TRANSIENT ANALYSIS AND COMPENSATOR DESIGN FOR BUCK CONVERTER

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Abstract: Dc-Dc converters are used to convert one voltage level to another level of voltage in dc. These Dc-Dc converters are used everywhere because of their high efficiency and single stage conversion. As the need of the portable devices are increasing day by day and the need for cheap and efficient regulated power supplies are increasing simultaneously. As the load current changes high ripples are observed in output voltage. As we know that buck converter is non-linear device so averaged model of buck converter is discussed in this paper. The design of a compensator is presented in this paper such that the ripples in voltage are settled down within the acceptable range in case of change in load current.

***Index Terms* – DC-DC Converter, MATLAB.**

I. INTRODUCTION

Dc-Dc converters are used everywhere because of their high efficiency and single stage conversion. The control of voltage is done by controlling the duty ratio of the switch. Commonly used switches are MOSFET, transistor, GTO, IGBT depending upon the circuit or the power transfer capability. Now a days the demand of portable devices like mobiles, laptops, aerospace application and automotive industries are increasing which require regulated voltage supply. In these systems the load voltage is kept constant irrespective of the changing load and voltage supply [2]. They are also used in the satellites where dc buses at different voltage levels are supplied through these dc-dc converters. The reason for their increased use is their cost effectiveness and simple circuitry. There is no energy generated inside the converter, all the energy that is supplied by source is transferred to load with little losses, to different voltage and current level. Furthermore, in a practical system circuit losses introduce an output voltage dependency on steady state load current which must be compensated for by the control system [3, 4].

Figure1 shows a dc-dc converter block diagram. It converts a dc input voltage, *Vg*, to a dc output voltage, *Vo*, with a magnitude other than the input voltage.

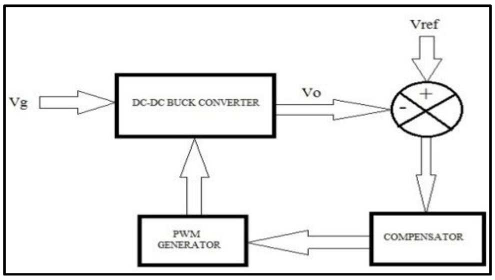

Fig1: Block diagram of a DC-DC converter

This conversion can be achieved by a variety of circuits based onand using switching devices. The widely used switching devices are diodes, thyristors, power MOS, etc. The converter often includes one MOSFET in order to control the output voltage, using the control signal (*t*). It is desirable that the conversion be made with low losses in the converter. To obtain low losses, resistors are avoided in the converters. Capacitors and inductors are used instead since ideally they have no losses. The electrical components can be combined and connected to each other in different ways, called topologies, each one having different properties [1, 4].

By using pulse-width modulation (PWM) control, regulation of output voltage is achieved by varying the duty cycle of the switch. Duty cycle refers to ratio of the period where power semiconductor is kept ON to the cycle period. Pulse width modulation (PWM) is a powerful technique for controllinganalog circuits. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. Control of PWM is usually effected by an IC, necessary for regulating the output. The MOSFET switch is the most important thing of the switched supply and controls the power supplied to the load. It is also stated that Power MOSFET's are more suitable than BJT at power output of the order of 50 W. Choosing of transistor also must consider its fast switching times and able to withstand the voltage spikes produced by the inductor [2, 3].

The proposed converter uses IGBT as the switching device. Use of IGBTs allows building cheaper and better converters. They have three attractive advantages: higher switching frequency, easy and simple gate control and no need for snubber circuits. IGBTs are continuously controllable during turn on and turn off. This makes overcurrent limitation much easier and allows dV/dt control to reduce the anddV/dt stresses. Many aspects must be considered in the case where a converter is to be designed. One such aspect is keeping the output voltage in the specified voltage interval. Here are some examples of changes that can decrease the variation of the output voltage:

- Change the properties of some of the components in the converter, e.g. increase the capacitance of the capacitor.
- Change the converter topology.
- Change to a more advanced controller.
- Increase the number of signals that are measured and used by the controller.

