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Design and Simulation of a DC - DC Boost Converter with PID Controller for Enhanced Performance

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Abstract— **This paper proposes the design and simulation of a DC-DC Boost converter employing PID controller, enhancing overall performance of the system. The main objective of a DC-DC converter is to maintain a constant output voltage despite variations in input/source voltage, components and load current. Designers aim to achieve better conversion efficiency, minimized harmonic distortion and improved power factor while keeping size and cost of converter within acceptable range. A simple PID (Proportional, Integral and Derivative) controller has been applied to a conventional Boost converter and tested in MATLAB-Simulink environment achieving improved voltage regulation. The proposed closed loop implementation of the converter maintains constant output voltage despite changes in input voltage and significantly reduces overshoot thereby improving the efficiency of the converter. The output of this investigation has the potential to contribute in a significant way in electric vehicles, industry, communication and renewable energy sectors.**

Keywords— DC-DC converter; voltage regulation; Boost converter; overshoot; PID; Block Diagram Reduction; stability

I. INTRODUCTION

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. 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 and many more [1]-[4]. 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 [5]-[8].

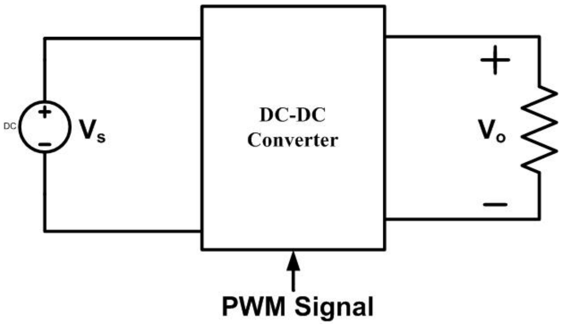


Fig. 1. Block Diagram of a DC-DC Converter

An electric power converter, DC-DC converter or more commonly known as a switched mode DC-DC converter as shown in Fig.1, either steps up or steps down the source voltage, V_s according to the requirement of the load connected, by making adjustments in the duty cycle applied to the switching device (in most cases MOSFETs and IGBT's).

In a DC-DC converter it is always desirable that a constant output voltage, V_o is achieved despite changes in the source voltage, V_s, the load current, i_{Load} and variations in element values of the converter circuit [10], [11]. These disturbances can be originated from second harmonic periodic variations of an off - line power system generated from the rectifier circuit and applied to the DC-DC converter, variation of the source voltage V_s due to switching (on/off) of neighboring power system loads and variations in the load current, i_{Load} amongst many. There are various types of DC-DC converters namely – Buck, Boost, Buck-Boost, Cuk, Sepic and Zeta. One of the most prominent research interests in this era is the application of DC-DC converters with high step-up voltage gain.

Several control techniques have been proposed to ensure stability as well as fast transient response namely - Fuzz Logic controller, Artificial Neural Network (ANN), PID controller and PI controller. Several Optimization techniques such as Genetic Algorithm, Particle Swarm Optimization, and Bacterial Foraging Optimization have also been proposed [11], [12], [20], [21].

Amongst all converters, most widely used DC-DC converter is the Boost converter, a step up converter which provides a higher voltage at the load side, V_o compared to the source voltage V_s. Open loop mode of operation of Boost converter exhibits substandard voltage regulation and undesirable dynamic response. Therefore, closed loop mode of operation is preferred for proper voltage regulation and performance enhancement.

In this paper proper voltage regulation of Boost converter is achieved employing PID controller, tuned using trial and error method to find appropriate values for the proportional, integral and derivative gains, thereby improving converter performance. Section II of this paper deals with the conventional Boost converter followed by a brief idea about PID Controller in Section III, Section IV depicts the proposed converter and finally the simulation and results are presented by comparing the conventional Boost converter with the proposed or modified Boost converter with PID controller in section V. The proposed circuit parameters, simulation and experimental results demonstrate the effectiveness and feasibility of the proposed scheme.

II. CONVENTIONAL BOOST CONVERTER

A conventional DC-DC Boost converter is composed of a boost inductor, two semiconductors (a diode and a transistor) and an output capacitor in parallel with the load as shown in Fig. 2.

