EXPERIMENTAL EVALUATION OF PID CONTROLLER FOR DC-DC CONVERTER.

This project report is submitted to
Yeshwantrao Chavan College of Engineering
(An Autonomous Institution Affiliated to Rashtrasant Tukdoji Maharaj Nagpur University)
In partial fulfillment of the requirement
For the award of the degree

Of

Bachelor of Engineering in Electrical Engineering

By

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Under the guidance of

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DEPARTMENT OF ELECTRICAL ENGINEERING

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YESHWANTRAO CHAVAN COLLEGE OF ENGINEERING,
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NAGPUR – 441 110

2022-23

CERTIFICATE OF APPROVAL

Certified that the project report entitled **"EXPERIMENTAL EVALUATION OF PID CONTROLLER FOR DC-DC CONVERTER."** has been successfully completed by

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in recognition to the partial fulfilment for the award of the degree of Bachelor in Electrical Engineering, **Yeshwantrao Chavan College of Engineering *(An Autonomous Institution Affiliated to Rashtrasant Tukadoji Maharaj Nagpur University)*, Nagpur.**

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Signature of External Examiner

Name:

Date of Examination:

DECLARATION

We certify that

a. The work contained in this project has been done by us under the guidance of our supervisor **Dr. P.M.Meshram.**

b. The work has not been submitted to any other Institute for any degree or diploma.

c. We have followed the guidelines provided by the Institute in preparing the project report.

d. We have confirmed the norms and guidelines given in the Ethical Code of Conduct of the Institute.

e. Whenever we have used materials (data, theoretical analysis, figures, and text) from other sources, we have given due credit to them by citing them in the text of the report and giving their details in the references. Further, we have taken permission from the copyright owners of the sources, whenever necessary.

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LIST OF ABBREVIATIONS

MATLAB	Matrix laboratory
AC	Alternating current
DC	Direct current
KVL	Kirchhoff's voltage law
KCL	Kirchhoff's current law
PI	Proportional-Integrator
PD	Proportional-Derivative
PID	Proportional-Integrator- Derivative
K_P	Proportional Gain
K_I	Integral Gain
K_D	Derivative Gain
PWM	Pulse width modulation

ABSTRACT

This thesis presents the design and implementation of a buck converter with closed-loop control using a PI controller. The buck converter is a widely used DC-DC power converter that steps down the input voltage to a lower output voltage. The closed-loop control system with a PI controller is implemented to improve the converter's output voltage regulation and reduce steady-state error. The PI controller is designed and tuned using the Root Locus method. The small signal modelling of DC-DC converters has been carried out. For controlling the output compensator i.e. PID design has also been done in root locus plot & the value of gains such as K_P, K_I, and K_D are calculated. The buck converter and PI controller are simulated in MATLAB/Simulink and then implemented on a hardware prototype using a various circuits. The performance of the closed-loop system is evaluated by measuring the output voltage response to load and input voltage variations. The results show that the closed-loop control system improves the converter's output voltage regulation and reduces steady-state error compared to the open-loop system.

Keywords: Buck, Modelling, MATLAB, Simulink, PID, K_P, $K_{I,}$ and $K_{D.}$

Course Outcomes and CO-PO/PSO Mapping

Session -2022-23

Semester/Year: VII (ODD-22-23) Mini project

Project Title- Design Considerations Of DC-DC Converters.

Project Guide name- Dr.P.M.Meshram

Course Objective:-

1. To apply knowledge of mathematics, science, and engineering in a global, economic, environmental, and societal context and engage in life-long learning.

2. To design a model, a system, or components considering environmental, economic, social, political, ethical, and sustainability and analyze and interpret the data.

3. To work on multidisciplinary teams, tackle engineering problems, understand professional and ethical responsibility and communicate effectively.

4. To apply knowledge of contemporary issues and use the techniques, skills, and modern engineering tools necessary for engineering practices.

Course outcome:

At the end of the program, the student will be able to

Level	Course Name: Mini/Major Project	
L1	CO1: **Identify** the research area of project work in Electrical Engineering.	
L2.L6	CO2: **Summarize** the literature review in the area identified, **propose** the objectives of project work.	
L3,L4	CO3: **Organize** requisite components with specifications for the project software/hardware prototype and **apply** suitable software/hardware tool in project work	
L2,L5,L6	CO4: **Compile**, **discuss** and **conclude** the results in project report and give presentation by effective communication	

CO-PO/PSO Mapping

Level	CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
L1	**CO1**	3	3	3	3	3	1	1	3	3	3	2	3	3	3
L2.L6	**CO2**	3	3	3	3	3	1	1	3	3	3	2	3	3	3
L3,L4	**CO3**	3	1	1	1	1	1	1	1	2	2	1	3	3	1
L2,L5,L6	**CO4**	3	1	1	1	1	1	1	1	3	2	1	3	3	3

Mapping	PO	Level	Justification
CO1	**PO1**	**3**	Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization project work in Electrical Engineering
CO2		**3**	
CO3		**3**	
CO4		**3**	
CO1	**PO2**	**3**	Students will analyze complex engineering problems related to electrical system and propose the objectives of project work.
CO2		**3**	
CO3		**1**	
CO4		**1**	
CO1	**PO3**	**3**	Students will Organize requisite components with specifications for the project software/hardware prototype and design electrical system components of project work
CO2		**3**	
CO3		**1**	
CO4		**1**	
CO1	**PO4**	**3**	Students can use research-based knowledge and methods including design of experiments, analysis and interpretation of data to provide valid conclusions which will be applied for project work.
CO2		**3**	
CO3		**1**	
CO4		**1**	
CO1	**P05**	**3**	Student will Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools for designing and modelling of project work
CO2		**3**	
CO3		**1**	
CO1		**1**	

CO1	**PO6**	**1**	Student will apply reasoning informed by the contextual knowledge related to project work to assess societal, health, safety, legal issues and the consequent responsibilities relevant to the professional engineering practice.
CO2		**1**	
CO3		**1**	
CO4		**1**	
CO1	**PO7**	**1**	Students will understand engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development in Electrical power system projects
CO2		**1**	
CO3		**1**	
CO4		**1**	
CO1	**PO8**	**3**	Student will apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice by implementing their project work.
CO2		**3**	
CO3		**1**	
CO4		**1**	
CO1	**PO9**	**3**	Student can function effectively in project work as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings
CO2		**3**	
CO3		**2**	
CO4		**3**	
CO1	**PO10**	**3**	Students will be able to comprehend and write effective project reports and design documentation, make effective presentations, and give and receive clear instructions.
CO2		**3**	
CO3		**2**	
CO4		**2**	
CO1	**PO11**	**2**	Students can apply engineering principles related to Electrical system to one’s own project work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
CO2		**2**	
CO3		**1**	
CO4		**1**	
CO1	**PO12**	**3**	

CO2		**3**	Students can get ability to engage in independent and life-long learning in the broadest context of technological change related to electrical power system by designing projects.
CO3		**3**	
CO4		**3**	
CO1	**PSO1**	**3**	Student will interpret, identify, analyse and evaluate indirectly problems in electrical Power system by applying innovative ideas in project work
CO2		**3**	
CO3		**3**	
CO4		**3**	
CO1	**PSO2**	**3**	Students can demonstrate knowledge to develop, control and assess electrical and electronic systems through their project work
CO2		**3**	
CO3		**1**	
CO4		**3**	

Dr.P.M.Meshram

Name and Sign of guide.

CHAPTER 1
INTRODUCTION

1.1 OVERVIEW

Over the years as the portable electronics industry progressed, different requirements evolved such as increased battery lifetime, and a demand for increased talk time in cellular phones. The ever increasing demand for power systems has placed power consumption at a premium. To keep up with these demands engineers have worked towards developing efficient conversion techniques which also have resulted in the subsequent formal growth of an interdisciplinary field of Power Electronics. However, it comes as no surprise that this new field has offered challenges owing to the unique combination of three major disciplines of electrical engineering: electronics, power, and control. Hence development of various converter devices comes into existence.

1.2 INTRODUCTION

The world is now habituated to electronic devices without which it is very difficult for mankind to keep going. So it is very important to develop the devices error-free and fast response with high efficiency. The research, the field is dc-dc converters. The dc-dc converters mean the input is dc and the output is also dc. The two basic dc-dc converters are buck converters and boost converters. Based on these two converters, all other converters are derived. The semiconductor devices are used as switching devices due to which the converters can operate at high frequencies. The different arrangement of inductors and capacitors in the converters operates as a filter circuit. The resistance act as a load in the circuit which can be varied to study the behavior during light load and heavy load. Different types of input dc sources are used like batteries, renewable energy sources, etc. The converter is operated at different frequency levels to improve the response of the converters.

1.3 OBJECTIVE OF THE PROJECT

- To study dc-dc converter.
- To study dc-dc converter and their simulation techniques.
- Evaluate the static and dynamic performance of some dc-dc converter topologies such as buck, boost, and buck-boost dc-dc converter.
- To predict the dynamic behavior of a dc-dc converter for changes in the source voltage or load current.
- To develop the prototype of buck converter.

1.4 APPLICATIONS

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 continuous 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 the regenerative braking of dc motors to return energy into the supply, and 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.

1.5 CONTRIBUTION

Chapter 1- Gives the overview of the project with objectives and thesis contribution.
Chapter 2- Discusses the details of literature survey.
Chapter 3- Discusses the brief introduction of mini project.
Chapter 4- Discusses the PID controller & Buck converter designing.
Chapter 5- Discusses the Simulation and Hardware experiment results.

CHAPTER 2
LITERATURE REVIEW

2.1 OVERVIEW

This Chapter reviews the various literature survey done on DC-DC Converters. This Chapter also discussed the work done by other researchers in the field of DC-DC Converters.

2.2 LITERATURE SURVEY

All the converters are derived based on the two basic converters such as buck converter and boost converter. The aims of developing the converters are high efficiency and high gain with fast response. Today's world demands low-power application devices which is the focus of researchers. There are so many parameters involved while developing those converters. A lot of computer software has been developed to design such types of converters. With the help of simulations, the behavior of the system can be easily analyzed without any hardware which can prevent damage. Research work has grown dramatically to provide service to mankind. [1-5]

Design and simulation of dc-dc converters. It contains the theoretical derivations and parameters equations with design and examples. Simulation results for the buck, boost, and buck-boost converters are shown with the chance of different input parameters. In this work, they have analyzed the equation of buck, boost, and buck-boost converters and proposed the design components and simulation of these converters. Changing the input parameters like inductance, capacitance, and switching frequency to observe the changes in output voltage has been added to the simulation graph. These parameters and their equations should be well understood before designing buck or boost or buck-boost converters. It completed the design and investigation of these three converters through mathematical examples and generated the circuits for simulating buck, boost, and buck-boost converters. And also have attained different output voltage curves with the change of input parameters. [8-11]

Various techniques are applied for extracting the model and transfer functions from control to output and from input to the output of a buck-boost converter. To investigate a controller necessity for the converter of assumed parameters, the frequency and time domain analysis is done and the open loop system characteristics are verified and the needed closed loop controlled system specifications are determined. Finally designing a controller for the mentioned converter system based on the extracted model is discussed. Then, a modern control design method is employed for regulator design. For this purpose, a full state feedback control for pole placement is applied. [14-18]

Design, analysis, and comparison of different types of dc-dc converters. Nowadays due to the lack of conventional energy sources like coal, petrol, diesel, etc., the electricity demand is rising day to day. To fulfill this demand for electrical energy alternative methods are very much important now. The researchers stand motivating in solar energy generation, dc-dc converters, etc. In this papers performance analysis of different dc-dc converters and a comparative study of them are focused on. All converters will work in Continuous conduction mode. The performance analysis of different converters (Buck, Boost, Buck-Boost, CUK, SEPIC). [21-24]

CHAPTER 3
BRIEF REVIEW OF MINI PROJECT

3.1 Overview

This chapter includes the brief introduction of work done in mini project work including equations, waveforms, etc.

3.2 DC-DC converters

DC-to-DC converters are electromechanical devices or electronic circuits that convert one direct current voltage or current level to another.[21] The dc converters can be used as switching mode regulators to convert a dc voltage, usually unregulated, to a regulated dc output voltage. A dc-dc converter can be considered as dc equivalent to an AC transformer with a continuously variable turn's ratio.[19]

There are several dc-dc converters that are used to modulate the input voltage depending upon their applications. Generally, there are two types of dc-dc converters which are isolated dc-dc converter and non-isolated dc-dc converter.[14] The types of various DC-DC Converters are shown in following figure 3.1.

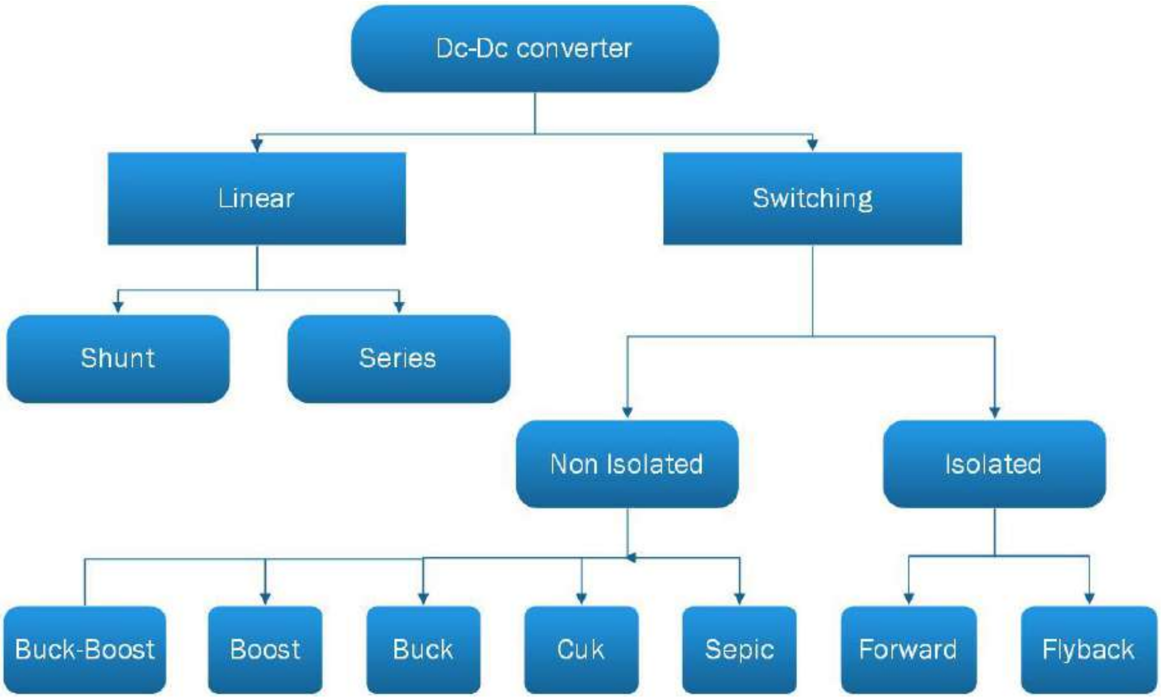

Figure 3.1 Converter topologies.

