Comparative Analysis and Simulation of Power Electronic Converters to Enhance Performance

Akansha Chourasia
Electrical Engineering Department
PIEMR
Indore, India
akanshach6@gmail.com

Dipesh Suryavanshi
Electrical Engineering Department
PIEMR
Indore, India
dipesh_surya@yahoo.com

Priyam Gour
Electrical Engineering Department
PIEMR
Indore, India
priyamgour12@gmail.com

***Abstract*— This work analyses the performance of different DC to DC power electronic converters. In today's world, power electronic converters are widely used in many domestic and industrial applications such as electric vehicles, Photovoltaic (PV) systems, uninterruptible power supply, wind system and fuel cell power system. It is always desired to get the regulated output voltage irrespective of change in input voltage, load and converter parameters. It uses the combination of converter with pulse generator, pulse width modulation and Proportional Integral Derivative (PID) controller to compare the parameters. Here, we have designed a closed loop control using open loop model. The results were obtained and validated with the help of MATLAB SIMULINK.**

***Keywords*— DC to DC converter, PID, Closed loop, Photovoltaic, Simulink**

I. Introduction

In AC circuits, the voltage level is stepped up or stepped down with the help of transformers but for DC circuit transformer cannot be used. To vary the voltage level in DC circuit, power electronic DC to DC converters are used. DC to DC converters are also known as choppers.To design a controller for any system first we have to know about system behavior. The study aims at modeling the different configurations of power electronic DC to DC converters with open loop response and closed loop response system. Open loop system uses pulse generator to drive the circuit and in closed loop system pulse width modulation and PID controller is used to regulate the output voltage of the converter [11]. Power Electronics is ushering in a new kind of industrial revolution due to its versatility in terms of fields of application like energy conservation, renewable energy system, bulk utility energy storage, electric and hybrid vehicles and industrial automation [6], [7]. When it comes to power conversion, a DC-DC converter plays a significant role resulting in widespread applications in cellular phones, laptop computers, LED drivers, maximizing energy harvest for photovoltaic systems and for wind turbines, electric vehicles, hydro power plants, Traction motor control in electric automobiles, Trolley cars, Marine Hoists, Forklift trucks, Mine Haulers and many more. This widespread application requires that the converter should achieve highest efficiency, minimized total harmonic distortion (THD) and improved power factor (PF) at the load side while at the same time reducing size and cost of the device and increasing availability [8]. The paper proposes the design of a simple PID controller for power electronics DC-DC converter topologies. Cost, size, switching speed, efficiency and simplicity are the important points of concern for the design of proposed PID controller.

II. Circuit Description

The DC to DC converter has following attributes:

- It converts the DC input voltage V_s to a DC output voltage V_o.
- It regulates the output voltage irrespective of variation in load.
- It isolates the input and output circuitry.
- It protects the system from electromagnetic interference.

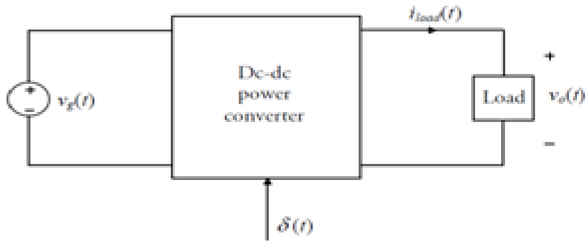


Fig. 1 Block Diagram of DC to DC Converter

Figure 1 shows the block diagram of a DC to DC converter as a black box. It converts a dc input voltage, v_g (t), to a dc output voltage, $v_o(t)$, with a magnitude other than the input voltage. This conversion takes place with the help of different switching devices available. Diodes, thyristors, power mosfet`s, IGBT`s are widely used. Here, in the proposed work, IGBT is used as a switching device. It is cheap, has higher switching frequency, easy and simple gate pulse control, no need of snubber circuit as in thyristors. The conversion with low conduction losses is desirable. The electrical components can be combined and connected to each other in different ways, called topologies, each one having different properties. The buck, boost, and buck-boost converters are three basic converter topologies [1], [2].

