COMPARISON OF PID TUNING TECHNIQUES FOR CLOSED LOOP CONTROLLER OF DC-DC BOOST CONVERTER

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ABSTRACT
The capability of PID controller to withstand practical industrial problems has led to its inclusive acceptance in industries and academics. It has been observed that PID controller tuning is quite difficult by classical methods using graphs and mathematical analysis. In this paper, PID theory is briefly summarized and some standard tuning methods are discussed using MATLAB. Accordingly compensator transfer function is derived by different methods and compared based on the steady state response and system characteristics. This effort inspects which method is best for conventional DC-DC boost converter.

KEYWORDS: *PID controller, tuning methods, MATLAB simulation, loop shaping.*

I. INTRODUCTION

In SMPS (Switched-mode power supply) DC-DC boost converter has played very important for handling high power. Boost converters are used in applications like photovoltaic (PV), hybrid electric vehicles (HEV), battery charging and aerospace industries for regulated power supply. In PV application the output of panel changes due to insolation level and temperature change. Whereas in HEV, Li-Po batteries [11] [12] are used where output changes according to discharging characteristics and the load change. So there is need of closed loop for boost converter in these applications. The load must be supplied with regulated power supply, keeping watch on the system characteristics like peak response, settling time, rise time and steady state. To achieve this, proportional integral derivative (PID) controller is used. PID controller is being used in 90% [7] of industries. PID is extensively used for it is simple in structure and has standard performance for most of the industries. But it is quite challenging to find gains of PID to meet response time and overshoot (phase margin) specifications. Manual tuning is purely trial and error process, time consuming and non-systematic. It may not produce optimal design and can lead to dangerous conditions. So some standard design procedures had been introduced like Ziegler-Nichols method, Chien-Hrones-Reswick method and pure numerical optimization approach (MIGO).

For analysis of a control system first a mathematical model of the boost converter is derived by state space averaging techniques [1]. The transfer function thus obtained is used to find the gains of controllers by different tuning methods mentioned above.

In this paper in section II basic theory of PID controller is given. In section III design of boost converter with control transfer function (G_{vd}) is presented [2]. In section IV different tuning methods are discussed and their respective compensator transfer functions are given. Various tuning methods are compared in section V with system characteristics. Finally the tuning method with best performance is chosen and is implemented to designed boost converter. The resultant control system is tested in simulation with dynamic load change and input voltage change.

II. MODEL OF PID CONTROLLER

The PID controller is used to regulate the time domain characteristics of the control system [5]. The governing s-domain equation is as follows;

$$Gc(s) = Kp + Ki\frac{1}{s} + Kd\frac{N}{1 + N\frac{1}{s}} \tag{1}$$

$$= Kp\left(1 + \frac{1}{Ti\,s} + Td\,s\right)$$

Where, Ti − Integral time
Td − Derivative time
Kp − Proportional gain constant
Ki − Integral gain constant
Kd − Derivative gain constant
N − Derivative filter

The error signal is difference between set point and measured plant output. The proportional gain is directly proportional to the measured error. When the proportional gain is increased steady state error is reduced but the affinity of oscillation in system increases. System may become unstable if the proportional gain is very high. When the integral gain increases the steady state error is vanished and peak overshoot increases. As the derivative gain increases, the peak overshoot and settling time decreases. On the other hand, it improves the stability of the system. Error signal always contains noise and when it is being differentiated noise is just amplified. So the good way to implement the derivative term is to filter the noise with low pass filter (N) and then differentiate them. So there must be compromise between these gains so as to get desired system performance. This is achieved by using different PID tuning methods.

III. DESIGN OF BOOST CONVERTER

Fig. 1 shows the boost converter arrangement for stepping-up a dc voltage. When a gate pulse G1 is given to the switch S at time t=0s, the inductor current I_L rises and L gets charged. If the gate pulse is removed at time t = Ts/4s, the energy stored in inductor is released through diode D1 and current falls. The converter is operated in continuous conduction mode and the respective waveforms are shown in fig. 2. The boost converter [12] [13] is designed as per the specifications given in table I. The ESR value of passive components have also been considered so as to get practical implications in the results.