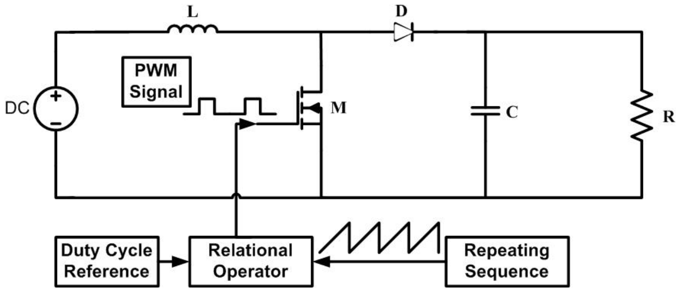
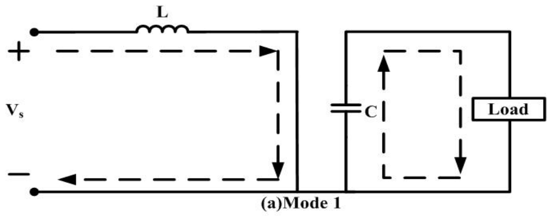


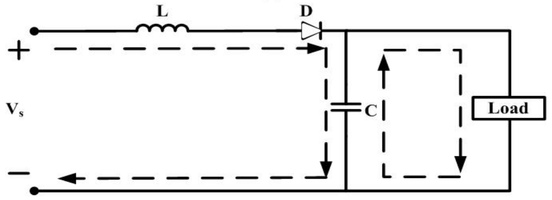
Fig. 2. Conventional Boost Converter

Boost converter also known as an up converter provides an output voltage that is greater than the input voltage. Input for a boost converter can be a simple DC source such as a battery, solar panel or can be obtained directly 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 is as follows:

- 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 as shown in Fig. 3(a) the load side is completely isolated from the source side.
- Mode 2 begins at $t = t_1$ 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 voltage across the inductor and the source minus the small forward voltage drop across the diode, *D* charges the capacitor, *C* and also supplies the load. The conduction path is shown in Fig. 3(b).



(a)Mode 1



(b)Mode 2

Fig. 3. Mode of operation of Boost Converter

Transistor switching period is given by

Mode 1 $$T_{on} = DT_p$$

Mode 2 $$T_{off} = (1-D)T_p \tag{1}$$

Voltage across the inductor,

Mode 1 $$L\frac{di}{dt} = V_i$$

Mode 2 $$L\frac{di}{dt} = -(V_i - V_o) \tag{2}$$

Putting equation (1) in equation (2)

Mode 1 $$L\frac{\Delta i}{DT_p} = V_i$$

Mode 2 $$L\frac{\Delta i}{(1-D)T_p} = V_o - V_i$$

Ripple current Δi , is given by

Mode 1 $$\Delta i_{on} = \frac{V_i DT_p}{L} \tag{3}$$

Mode 2 $$\Delta i_{off} = \frac{(1-D)(V_o - V_i)T_p}{L} \tag{4}$$

Equating the ripple current equation (3) and (4) of Mode 1 and Mode 2

$$\Delta i_{on} = \Delta i_{off}$$

$$V_i D = V_o - V_i - DV_o + DV_i$$

$$V_i = V_o - DV_o$$

$$V_i = V_o(1-D)$$

$$\frac{V_o}{V_i} = \frac{1}{1-D} \tag{5}$$

Where,

V_i	Input Voltage, V
V_o	Output Voltage, V
t_{on}	MOSFET on, sec
t_{off}	MOSFET off, sec
T_p	Switching Period, sec
D	Duty Cycle
Δi	Ripple current

III. PID CONTROLLER

One of the simplest and most widely used controller for decades is the PID controller. PID stands for proportional (P), integral (I) and derivative (D) controller. Fig. 4 shows the block diagram of a typical PID controller.

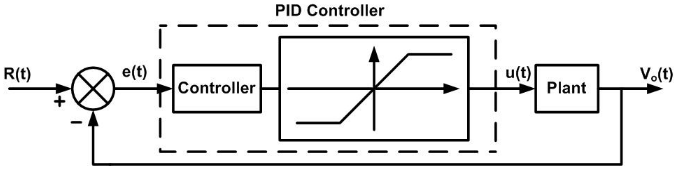


Fig. 4. Typical PID control Structure

The system under study is the plant to which necessary excitation is provided thereby achieving overall closed loop control effectively. A PID can be expressed as –

$$C(s) = \frac{K_D s^2 + K_P s + K_I}{s}$$

$$C(s) = K_P + \frac{K_I}{s} + K_D s \qquad (6)$$

Where,

K_P	Proportional gain
K_I	Integral gain
K_D	Derivative Gain

The signal *e(t)* as shown in Fig. 4 represents the tracking error obtained from the difference between the reference signal which serves as the input *R(t)* and the actual output signal $V_o(t)$. The tracking error is fed on to the PID controller which computes the derivative and integral of the signal provided. The output of the PID controller *u(t)* to be applied to the plant is equal to the proportional gain (K_P) times the magnitude of the error signal plus the integral gain (K_I) times the integral of the error signal plus the derivative gain (K_D) times the derivative of the error signal.