A. Boost Converter

The input voltage is always less than the output voltage in this type of converters. Input for a boost converter is a simple DC source such as battery, solar panel or can be directly obtained from an AC source through a rectifier. The inductors tendency to resist current variations due to changes in the magnetic field is the key principle that drives the Boost converter. Boost converter is said to operate in two modes. The switching is achieved using either a MOSFET or an IGBT. In low voltage applications MOSFET is preferred over IGBT due to its higher computational speed compared to IGBT. Modes of operation of boost converter are as follows:

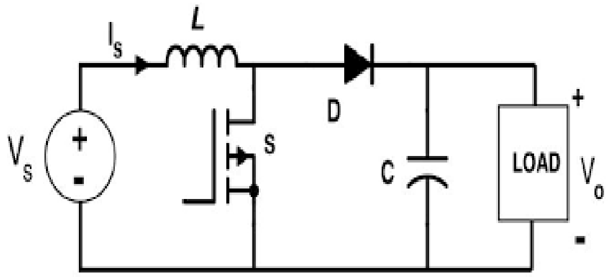


Fig. 2 Conventional Boost Converter

- Mode 1 begins at t = 0s when the transistor is switched on causing the rising input current to flow through the inductor L, storing energy in its magnetic field. During this mode of operation the load is completely isolated from the source as shown in figure 3 (a).

- Mode 2 begins at $t = t1$ when the transistor is switched off. Inductor, *L* produces a back emf having opposite polarity of the mode 1 due to rapid drop in current. The difference between the voltage across the inductor and the small forward voltage drop across the diode, D charges the capacitor C and also supplies the load.

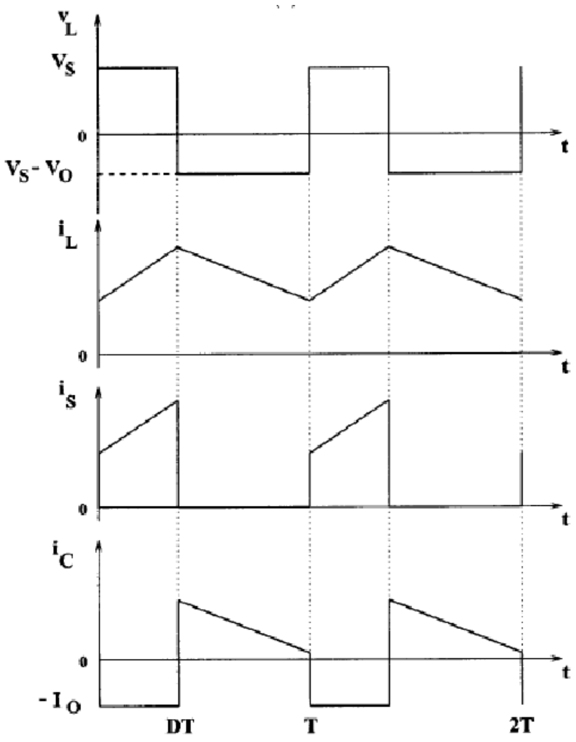


Fig. 3 Theoretical Waveform of Boost Converter

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

$$\frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0$$

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

B. Buck Converter

The input voltage is always more than the output voltage in this type of converters.