The mini project focuses especially on buck, boost and buck-boost converter topologies.[17] The boost is one of the fundamental switch-mode power topologies. The other being is the buck converter. From these two topologies, all other topologies switch-mode power supply topologies are derived.

3.3 Buck converter

A Buck converter is a step down DC-DC converter consisting mainly of inductor and two switches (usually a transistor switch and a diode) for controlling inductor. It fluctuates between connection of inductor to source voltage to accumulate energy in inductor and then discharging the inductor's energy to the load.[3]

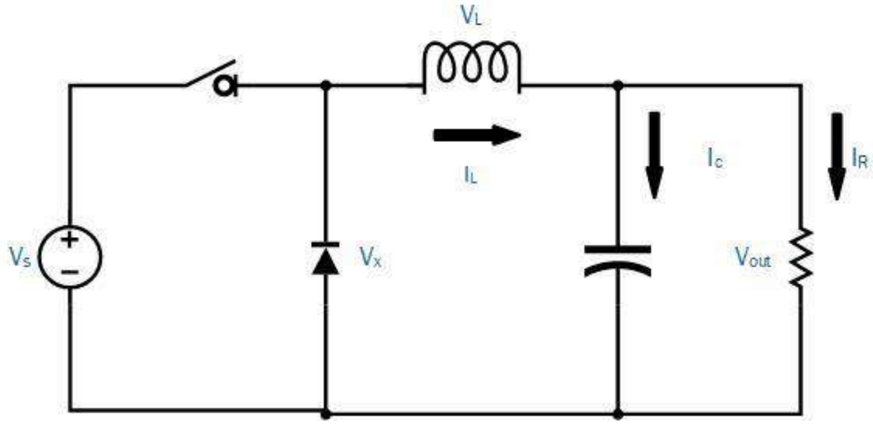

Figure 3.2 Buck converter.

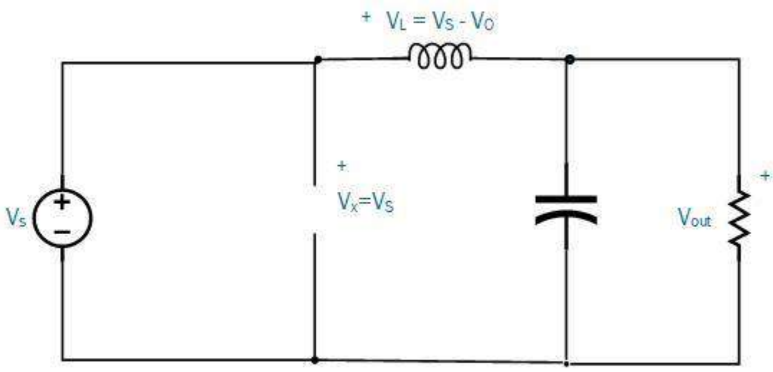

Figure 3.3 Buck converter when switch is closed.

The equation of average current through inductor when switch is closed is

$$(\Delta i_L)_{closed} = \frac{V_s - V_0}{L} DT \tag{3.1}$$

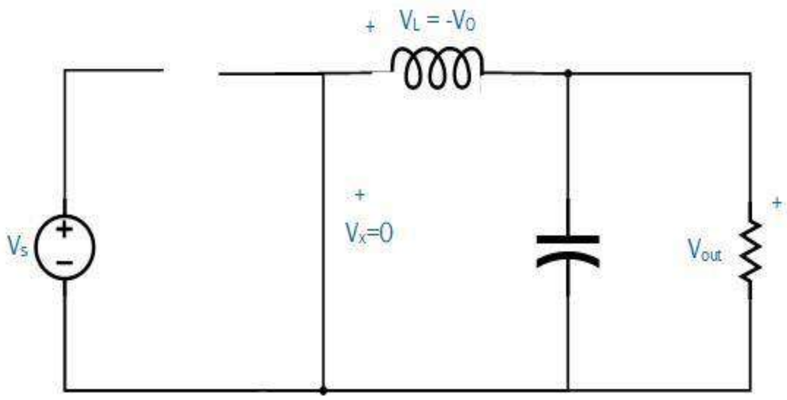

Figure 3.4 Buck converter when switch is open.

The equation of average current through inductor when switch is open is

$$(\Delta i_L)_{open} = \frac{V_0}{L}(1-D)T \tag{3.2}$$

After equating both equations we get,

$$(\Delta i_L)_{closed} = (\Delta i_L)_{open} \tag{3.3}$$

$$\boxed{V_o = V_s D} \tag{3.4}$$

The buck converter produces an output voltage that is less than or equal to the input.

Maximum and minimum inductor currents are determined by using the average value and the change in the current.[7]

$$\left.\begin{aligned} I_{\max} &= I_L + \frac{\Delta i_L}{2} = V_0\left(\frac{1}{R} + \frac{1-D}{2Lf}\right) \\ I_{\min} &= I_L - \frac{\Delta i_L}{2} = V_0\left(\frac{1}{R} - \frac{1-D}{2Lf}\right) \end{aligned}\right\} \tag{3.5}$$

The minimum inductor required will be,

$$\boxed{L_{min} = \frac{(1-D)R}{2f}} \tag{3.6}$$

The capacitor size required will be,

$$\boxed{C = \frac{1-D}{8L(\Delta V_0 / V_0) f^2}} \tag{3.7}$$

3.4 Boost converter

A boost converter (step-up converter), as its name suggests steps up the input DC voltage value and provides at output.[6] This converter contains basically a diode, a transistor as switches and at least one energy storage element. Capacitors are generally added to output so as to perform the function of removing output voltage ripple.

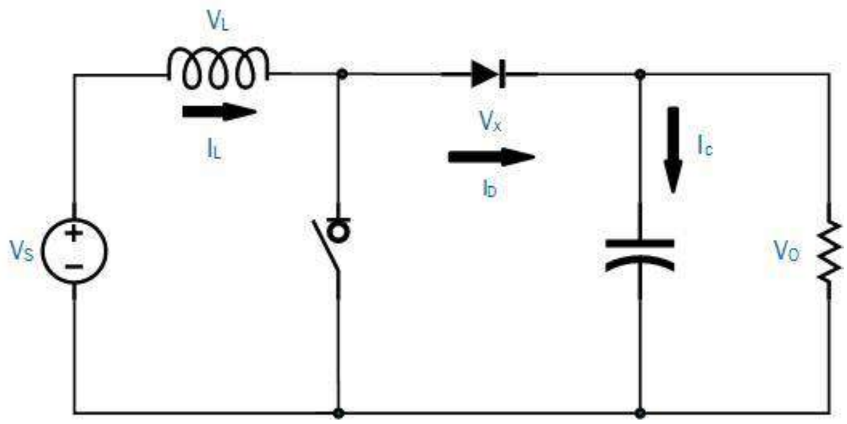

Figure 3.5 Boost converter.

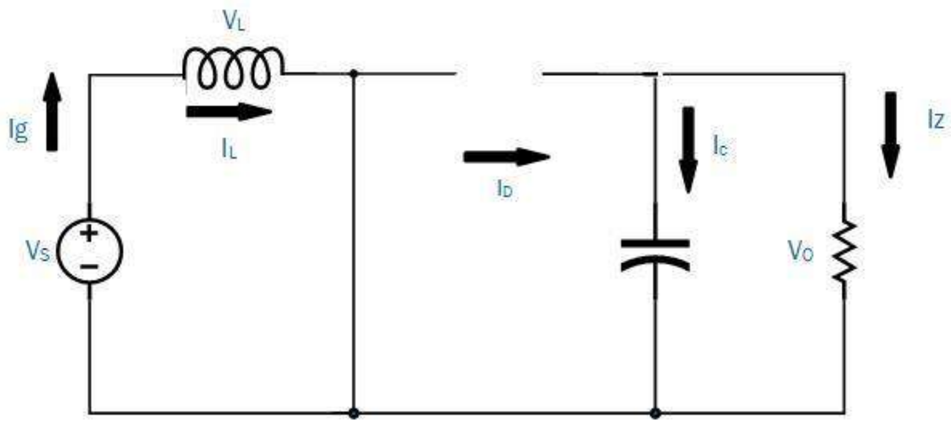

Figure 3.6 Boost converter when switch is closed.

The equation of average current through inductor when switch is closed is

$$(\Delta i_L)_{closed} = \frac{V_s DT}{L} \tag{3.8}$$

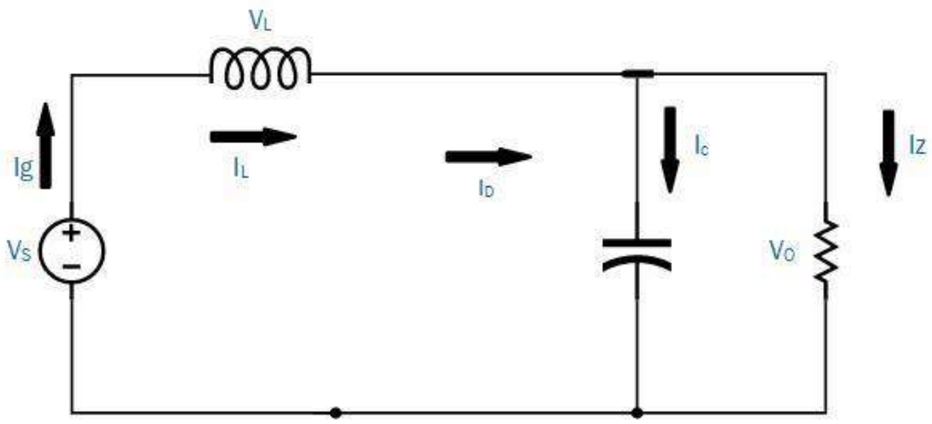

Figure 3.7 Boost converter when switch is open.

The equation of average current through inductor when switch is open is

$$(\Delta i_L)_{open} = \frac{-(V_s - V_0)(1-D)T}{L} \tag{3.9}$$

$$\boxed{V_0 = \frac{V_s}{1-D}} \tag{3.10}$$

It is called a boost converter because the output voltage is larger than the input.

$$\boxed{I_L = \frac{V_s}{(1-D)^2 R}} \tag{3.11}$$

Maximum and minimum inductor currents are determined by using the average value and the change in current,

$$\left.\begin{aligned} I_{\max} &= I_L + \frac{\Delta i_L}{2} = V_0\left(\frac{1}{R} + \frac{1-D}{2Lf}\right) \\ I_{\min} &= I_L - \frac{\Delta i_L}{2} = V_0\left(\frac{1}{R} - \frac{1-D}{2Lf}\right) \end{aligned}\right\} \tag{3.12}$$

$$\boxed{L_{\min} = \frac{D(1-D)^2 R}{2f}} \tag{3.13}$$

The Output voltage ripple can be derived as above it can be calculated as

$$\boxed{C = \frac{D}{R(\Delta V_0 / V_0) f}} \tag{3.14}$$

3.5 Modelling of DC-DC Converter

The modelling of DC-DC converter is carried out to find the transfer function for the buck converter topologies.[21] The modelling is carried out using state space averaging method. It is the general method for describing a circuit that changes over a switching period is called state-space averaging. The steps are as follows,

- Draw the linear switched circuit model for each state of the switching converter.
- Write state equations for each switched circuit model using Kirchhoff's voltage and current laws
- Averaging the State- space Equation using the duty ratio.

$$\dot{X} = Ax + Bu \quad ; \quad y = Cx + Du \tag{3.15}$$

- Transform the equations into S- domains to solve for the Transfer Function.

3.6 Buck Converter Modelling

During ON mode -

Using KVL
$$L\frac{di}{dt} = Vs - Vc \tag{3.16}$$

Using KCL
$$C\frac{dVc}{dt} = i_L - \frac{Vc}{R} \tag{3.17}$$

In state-space form

$$\begin{bmatrix} \dot{i}_L \\ \dot{v}_C \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} [Vs] \tag{3.18}$$

Output voltage Equation
$$v_o = [O \;\; 1] \begin{bmatrix} i_L \\ v_c \end{bmatrix} \tag{3.19}$$

During OFF mode -

Using KVL
$$L\frac{di_L}{dt} = -Vc \tag{3.20}$$

Using KCL $$C\frac{dVc}{dt}=i_L-\frac{Vc}{R} \quad (3.21)$$

In state-space form

$$\begin{bmatrix}\dot{i}_L\\ \dot{v}_C\end{bmatrix}=\begin{bmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{bmatrix}\begin{bmatrix}i_L\\ v_C\end{bmatrix}+\begin{bmatrix}0\\ 0\end{bmatrix}[Vs] \quad (3.22)$$

Output voltage Equation $$v_o=[0\ 1]\begin{bmatrix}i_L\\ v_c\end{bmatrix} \quad (3.23)$$

State space averaging techniques are employed to get a set of equations that describe the system over one switching period.[4] After applying the averaging technique to equations, we get the following expression

$$X_{avg}=X_{dT}.D+X_{(1-d)T}(1-D) \quad (3.24)$$

Averaged Model –

$$\left.\begin{aligned}A&=A_1d+A_2(1-d)\\ B&=B_1d+B_2(1-d)\\ C&=C_1d+C_2(1-d)\\ D&=D_1d+D_2(1-d)\end{aligned}\right\} \quad (3.25)$$

Using the above equations we got matrix equations as follows

$$A=A_1d+A_2(1-d) \quad (3.26)$$

$$A=\begin{bmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{bmatrix}.d+\begin{bmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{bmatrix}(1-d)=\begin{bmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{bmatrix} \quad (3.27)$$

$$B=B_1.d+B_2(1-d) \quad (3.28)$$

$$B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} .d + \begin{bmatrix} 0 \\ 0 \end{bmatrix} (1-d) = \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix} = \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix} \tag{3.29}$$

$$C = [0 \ \ 1] \qquad ; \qquad D = [0] \tag{3.30}$$

We know that,

Large signal = Steady state + Small signal

The small-signal transfer characteristic is developed above from the equation

$$\hat{x} = A\hat{x} + BV_S\hat{d} \tag{3.31}$$

Taking Laplace transform,

$$\left. \begin{aligned} s\hat{x}(s) &= A\hat{x}(s) + BV_S\hat{d}(s) \\ [sI - A]\hat{x}(s) &= BV_S\hat{d}(s) \\ \hat{x}(s) &= [sI - A]^{-1} BV_S\hat{d}(s) \end{aligned} \right\} \tag{3.32}$$

The output equation we have

$$\left. \begin{aligned} \hat{y} &= C\hat{x} + D\hat{u} = C\hat{x} = [0 \ 1] \begin{bmatrix} \hat{i}_L \\ \hat{v}_c \end{bmatrix} \\ \hat{y}(s) &= C\hat{x}(s) \\ \hat{y}(s) &= C[sI - A]^{-1} BV_S\hat{d}(s) \end{aligned} \right\} \tag{3.33}$$

