

# A Study of Step-Up DC-DC Converter for Renewable Energy Systems Using PSPICE

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**Abstract :** Manufacturing In this paper, conventional boost converter have been taken and designed for photovoltaic and fuel cell-based renewable energy systems. The output voltages created by renewable energy sources such as photovoltaic arrays and fuel cell stacks are generally low. It has been required to be increased to high output voltage levels. The Step-Up DC-DC Converter, which are suitable for low-voltage high-power applications. The PSPICE Simulation of Step-Up DC-DC Converter has been studied in this paper.

**IndexTerms - Step-Up DC-DC Converter (Boost Converter), photovoltaic array, fuel cell, renewable energy.**

## I. INTRODUCTION

Many applications need efficient and high step-up DC-to-DC converters. For instance, in high intensity discharge (HID) lamp ballast, which is used in headlamps of automobiles in which the starting voltage is up to 400 V [1], the DC-to-DC converter needs to step-up the 12 V of the battery voltage up to 100 V.

The voltages produced by renewable energy sources such as photovoltaic (PV) arrays and fuel cell stacks are generally low. These voltages need to be increased to high voltages for certain applications such as 380 V for full-bridge inverter and 760 V for half-bridge inverter of a 220 V AC grid-connected system. One of the challenges in the development of renewable energy systems, which are based on photovoltaic modules and fuel cell stacks, is the conversion of relatively low DC voltage to high DC voltage. [3]

PSpice simulation of the step –up dc-dc converter has been done to verify the designs.

## II. DESIGN OF A STEP-UP DC-DC CONVERTER

Power for the boost converter can taken from any suitable DC sources, such as DC generators, batteries, solar panels and rectifiers. The method that changes one DC voltage to a different DC voltage is called DC to DC conversion. Generally, a boost converter is a DC to DC converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it “steps up” the source voltage. Since power ( $P = V I$ ) must be conserved, the output current is lower than the source current. [2]

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950s represented a major milestone that made SMPSs such as the boost converter possible. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry’s need for small, lightweight, and efficient power converters led to the converter’s rapid development.

Switched systems such as SMPS are a challenge to design since their models depend on whether a switch is opened or closed. R. D. Middlebrook from Caltech in 1977 published the models for DC to DC converters used today. Middlebrook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped the growth of SMPS. [2]

In a boost converter, the output voltage is greater than the input voltage – hence the name “boost”. A boost converter using a power MOSFET is shown below.

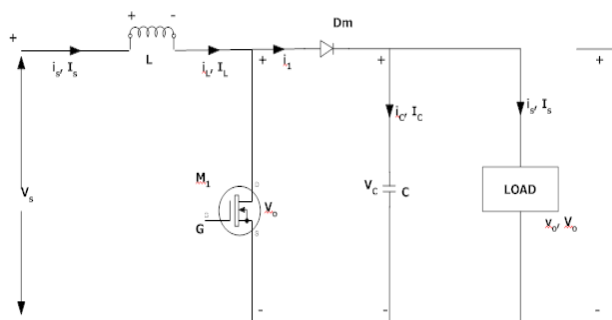


Figure 1: Circuit diagram of Boost Converter

The function of boost converter can be divided into two modes, Mode 1 and Mode 2. Mode 1 begins when transistor M1 is switched on at time  $t=0$ . The input current rises and flows through inductor L and transistor M1.

Mode 2 begins when transistor M1 is switched off at time  $t=t_1$ . The input current now flows through L, C, load, and diode Dm. The inductor current falls until the next cycle. The energy stored in inductor L flows through the load.

The circuits for the two modes of operation are shown below:

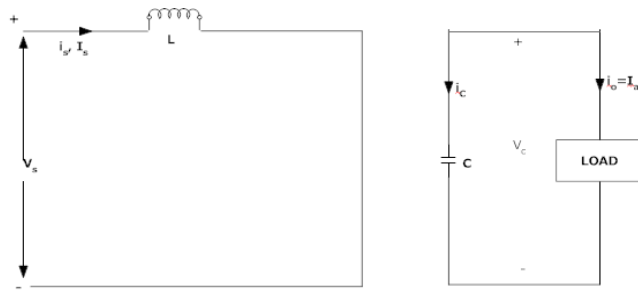


Figure 2: Circuit operation Mode 1

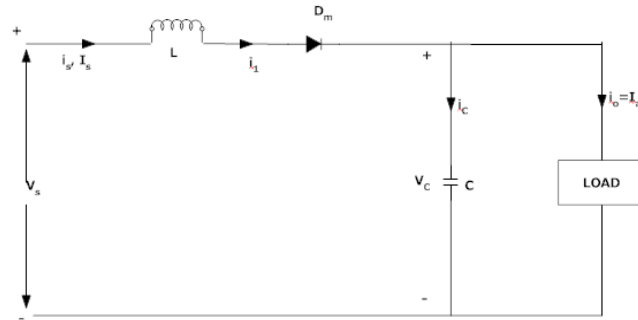


Figure 3: Circuit operation Mode 2

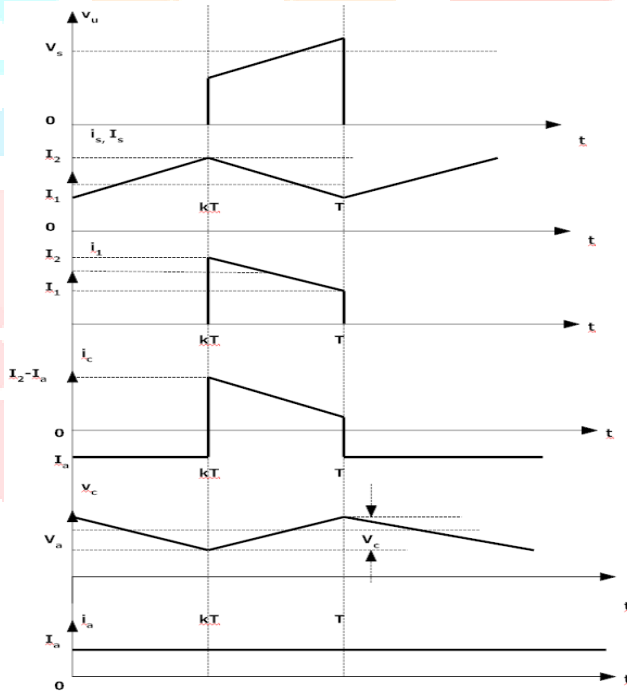


Figure 4: Waveforms

The voltage-current relation for the inductor L is:

$$i = \frac{1}{L} \int_0^t v dt + i_o$$

Or

$$V = L \frac{di}{dt}$$

For a constant rectangular pulse:

$$i = \frac{Vt}{L} + i_0$$

When the transistor M1 is switched:

$$i_{pk} = \frac{(V_{in} - V_{Trans})T_{on}}{L} + i_0$$

Or

$$\Delta i = \frac{(V_{in} - V_{Trans})T_{on}}{L}$$

And when the transistor is switched off the current is:

$$i_0 = i_{pk} - \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

Or

$$\Delta i = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

Here  $V_D$  is the voltage drop across the diode  $D_m$ , and  $V_{Trans}$  is the voltage drop across the transistor M1.

By equating through delta i, we can solve for  $V_{out}$ :

$$\frac{(V_{in} - V_{Trans})T_{on}}{L} = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}$$

$$V_{in} - V_{Trans}D = (V_{out} + V_D)(1 - D)$$

$$V_{out} = \frac{V_{in} - V_{Trans}D}{(1 - D)} - V_D$$

Neglecting the voltage drops across the diode and the transistor:

$$V_{out} = \frac{V_{in}}{1 - D}$$

So, it is clear that the output voltage is related directly to the duty cycle. The main challenge when designing a converter is the sort of inductor to be used. From above equations, it can be seen that the inductance is inversely proportional to the ripple current. So, to reduce the ripple, a larger inductor should be used. [4] [5]

### III. PSPICE MODEL OF STEP-UP DC-DC CONVERTER

This circuit is used to measure output voltage across the resistor R1

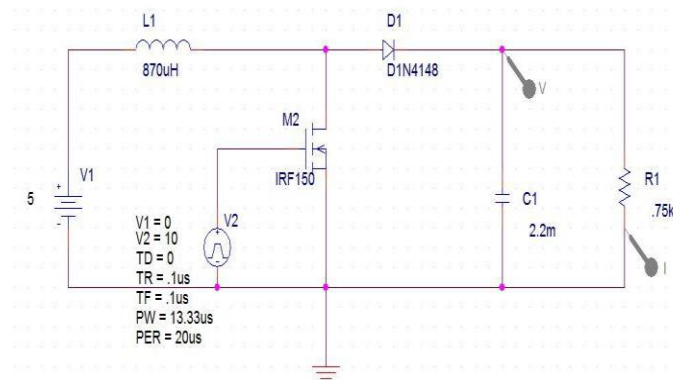


Figure 5: Circuit Diagram of Step Up DC – DC Converter (Boost Converter) used in PSPICE