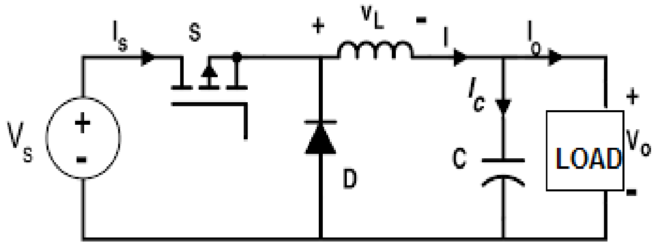


Fig. 4 Conventional Buck Converter

For steady state operation:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

$$(V_i - V_o)DT - V_o(1-D)T = 0$$

$$V_o - DV_i = 0$$

$$D = \frac{V_o}{V_i}$$

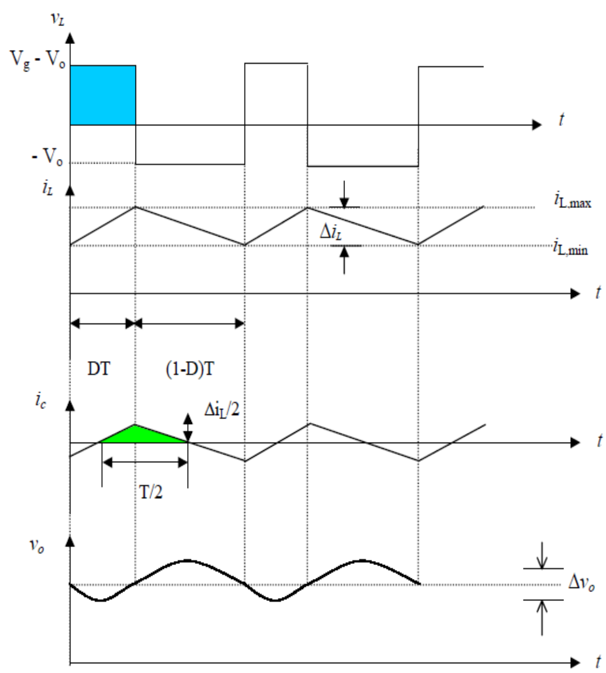
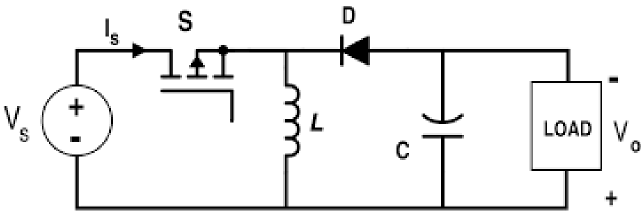


Fig. 5 Theoretical Waveform of Buck Converter

C. Buck Boost Converter

The Buck-boost converter provides an output voltage can be either higher or lower than the input voltage. The output voltage polarity is opposite to that of the supply voltage. It is also known as inverting regulator. It has an increased efficiency.



$$\Delta I_{\mathrm{LOn}} + \Delta I_{\mathrm{LOff}} = 0$$

Fig. 6 Conventional Buck Boost Converter

$$\Delta I_{\mathrm{LOn}} + \Delta I_{\mathrm{LOff}} = \frac{V_i DT}{L} + \frac{V_o(1-D)T}{L} = 0$$

$$V_{out} = [D/(1-D)]V_{in}$$

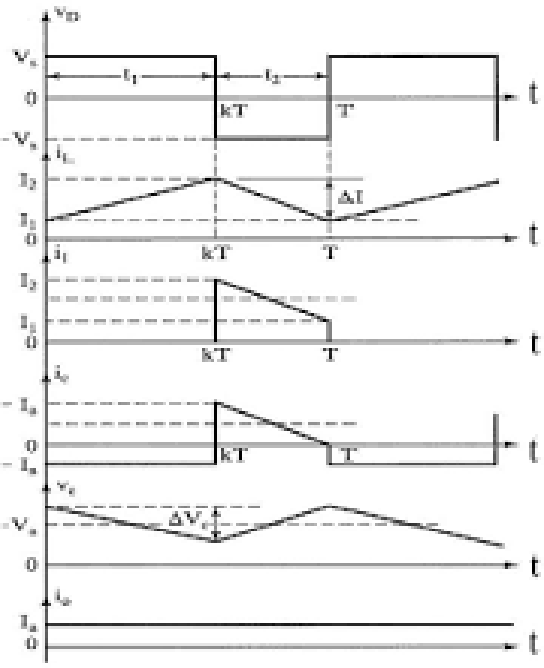


Fig. 7 Theoretical Waveform of Buck Boost Converter

III. Proportional Integral Derivative controller

PID controller has been used a controller for several decades in industries for control applications. Proportional integral derivative comprises of three individual controllers namely proportional, integral and derivative controllers as shown in figure.5. It is a closed loop control system. On changing these three controller parameters, we can control the output DC voltage of the converter. For tuning of PID controller, there are various methods to control the input signal to the converter but hit and trial method is generally used.