The transfer function of the plant will be

$$\frac{\hat{y}(s)}{\hat{d}(s)} = C[sI - A]^{-1} BV_S \tag{3.34}$$

$$\frac{\hat{y}(s)}{\hat{d}(s)} = [0 \ \ 1] \left[s\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \right]^{-1} \begin{bmatrix} \frac{D}{L} \\ 0 \end{bmatrix} V_S \tag{3.35}$$

On solving we get,

$$\boxed{\frac{\hat{y}(s)}{\hat{d}(s)} = \frac{\frac{V_S}{LC}}{s^2 + \frac{s}{RC} + \frac{1}{LC}}} \tag{3.36}$$

3.7 Boost Converter Modelling

During ON mode -

Using KVL $$L\frac{di_L}{dt}=Vs \tag{3.37}$$

Using KCL $$C\frac{dVc}{dt}=-\frac{Vc}{R}-i_Z \tag{3.38}$$

In state-space form $$\begin{bmatrix}\dot{i}_L\\ \dot{v}_C\end{bmatrix}=\begin{bmatrix}0 & 0\\ 0 & -\frac{1}{RC}\end{bmatrix}\begin{bmatrix}i_L\\ v_C\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}[V_S]+\begin{bmatrix}0\\ \frac{-1}{C}\end{bmatrix}[i_Z] \tag{3.39}$$

Output voltage Equation $$\begin{bmatrix}v_O\\ i_g\end{bmatrix}=\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}\begin{bmatrix}i_L\\ v_C\end{bmatrix} \tag{3.40}$$

During OFF mode -

Using KVL $$L\frac{di_L}{dt}=V_S-V_C \tag{3.41}$$

Using KCL $$C\frac{dVc}{dt}=i_L-\frac{Vc}{R}-i_Z \tag{3.42}$$

In state-space form $$\begin{bmatrix}\dot{i}_L\\ \dot{v}_C\end{bmatrix}=\begin{bmatrix}0 & -\frac{1}{L}\\ \frac{1}{C} & -\frac{1}{RC}\end{bmatrix}\begin{bmatrix}i_L\\ v_C\end{bmatrix}+\begin{bmatrix}\frac{1}{L}\\ 0\end{bmatrix}[Vs]+\begin{bmatrix}0\\ \frac{-1}{C}\end{bmatrix}[i_Z] \tag{3.43}$$

Output voltage Equation $$\begin{bmatrix}v_O\\ i_g\end{bmatrix}=\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}\begin{bmatrix}i_L\\ v_C\end{bmatrix} \tag{3.44}$$

State space averaging techniques are employed to get a set of equations that describe the system over one switching period.[23] After applying the averaging technique to equations, we get the following expression

$$X_{avg}=X_{dT}.D+X_{(1-d)T}(1-D) \tag{3.45}$$

Averaged Model –

$$\left.\begin{aligned} A &= A_1 d + A_2(1-d) \\ B &= B_1 d + B_2(1-d) \\ C &= C_1 d + C_2(1-d) \\ D &= D_1 d + D_2(1-d) \end{aligned}\right\} \tag{3.46}$$

Using the above equations we got matrix equations as follows

$$A = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix} d + \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} (1-d) = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{(1-d)}{C} & -\frac{1}{RC} \end{bmatrix} \tag{3.47}$$

$$B = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \end{bmatrix} .d + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \end{bmatrix} (1-d) = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & -\frac{1}{C} \end{bmatrix} \tag{3.48}$$

$$C = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad ; \qquad D = [0] \tag{3.49}$$

Using above average model we get,

$$\begin{bmatrix} \dot{i}_L \\ \dot{v}_C \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{(1-d)}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} [Vs] + \begin{bmatrix} 0 \\ \frac{-1}{C} \end{bmatrix} [i_Z] \tag{3.50}$$

We know that,

Large signal = Steady state + Small signal

By putting,

$$d = D + \hat{d}\,; \quad v_S = V_S + \hat{v}_S\,; \quad v_C = V_C + \hat{v}_C\,; \quad i_L = I_L + \hat{i}_L\,; \quad i_Z = I_Z + \hat{i}_Z\,. \tag{3.51}$$

So small signal model becomes,

$$\left.\begin{array}{l}\begin{bmatrix}\dot{\hat{i}}_L \\ \dot{\hat{v}}_C\end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{(1-D-\hat{d})}{L} \\ \dfrac{(1-D-\hat{d})}{C} & -\dfrac{1}{RC}\end{bmatrix}\begin{bmatrix} I_L + \hat{i}_L \\ V_C + \hat{v}_C\end{bmatrix} + \begin{bmatrix}\dfrac{1}{L} \\ 0\end{bmatrix}[V_S + \hat{v}_S] + \begin{bmatrix} 0 \\ \dfrac{-1}{C}\end{bmatrix}[I_Z + \hat{i}_Z] \\ \begin{bmatrix}\dot{\hat{i}}_L \\ \dot{\hat{v}}_C\end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{(1-D)}{L} \\ \dfrac{(1-D)}{C} & -\dfrac{1}{RC}\end{bmatrix}\begin{bmatrix}\hat{i}_L \\ \hat{v}_C\end{bmatrix} + \begin{bmatrix}\dfrac{v_C}{L} \\ \dfrac{-I_L}{C}\end{bmatrix}[\hat{d}] + \begin{bmatrix}\dfrac{1}{L} \\ 0\end{bmatrix}[\hat{v}_S] + \begin{bmatrix} 0 \\ \dfrac{-1}{C}\end{bmatrix}[\hat{i}_Z]\end{array}\right\} \quad (3.52)$$

$$\begin{bmatrix}\hat{v}_O \\ \hat{i}_g\end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0\end{bmatrix}\begin{bmatrix}\hat{i}_L \\ \hat{v}_C\end{bmatrix} \quad (3.53)$$

The small-signal transfer characteristic is developed which in the case of the boost converter results in

$$\hat{y}(s) = C[sI - A]^{-1} B\hat{d}(s) \quad (3.54)$$

The transfer function of the plant will be

$$\frac{\hat{y}(s)}{\hat{d}(s)} = C[sI - A]^{-1} B \quad (3.55)$$

$$\frac{\hat{y}(s)}{\hat{d}(s)} = [0 \;\; 1]\left[s\begin{bmatrix} 1 & 0 \\ 0 & 1\end{bmatrix} - \begin{bmatrix} 0 & -\dfrac{(1-D)}{L} \\ \dfrac{(1-D)}{C} & -\dfrac{1}{RC}\end{bmatrix}\right]^{-1}\begin{bmatrix}\dfrac{v_C}{L} \\ \dfrac{-I_L}{C}\end{bmatrix} \quad (3.56)$$

On solving we get,

$$\boxed{\frac{\hat{y}(s)}{\hat{d}(s)} = \frac{V_S\left(1 - \dfrac{Ls}{R(1-D)^2}\right)}{(1-D)^2\left(1 + \dfrac{sL}{R(1-D)^2} + \dfrac{s^2 LC}{(1-D)^2}\right)}} \quad (3.57)$$

3.8 Loop Control Transfer Functions

Transfer function represents the relationship between the output signal of a control system and the input signal, for all possible input values.[8]

The transfer function for the PID converter in laplace domain will be,

$$G_c(s) = \frac{K_D s^2 + K_P s + K_I}{s} \quad (3.58)$$

Where,

- ❖ **K_P** – Proportional gain
- ❖ **K_I** – Integral gain
- ❖ **K_D** – Derivative gain

\- For open loop control transfer function of the system will be

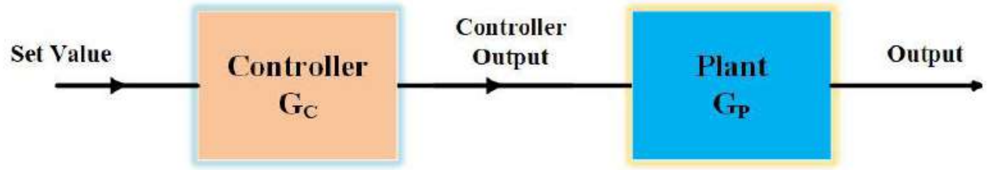

Figure 3.8 Open loop system.

$$\boxed{T.F = G_P * G_C} \tag{3.59}$$

\- For closed loop control transfer function of the system will be

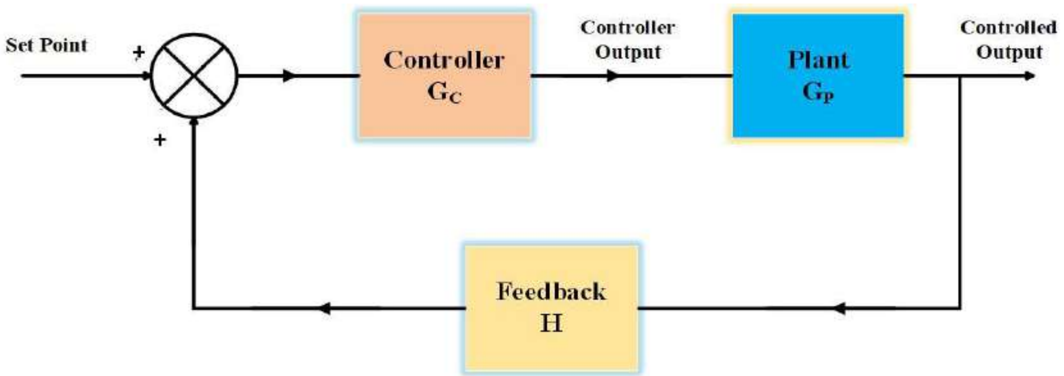

Figure 3.9 Closed loop system.

$$\boxed{T.F = \frac{G_P * G_C}{1 + G_P * G_C * H}} \tag{3.60}$$

Where,

- G_P – Plant gain
- G_C – Controller gain
- H – Feedback gain

CHAPTER 4

DESIGNING OF PI CONTROLLER OF BUCK CONVERTER

4.1 Controllers

When the plant's performance isn't as per the system's requirements, a closed loop control system can be handy, instead of a new plant. The error between the actual and the required outputs derived the controller.[18] This controller in turn produces the necessary correcting actions upon the plant pulling the actual output towards the required one.

There are two types of errors:

- Transient error
- Steady state error

To remove transient error we can adjust the three gains—K_P, K_I and K_D for the Proportional, Integral and Derivative controller actions can decide the contribution of each one in the final controller action.[20]

- A **Proportional controller** is used to reduce the rise time and speed up the response. This controller makes no changes in the phase response of the plant.
- A **Derivative controller** is required to minimise the transient errors like overshoot and oscillations in the output of the plant. But this can create heavy instability in noisy environments. Be careful to use smaller gain with this controller. It provides a phase lead to the output when compared with the input. , usually with no change in magnitude.
- An **Integral controller** corrects the time invariant errors. This provides a phase lag and no change in magnitude in the output.
- A **PI controller** helps in reducing both the rise time and the steady state errors of the system. To be useful whenever you need to change magnitude and lag the phase together.
- A **PD controller** reduces the transients like rise time, overshoot, and oscillations in the output. Useful for changing magnitude and want to add phase lead to the output.
- A **PID controller** is a general form of controller. The gains of the three control actions can be adjusted to achieve any controller. The change in magnitude along with either lead or lag in phase in the output can be made available through this general model of controller.

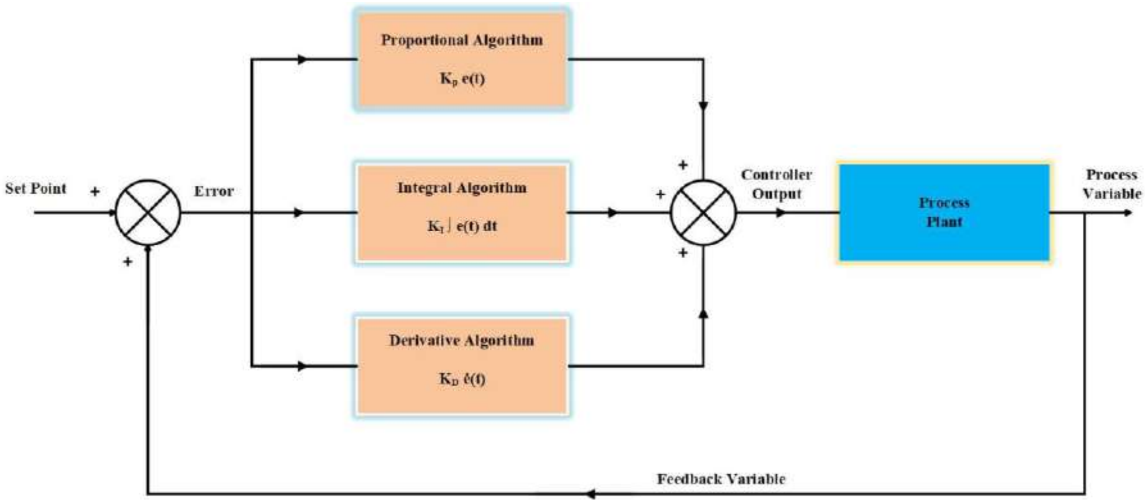

Figure 4.1 PID block diagram.

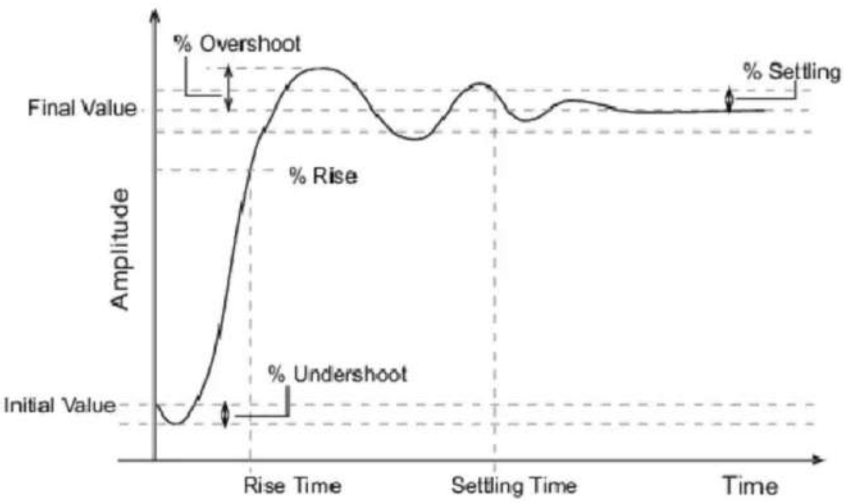

Figure 4.2 Step response analysis.

Here,

- **Rise Time** :- It is the time required for the output response to reach 100% of its final value in first attempt.

- **Peak Overshoot** :- It indicate normalized difference between the time response peak and the steady state output.

- **Settling Time** :-It is the time required for the output response to reach and stay within the specified tolerance band (usually 2% - 5%).