Time domain representation of the signal u(t) fed to the plant is given by –

$$u(t) = K_P e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt} \qquad (7)$$

The plant on receiving the signal *u(t)* will generate a modified output $V_o(t)$ which will be again compared to the reference signal until the desired level is reached thereby forming a close loop system. Effect of proportional, integral and derivative control on close loop system is summarized in the Table I. provided below.

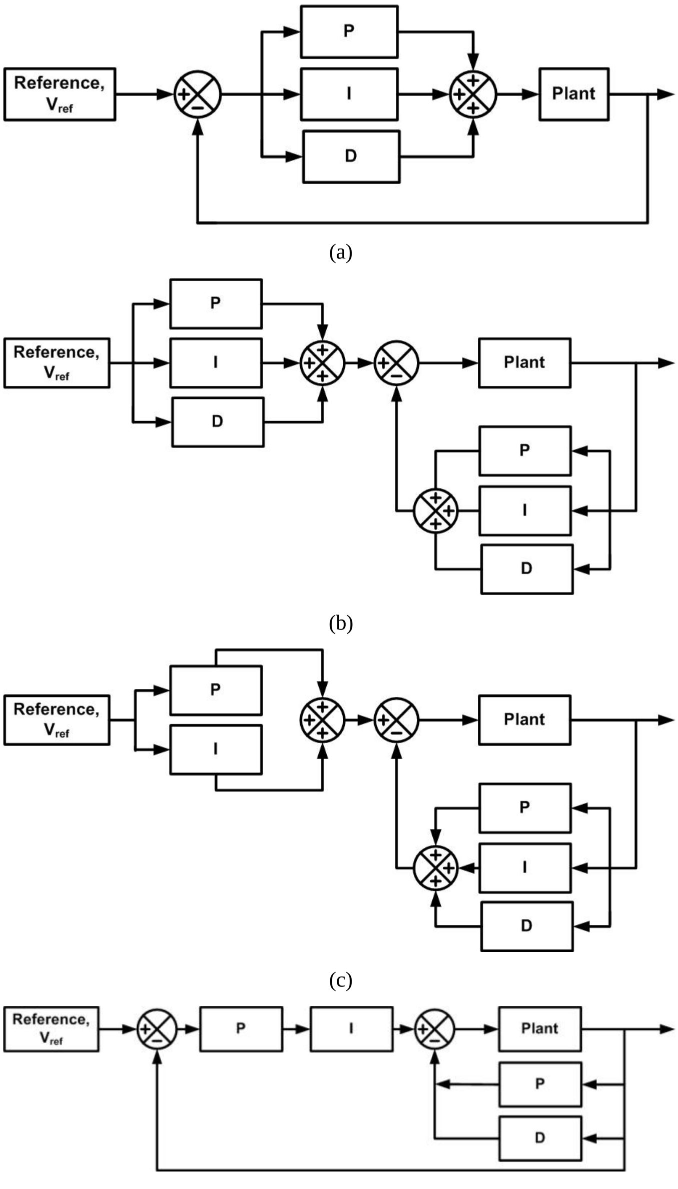
TABLE I. EFFECT OF PID ON CLOSE LOOP SYSTEM

	Rise Time	Overshoot	Settling Time	Steady State Error
Proportional	Decrease	Increase	Small Change	Decrease
Integral	Decrease	Increase	Increase	Eliminate
Derivative	Small Change	Decrease	Decrease	Small Change

The controllers can be implemented individually as well as in combination, with the converters to obtain the desired result.

IV. PROPOSED CONVERTER

The proposed converter as shown in Fig. 6 is similar to the conventional Boost converter as shown in Fig. 2 but differs only in the incorporation of a PID controller which is extensively used in many practical applications for better performance. The proposed PID controller has been obtained by block diagram reduction method in four stages as shown in Fig. 5. The first figure, Fig. 5(a) depicts a conventional PID controller block diagram when in successive stages as shown in Fig. 5(b), Fig. 5(c) and Fig. 5(d), by block diagram reduction technique the proposed control scheme for the Boost converter was obtained as shown in Fig. 5(d) which is feasible for proposed converter. Initial overshoot is a prime concern for operating machines in industries and researchers aim for designing a converter with good voltage regulation and overshoot reduction.