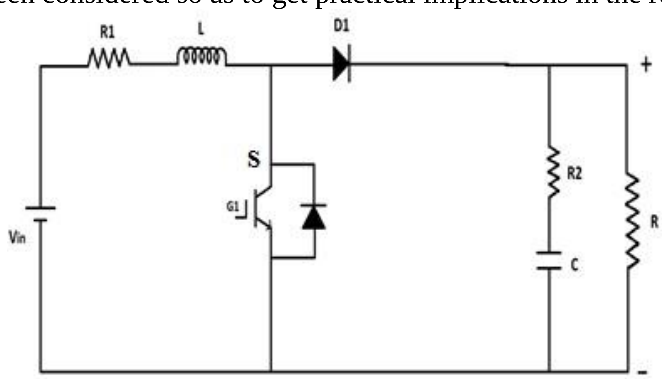

Fig. 1 Circuit of Boost Converter

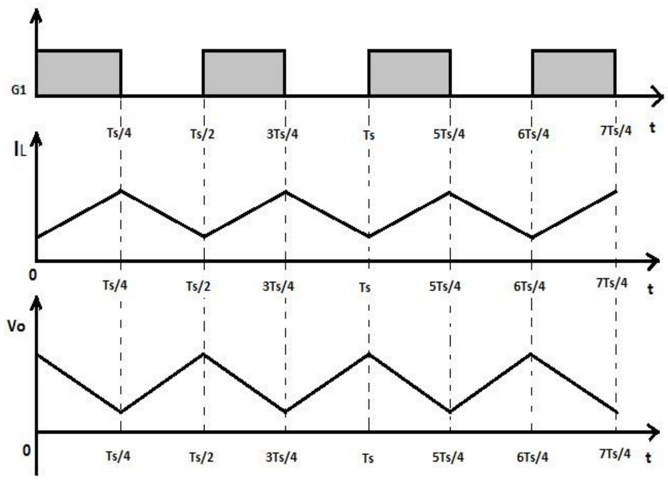

Fig. 2 Inductor current and output voltage waveforms operating in continuous mode

TABLE I.
Design parameters of Boost converter

Vin = 24 V
F = 100 kHz
R = 80 Ω
C = 1.311 µF
L = 117.47 µH
D = 50%
R1 = 80 m Ω
R2 = 5 m Ω
Vo = 48 V

The control transfer function (G_{vd}) of the boost converter is derived by using state space averaging method given by equation (2).

Where v_o − Output voltage
d − Duty cycle

$$G_{vd}(s) = \frac{v_o(s)}{d(s)} = \frac{(4.786 \times 10^{34})\, s - (7.468 \times 10^{39})}{(4.836 \times 10^{28})\, s^2 + (4.95 \times 10^{32})\, s + (7.266 \times 10^{37})} \quad (2)$$

Fig. 3 shows the basic structure of the PID controller. The controller is in series with the system with unity feedback. R is the reference input, Y is the output, e is the error signal and u is the regulated voltage.

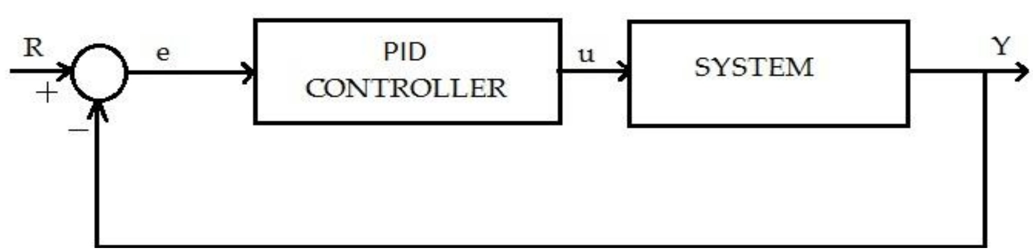

Fig. 3 Basic structure of PID controller

IV. VARIOUS PID TUNING METHODS

4.1. Ziegler-Nichols step response method

Ziegler and Nichols suggested method for determining the value of Kp, Ti and Td centred on transient response of the plant. So this method is useful even when transfer function of the plant is not known. First a step response of the plant is obtained. If the plant do not have integrator and dominant conjugate

