

Modeling and Simulation of a DC-DC Boost converter and its performance analysis based on various parameters

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Abstract— This paper describes the modeling and simulation of dc-dc Boost converter for renewable energy system. It presents the operation principle of CCM mode of boost converter. The equations of ON and OFF states were obtained by applying Kirchhoff's law in each of the operating mode and the simulation results were obtained using MATLAB Simulink model. By these results, different parameters are calculated and their graphs have been plotted for the validation of the mathematical model of the system.

Keywords— Boost converter, CCM mode, Renewable energy.

I INTRODUCTION

Every Electronic circuit is assumed to operate off some supply voltage which is usually assumed to be constant. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of dc-dc converters. For renewable energy supply that converters are used for constant and boosted supply of voltage.

In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A dc-dc converter converts directly from dc to dc and is simply known as a dc converter. A dc converter can be considered as dc equivalent to an ac transformer with a continuously turns ratio. Like a transformer, it can be used to step down or step up a dc voltage source. The dc-dc converters are widely used for traction motor control in electronic automobiles, trolley cars, marine hoists, forklift trucks, and mine haulers. They provide smooth acceleration control, high efficiency, and fast dynamic response. DC-DC converters can be used in regenerative braking of dc motors to return energy back into the supply, than this feature results in energy savings for transportation systems with frequent stops. DC converters are used in dc voltage regulators and also are used in conjunction with an inductor, to generate a dc current source, especially for the current source inverter.

Different topologies

The isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters, in that; their output voltage is often (but not always) the same as the input voltage. The dc converters can be used as switching mode regulators to convert a dc voltage, usually unregulated, to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching driver is normally BJT, MOSFET, or IGBT. The power regulator can be inductor based, switch-mode power converter, a switch capacitor charge pump or a linear regulator. Each regulator has its own advantages and disadvantages, but it is the particular application requirements that determine which type of power regulator is best suited [1][3].

The various topologies of the DC to DC converter can generate voltages higher, lower, higher and lower or negative of the input voltage namely:

- Buck converter
- Boost converter
- Buck boost converter
- Cuk converter
- Sepic converter

This paper focuses especially on boost regulator topologies. The boost is one of the fundamental switch-mode power topologies. The other being is the buck regulator. From these two topologies, all other topologies switch-mode power supply topologies are derived.

II THEORETICAL BACKGROUND

Boost Converter and Its Operation

The figure shows a step up or PWM boost converter. It consists of a dc input voltage source V_g , boost inductor L , controlled switch S , diode D , filter capacitor C , and the load resistance R . When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time[2]. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

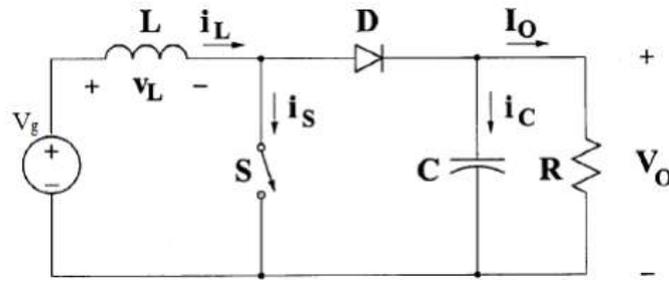


Figure 1 : Circuit diagram of Boost converter

Ideal circuit analysis steady state analysis of the boost converter

(a) **OFF STATE:** In the OFF state, the circuit becomes as shown in the Figure 2 below ;

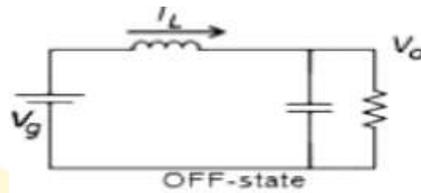


Figure 2: The OFF state diagram of the boost converter.

When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage.