Each one of these changes has one or several disadvantages such as:

- Higher cost.
- Increased weight and volume.
- Lower reliability.
- Lower efficiency.

It is essential to develop accurate switching power converters, which can reduce more wasted power energy as the load current changes high ripples are observed in output voltage. As we know that buck converter is non-linear device so averaged model of buck converter is discussed in this paper. From averaged model transfer function is calculated. The design of a compensator is presented in this paper such that the ripples in voltage are settled down within the acceptable range in case of change in load current [2, 3, 8].

II. Mathematical modeling

Dynamics of dc-dc buck converter can be understood by state space representation. There are two modes of operation of buck converter as shown in Figure 2 [8].

Mode-1 Operation: (Switch S1 is on and S2 is off)

$$L\frac{di_L}{dt} = V_g - v_c$$

$$C\frac{dv_c}{dt} = i_L - i_R$$

Fig2: Operation mode of a DC-DC converter

$$C\frac{dv_c}{dt} = i_L - \frac{v_c}{R}$$

$$\begin{bmatrix} i_L \\ v_c \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} [V_g]$$

$\dot{x} = A_1x + B_1u$: Where $A_1 = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}$ and $B_1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}$

$$v_o = [0 \quad 1] \begin{bmatrix} i_L \\ v_c \end{bmatrix}$$

$y = C_1x + D_1u$

Where $C_1 = [0 \quad 1]$ and $D_1 = [0]$

Mode-2 Operation: (Switch S1 is off and S2 is on)

$$L\frac{di_L}{dt} = 0 - v_c$$

$$C\frac{dv_c}{dt} = i_L - i_R$$

$$C\frac{dv_c}{dt} = i_L - \frac{v_c}{R}$$

$$\begin{bmatrix} i_L \\ v_c \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_c \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} [V_g]$$

$\dot{x} = A_2x + B_2u$: Where $A_2 = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}$ and $B_2 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

$$v_o = [0 \quad 1] \begin{bmatrix} i_L \\ v_c \end{bmatrix}$$

$y = C_2x + D_2u$

Where $C_2 = [0 \quad 1]$ and $D_2 = [0]$

$d\dot{x} + (1-d)\dot{x} = A1xd + B1ud + A2x(1-d) + B2u(1-d)$

$\dot{x} = Ax + Bu$

Where $A = A1d + A2(1-d)$

$B = B1d + B2(1-d)$

Small Signal Model of DC-DC converter:

$(X \dot{+} \hat{x})$ = A.$(X + \hat{x})$ + B.$(U + \hat{u})$

$(X \dot{+} \hat{x})$= [A_1d+A_2(1-d)].$(X + \hat{x})$+ [B_1d+B_2(1-d)].$(U + \hat{u})$

$(X \dot{+} \hat{x})$=[A_1.(D+$\hat{d}$)+A_2(1-(D+$\hat{d}$))]$(X + \hat{x})$+[B_1.(D+$\hat{d}$)+B_2(1-(D+$\hat{d}$))].$(U + \hat{u})$

As

1. *$(\hat{x}.\hat{d})$ is very small so we can neglect this part of equation.*
2. *X is steady state value so* $\dot{X}$ = 0 = AX+BU.

$\dot{\hat{x}}$ = A$\hat{x}$ + B$\hat{u}$ + [(A_1-A_2).X + (B_1-B_2).U]$\hat{d}$

$\hat{y}$ = C$\hat{x}$ + D$\hat{u}$ + [(C_1-C_2).X + (D_1-D_2).U]$\hat{d}$

Average model of buck converter [9]

A = A_1.D + A_2 (1-D)

$$A = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}.D + \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}.(1-D)$$

$$A = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}$$

B = B_1.D + B_2 (1-D)

$$B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}.D + \begin{bmatrix} 0 \\ 0 \end{bmatrix}.(1-D)$$

$$B = \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix}$$

Using averaged state space model we can find transfer function of dc-dc buck converter which is given as: [10]

$$G(S) = \frac{Vg}{LCS^2 + \left(\frac{L}{R}\right)S + 1}$$

III. Methodology

Fixed structure compensators are those compensators whose design remain fixed for a particular DC-DC converter and for a change in plant only values of the resistance and capacitance values need to be changed. There are many ways to design these compensators based on the time-domain and frequency-domain specification as these characteristics define the characteristics of the system. Here we will show how to design the compensator based on the frequency-domain specification.