TABLE II. Ziegler-Nichols Tuning Rule Based on Step Response of Plant

Type of Controller	Kp	Ti	Td
P	$\frac{1}{a}$	∞	0
PI	$0.9\frac{1}{a}$	3L	0
PID	$1.2\frac{1}{a}$	2L	0.5L

poles then the unit step response curve will show S-shaped curve. This curve have two constants, delay time L and time constant T as shown in fig.4 [11] [15]. These constants are obtained by drawing a tangent at the inflection point of the curve and find the intersection of the tangent with time axis and line c(t) = K. The compensator transfer function can be obtained by the formulae given in the table II. The compensator transfer function is given by equation (3) and step response with Ziegler-Nichols PID tuning is given in fig. 5.

$$C = -245.19 \times \frac{(1 + (4.1 \times 10^{-5})s + (4.41 \times 10^{-10})s^2)}{s(1 + (9.9 \times 10^{-7})s)} \quad (3)$$

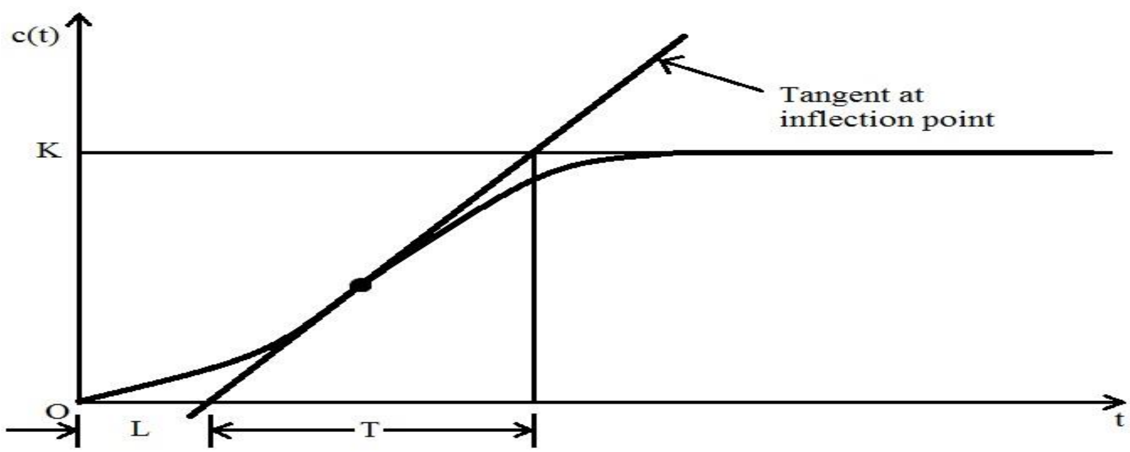

Fig. 4 Step response of plant (s-shaped curve)

