 2013).

$$L = \frac{V_s D}{\Delta I_L F} \tag{2}$$

where,
F is the operating frequency,
$\triangle I_L$ is the change in inductor current.
The value of capacitor can be selected from (3) (Fathah, 2013).

$$C = \frac{D}{(\Delta V_c / I_o) F} \tag{3}$$

where
$\triangle V_C$ is the change in capacitor voltage.
The efficiency η of the boost converter can be obtained from 4. (Erickson, 2001).

$$\eta = \frac{1}{1 + \frac{R_L}{(1-D)^2 R}} \tag{4}$$

where,
R_L is the load resistance,
R is the inductor resistance

It should be noted that for the inductor current, a typical value of switching ripple or change in inductance current at maximum load is 10% to 20% of the DC component of current, while the change in output voltage is also the output ripple voltage across capacitor C and the switching ripple typically required is about 1% or less of the dc output voltage (Erickson, 2001).

In this article, the PI close loop control system based on the PID in which the D (derivatives) algorithm is eliminated is proposed. The PID controller is illustrated in figure 3 and the transfer function *(G (s)* of the PID close loop control system is presented in 5. (Chatterjee et al., 2018).

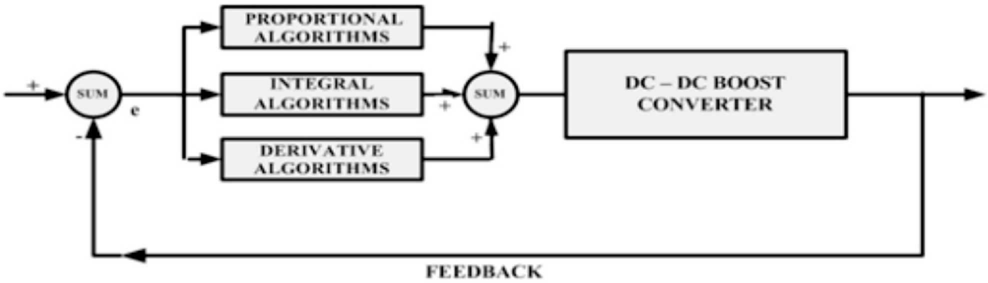


Figure 3. Block diagram of a PID close loop control system and DC –DC converter

$$G(s) = K_P + K_I \frac{1}{s} + K_D \tag{5}$$

where
K_P is the proportional gain,
K_I the integral gain,
K_D the derivative gain

By eliminating the last term in (5) the transfer function of the PI controller is obtained

$$G(s) = K_P + K_I \frac{1}{s} \tag{6}$$

1.0. METHODOLOGY

Boost Circuit Design

The DC – DC boost circuit specification is as follows:
Out power (P_O) = 300W
Input voltage (V_{in}) = 12V
Output voltage (V_O) = 24V
Operating frequency F = 50 kHz

The output current (I_O)equation is given in 7 (Navas 2018).

$$L_O = P_O/V_O \tag{7}$$

$$L_O = 300/24 = 12.5$$

From (2), $$D = 1 - \frac{V_{in}}{V_{out}}$$

$$D = 1 - \frac{12}{24}$$

$$D = 0.5$$
$$D = 50\%$$

The relationship between the input power (P_{in}), output power (P_O) and power – transfer efficiency is given in 8 (Luo et al., 2010).

$$\eta = \frac{P_o}{P_{in}} \tag{8}$$

or

$$\eta = \frac{I_o V_o}{I_{in} V_{in}}$$

Where
is the efficiency and
is the input current
The maximum input current is also the maximum current through the inductor, it is denoted as (can be obtained from 8:

$$I_{L\,max} = \frac{I_o V_o}{\eta V_{in}}$$

$$I_{Lmax} = \frac{12.5 \times 24}{0.92 \times 12}$$

$$I_{Lmax} = 27.17A$$

The inductor sizes are chosen such that the change in inductor current is no more than 10 % of the average inductor current.

