NUST COLLEGE OF ELECTRICAL &
MECHANICAL ENGINEERING

DC VARIABLE POWER SUPPLY

PROJECT REPORT

DE-40 (DEE)

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BACHELOR'S IN ELECTRICAL ENGINEERING

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NUST COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

PESHAWAR ROAD, RAWALPINDI

Certificate of Approval

It is to certify that the project “**DC Variable Power Supply**” is done by GC Nangyal Ahmad, NC Muneeb Ahmed, and GC Mustaneer ul Hassan under the supervision of Asst. Prof. Dr. Taosif Iqbal.

This project is being presented to the Department of Electrical Engineering, College of Electrical &Mechanical Engineering, Peshawar Road, Rawalpindi, Pakistan, in partial fulfilment of the Bachelor of Engineering in Electrical Engineering degree requirements.

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Declaration

Asst. Prof. Dr. Taosif Iqbal's "Department of Electrical Engineering" at NUST has accepted our project work titled "Variable DC Power Supply" as written evidence of our work performance. This declaration is made official by the submission of this project to the "Department of Electrical Engineering." An electrical engineering bachelor's degree requirement is partially met by the submission of this document and the associated project work. To the best of my knowledge, no other university or institute has accepted this paper or its results for the award of any degree or certificate

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Thank you.

Abstract

A variable AC to DC power supply converts AC to a Desired value of DC Voltage. Variable power supplies are mainly used in industries and labs for experimental purposes of different circuits which require different voltages and currents for their operation. Regulated and unregulated AC power supply are available. When the input voltage or load fluctuates, an unregulated power supply cannot maintain a constant voltage for the load, while regulated power supplies provide consistent voltage despite the change in input voltage or load applied. Linear power supplies are least complex but produce much heat, on the other hand Switching Mode Power supplies (SMPS) are much more complicated and cooler but create more noise.

This project is on the design, simulation, and implementation of a digitally controlled AC to DC power supply. This power supply has a maximum output current of 15A and a voltage range of 0 to 300V. The approach to achieve the goals will be to design an embedded system around an intelligent microcontroller. To regulate the output voltage, the microcontroller will send a pulse width modulated (PWM) signal. It will be a feedback system i-e the microcontroller will constantly monitor the output voltage and will change the PWM signal if the output voltage value is not matching with the desired value of the user.

The proteus is used to simulate this project. And after Successful simulation the circuit is fabricated on a PCB, and a final product is obtained.

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Chapter 1: Introduction

1.1. Introduction

The electricity supplied by the power system in most developing countries is alternating current(AC). Most wall outlets have a 220V effective AC voltage and a 50Hz frequency (depending upon the region). Although energy available from wall outlet essentially limited, it must be transformed from alternating current (AC) to direct current (DC) and customized allow for the proper voltage for electronic equipment. A DC power supply unit cab be used to perform this task. It is most commonly applied to power supply units that are integrated into the devices they power, such as computers and home gadgets. Laboratory bench supply is the term used for a power supply that is used in the laboratory for experimental purposes. It’s a variable output power supply unit that can power the load in either unipolar or bipolar mode. To determine the qualities and specifications of electronic equipment, tests are required. As a result, a bench power supply is a necessary component of laboratory equipment for testing low-power devices. Experiments must be carried out with consistency and precision. Errors can be introduced into the experiment if the voltage or current provided by the power supply unit is incorrect.

Furthermore, most power supplies available to us in electronic equipment stores and in laboratories do not supply us with very high voltages and currents and consequently power.

They're well-known power supplies since linear power supplies were the industry standard until mode power supplies were developed. Depending on its intended use, these power supplies have a variety of benefits and drawbacks. Because of its simplicity, durability, minimal noise, and low cost, linear mode power supplies are popular. Engineers can easily cope with these power supplies, also known as linear regulators, due to their simple design and limited number of components (LRs). Linear power supply are more reliable as a result of this design's reduced complexity. Linear mode power supplies have a significant advantage in terms of noise reduction. For applications where noise sensitivity is critical, linear regulators are the best option. Finally, linear power supplies have a low component count, making them an interesting power supply alternative when a linear regulator solution is required to meet the application's requirements.

There are certain disadvantages to linear mode power supply, in addition to the numerous advantages. The restrictions of linear regulators become increasingly evident when greater power is required. Linear regulators can be used in a variety of low-power applications. Size, high heat loss, and lower efficiency levels are all downsides of linear power supplies versus switch-mode power supplies. Linear power supply units need a larger transformer and other critical components to accommodate high-power applications. In order to distribute the weight of a power supply more evenly, larger components must be used, which increases the power supply's overall size and weight.