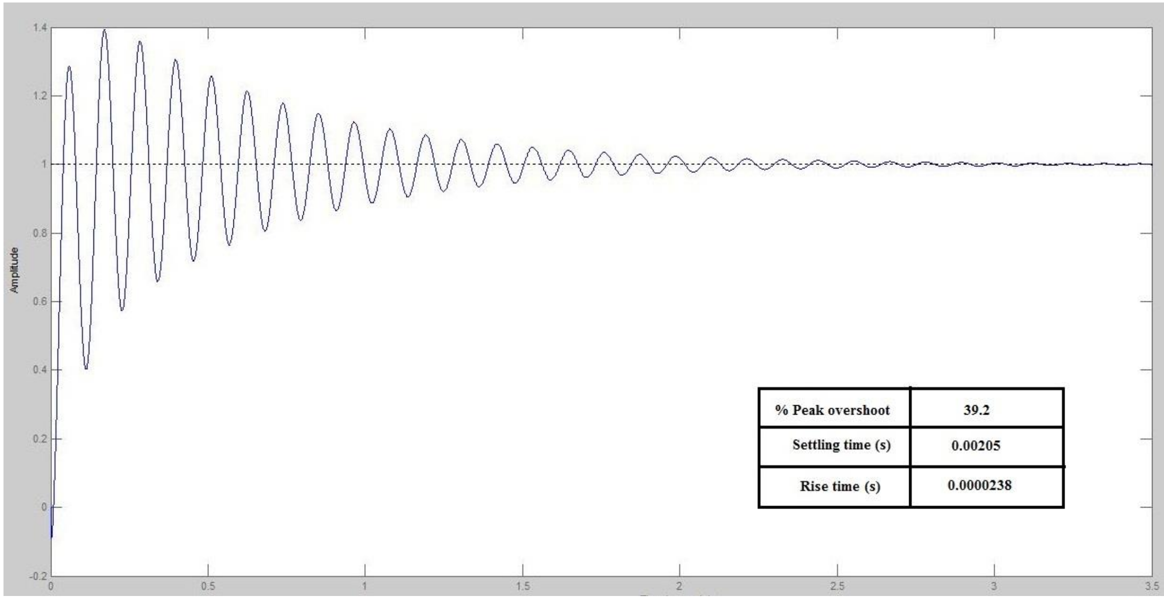

Fig. 5 Step response of plant with Ziegler-Nichols tuning

4.2. Chien-Hrones-Reswick method

The Chien-Hrones-Reswick (CHR) PID tuning is also called modified Ziegler-Nichols method. This method accentuates on the set point regulation or noise rejection. Also the response of the system and overshoot can be controlled. This method uses the time constant T explicitly than the Ziegler-Nichols tuning formula. This method gives better performance even at higher order (more than two). The design formulae for 20% overshoot is given in table III. The compensator transfer function is given by equation (4) and step response with PID control is given in fig. 6.

$$C = -163.11 \times \frac{(1 + (1.2 \times 10^{-5})s)\,(1 + (3.6 \times 10^{-5})s)}{s(1 + (8.3 \times 10^{-7})s)} \quad (4)$$

TABLE III. Chien-Hrones-Reswick Tuning Rule Based on Step Response of Plant

Overshoot	20%		
Type of Controller	Kp	Ti	Td
P	$\frac{0.3}{a}$	∞	0
PI	$0.35\frac{1}{a}$	$1.2T$	0
PID	$0.6\frac{1}{a}$	T	0.5L

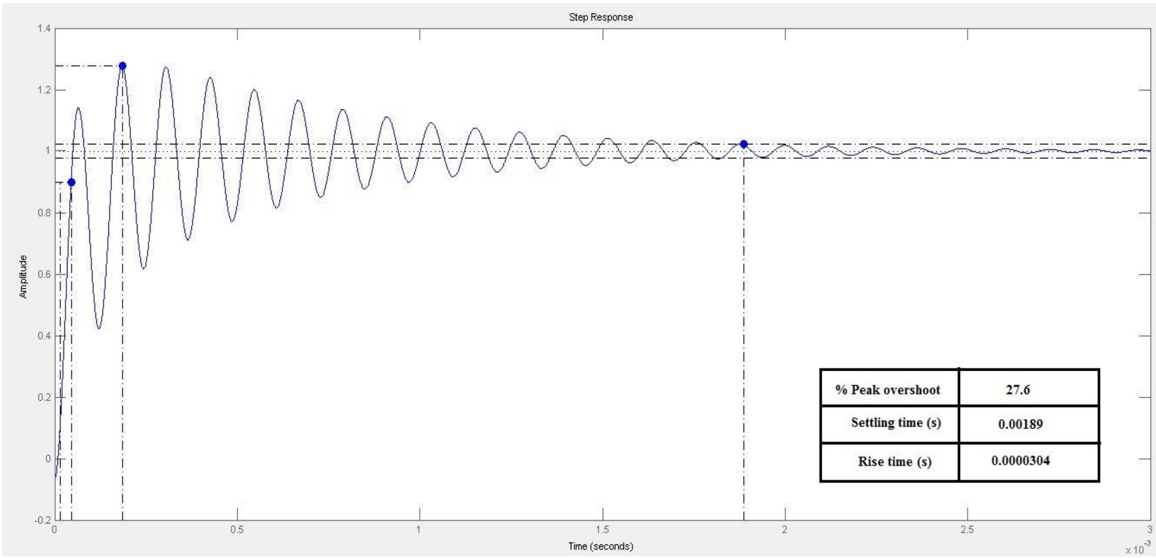

Fig. 6 Step response of plant with Chien-Hrones-Reswick tuning

4.3. Approximate MIGO (M – constrained integral gain optimization) frequency response method

The procedure of MIGO (M – constrained integral gain optimization) is similar to that of Ziegler-Nichols method. Generally the time constant for this method is obtained by equations given by Aström and Hägglund [9] [10]. In this paper AMIGO method is implemented using the sisotool in the MATLAB/Simulink. The compensator transfer function is given by equation (5) and step response with PID control is given in fig. 7.