(b) **ON STATE:** In the ON state, the circuit diagram is as shown below in Figure (3):

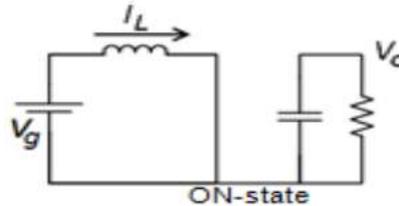


Figure 3: The ON state diagram of the boost converter.

When the switch is ON, the inductor is charged from the input voltage source V_g and the capacitor discharges across the load. The duty cycle, D where T From the inductor voltage balance equation, we have

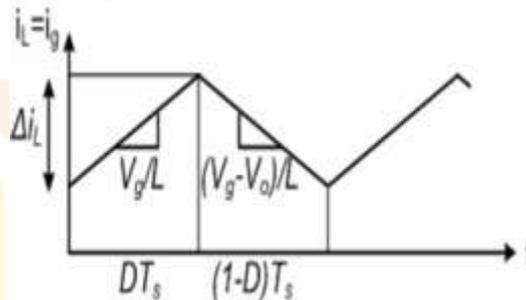


Figure 4: Inductor current waveform

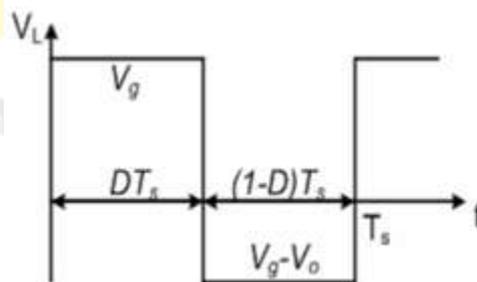


Figure 5: Inductor voltage waveform

From the inductor voltage balance equation, we have

$$V_g(D.T_s) + (V_s - V_o)(1 - D)T_s = 0 \quad \dots(1)$$

$$V_g(D.T_s) - V_g(D.TS) - V_g.Ts + V_o(D.Ts) - (V_o.Ts) = 0 \quad \dots(2)$$

$$V_o = \frac{V_g}{(1-D)} \quad \dots(3)$$

$$\text{Conversion ratio } M = \frac{V_o}{V_g} = \frac{1}{(1-D)} \quad \dots(4)$$

From inductor current ripple analysis, change in inductor current,

$$I_L = (I_{max} - I_{min}) \quad \dots(5)$$

$$I_L = \frac{V_g}{L} * (D * T_s) \quad \dots(6)$$

$$L = \frac{V_g * D}{f_s * I_L} \quad \dots(7)$$

The boost converter operates in CCM (continuous conducting mode) for $L > L_b$ where: The current supplied to the output RC circuit is discontinuous. Thus a large filter capacitor is used to limit the output voltage ripple[2][4]. The filter capacitor must provide the output dc current to the load when the diode d is off.

Necessary Parameters of the Power Stage

The following four parameters are needed to calculate the power stage:

- Input Voltage Range: $V_{IN(min)}$ and $V_{IN(max)}$
- Nominal Output Voltage: V_{OUT}
- Maximum Output Current: $I_{OUT(max)}$
- Integrated Circuit used to build the boost converter.

This is necessary, because some parameters for the calculations have to be taken out of the data sheet. If these parameters are known the calculation of the power stage can take place.

Calculate the Maximum Switch Current

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$$D = 1 - \frac{V_{IN(MIN)} * \eta}{V_{OUT}} \quad \dots(8)$$

$V_{IN(min)}$ = minimum input voltage

V_{OUT} = desired output voltage

η = Efficiency of the converter, e.g. Estimated 80%

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

Either an estimated factor, e.g. 80% (which is not unrealistic for a boost converter worst case efficiency), can be used or see the Typical Characteristics section of the selected converter's data sheet[5].