(a)

(b)

(c)

(d)

Fig. 5. Block diagram reduction of proposed PID controller

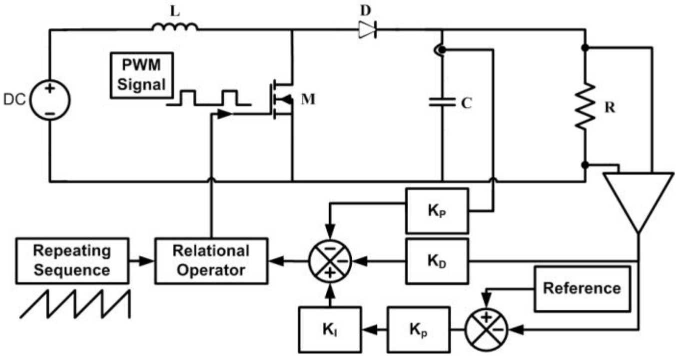


Fig. 6. Proposed Boost converter with PID controller for voltage regulation and overshoot reduction

Incorporating a PID controller with the converter improves the dynamic response and reduces the steady-state error. The derivative controller (K_D) ameliorates the transient response and the integral controller (K_I) will reduce the steady state error of the system. Our proposed system maintains an output of 200V when the input is in the range of 90V-110V which makes it quite feasible to apply in different industrial purposes.

V. RESULT AND SIMULATION

Simulation was done in MATLAB-Simulink environment. The parameters used for this simulation are given Table II. as shown below –

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Input Voltage	90V-110V
Output Voltage	200V
Rated Power	800W
Duty cycle	0.5
Boost Inductor	400μH
Filter Capacitor	100μ
Resistive Load	50Ω
K_P	0.0033
K_I	6.43
K_D	0.0027

Conventional Boost converter as shown in Fig. 7, was simulated at 50% duty cycle and the output wave shapes observed for variations of input voltage from 90V – 110V with increment of 10V. It can be observed that the output voltage fluctuates with variation of input voltage by a large amount. Moreover the converter exhibits significant increase in overshoot as the input voltage varies as shown in Fig. 8.

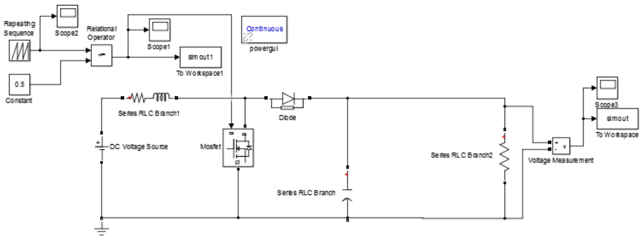
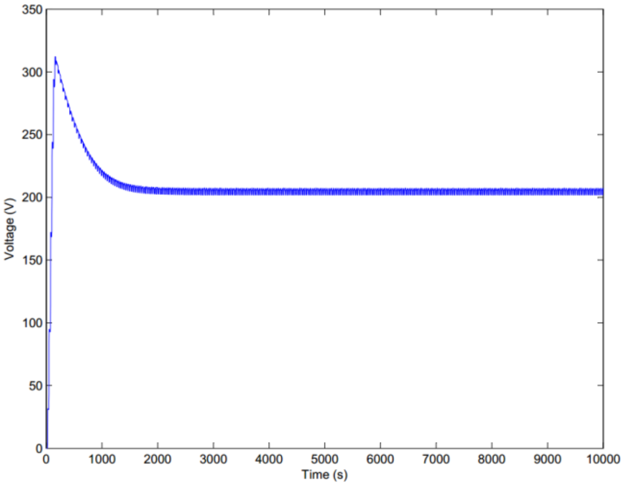
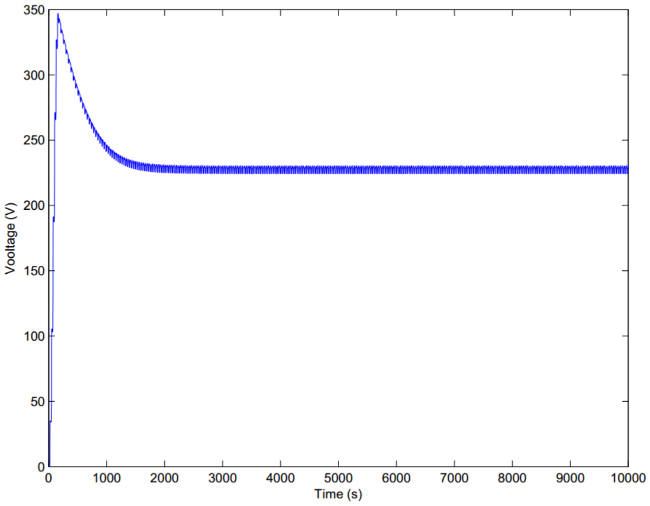