$$C = -97.7 \times \frac{(1 + (2.4 \times 10^{-5})s + (2.56 \times 10^{-10})s^2)}{s(1 + (9.5 \times 10^{-7})s)} \tag{5}$$

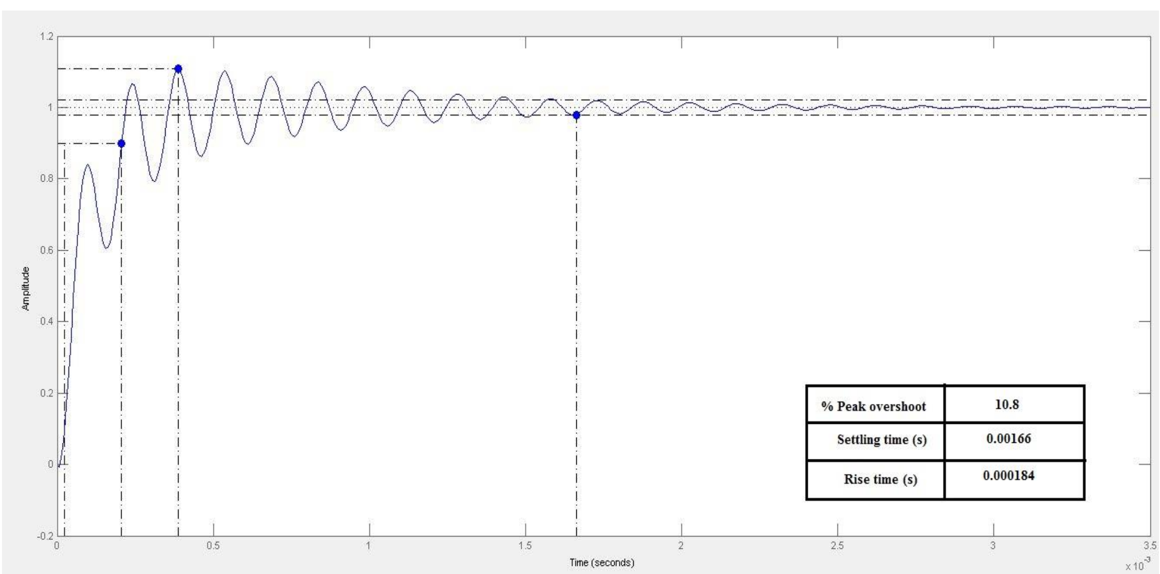

Fig. 7 Step response of plant with Approximate MIGO tuning

4.4. Loop shaping method

The loop shaping is a design method in which the compensator transfer function is designed such that the response gets the desired shape. This method is easy to implement. The compensator transfer function is designed with the help of root locus plots. First, the desired parameters are added in the sisotool and accordingly the region of stability is highlighted in the step response plot [17]. By adding poles and zeros in the root locus plot desired shape of loop is achieved within the highlighted region. The compensator transfer function's step response with loop shaping PID tuning is given in fig. 8. The gain constants obtained are, Kp = 11.2222, Ki = 62234.0092, Kd = 0.00025621 and N =5.