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. So either use the recommended inductor value to calculate the ripple current, an inductor value in the middle of the recommended range or, if none is given in the data sheet, the one calculated in the Inductor Selection section of this application note [5].

$$\Delta I_L = \frac{V_{IN(min)} * D}{f_s * L} \quad \dots(9)$$

$V_{IN(min)}$ = minimum input voltage

D = Duty cycle

f_s = minimum switching frequency of the converter

L = selected inductor value

III SIMULINK MODELING, CONTROL AND IMPLEMENTATION OF BOOST CONVERTER

Simulink Model

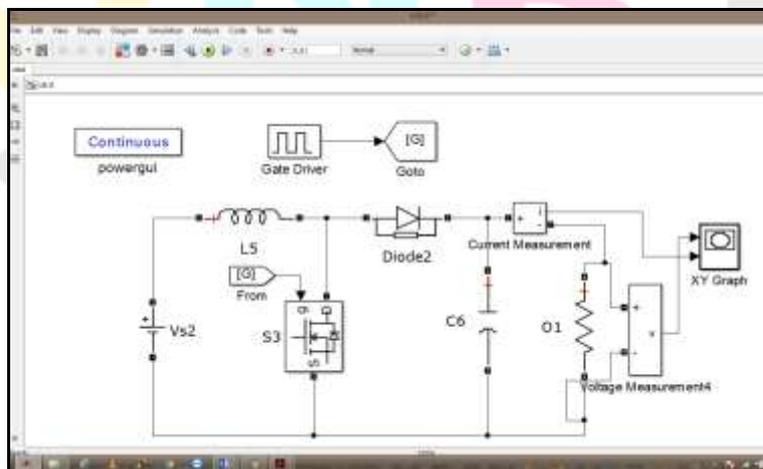


Figure 6: MATLAB Simulink model of BOOST converter.

MATLAB Simulation Results:

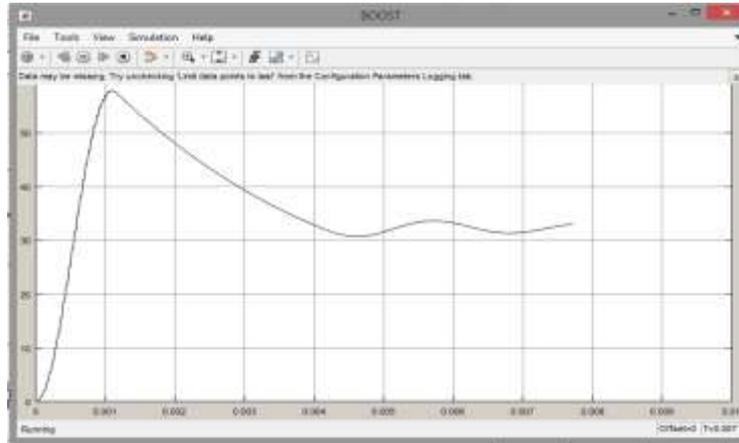


Figure 7: Output voltage of Boost converter vs Time in MATLAB.

Given above is a circuit diagram used for MATLAB simulation of boost converter. The purpose of this circuit is to measure output voltage and current waveform

The frequency of operation is 50 kHz. Fig. 7 shows the output voltage obtained from simulation, which is 32Volt. Duty Cycle is maintained above 50%

Performance Analysis of Parameters of Boost Converter

Case I: When input voltage $V_i = 20\text{Volt}$

Table 1: Boost Converter Performance Parameters

Parameters	Boost converter
Output(Vdc)	32.39 Volt
Output current(Idc)	1.6195 A
Output power(Pdc)	52.455605 Watt
Voltage Gain	1.695
Efficiency	53%
Power Loss	4.5444 Watt

By this simulation result it is concluded that boost converter enhances the input voltage. And by varying the input voltage obtained result is shown in case II.