Frequency-Domain Specifications:

1. *Gain Margin*: it is the amount of change required in open loop gain to make the system unstable.
2. *Phase Margin*: it is the amount of change required in open loop phase shift to make a closed loop system unstable.
3. *Bandwidth:* the bandwidth is frequency at which the closed loop systems gain falls to -3db.
4. *Nyquist Slope*: its new and effective method to shape the loop characteristics.

Effects of Frequency Domain Specifications on the System:

1. Gain Margin: increasing gain margin helps us to remove low frequency noise problems and increase in dc gain also makes system a little fasters.

2. *Phase margin*: low phase margin causes closed loop system to exhibit overshoot and ringing. It is closely related to closed loop damping factor.

3. *Bandwidth*: it helps to remove the sensor noise used to sense the current/voltage in the closed loop system. It also affect the rise time of the system.

4. *Nyquist slope*: it helps to shape the loop so that the slope of magnitude curve is -20db/decade at crossover frequency and the phase curve gives phase margin of the -90 so that robust controllers may be designed.

Selection of compensator:

There are four compensators among which we have to choose P, PI, PD and PID. The selection is based on the following characteristics:

a. Rise Time
b. Maximum Overshoot
c. Steady State Error
d. Settling Time

We have to select what suits best to our requirement. In this paper PD and PID compensator design using MATLAB is shown below:

a. Proportional plus Derivative (PD):

It is mainly used to boost the dynamics of the system and increase the stability of the system. The derivative control is not used alone because of the problem of amplifying the noise.it has very less effect on the steady state error of the system.

b. Proportional plus Integral plus Derivative (PID):

PID has fast dynamics, zero steady state error and nooscillations with high stability. It has the advantage is that it can be applied to system of any order. Derivative gain in addition to PI is to increase the speed of response and decrease overshoot and oscillations. There are lots of tuning methods available including online tuning including iterative procedures, offline tuning using the pen and pencil. According to the advantages offered by PID over other we select PID.

IV. RESULT AND DISCUSSION

With regard to the transfer function for the buck converter, open loop bode plot is shown in figure 3.

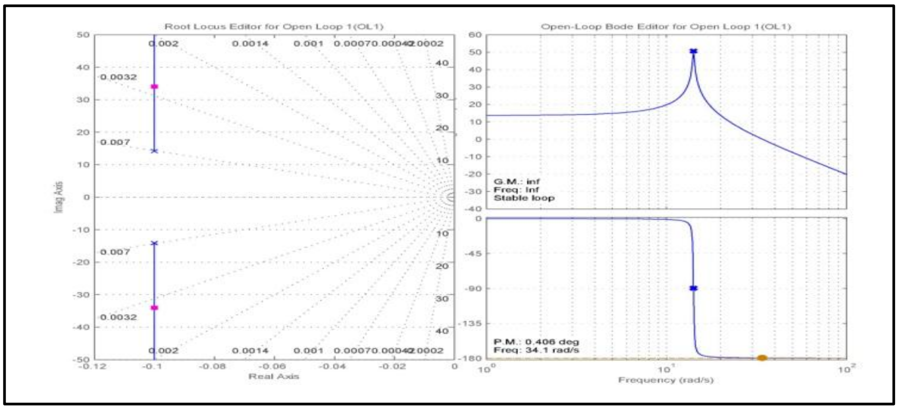

Fig3: Open loop Bode Plot of Buck Convert

Open loop response of dc-dc buck converter without and with load disturbance is shown in figure 4(a) and 4(b) respectively.