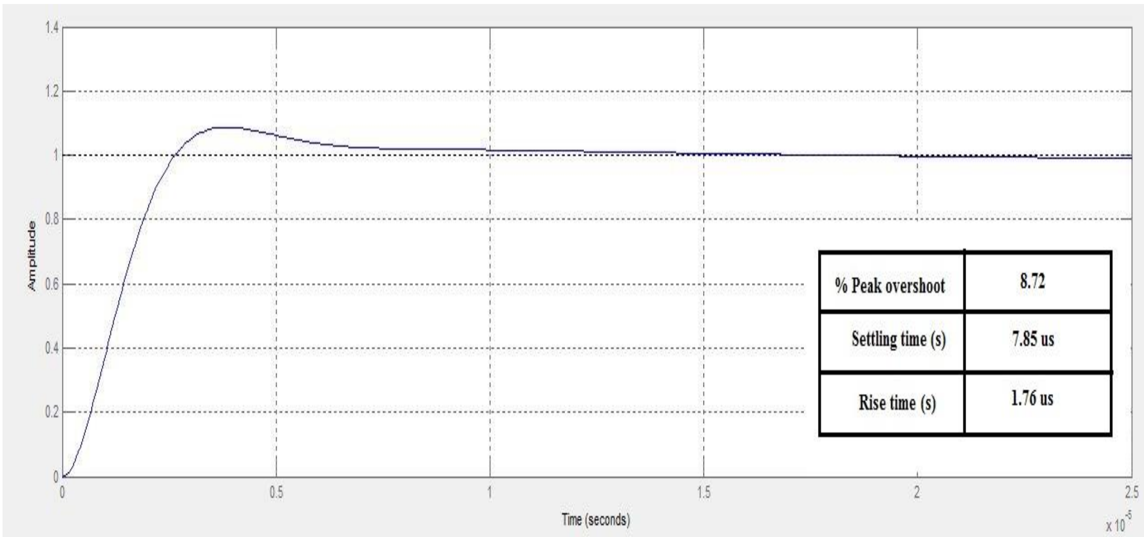

Fig. 8 Step response of plant with loop shaping method

V. COMPARISON OF DISCUSSED TUNING METHODS

Various tuning methods comparison is given in table IV. It is observed that loop shaping method gives best performance in terms of less peak overshoot, less settling time and less rise time. Moreover, loop shaping method is easy to implement with MATLAB/Simulink.

TABLE IV. Comparison of system characteristics

Tuning method	% Peak overshoot	Settling time	Rise time
Zeigler-Nichols	39.2	0.00205	2.38×10^{-5}
Chien-Hrones-Reswick	27.6	0.00189	3.04×10^{-5}
Approximate MIGO	10.8	0.00166	0.000184
Loop shaping	8.72	7.85×10^{-6}	1.76×10^{-6}

Further for testing the performance of loop shaping method a closed loop simulation of boost converter is done with above PID gains. Two types of disturbances are introduced in the simulation.

a) Dynamic Load change

Load is the primary disturbance faced by the boost converter in all its application. The rated load is 80Ω. The load change may be underload or overload. An underload of 60Ω is introduced at 0.1s and an overload of 100Ω is introduced at t=0.2. It is observed that the voltage is regulated at 48V after change in load as shown in fig. 9.