Case II: When input voltage is variable

Table 2: Output voltage with variance in input voltage

Boost converter	
Input Voltage (Volt)	Output Voltage (Volt)
10	15.8
20	32.39
30	48.99
40	65.58
50	82.18
60	98.77
70	115.4

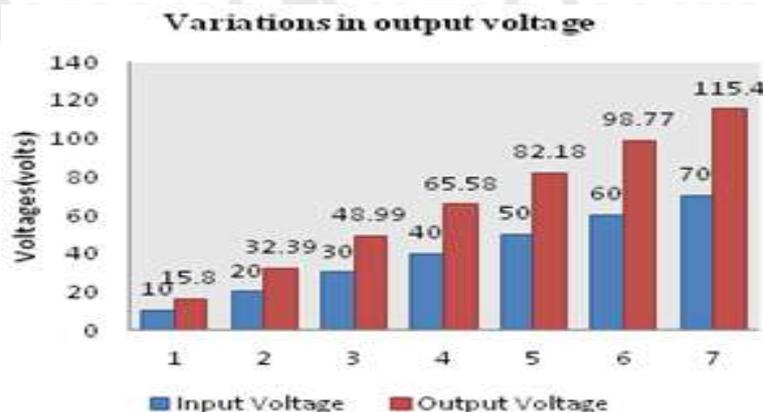


Figure 8: Determination of Output Voltage Curve with the Variation in Input Voltage

Fig 8 shows the comparison between input and output voltages, as input voltage is increasing the output voltage is also increasing.

Case III: When input power is varied

Table 3: Output Power with Variance in Input Power

Input Voltage (Volt)	Input Current (A)	Input Power (Watts)	Output Power (Watts)
10	1	10	15.8
20	2	40	64.78
30	3	90	146.97
40	4	160	262.32
50	5	250	410.9
60	6	360	592.62
70	7	490	807.8

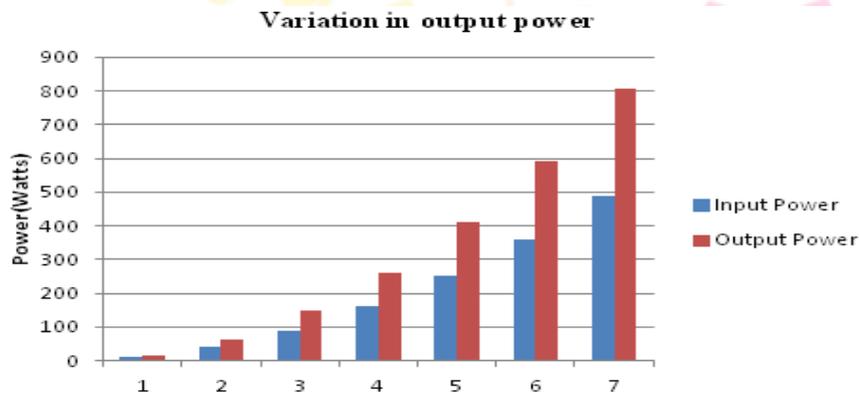


Figure 9 : Determination of Output Power Curve with the Variation in Input Voltage And Current

Case III: When input power is varied and power loss is determined

Table 4 : Output Power with Variance in Input Power Loss

Input Voltage (Volt)	Input current (A)	Input Power (Watts)	Power Loss (Watts)
10	1	10	5.8
20	2	40	24.78
30	3	90	56.97
40	4	160	102.32
50	5	250	160.9
60	6	360	232.62
70	7	490	317.8

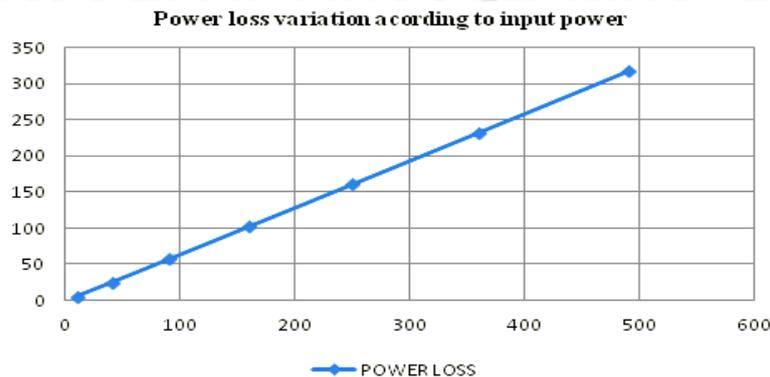


Figure 10: Determination of Power Loss Curve with the Variation in Input Power

When input voltage and Current is varied accordingly input power is calculated and by the result of simulation power loss is calculated that is shown in fig 10.