4.2 Controller Design

There are several methods for designing a digital controller. One method is to discretize the existing continuous-time controller. The most popular method is to design the digital controller directly by extending all known continuous-time design methods to the case of discrete-time systems. Following this approach, we present digital controller design methods via

1. Root locus,
2. Bode diagram,
3. Nyquist diagrams.

For controller design we had used **Root locus method**.

Root locus analysis is a graphical method for examining how the roots of a system change with variation of a certain system parameter, commonly a gain within a feedback system.[15] This is a technique used as a stability criterion which can determine stability of the system. The root locus plots the poles of the closed loop transfer function in the complex s-plane as a function of a gain parameter.[24]

Steps :-

1. Finding plant transfer function (Gp), controller transfer function (Gc).
2. We have to define feedback transfer function (H).
3. Combining them to overall closed loop transfer function.
4. Plotting the root locus plot.
5. Find actual gains for stable controlling output.

Example :- For the given plant transfer function is $G_P(s) = \dfrac{1}{(s+3)(s+1)}$.

The open loop plant root locus plot and step response is shown below

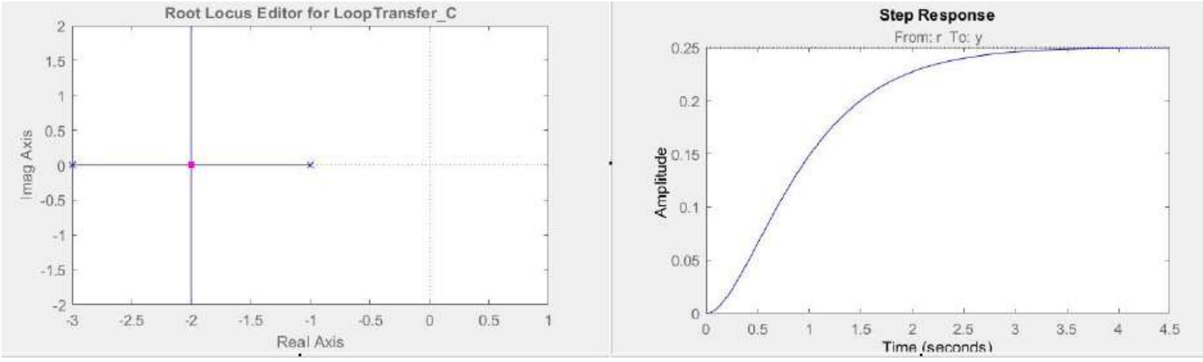

Figure 4.3 Root locus and Step response of plant.

When we add one pole at s = -10; the system will be shown as below

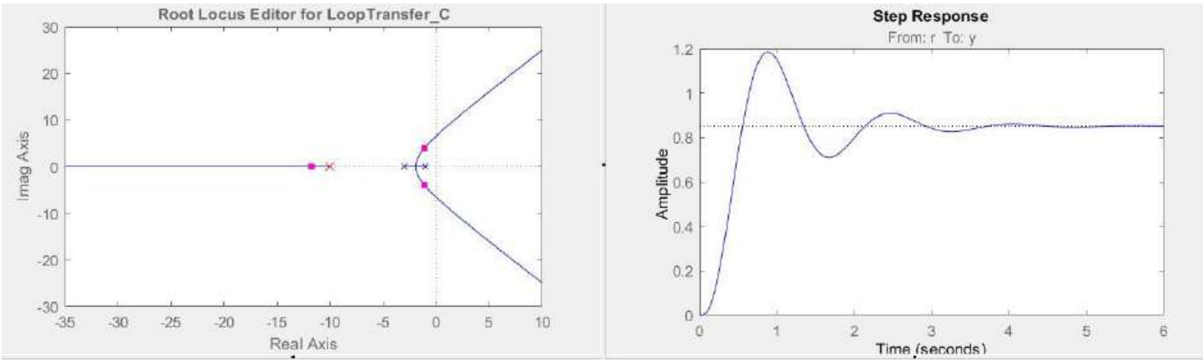

Figure 4.4 Root locus and Step response of plant when pole added at s = -10.

When we add one zero at s = -10; the system will be shown as below

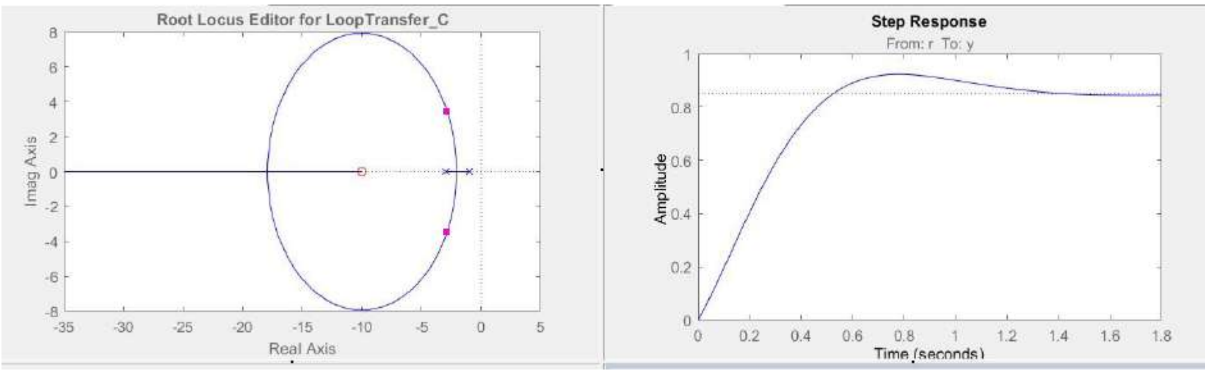

Figure 4.5 Root locus and Step response of plant when zero added at s = -10.

When we add one complex pole at s = -12+8i; the system will be shown as below,

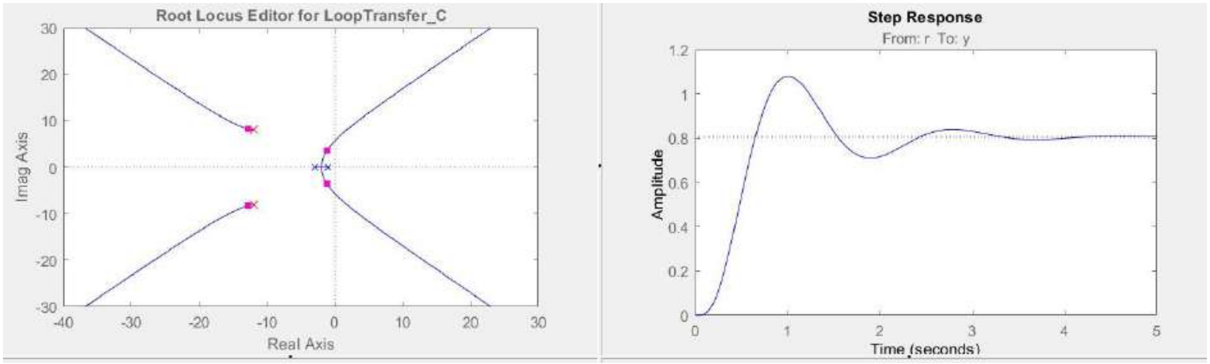

Figure 4.6 Root locus and Step response of plant when complex pole added at s = -12+8i.

When we add one complex zero at s = -12+8i; the system will be shown as below,

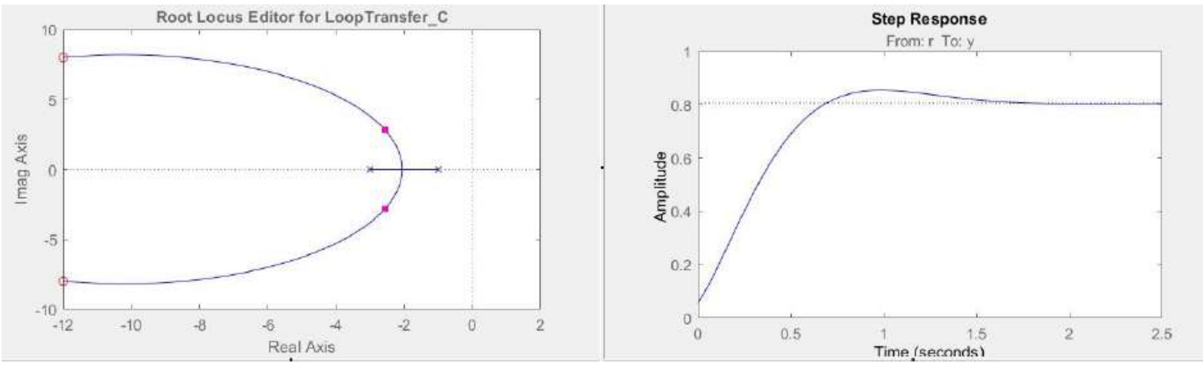

Figure 4.7 Root locus and Step response of plant when complex zero added at s = -12+8i.

In this way by adjusting the location of poles and zero we can observe the changes occurs in the system. We can achieve the required stability in the system by adjusting the controller gains.

Using above techniques the gains of PI controller is calculated that values are as follows:

K_P = 1.875;

K_I = 1.26;

4.3 Analog PI implementation:-

For implementing the PI controller we can use both digital and analog circuits. Digital PI is implemented using integrated circuits while we can use various circuits using operational amplifiers in case of analog design of which one is shown below,

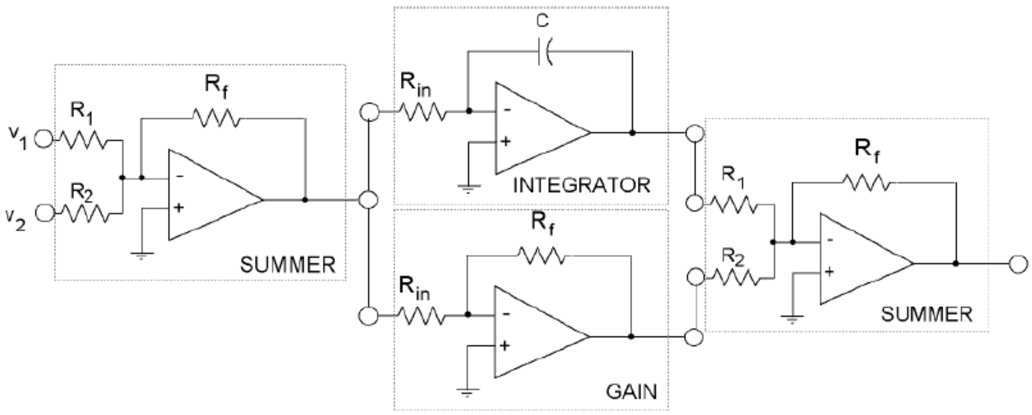

Figure 4.8 PI Controller Circuit.

4.3.1 Summer circuit:-

This circuit helps in summing up various signals .Here, output voltage is given by $V_{OUT} = V_1 + V_2$

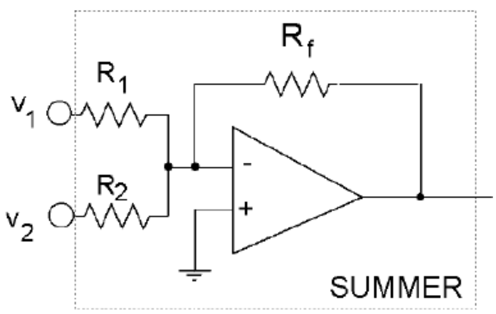

Figure 4.9 Summer Circuit.

For summer circuit the values of resistors can be selected 10K ohm.

4.3.2 Gain circuit:-

This circuit changes the polarity of the input signal with amplification and the gain value is,

$$Gain = \frac{R_f}{R_{in}}$$

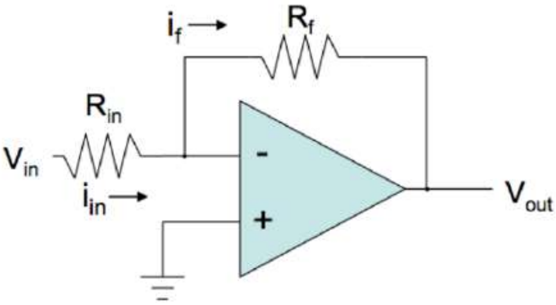

Figure 4.10 Gain Circuit.

The value of gain will be 1.875 this can be obtained by selecting R_f = 3K ohm & R_{in} = 1.6K ohm.

4.3.3 Integrator circuit:-

This circuit helps in summing up various signals .Here, output voltage is given by

$$Gain = \frac{1}{R_{in} * C_f}$$

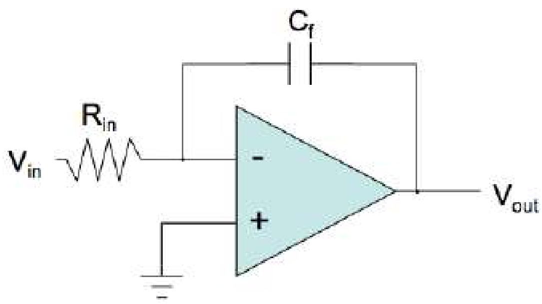

Figure 4.11 Integrator Circuit.

The value of gain will be 1.875 this can be obtained by selecting C_f = 3.3uF & R_{in} = 240K ohm.

CHAPTER 5

SIMULATION & HARDWARE RESULTS OF BUCK CONVERTER

5.1 Design Problem for Buck Converter

Design a buck converter to produce an output voltage of 18 V across a 10 ohm load resistor. The output voltage ripple must not exceed 0.5 percent. The dc supply is 48 V. Design for continuous inductor current. Specify the duty ratio, the switching frequency, the values of the inductor and capacitor, the peak voltage rating of each device, and the RMS current in the inductor. Assume ideal components. [7]

=>

The duty ratio for continuous-current operation

$$D = \frac{V_0}{V_s} = \frac{18}{48} = 0.375 \tag{5.1}$$

Let the switching frequency arbitrarily be 40 kHz, which is well above the audio Range and is low enough to keep switching losses small. The minimum inductor size is

$$L = 1.25L_{\min} = (1.25)(78\mu H) = 97.5\mu H \tag{5.2}$$

Let the inductor be 25 percent larger than the minimum to ensure that inductor current is continuous

$$L_{\min} = \frac{(1-D)(R)}{2f} = \frac{(1-0.375)(10)}{2(40,000)} = 78\mu H \tag{5.3}$$

Average inductor current and the change in current are

$$\Delta i_L = \left(\frac{V_s - V_0}{L}\right)DT = \frac{48-18}{97.5(10)^{-6}}(0.375)\left(\frac{1}{40,000}\right) = 2.88A \tag{5.4}$$

$$I_L = \frac{V_0}{R} = \frac{18}{10} = 1.8A \tag{5.5}$$

The maximum and minimum inductor currents are

$$I_{\max} = I_L + \frac{\Delta i_L}{2} = 1.8 + 1.44 = 3.24A \tag{5.6}$$

$$I_{\min} = I_L - \frac{\Delta i_L}{2} = 1.8 - 1.44 = 0.36A \tag{5.7}$$

The inductor must be rated for rms current

$$I_{rms} = \sqrt{I_L^2 + \left(\frac{\Delta i_L / 2}{\sqrt{3}}\right)^2} = \sqrt{(1.8)^2 + \left(\frac{1.44}{\sqrt{3}}\right)^2} = 1.98A \tag{5.8}$$

The capacitor is selected will be

$$C = \frac{1 - D}{8L(\Delta V_0 / V_0) f^2} = \frac{1 - 0.375}{8(97.5)(10)^{-6}(0.005)(40,000)^2} = 100\mu F \tag{5.9}$$

All the required values of components calculated above, those simulation parameters are shown below in Table 5.1.