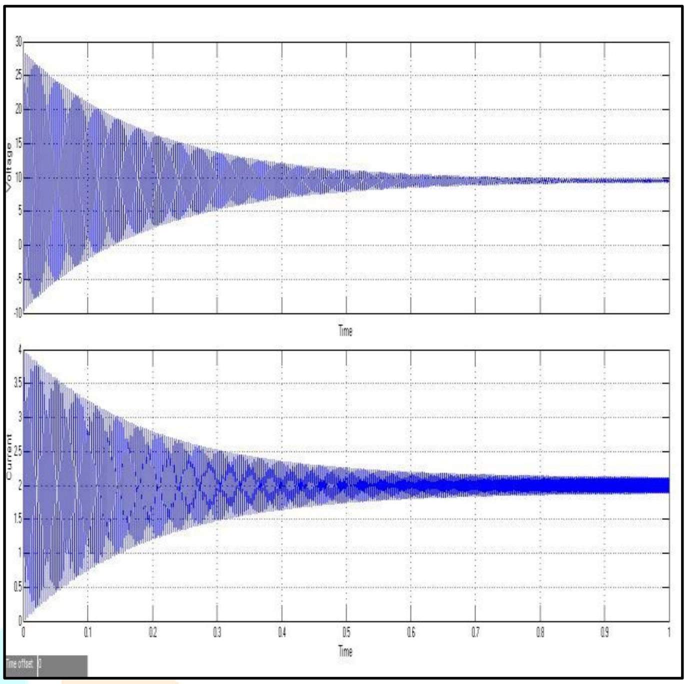

Fig4: (a) Open loop response of dc-dc buck converter without load disturbance

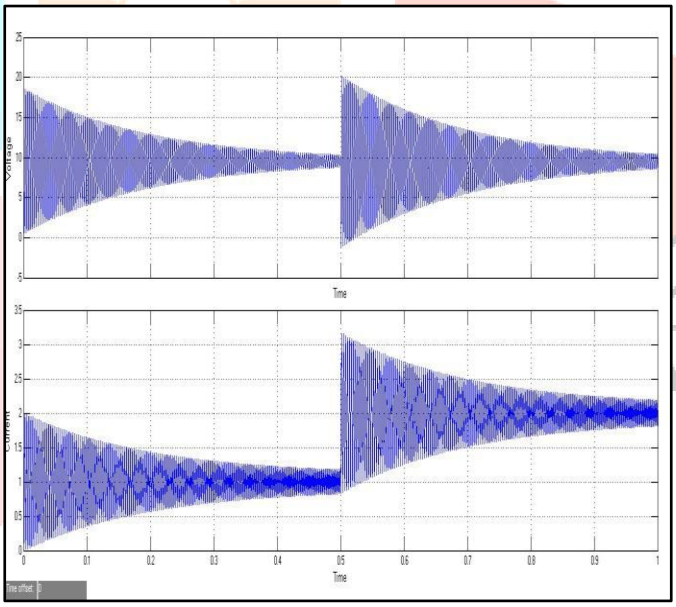

Fig4: (b) Open loop response of dc-dc buck converter with load disturbance

Bode plot dc-dc buck converter after design of PD compensator is shown in figure 5.

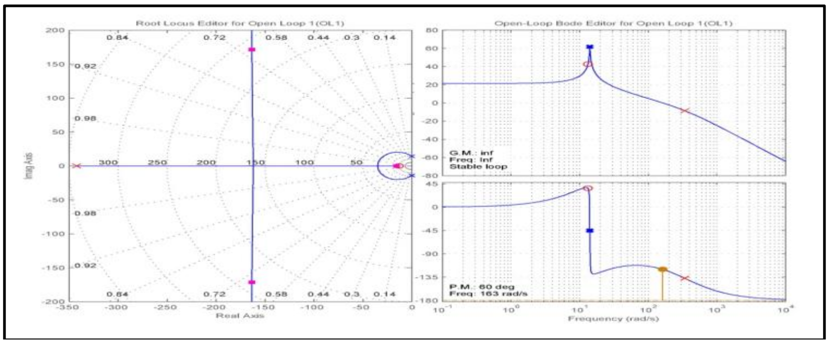

Fig5: Bode plot dc-dc buck converter after design of PD compensator

Closed loop response with PD compensator of dc-dc buck converter without and with load disturbance is shown in figure 6(a) and 6(b) respectively.