$$\Delta I_L = 0.1 \times I_{Lmax}$$

Applying 2, the ripple change in the inductor current would require an inductor size of;

$$L_1 = \frac{12 \times 0.5}{2.71 \times 50000}$$

$$L_1 = 44.28\mu\text{H}$$

The variation in output voltage is expected to be less than 0.1 x 24 = 2.4. However, a value of 1V was selected.
Output voltage variation ($\Delta V_{O)}$ = 1V. From 3,

$$C_1 = \frac{0.5}{(^1/_{12.5})50000}$$

$$C = 125\mu\text{F}$$

A 150 μF capacitor was selected.
The DC – DC boost circuit was simulated in MATLAB Simulink, based on the calculated parameters. These parameters i.e. Duty cycle, inductor, capacitor, DC input voltage source were inputted in their various block and a MOSFET switch was selected. The Simulink model without the controller is shown in figure 4.

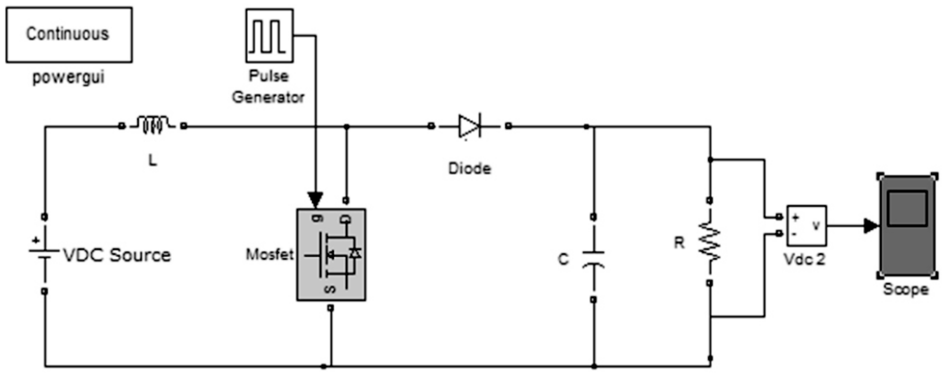


Figure 4: DC – DC boost circuit without controller in MATLAB Simulink

A Proportional Integral PI close loop controller was added to the boost circuit to enhance the output voltage and improve the efficiency. The Simulink model of the boost circuit and controller is shown in figure 5.

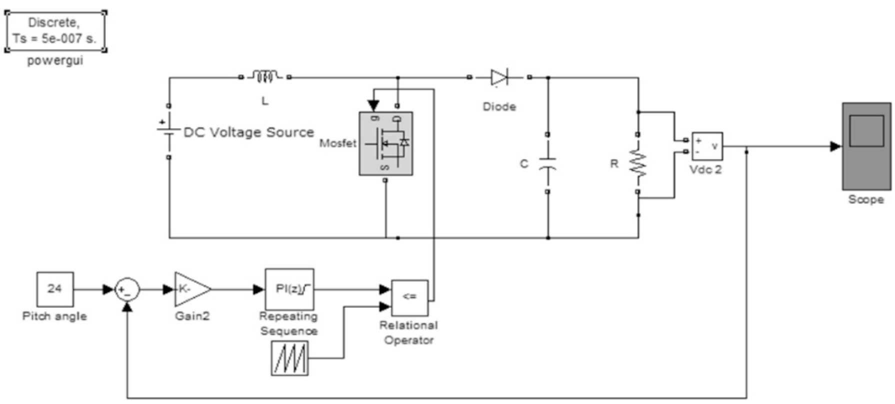
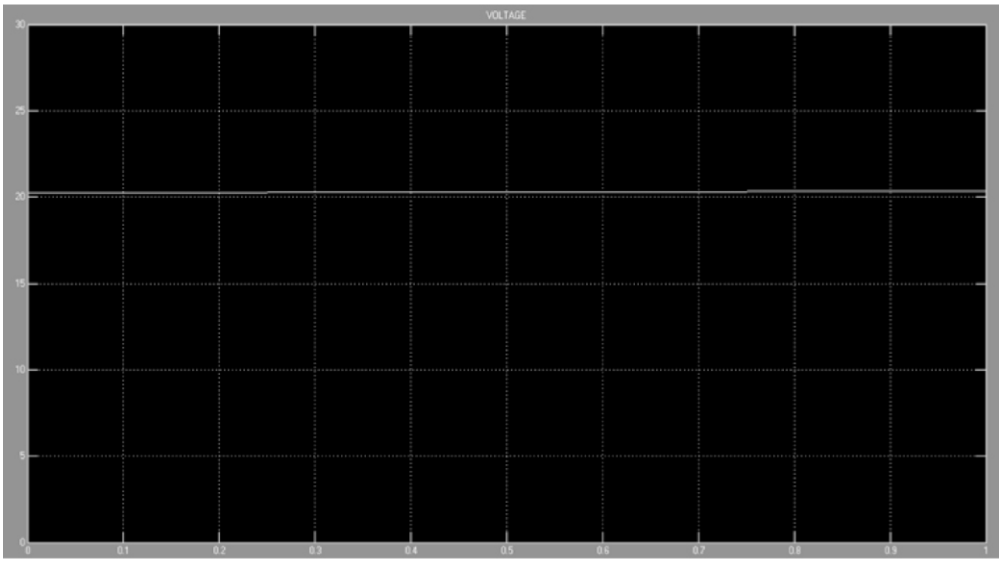