Table 5.1 Simulation Parameters of Buck Converter.

PARAMETERS	**VALUES**
Input voltage (V_S)	48 V
Duty cycle (D)	0.375
Inductance (L)	97.5 µH
Capacitance(C)	100 µF
Load resistance (R)	10 ohm
Switching frequency(f)	40 kHz
Output voltage ripple	0.005

5.2 Simulation Results :-

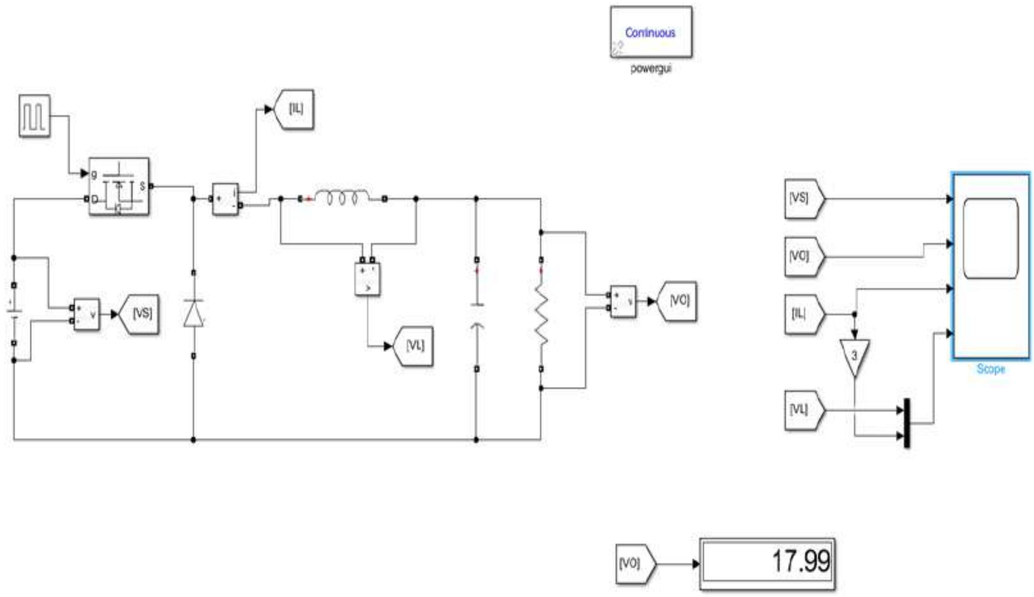

Figure 5.1 Matlab simulation of buck converter.

The above figure contains circuit of buck converter in open loop which is designed using matlab software. The below figure shows the waveforms of the input and output voltage simulated using above circuit.

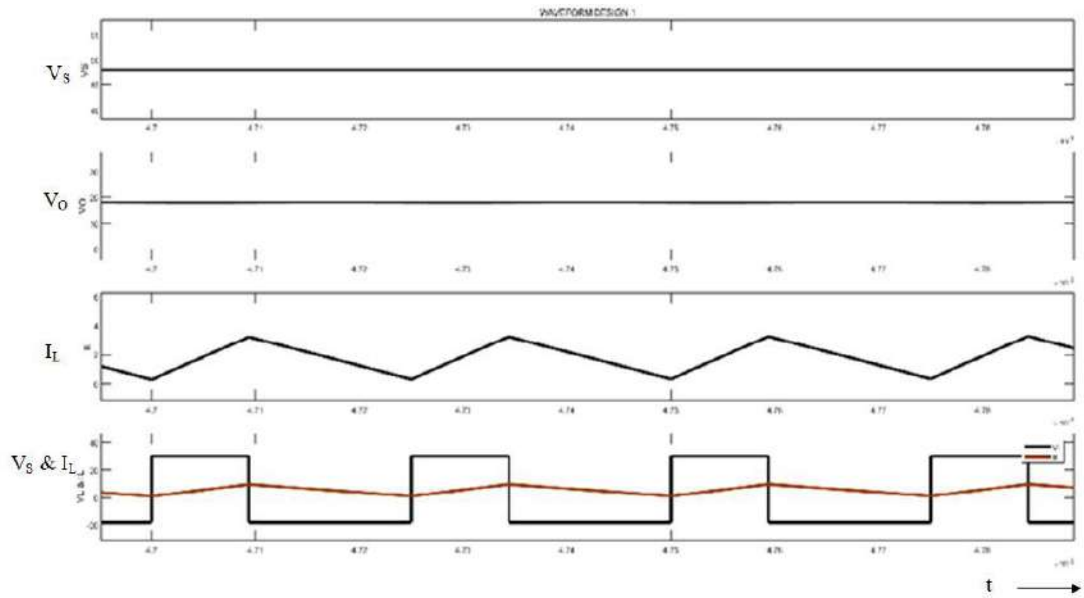

Figure 5.2 Waveforms (a) Input voltage (b) Output voltage

(c) Current across inductor (d) Input voltage & Current across inductor.

Table 5.2 Observation Table for Buck Converter.

	PARAMETERS	VALUES	
		CALCULATED	OBSERVED
OUTPUT CURRENT	$I_{L\,max}$	3.24	3.28
	$I_{L\,min}$	0.36	0.34
	$I_{L\,avg}$	1.8	1.82
	$I_{L\,rms}$	1.98	2.05
	ΔI_L	2.88	2.94
OUTPUT VOLTAGE	$V_{O\,max}$	18	17.98
	$V_{O\,min}$	18	17.88
	$V_{O\,avg}$	18	17.93
	$V_{O\,rms}$	18	17.93
	$\Delta V_O/V_O$(Ripple)	0.005	0.005

Above table contains the observed and calculated output results of buck converter circuit.

Here below is the circuit of buck converter circuit in closed loop which contains buck converter & PI controller with gains as $K_P = 1.89$; $K_I = 1.26$.

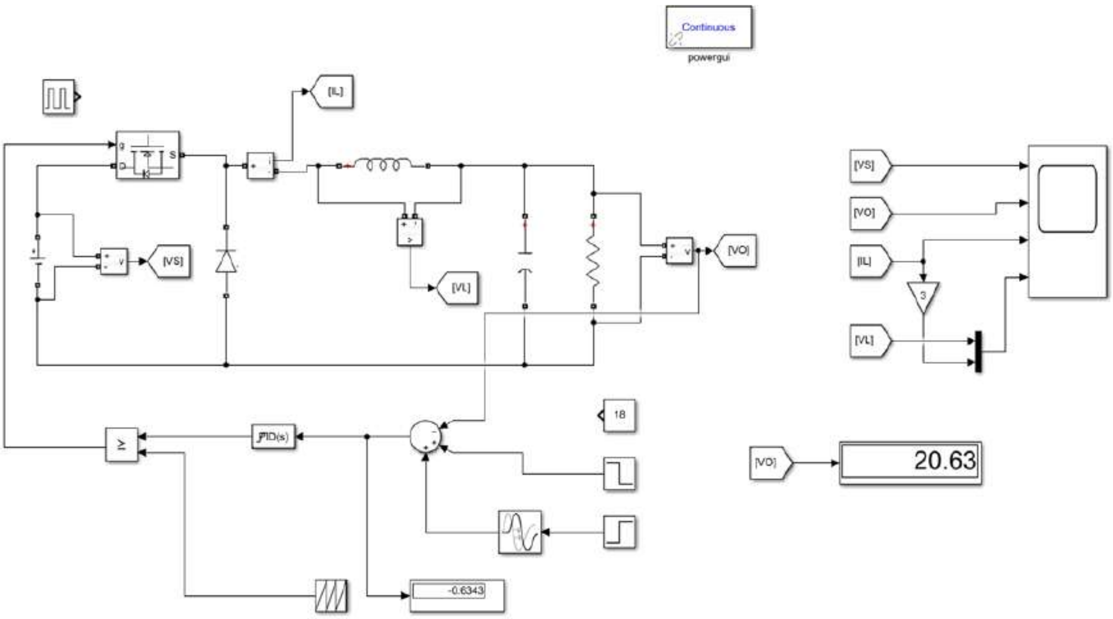

Figure 5.3 Matlab simulation of buck converter with controller.

Transfer function & Root locus plot of the plant is shown below,

```
Gp =

         46.8
  ---------------------
  s^2 + 1e-05 s + 1.026
```

(5.10)

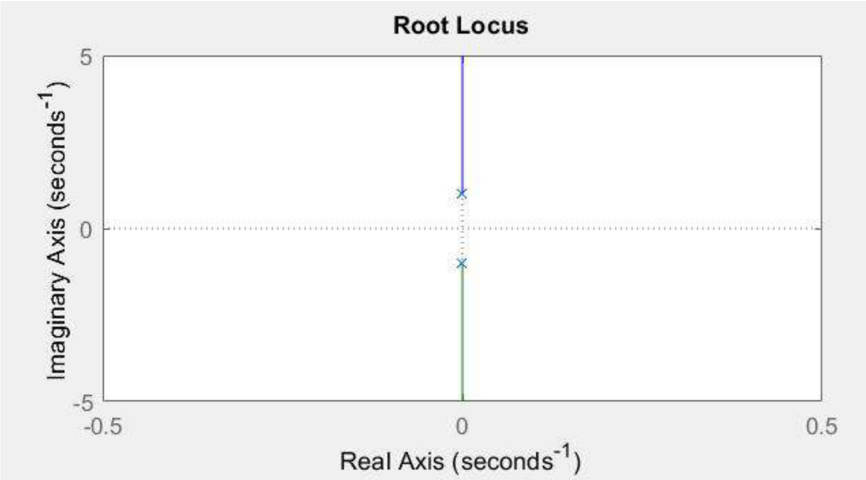

Figure 5.4 Root locus plot of the plant.

Transfer function & Root locus plot of the whole system is shown below,

```
Gscl =

    3.446e09 s^2 + 9.305e09 s + 6.203e09
  ------------------------------------------
  s^3 + 3.446e09 s^2 + 9.407e09 s + 6.203e09
```

(5.11)

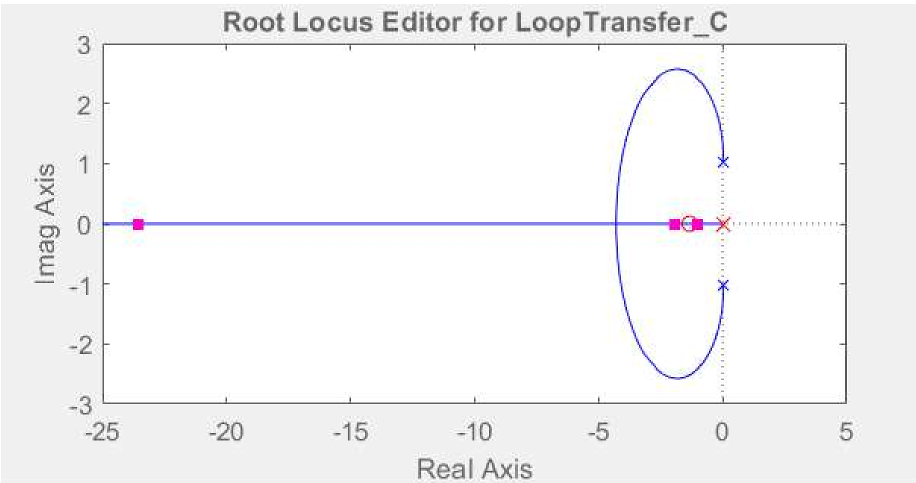

Figure 5.5 Root locus plot of the system.

Step response of the system is shown in below figure with following characteristics,

- Max. Overshoot(%) = 7%
- Settling Time = 0.61 sec
- Rise Time = 0.06 sec

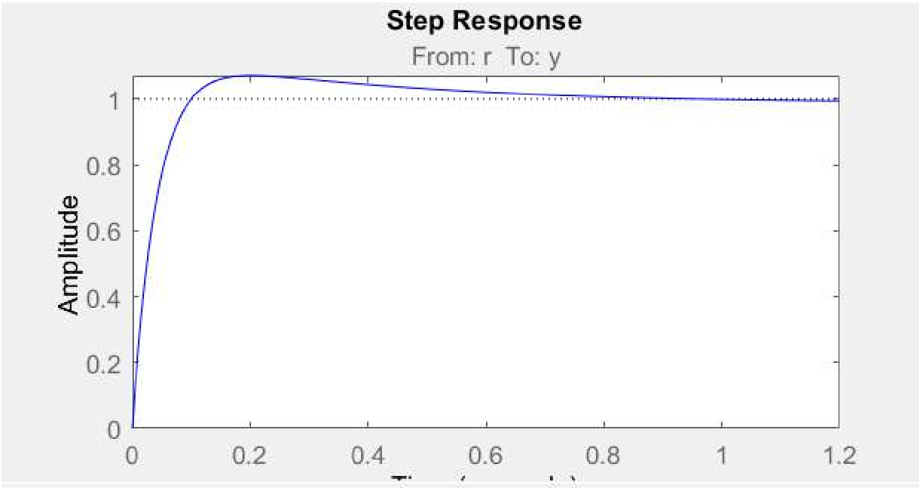

Figure 5.6 Step response of the system.

The output voltage waveforms are shown below where first figure contains the waveform with constant reference voltage of 18v. The next figure contains the waveform with provided step of 16 V to reference voltage at 0.01sec. In the third figure there are two steps of 16V & 20V provided to the reference voltage which are at 0.01sec and 0.02sec respectively.

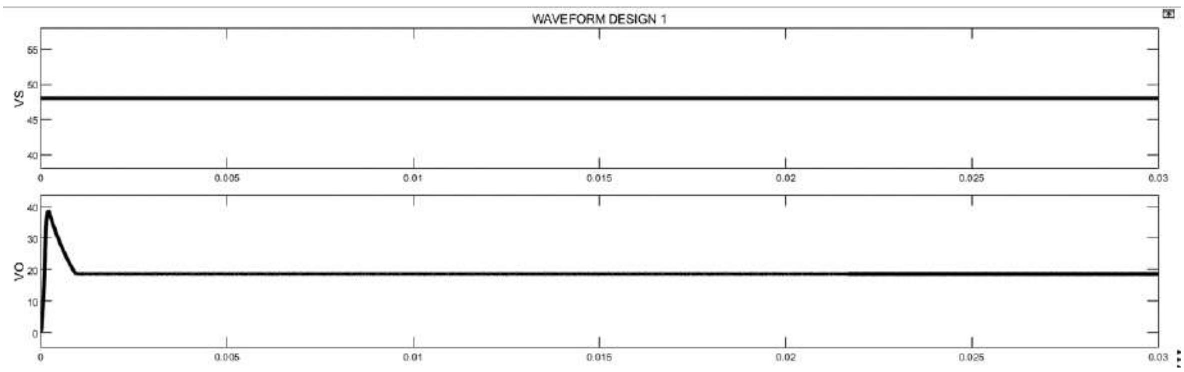

Figure 5.7 Waveform with constant reference voltage.