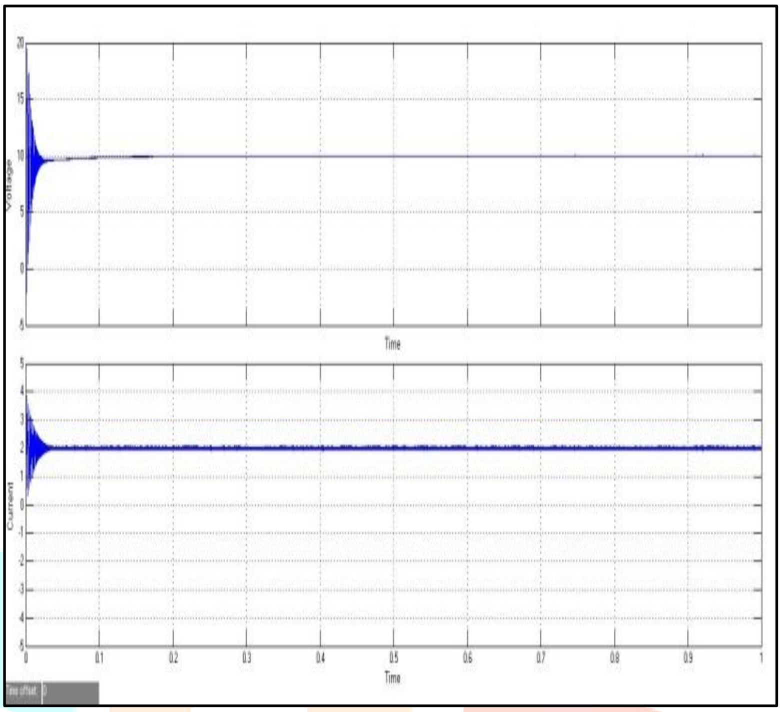

Fig6: (a) Close loop response of dc-dc buck converter with PD compensator and without load disturbance

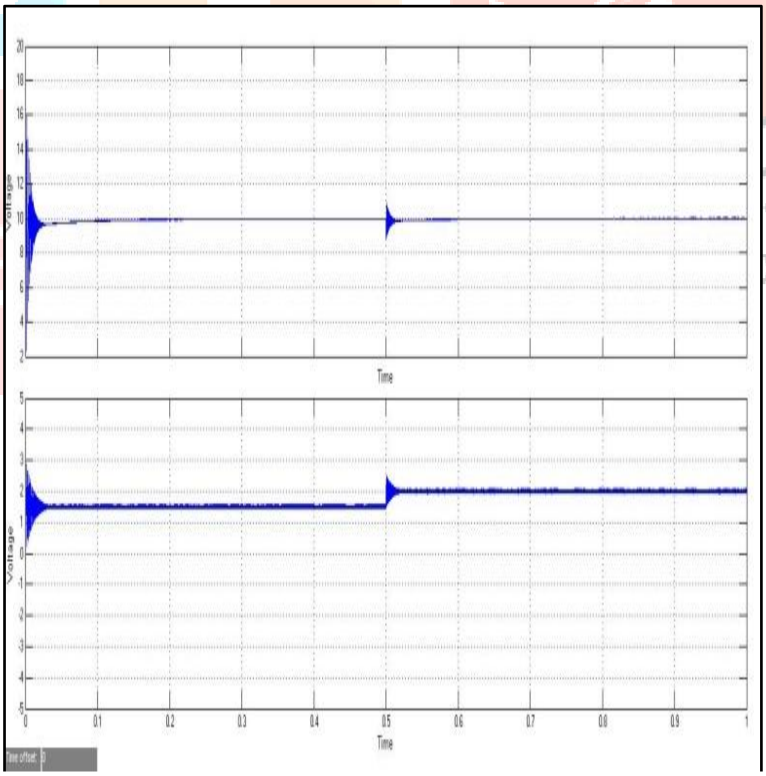

Fig6: (b) Close loop response of dc-dc buck converter with PD compensator and load disturbance

Bode plot dc-dc buck converter after design of PID compensator is shown in figure 7.