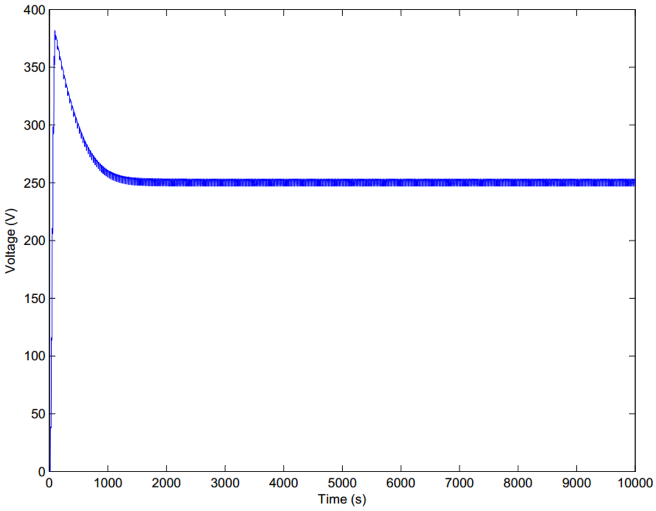
Fig. 7. MATLAB-Simulink model of conventional Boost converter



(a)



(b)



(c)

Fig. 8. Output voltage plot of conventional Boost converter operating at 50% duty cycle for input voltages (a) 90V, (b) 100V and (c) 110V

For proper voltage regulation and overshoot reduction the proposed Boost converter as shown in Fig. 9, was simulated for input voltage 90V – 110 V with increments of 10V and output wave shapes observed as shown in Fig. 10. It can be observed that the output voltage remains constant at the desired voltage of 200V and does not vary with variation of input voltage. Moreover, a significant reduction is overshoot has also been observed.

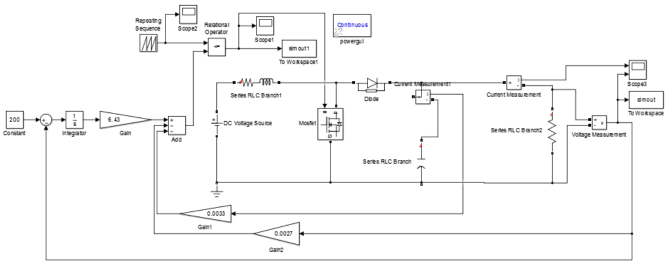
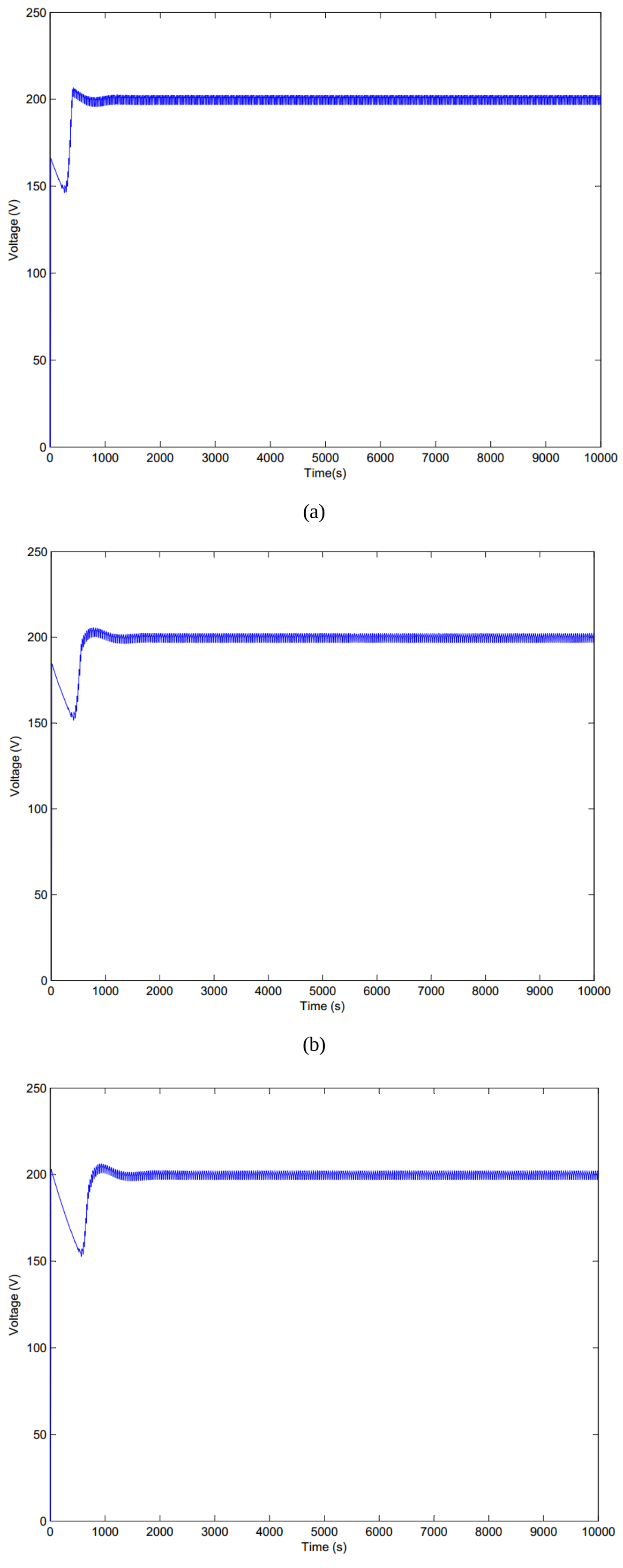