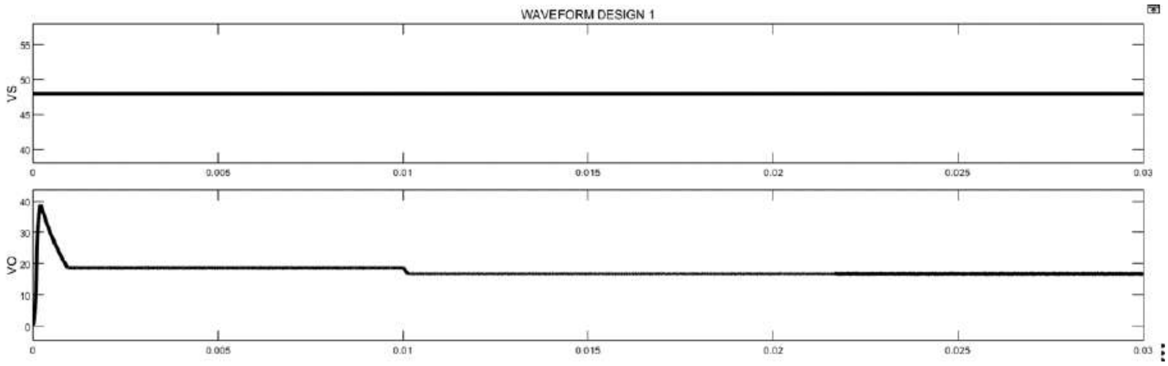

Figure 5.8 Waveform with single step reference voltage

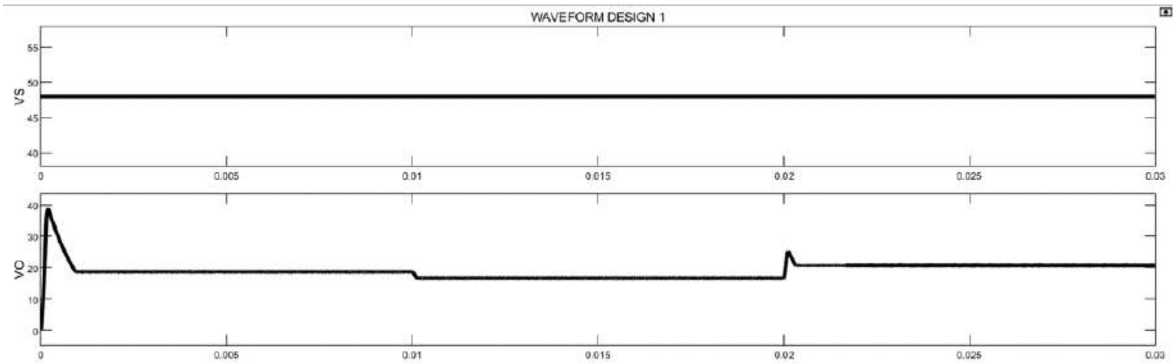

Figure 5.9 Waveform with double step reference voltage.

5.3 Hardware Design :-

Hardware is designed by developing PCB using Eagle software. The steps to PCB design are as follows,

1. Schematic design: Create a schematic diagram of the circuit you want to build using Eagle's schematic editor. Add components and connect them with wires to create a complete circuit.
2. PCB layout: Once your schematic is complete, use Eagle's PCB layout editor to place the components on the board and route the traces that connect them. The layout editor will show you a 3D rendering of the board as you work.
3. Design rule check (DRC): Run a design rule check to ensure that the layout meets all electrical and manufacturing requirements. The DRC will flag any errors, such as improperly spaced traces or incorrectly connected components.
4. Gerber file generation: Once you have completed the PCB layout and DRC, generate a set of Gerber files that can be used to manufacture the board. These files contain information about the location and size of all components, as well as the traces and copper pours on the board.
5. PCB fabrication: Send the Gerber files to a PCB manufacturer to have the board fabricated. The manufacturer will use the files to create the physical board, which will be populated with components and tested before being shipped to you.

The various components required for circuit are as follows,

5.3.1 Resistance & Capacitors :-

A resistor and capacitor are two basic passive electronic components that are commonly used in electronic circuits.

A resistor is an electrical component that resists the flow of current in a circuit. It is typically made of a material that has high electrical resistance, and is used to limit the amount of current flowing through a circuit, to provide voltage division, and to generate heat.

A capacitor, on the other hand, is an electrical component that stores electrical charge. It consists of two conductive plates separated by a dielectric material, and is used to filter, block, or store electrical energy. Capacitors can be used to smooth out voltage fluctuations in a circuit, or to store energy for use in a later stage of the circuit.

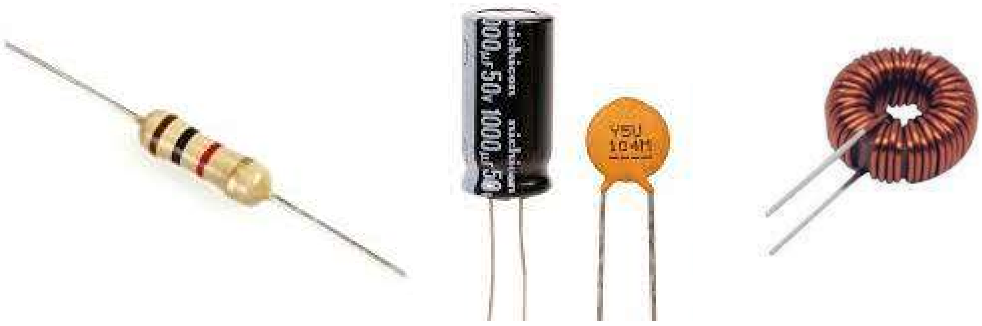

Figure 5.10 (A) Resistor (B) Capacitor (C) Inductor.

5.3.2 Inductor :-

A toroidal inductor is an electronic component that is commonly used in circuits for filtering, energy storage. A toroidal inductor consists of a coil of wire wound around a ferromagnetic core that forms the toroid shape. The core material is typically made of iron powder or ferrite, which provides high magnetic permeability to enhance the inductance of the coil. The wire used to make the coil is usually made of copper or aluminium.

5.3.3 MOSFET & Transistor :-

The IRF510 is a type of MOSFET (metal-oxide-semiconductor field-effect transistor) that is commonly used in electronic circuits as a switch or amplifier. It is a n-channel MOSFET, which means that it uses a negatively charged channel between the source and drain to control the flow of current.

A transistor is a three-terminal semiconductor device that can amplify or switch electronic signals and electrical power. NPN and PNP are two types of bipolar junction transistors (BJTs), which are the most commonly used transistors.

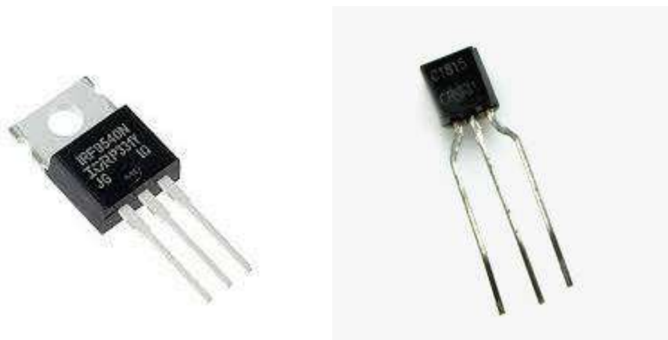

Figure 5.11 (A) MOSFET (B) Transistor.

5.3.4 The 741 OpAmp:-

The OPAMP stands for operational amplifier. The OpAmp is an amplifier with some specific important characteristics. As the word amplifier suggests, the function of an operational amplifier (op amp) is to amplify a voltage. The op amp schematic and the chip that we'll use are shown in figure below. Generally it is available in integrated chips. The pin configuration of 741 IC is as shown below.

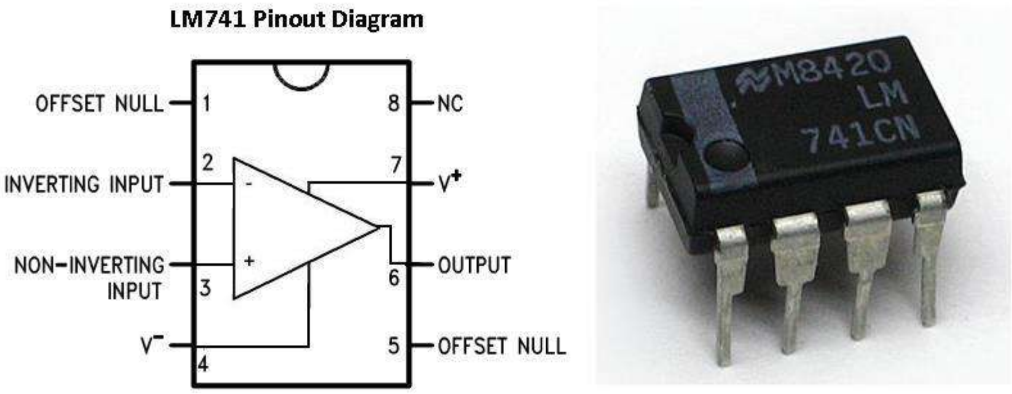

Figure 5.12 (A) LM741 Pin out diagram (B) LM741 Op-amp IC.

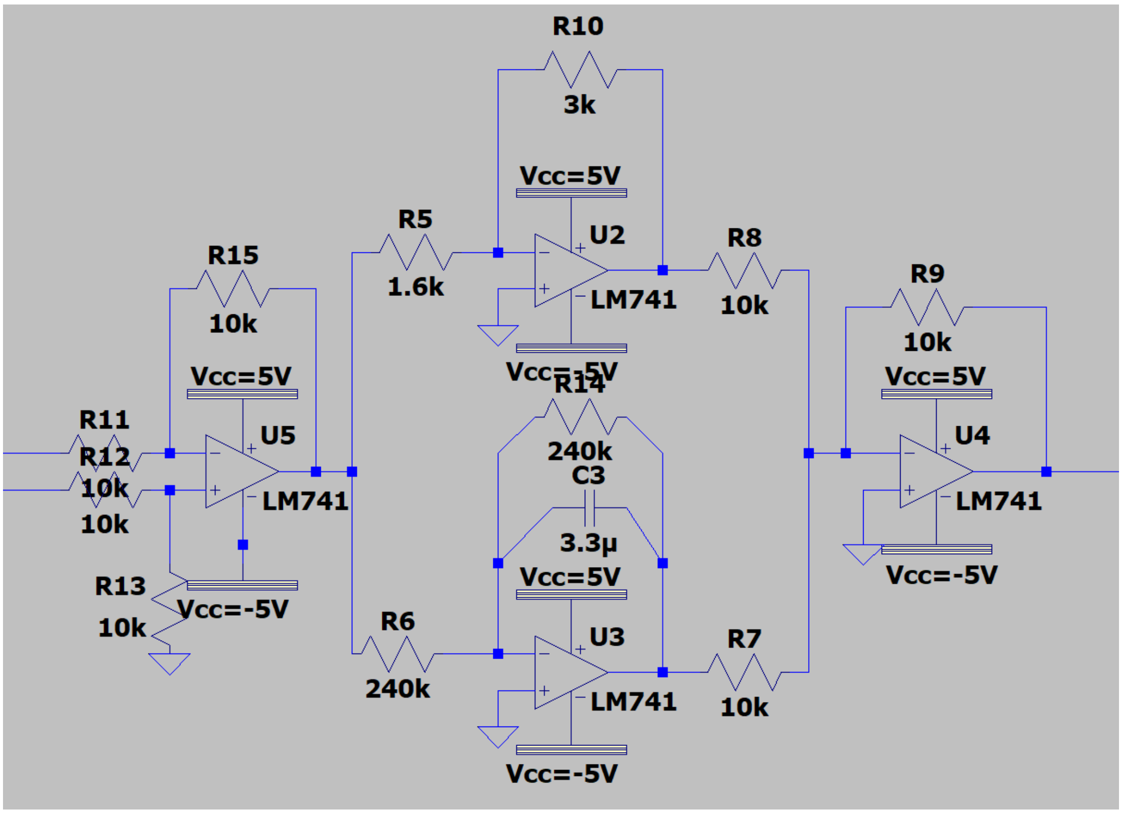

Figure 5.13 PI Controller Simulation Diagram.

5.3.5 LM555 Timer IC:-

The NE555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor.

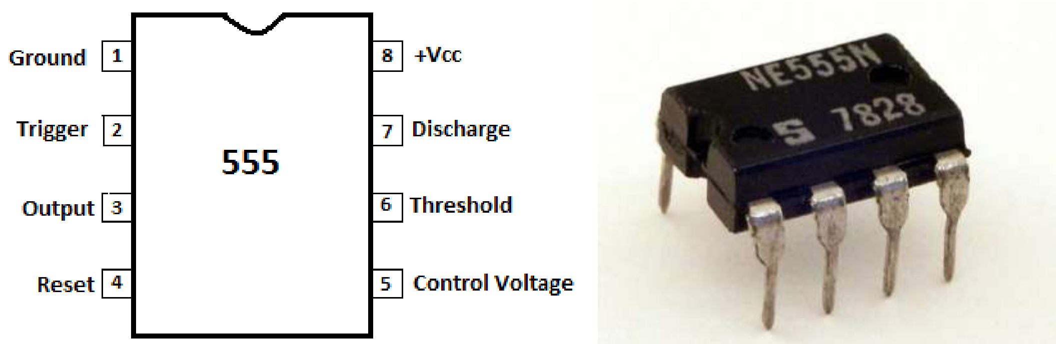

Figure 5.14 (A) NE555 Pin out diagram (B) NE555 Timer IC.

5.3.6 Circuits Using LM555:-

Here below is the circuit to generate PWM square wave of 40 KHz with 37.5% Duty Cycle which required to drive Mosfet.