Another disadvantage of linear regulators is that when regulating a high-power load, they waste a lot of heat. Because of the linear arrangement, the high output current must pass via the power transistor. To disperse the energy loss caused by this thermal stress, a linear power supply heat sink must be installed. Depending on how the linear model power supply is fitted to its system, this could be considered a negative. Last but not least, when the input and output voltages differ significantly, the linear regulator is less efficient than a switch-mode power supply. A number of criteria, including dropout voltage and load voltage, must be considered when assessing the efficiency of a linear mode power supply for your application.

There are numerous advantages and downsides to linear mode power supply, such as a low total cost and a simple design, but they also have drawbacks such as excessive heat loss and changeable efficiency levels. Other than size, cost, and efficiency, there are several factors to consider when choosing a power supply for a certain application. If an electrical engineer decides to employ a linear power supply in their design, they will be able to choose from a choice of linear power supply units.

In addition, 500W to 1000W power supplies, available online or in stores, cost around Rs 9,000 to Rs 42,000. Therefore, a need for a highly efficient, as well as cost effective, variable power supply that can give us high output voltages and currents arises.

The variable power supply that we have designed does not cost more than Rs 7,000 and the output power it yields is around 5000W. The power supply we have used is a switching-mode power supply, its advantages over a linear supply as well as its disadvantages shall be discussed in the further parts of our research paper.

1.2. General Problem Statement

With the severity of the energy crisis growing, active mode high-efficiency power supply is gaining lot of attention. A power supply that is inefficient wastes a lot of energy. Furthermore, when power supplies are lost, heat is generated, worsening the environment even more.

Linear mode power sources provide a number of advantages, but they also have certain disadvantages. Many low-power applications are well-suited to linear regulators, the limitations become more evident when a larger power is required. A switch-mode power supply has many advantages over a linear power supply, such as its smaller size and lesser efficiency.

Linear power supply devices have the disadvantage of requiring a big transformer and other bulky components when used in high-power applications. The weight and size of a power supply may be modified by the weight distribution of the application if larger components are used.

When used to control a high-power load, linear regulators lose a lot of heat. The power transistor is required to carry the high output current due to the linear structure. A heat sink must be included in a linear power supply to decrease energy loss due to thermal stress. This may or may not be a negative depending on how the linear mode power supply is implemented in the system. Finally, when the input and output voltages differ significantly, linear regulators are less efficient than switch-mode power supplies.

1.3. Objective

The main objective of the project is to design an efficient and cheap power supply to gain high voltage.