Fig. 9. MATLAB-Simulink model of proposed Boost converter with PID controller



(a)

(b)

(c)

Fig. 10. Output voltage plot of proposed Boost converter with PID controller operating at 50% duty cycle for input voltages (a) 90V, (b) 100V and (c) 110V

Simulation data obtained as shown in Table III was plotted in MATLAB and comparison was done between conventional and proposed Boost converter in terms of output voltage as shown in Fig. 11 and percentage overshoot as shown in Fig. 12.

TABLE III. COMPARISON BETWEEN CONVENTIONAL AND PROPOSED BOOST CONVERTER

	Conventional		Proposed	
Input Voltage, V_i (V)	Output Voltage, V_o (V)	Percentage Overshoot (%)	Output Voltage, V_o (V)	Percentage Overshoot (%)
90	204.8	52.44	200.8	2.88
100	228.3	51.99	200.6	2.19
110	248.8	53.50	200.4	2.20

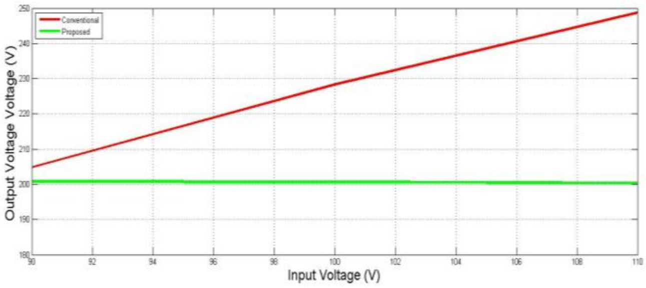


Fig. 11. Output voltage comparison between conventional and proposed Boost converter

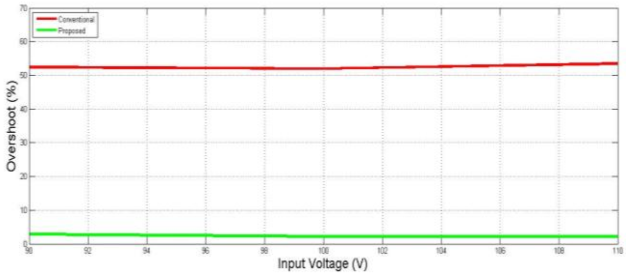


Fig. 12. Percentage overshoot comparison between conventional and proposed Boost converter

Experimental results show that the proposed PID controller when used with Boost converter provides better output voltage regulation and overshoot reduction, thereby improving the performance of the system.

VI. CONCLUSION

The proposed Boost converters with PID controller provides better voltage regulation, overshoot reduction and improves the converter performance compared to the conventional Boost converter. This paper successfully provides a method to satisfy the objective of DC-DC converter to maintain a constant output voltage at the load side. The proposed circuit is simple, easy to understand and can be implemented with no additional components thereby keeping size and cost of manufacturing the converter within considerable range.

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