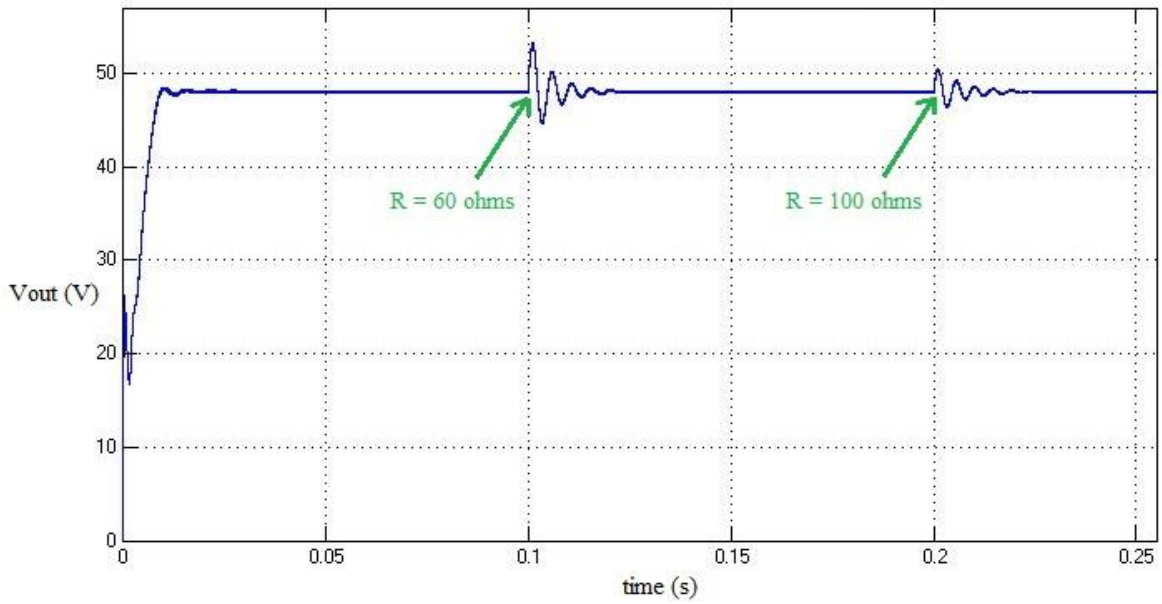

Fig. 9 Dynamic load change

b) Dynamic input voltage change

When the battery is used as source to the converter, which is a non-linear source, the output characteristics depends on the discharging characteristics of the battery. Also in PV application the output voltage of PV panels changes according to insolation levels. Thus the converter has to withstand this change in input voltage (24V) and regulate the output voltage (48V). An under voltage of 14V is introduced at t=0.1s and over voltage of 34V is introduced at t=0.2s. The PID controller has regulated the output voltage in both the cases as shown in fig. 10.

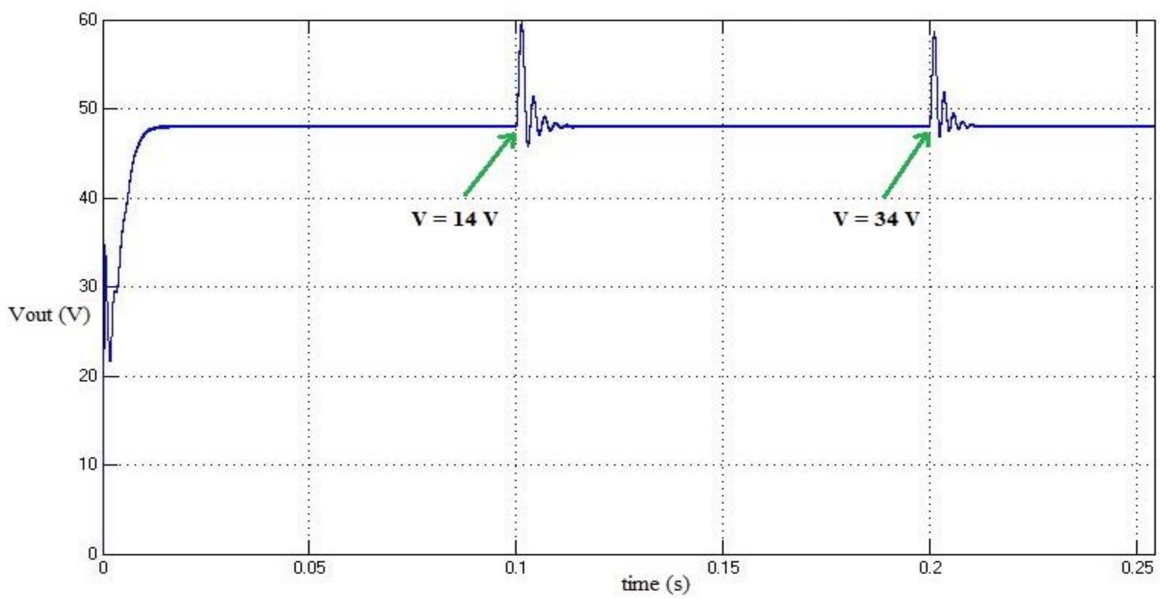

Fig. 10 Dynamic input voltage change

VI. CONCLUSIONS

Different PID tuning methods are discussed in this paper. Step response of all methods and their system characteristics are compared. It is concluded that loop shaping method is easy to implement and gives the desired results using MATLAB/Simulink effortlessly. Further the designed controller is implemented on boost converter using PID block in Simulink simulation. When the system is subjected to dynamic load change and dynamic input voltage change it comes back to initial state.

VII. FUTURE WORK

Further loop shaping tuning method can be applied to other converters. For implementing this controller in hardware the PID block can be converted into C or HDL code using MATLAB/Simulink. This code can be used for hardware in loop or can be implemented on separate processor.

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