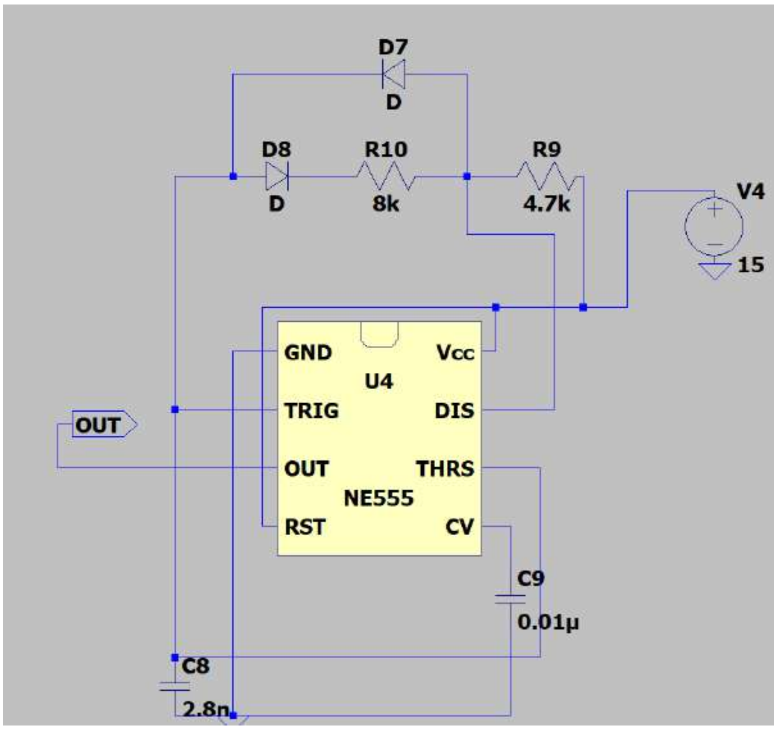

Figure 5.15 PWM Square Wave Generator Circuit.

This circuit generates saw tooth waveform to provide close loop control to the buck converter.

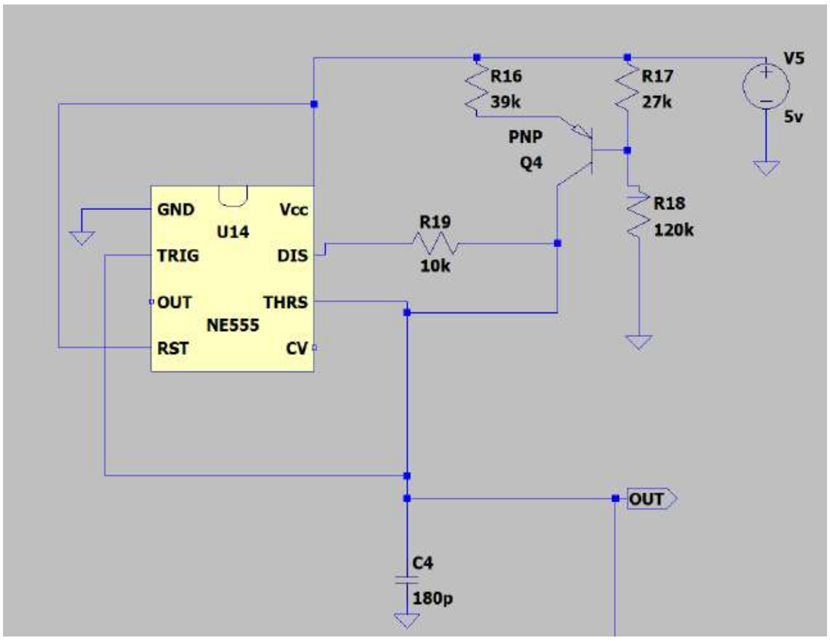

Figure 5.16 Saw tooth Waveform Generator Circuit.

Below is the circuit to compare output of PI controller and saw tooth generator by comparing them this circuit generates PWM to drive Mosfet.

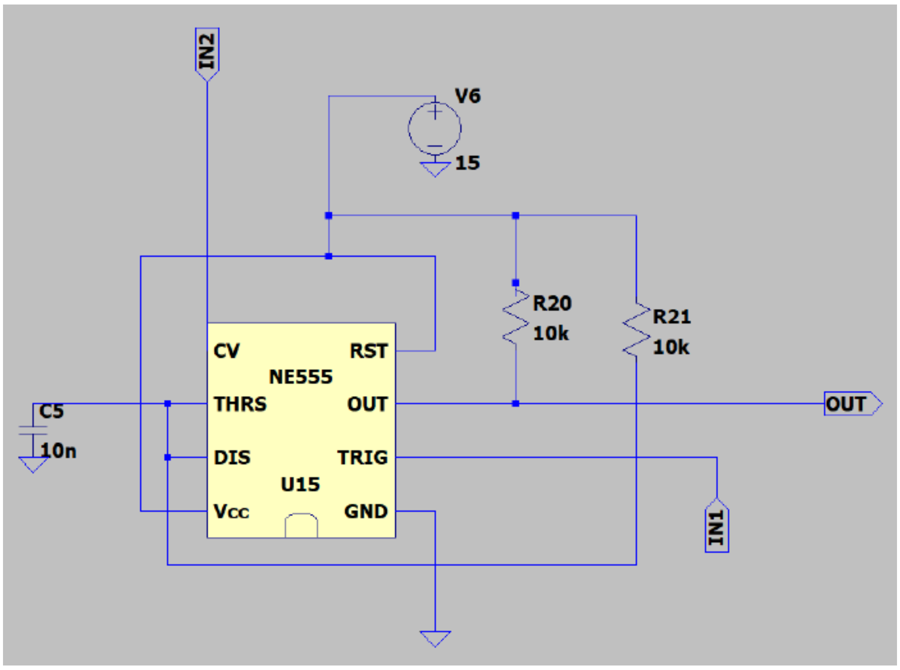

Figure 5.17 PWM Square Wave Generator Circuit by comparing PI Controller Output & Saw tooth Output.

5.3.7 MOSFET Driver Circuit:-

A MOSFET push-pull driver circuit is a commonly used circuit in electronic systems to drive a load with a high current or voltage. The basic idea of a MOSFET push-pull driver circuit is to use a pair of complementary MOSFET transistors that are configured as a push-pull amplifier.

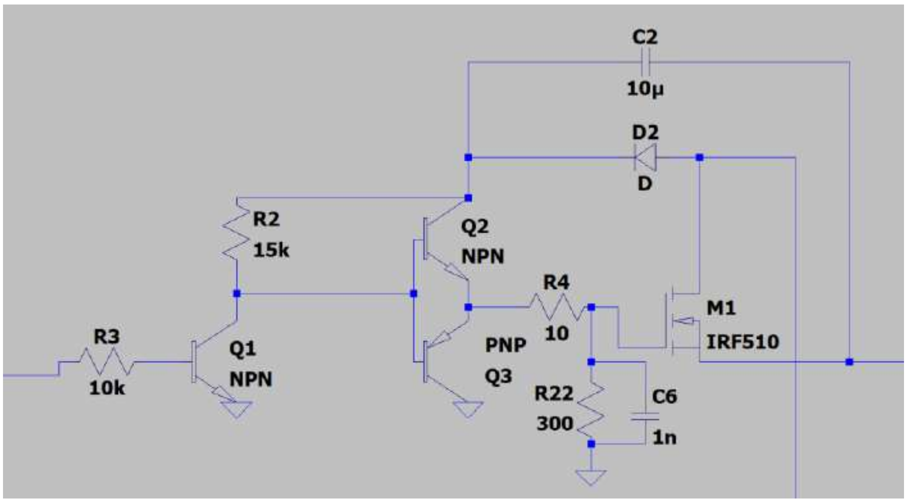

Figure 5.18 Push-Pull Mosfet Driver Circuit.

5.4 Experimental Results :-

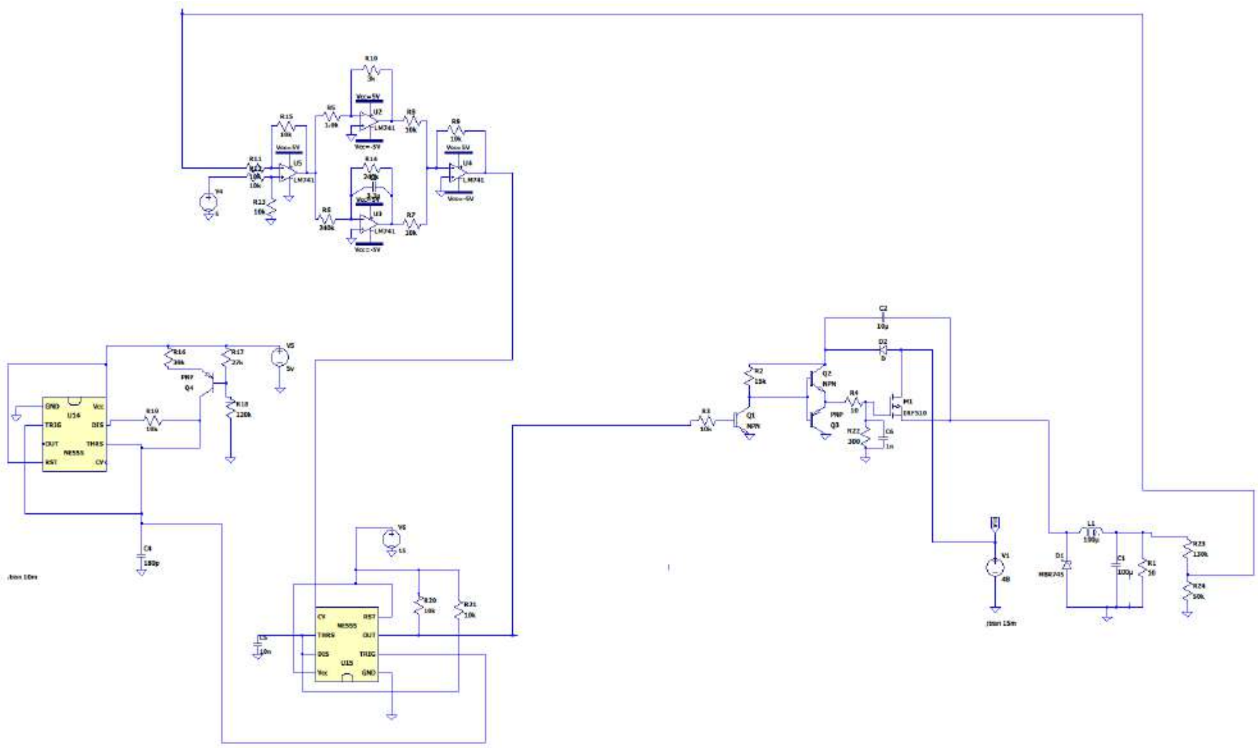

Figure 5.19 Simulation Circuit of Buck Converter with PI Controller.

The above figure contains circuit for buck converter in closed loop designed using Ltspice software. Software allows to create circuit using real components. Provides proper simulation results. Here below are the figures which contains output voltage waveform & Gate pulse generated in above circuit.

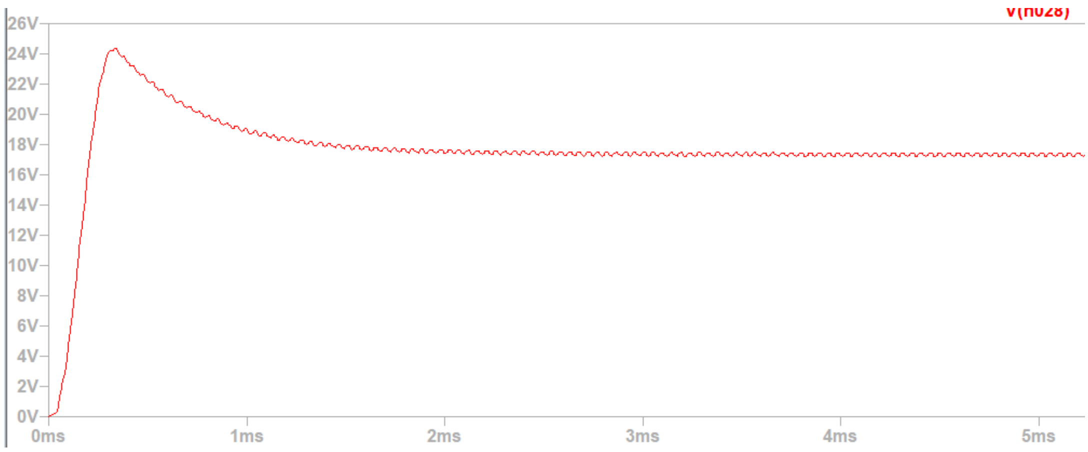

Figure 5.20 Output Voltage Waveform.

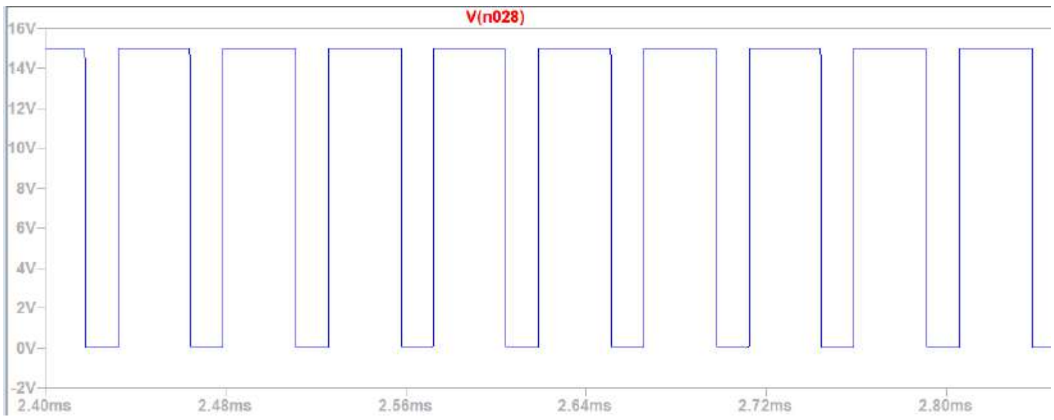

Figure 5.21 Output of PWM Generator.

Using all the above circuits the buck converter with closed loop converter is designed.

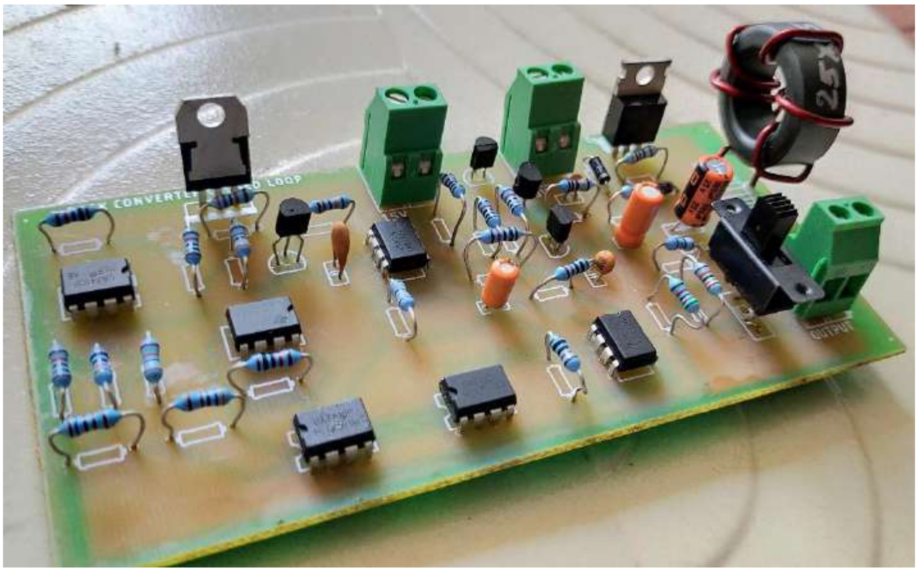

Figure 5.22 Buck Converter with PI Controller.