Output Voltage = 0-300V

Output Current = 0-15A

Maximum Power = 5kW

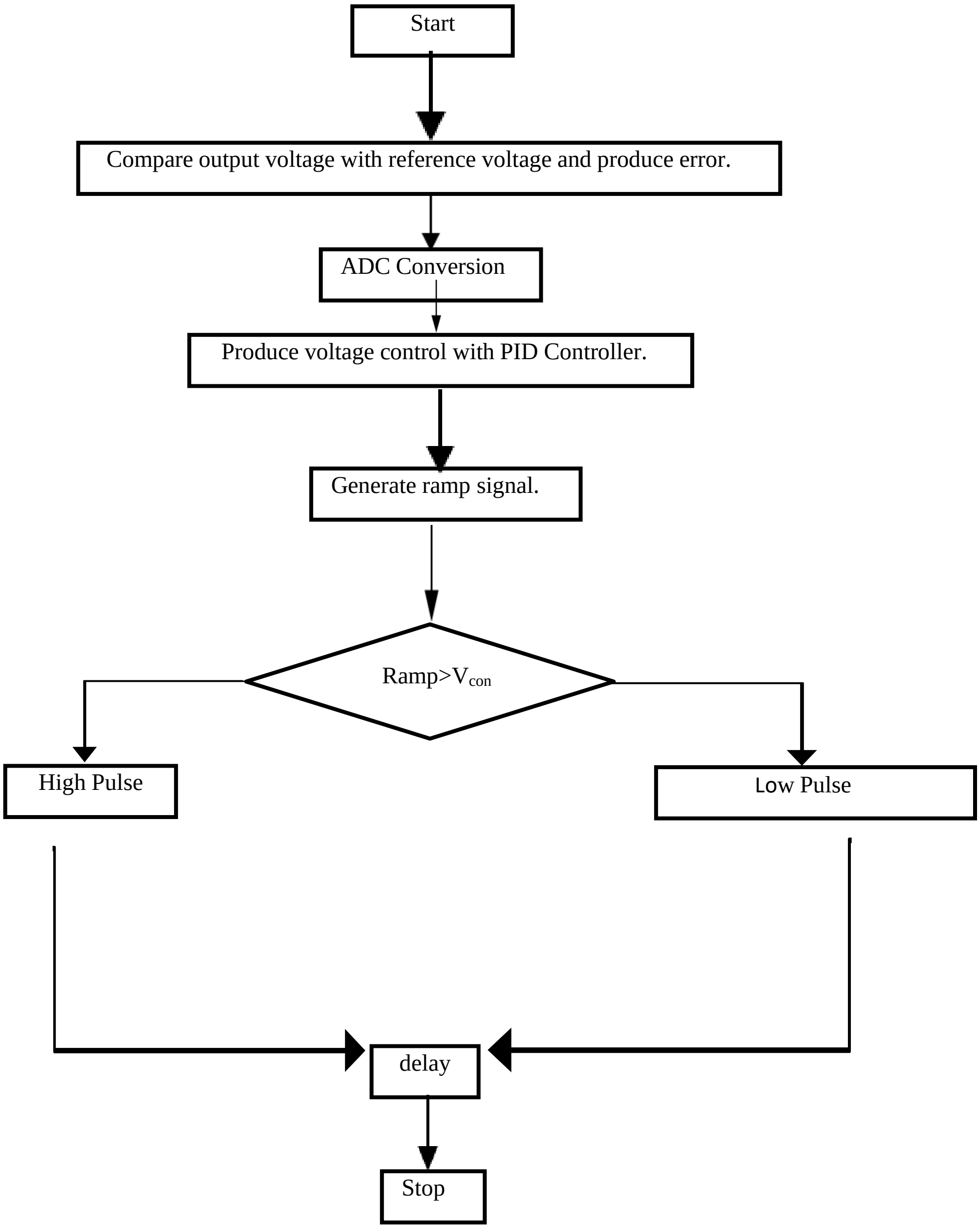

Figure 1 Design Flowchart

Chapter 2: Literature Review

2.1. Power Supply

An electrical device that provides the load with electrical power is known as a power supply, Converting input current or electric current from one source to another in order to power the load is its primary function. For this reason, power converters are another name for these devices. Both stand-alone power supply and those integrated within the load appliances they serve are in use today. Power supplies also perform many other functions like power conditioning so that electric noise or surges in voltage on the input can be prevented from reaching the load, can act as current limiters, in case of an electrical fault can shut off the current, provide power-factor correction and can also store energy in order to continue the process of powering the load in case of a temporary disturbance in the incoming power. The functional qualities of a power supply can be used to categorize a power supply. The output voltage or current of a regulated power supply, for example, remains constant no matter how much input voltage or load current changes. Unregulated power supplies have a substantial shift in output voltage when the voltage at the input is changed or the load current is changed. Mechanical controls (such as knobs on the front panel of a supply) or an electronic control input can be used to set the output voltage or current in adjustable power supplies. "Adjustable Controlled Power Supply" refers to a power supply that can be regulated as well as regulated. If the output power is not dependent on the input power, it is referred to as an isolated power supply. In comparison to other supplies, this one only has a single wire connecting it to the power source.

<u>Types</u>:

1. DC power supplies:
    - Linear
    - Switching/switch/switched mode (Switcher/SMPS)
    - Capacitive
    - Linear regulator
2. AC power supplies:
    - AC adapter