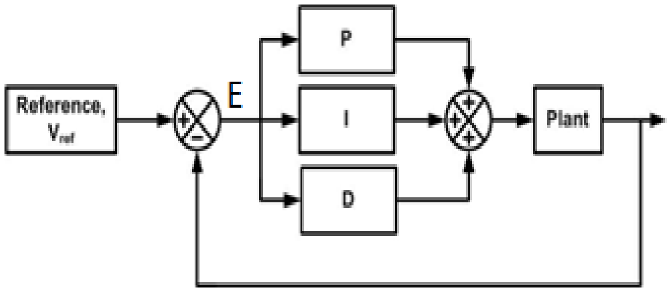


Fig. 8 Block Diagram of PID Controller

The variable E represents the error and it is the difference between the actual output and the reference input V_{ref}. The error signal will be sent to the PID controller and computes the error. The input signal pass through the controller and is now equal to the addition of proportional gain K_p times the magnitude of the error signal, integral gain K_i times the derivative of the error and then the signal will be sent to the plant and the new output will be obtained. This new output will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and its integral again [6], [7]. This process goes on and on, this signal (u) is obtained as follows:

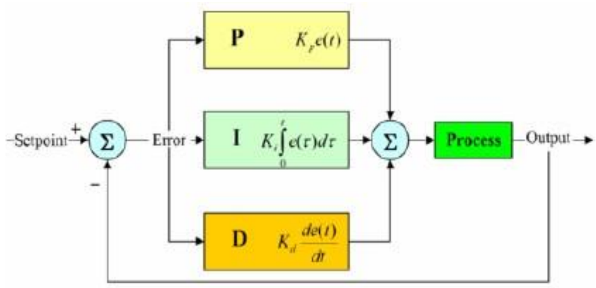


Fig. 9 PID Controller

$$U(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

Where,

K_P	Proportional gain
K_I	Integral gain
K_D	Derivative Gain

IV. Simulation Results

The proposed open loop and closed loop response of three converters i.e. boost, buck, buck boost converter is simulated using MATLAB / SIMULINK. The ultimate aim is to achieve a robust controller in spite of uncertainty and large load disturbances. Here, in the proposed work different topologies of DC to DC power electronic converters are simulated in SIMULINK. In the model given below it is observed that the load voltage profile is improved in case of PID controller.