Figure 5: DC – DC boost circuit with PI close loop controller in MATLAB Simulink

1.0. RESULTS

The voltage output of the boost converter in MATLAB Simulink with and without the PI close loop controller is presented in figure 6 and 7.



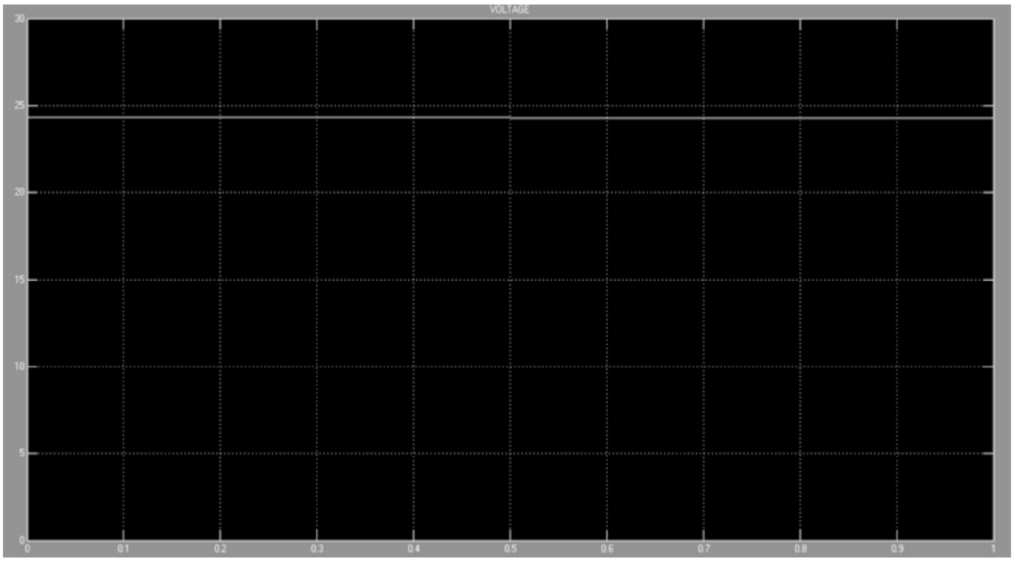


Figure 7: Voltage output of the DC – DC boost circuit with PI controller in MATLAB Simulink

From the results presented, at a voltage input of 12VDC, the output voltage without the use of a controller as shown in figure 6 was 20.4V. At this voltage level, the output is less than the desired or specified voltage level of 24VDC. When the PI voltage controller was added, the output voltage increased to 24.24VDC which is within the range of the specified voltage. At 24V, the output voltage and efficiency has been enhanced by the used of the PI controller.

CONCLUSION:

A DC – DC boost converter design was proposed and simulated in MATHLAB Simulink, the design specified an input voltage of 12V and an output voltage of 24V. The design was simulated in MATHLAB Simulink with and without the use of a close loop controller. Without the use of a controller, the output voltage was 20.4V and with the used of the PI controller, the output voltage was 24V. The results indicates that the DC – DC boost controller can increase the voltage level of a DC supply and the close loop voltage controller can stabilize and enhance the efficiency of a system.

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