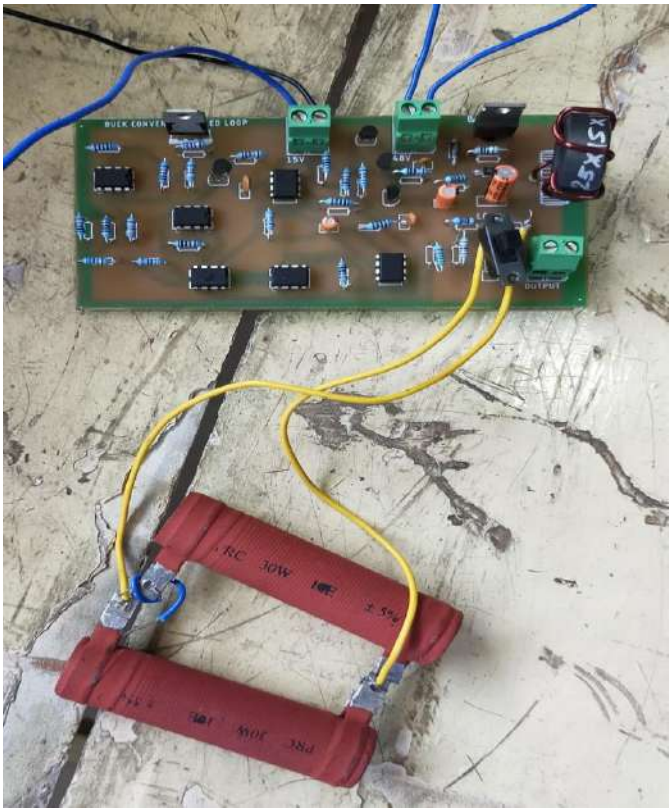

Figure 5.23 Hardware Setup Of Buck Converter.

The experimental setup is shown in this figures. The resistive load is being used to check the behaviour of converter after the load changes.

Figure 5.24 Experimental Setup.

Below is the output of the gate pulse generator is shown which is send to the mosfet driver circuit which control the switching of mosfet. Circuit generates PWM of the 40 KHz frequency.

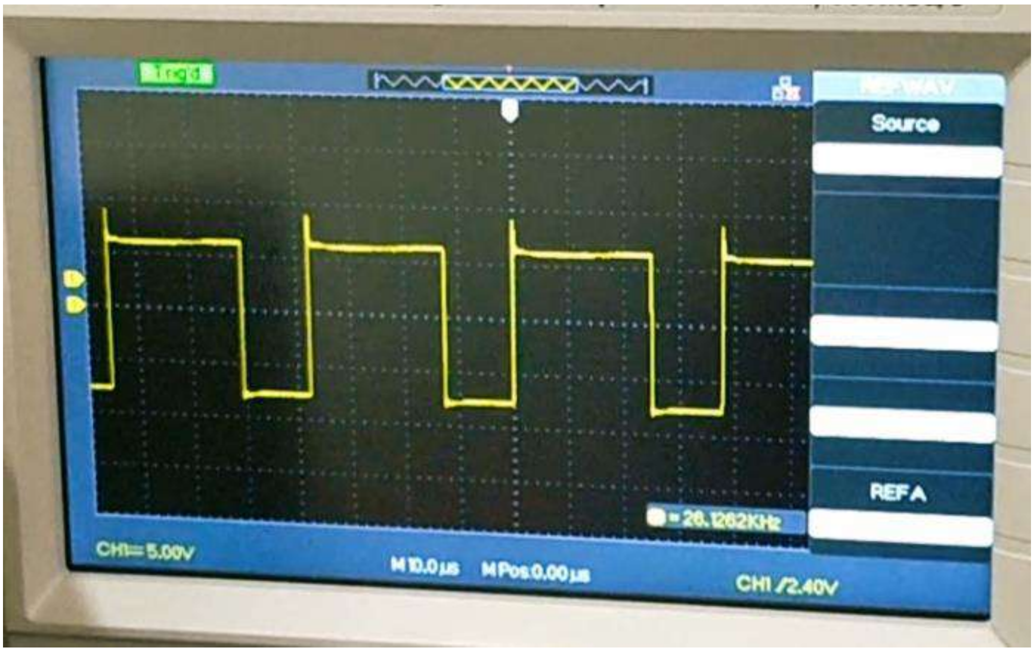

Figure 5.25 Gate Pulse.

Below is the figure of output voltage across the load of buck converter & it is observed as 3.2V when supplied 10V input.

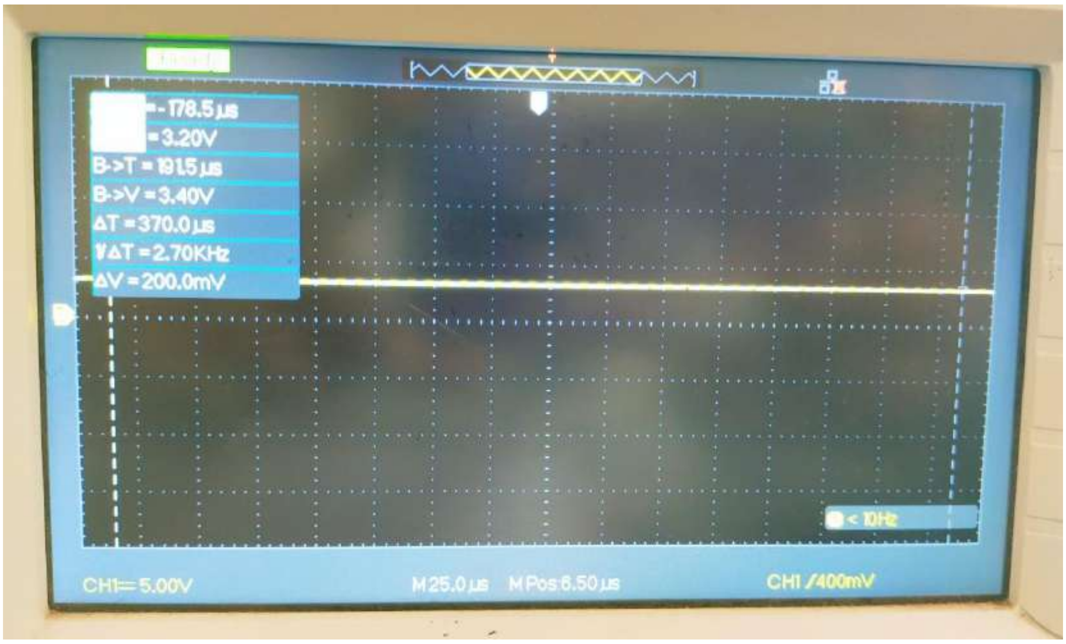

Figure 5.26 Output Voltage for 10V Input Supply.

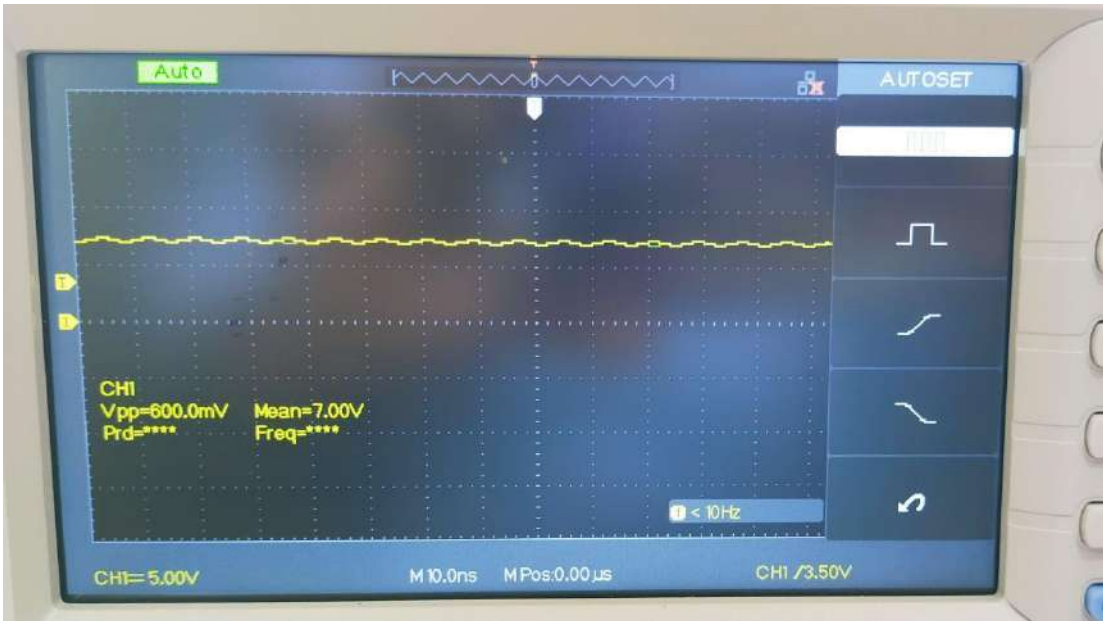

Figure 5.27 Output Voltage for 18V Input Supply.

Above figure shows the output voltage of buck converter when input voltage is 18V. It can be observed as 7V which is as per the expectations. The next figure shows the output voltage after connection of another load which comes out to be 7.2V.

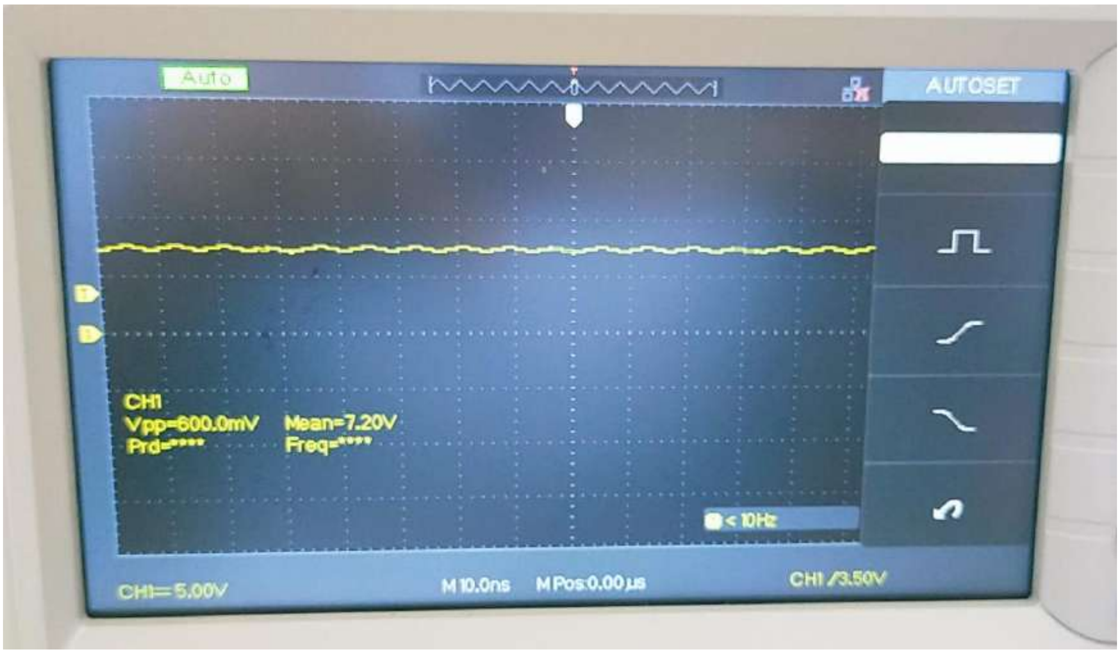

Figure 5.28 Output Voltage for 18V Input Supply after Load Change.

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CHAPTER 6
SUMMARY, CONCLUSION AND FUTURE SCOPE

6.1 SUMMARY

The Buck Converter is a type of DC-DC converter that is widely used in power electronics applications to step-down a DC voltage to a lower DC voltage. In this project, a Buck Converter with closed loop control using a PI controller is implemented. The PI controller is used to regulate the output voltage of the Buck Converter by adjusting the duty cycle of the PWM signal. The PI controller calculates the error between the reference voltage and the measured output voltage, and then adjusts the duty cycle of the PWM signal based on this error. The Proportional term of the controller reacts to the current error, while the Integral term integrates the past error and helps to eliminate the steady-state error.

The closed loop control system is designed using a feedback loop, which consists of a voltage divider circuit, Op-amp based PI controller, and a pulse width modulation (PWM) circuit. The voltage divider circuit measures the output voltage of the Buck Converter, and the PI controller nullify the error then those signal sent to the 555 based PWM generator circuit. The circuit generates PWM signal for required duty cycle and sends to Mosfet driver circuit.

The performance of the Buck Converter with closed loop control using a PI controller is evaluated using simulations and experimental results. The simulations are carried out using MATLAB/Simulink, while the experimental results are obtained by implementing the Buck Converter with a PI controller on a printed circuit board (PCB).The results of the simulations and experiments show that the closed loop control system with a PI controller is able to regulate the output voltage of the Buck Converter within a small error range. The system is also able to respond quickly to changes in the load current and maintain a stable output voltage.

Overall, this project demonstrates the design and implementation of a Buck Converter with closed loop control using a PI controller, which can be used in various power electronics applications.

6.2 CONCLUSION

In conclusion, the buck converter project with closed-loop control using a PI controller has proven to be a successful endeavor. The project aimed to efficiently step down a higher voltage source to a lower voltage output, and the addition of the closed-loop control system helped maintain a steady output voltage despite changes in load and input voltage.

The PI controller utilized feedback from a voltage sensor to continuously adjust the duty cycle of the converter's switch, thereby regulating the output voltage. This controller was able to effectively reduce overshoot and undershoot, leading to a stable and precise output voltage.

The project demonstrated the importance of closed-loop control in regulating the output voltage of a power converter. It also highlighted the significance of choosing the appropriate values for the controller's gain constants to achieve the desired performance.

Overall, the successful implementation of the buck converter project with closed-loop control using a PI controller provides a solid foundation for future power electronics projects. The use of closed-loop control systems can be applied to a wide range of power electronics systems, providing stable and efficient power conversion.

6.3 FUTURE SCOPE

1. Some more classical control methods may be investigated to tune the PID controller.

2. Self-tuning (Auto tuning) may be carried out such as AI, fuzzy, AI + fuzzy, etc.

3. The tuning of parameters such as K_P, K_I & K_D may also been calculated by any optimization techniques.

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Societal Relevance

- This thesis mainly focuses on DC-DC converters which have wide applications in Electrical vehicles, Renewable energy, and so on…

- The modelling and PID tuning have been carried out in this thesis.

- This thesis may help society to create awareness of dc-dc converters, modelling, and tuning process.