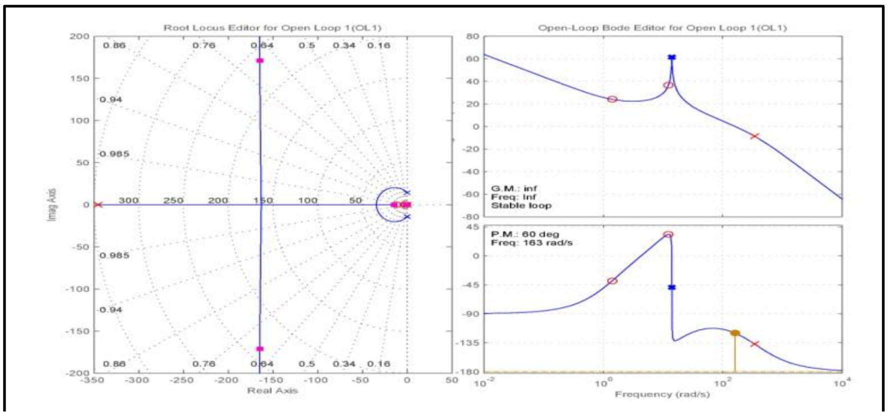

Fig7: Bode plot dc-dc buck converter after design of PID compensator

Closed loop response with PD compensator of dc-dc buck converter without and with load disturbance is shown in figure 8(a) and 8(b) respectively.

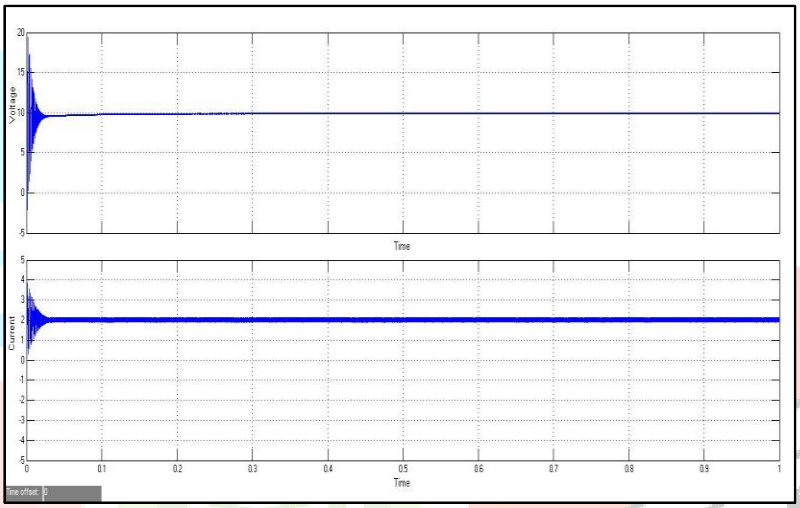

Fig8: (a) Close loop response of dc-dc buck converter with PID compensator and without load disturbance