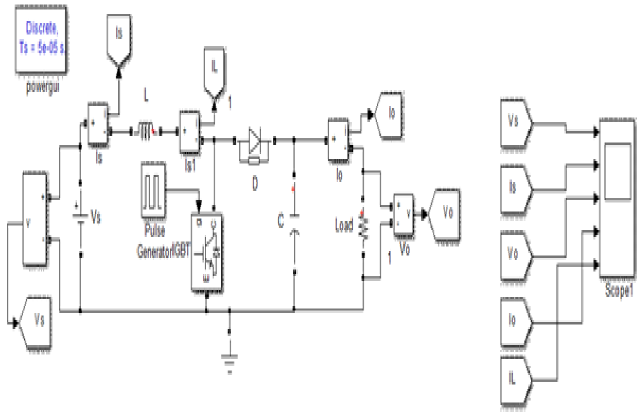


Fig. 10 Open loop Boost Converter with Pulse Generator

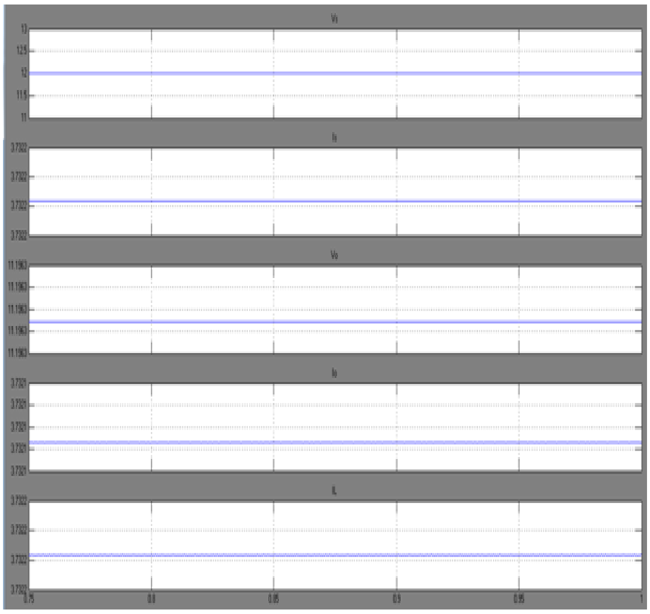


Fig. 11 Response of Open loop Boost Converter with Pulse Generator

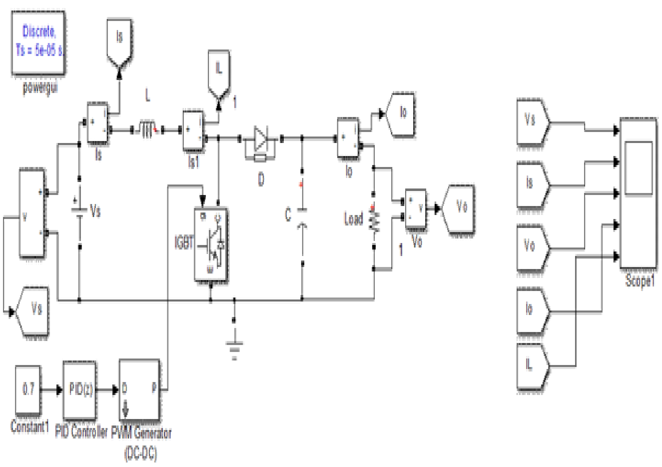


Fig. 12 Closed loop Boost Converter with PID Controller

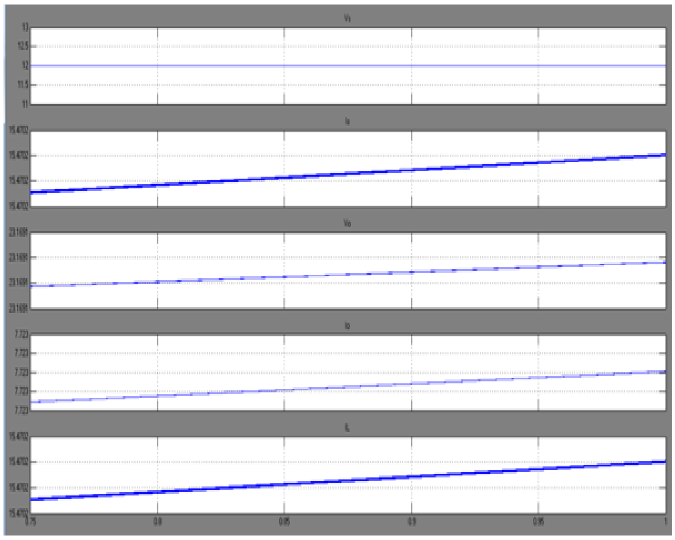


Fig. 13 Response of Open loop Boost Converter with PWM

Table 1. Boost Converter Parameters

S.No	***Parameters***	***Symbol***	***Value***
1	Source Voltage	V_s	12V
2	Switching Frequency	f_s	50KHz
3	Inductor	L	100 µH
4	Capacitor	C	200 µF