Case IV: When input power is varied and efficiency is determined

Table 5: Efficiency with Variance in Input Power

Input Voltage (Volt)	Input current (A)	Input Power (Watts)	Efficiency (%)
10	1	10	58
20	2	40	61.95
30	3	90	63.3
40	4	160	63.95
50	5	250	64.36
60	6	360	64.61
70	7	490	64.8571

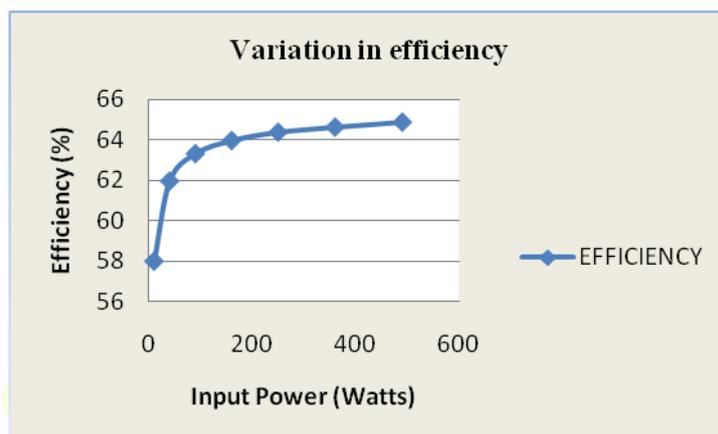


Figure 11: Determination of Efficiency curve with the Variation in Input Power

IV CONCLUSIONS

From the results obtained, it is clearly observed that the boost converter steps up the voltage from 20 to 32volt in accordance with the parameters derived earlier, fulfilling the desired conditions of output current being 1.6195A at frequency 50kHz. The efficiency of the boost converter is 61.95 %.And the power loss parameter is 24 Watts for the input voltage of 20 Volt. And graphical comparison is done by variation in input parameters (Voltage and current).

All of the specifications stated previously have been met by this boost converter design. MATLAB simulations using calculated parameters were performed and corresponding waveforms were obtained.

V Acknowledgment

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References

- [1] http://www.mathworks.in/webex/recordings/Solar_111809/index.html
- [2] <http://www.matlabcentral.in>
- [3] Salas, V., 2006, Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems, Solar Energy Materials and Solar Cells, Vol.90(11), PP: 1555-1578.
- [4] Khanna, Vandana, BijoyKishore Das, and Dinesh Bisht, 2013, MATLAB/SIMELECTRONICS Models Based Study of Solar Cells, International Journal of Renewable Energy Research (IJRER) Vol.3(1) PP: 30- 34.
- [5] SalmiTarak,2012, MATLAB/Simulink Based Modeling of Photovoltaic Cell, International Journal of Renewable Energy Research (IJRER), Vol.2(2), PP: 213-218
- [6] Alsadi, Samer, and Basim Alsayid, 2012, Maximum Power Point Tracking simulation for photovoltaic systems using Perturb and Observe algorithm, International Journal of Engg and Innovative Technology (IJEIT), Vol.2.
- [7] Nedumgatt, Jacob James., 2011, Perturb and observe mppt algorithm for solar pv systems-modeling and simulationIndiaConference .
- [8] Petreuş, Dorin, CristianFărcaş, and IonuCiocan, 2008, Modelling and simulation of photovoltaic cells, ActaNapocensis, Electronics and Telecommunications, PP: 42-47.
- [9] Venkateswarlu, G., and P. SangameswarRaju., 2013, Simscape model of photovoltaic cell, International Journal of Amsdvanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 2(5)