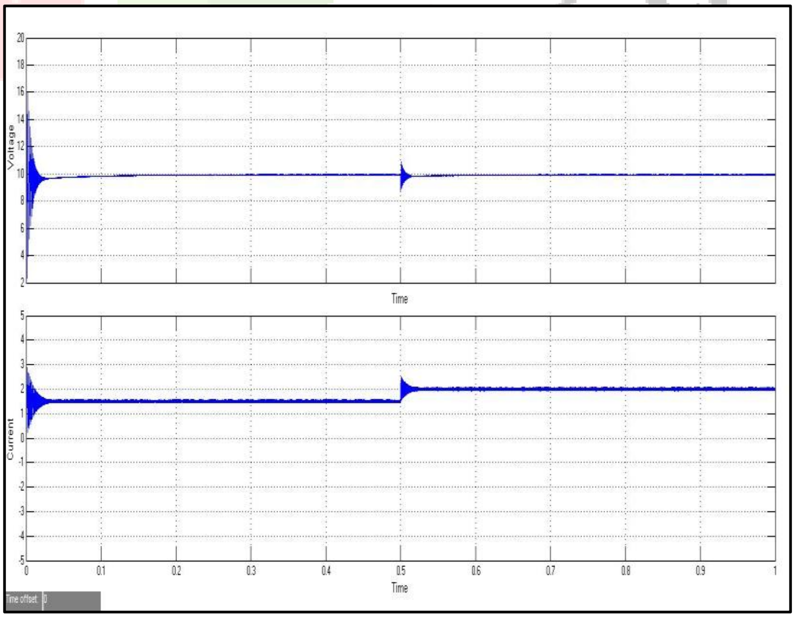

Fig8: (b) Close loop response of dc-dc buck converter with PID compensator and load disturbance

The transient performance parameters with PD and PID compensator is shown in table below:

TABLE I: Parameters for different compensator

S.No	Parameters	No Compensator		PD Compensator		PID Compensator	
		A	B	A	B	A	B
1	Settling Time (in sec)	0.9	1.4	0.007	0.007	0.006	0.006
2	Maximum Overshoot (%)	66.6 7	75	15	15	15	15
3	Steady State Error (volt)	0.2	0.4	0	0	0	0

Here A and B represents no load disturbance and with load disturbance respectively.

V. CONCLUSION

PD and PID compensators for dc-dc buck converter are designed and results are discussed in this paper. Bode plot of dc-dc buck converter in open loop, with PD and PID compensator has been seen. It is concluded that the performance of dc-dc buck converter is improved with PD compensator. The performance further improved with PID compensator and it also gives the desired results & the ripples in voltage are settled down within the acceptable range in case of change in load current.

VI. FUTURE SCOPE

Further design of PD and PID compensator can be applied to other converter. Hardware model of the compensator can also be implemented by generating c or HDL code using MATLAB/Simulink. This code can be used for hardware in loop or can be implemented on separate processor.

REFERENCES

[1]Dharmendra Jain, Dr. M.K. Bhaskar, and Manoj Kumar, "Comparative Analysis of Different Methods of Tuning the PID Controller Parameters for Load Frequency Control Problem", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 3, Issue 11, pp. 13144-13154,November 2014, ISSN.

[2] Hebertt J. Sira-Ramirez & Ramón Silva-Ortigoza,Control Design Techniques in Power Electronics Devices Springer-Verlog, 2010.

[3] Mohan, Undeland and Robbins.Power Electronics: Converters, Applications and Design. – Wiley, 1989.

[4] B.K.Bose, Power Electronics and Variable Frequency Drives,IEEE press, 1997.

[5] Modelling and Control of DC-DC Converters,Tutorial, Power Engineering Journal, 1998.

[6] HemantMehar,"MATLAB Simulation Techniques in Power Electronics", IEEE Technology and Engineering Education, Vol.7 No.4, Dec 2012.

[7] Robert W. Erickson and DraganMaksimovi´c. Fundamentals of Power Electronics.Springer Science+Business Media, LLC, second edition, 2001.

[8] Raymond T. Stefani, BahramShahian, Clement J. Savant, and Gene H. Hostetter. Design of Feedback Control Systems. Oxford University Press, fourth edition, 2002.

[9] Ms.KashmiraRathi(Kasat) and Dr.M.S.Ali, "Design and Simulation of PID Controller for Power Electronics Converter Circuits", International Journal of Innovative and Emerging Research in Engineering Volume 3, Issue 2, 2016.

[10] Mohammad Reza, "An Improved State Space Average Model of Buck DC-DC Converter with all of the System Uncertainties", in International Journal on Electrical Engineering and Informatics, Volume 5, No 1, March 2013.

[11] Power Electronics Circuits, Devices and Applications By Muhammad H. Rashid Second Edition PHI.

[12] Chun T. Rim, Gyu B. Joung, and Gyu H. Cho, "Practical Switch Based State-Space Modelling of DC-DC Converters with All Parasitics," IEEE Trans. on power electronics, vol. 6 No. 4 October 1991.