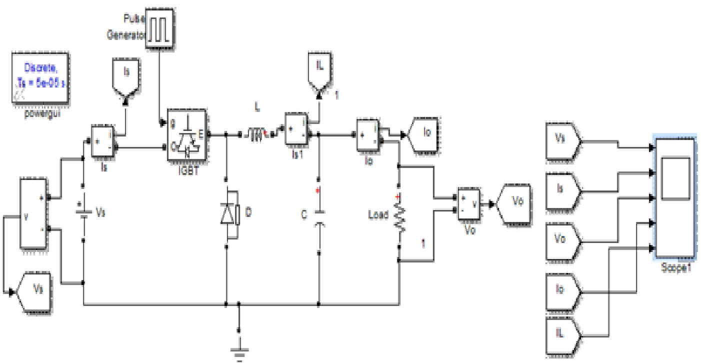


Fig. 14 Open loop Buck Converter with Pulse Generator

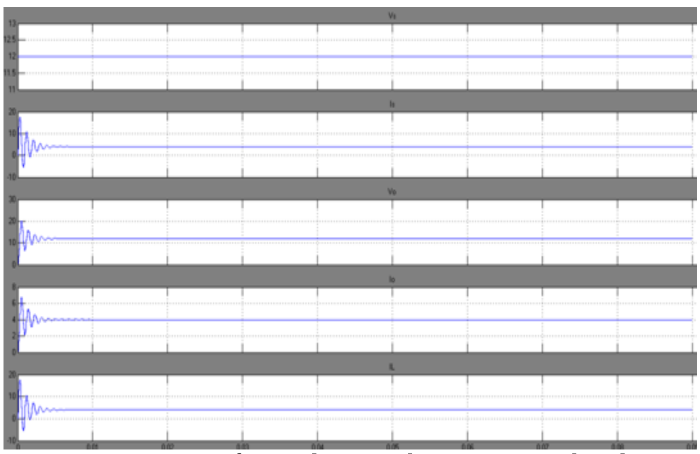


Fig. 15 Response of Open loop Buck Converter with Pulse Generator

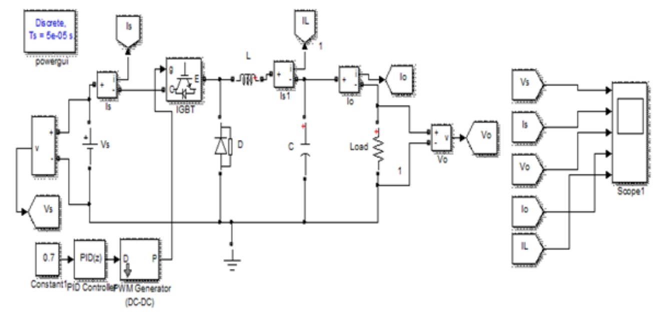


Fig. 16 Response of Open loop Buck Converter with PID Controller

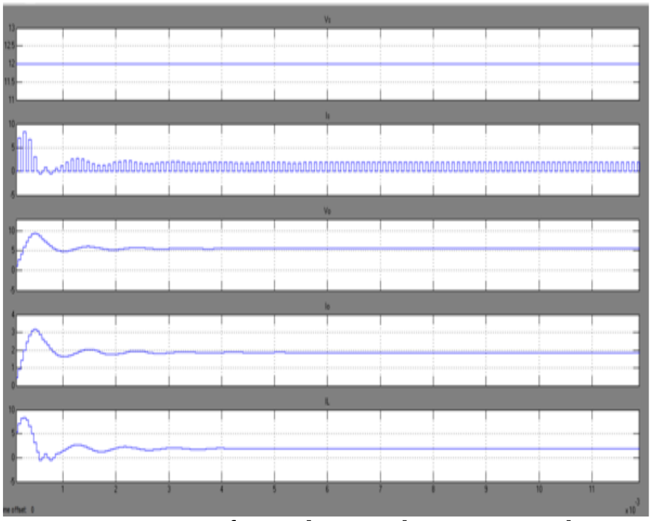


Fig. 17 Response of Open loop Buck Converter with PID Controller

Table 2. Buck Converter Parameters

S.No	*Parameters*	*Symbol*	*Value*
1	Source Voltage	V_s	12V
2	Switching Frequency	f_s	50KHz
3	Inductor	L	100 µH
4	Capacitor	C	200 µF