#### IV. PSPICE SIMULATION RESULT OF STEP-UP DC-DC CONVERTER

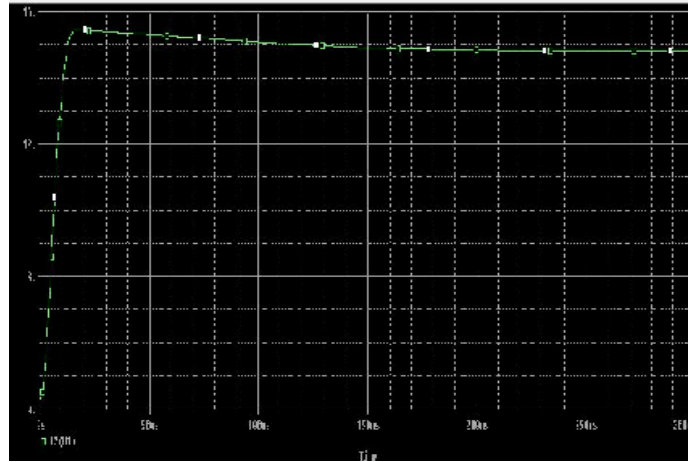


Figure 6: Vout (output voltage) vs. Time in PSPICE

#### V. COMPONENT CALCULATIONS

$$\text{Load Resistance} = V_0 / I_0 ; I_0 = 0.4$$

$$= 15 / 0.4$$

$$= 37.50\Omega$$

$$\text{Duty cycle} = 1 - V_{in} / V_0$$

$$= 0.67$$

Capacitor

$$\Delta V = ESR (I_0 / 1-D + \Delta I_L / 2)$$

$$= 2.622 \times 10^{-3} \text{ V}$$

$$C = I_0 \times D / f_s \times \Delta V_0$$

$$= 0.4 \times 2 / 3 \times 50 \times 2.622$$

$$= 2.034 \times 10^{-3} \text{ F}$$

$$\text{New Ripple Voltage} = I_0 \times D / f_s \times C$$

$$= 2.424 \times 10^3 \text{ V}$$

Inductor

$$L = V_s \times D / f_s \times \Delta I_0$$

$$\text{Ripple current } \Delta I_0 = 10\% I_0$$

$$L = 870 \mu\text{H}$$

Loss Calculation

$$\text{Diode loss} = V_d \times I_0 \times (1-D)$$

$$= 0.07 \text{ W}$$

Switching loss

$$V_{GS} = V_{\text{Threshold}}$$

$$E_1 = t_1 V_s I_0 / 2$$

$$E_2 = t_2 V_s I_0 / 2$$

$$\text{PSW} = (t_1 + t_2) V_s I_0 f_s / 2$$

Gate circuit loss

Assuming

$$R_{\text{driver pull up}} = 5 \Omega$$

$$R_{\text{driver pull up}} = 2 \Omega$$

$$R_{\text{gate}} = 1.5 \Omega$$

$$V_{\text{DD}} = 10 \text{ V}$$

When gate signal is rising

$$I = \frac{V_{\text{DD}} - V_{\text{SP}}}{R_{\text{driver}} + R_{\text{gate}}}$$

$$= 0.31 \text{ A}$$

$$t_1 = Q / I = 168.8 \text{ ns}$$

$$t_2 = Q / I = 22.8 \text{ ns}$$

So,

$$P_{\text{SW}} = (t_1 + t_2) V_{\text{s}} I_{\text{o}} f_{\text{s}} / 2$$

$$= 0.3 \text{ W}$$

Conduction loss

$$I_{\text{o}}^2 \times D \times R = 0.21 \text{ mW}$$

Efficiency Calculation

$$\text{Efficiency} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

$$= \frac{6}{6 + 0.3 + 0.7 + 0.0021}$$

$$= 94.16 \%$$

$$\text{Efficiency} = 94.16 \%$$

## VI. CONCLUSION

The Result of simulation shows that the switching converter will boost voltage from 5 volts to 15 volts. From this result, it is clear that the boost converter steps up the voltage from 5 to 15 volt in accordance with the parameters derived earlier, fulfilling the desired conditions of output current being 0.4 A and efficiency 94.16% .

## REFERENCES

- [1] R. Fiorello, "Powering a 35w DC metal halide high intensity discharge (hid) lamp using the ucc3305 hid lamp controller," *Unitrode Application Handbook U-161*, 1995.
- [2] Carl Nelson & Jim Williams, "*Linear Technology, LT1070 Design Manual*", 1986.
- [3] Abdar Ali, Rizwan Ullah, Zahid Ullah "DC-to-DC Converters for Low-Voltage High-Power Renewable Energy Systems ", 2015. \
- [4] D. M. Mitchell, "*DC-DC Switching Regulator Analysis*", New York: McGraw-Hill, 1988.
- [5] Muhammad H. Rashid, "*Power Electronics, Circuits, Devices, and Applications*", Third Edition, Pearson Education, Inc., 2004.