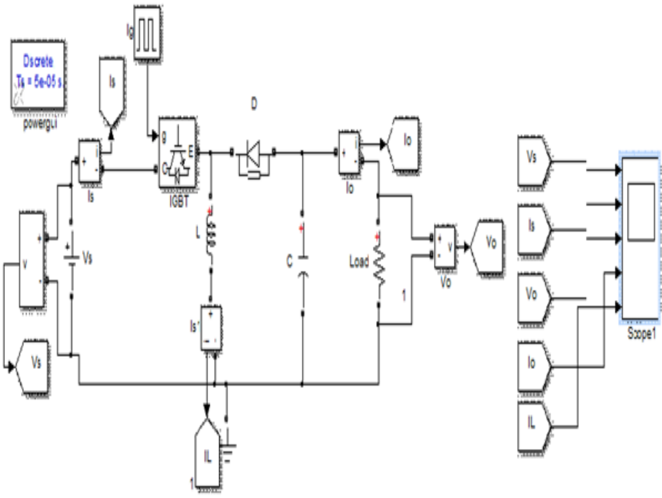


Fig. 18 Open loop Buck Boost Converter with Pulse Generator

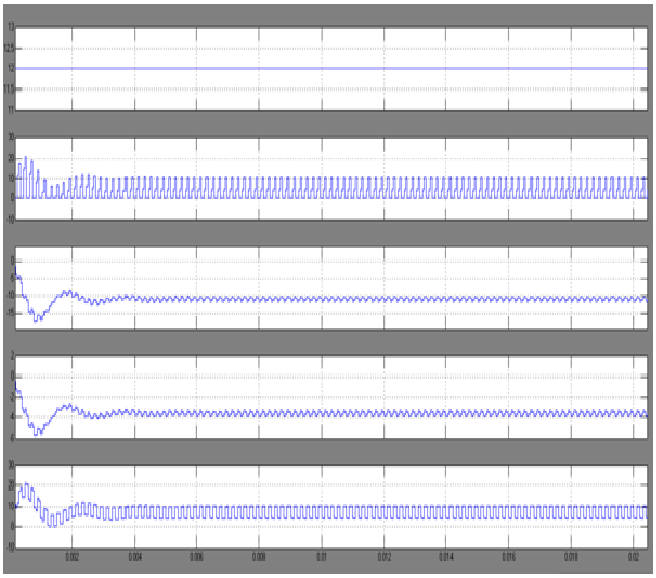


Fig. 19 Response of Open loop Buck Boost Converter with Pulse Generator

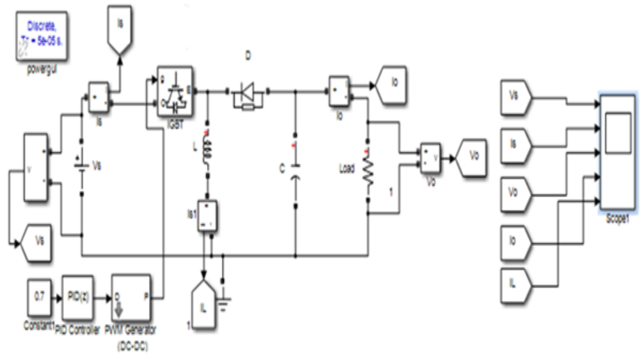


Fig. 20 Closed loop Buck Boost Converter with PID Controller

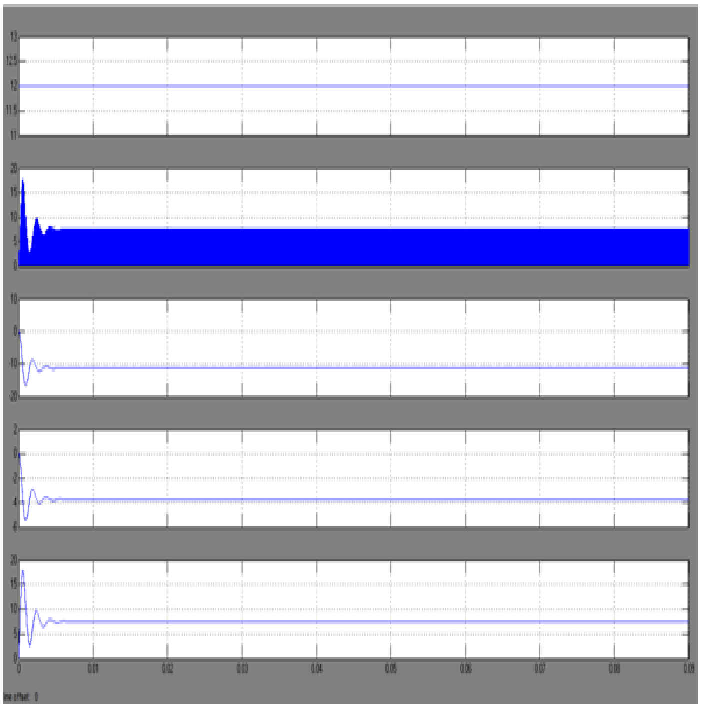


Fig. 21 Response of Closed loop Buck Boost Converter with PID Controller

Table 3. Buck Boost Converter Parameters

S.No	***Parameters***	***Symbol***	***Value***
1	Source Voltage	V_s	12V
2	Switching Frequency	f_s	50KHz
3	Inductor	L	100 µH
4	Capacitor	C	100 µF

V. CONCLUSION

The paper provides the dynamic behavior of power converters in an open loop and closed loop system. Power electronic converters boost, buck, buck boost DC to DC converters are discussed in this paper which are very useful for both academic and industrial application. To overcome the deviation of the circuit operation problem a proper PID controller or compensator needs to be designed. Here, the circuit proposed is very easy to understand and can be implemented with no additional components thereby keeping cost of manufacturing, size of the converter circuit within a considerable range. The proposed design of DC to DC converters operates effectively when PID controller is used.

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