3. Programmable
4. Uninterruptible
5. High Voltage

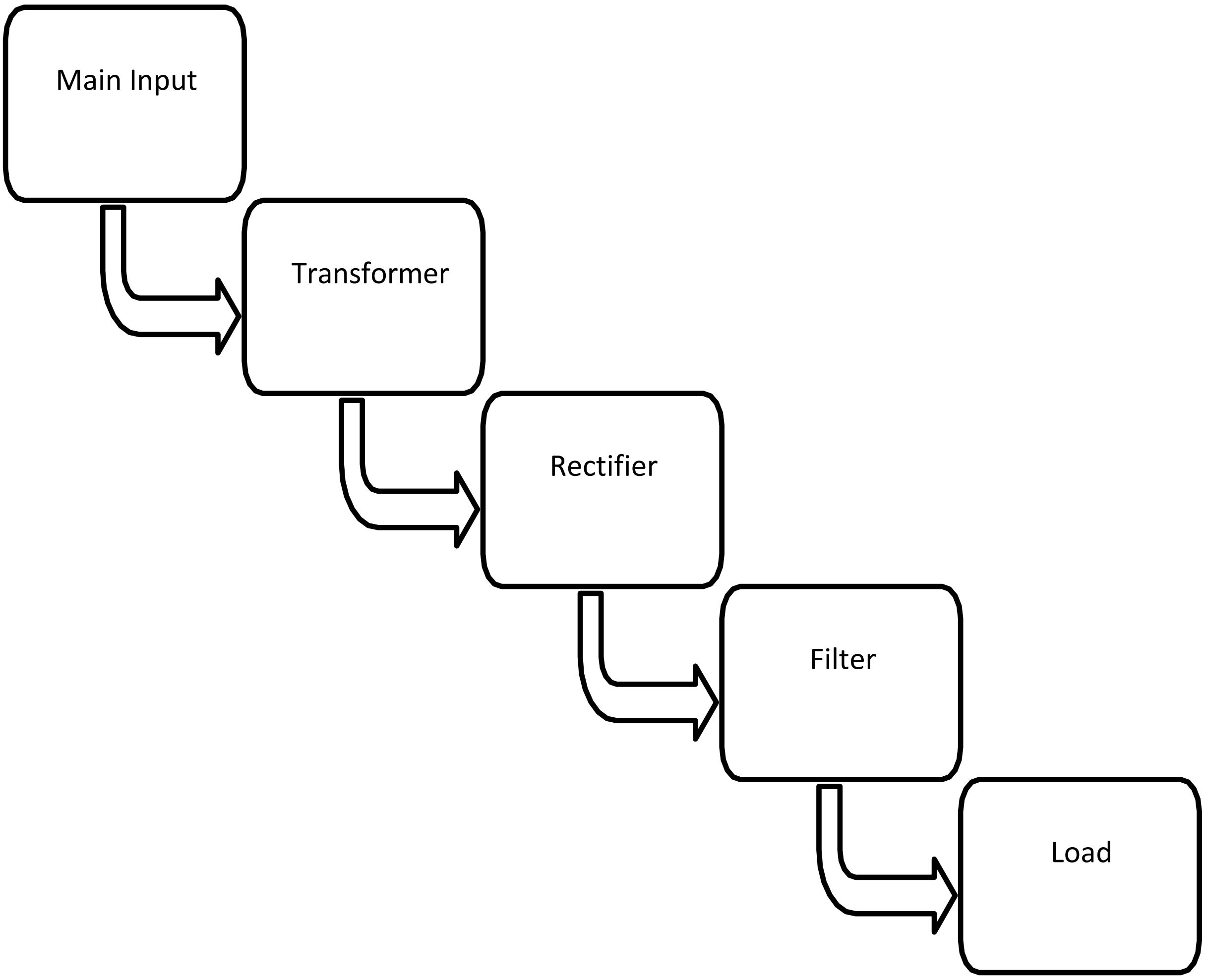

Figure 2 Linear Power Supply block diagram

2.2. Switching Mode Power Supply (SMPS)

The output of a power supply cannot be controlled without switching mode , without switching mode the power supply is like a fixed power supply and cannot vary its output .

Switchers and electronic power supply with switching regulators can be used to efficiently convert electrical energy. An SMPS alters voltage and current characteristics in order to convey power from a source (DC or AC) to loads (DC). In contrast to linear power supply, switchers' pass transistors shift between low dissipation, completely on and fully off states all the time, wasting less energy during transitions with high dissociation. A good switcher uses little energy. Voltage can be adjusted by varying the on/off time ratio (also known as duty cycles).

Comparison of Linear power Supply with SMPS:

Surplus power is lost through Ohmic losses in a non-SMPS linear power supply, resulting in the required output voltage. Using heat as a means of limiting output voltage or current, a linear regulator reduces power consumption by squandering the voltage difference. As a result, its maximum power efficiency is defined as voltage out/voltage in.

The output voltage and current of a switcher, on the other hand, are modulated by switching lossless storage components (such as inductors and capacitors) between various electrical configurations. To ensure that the load receives the full input power, ideal components ensure that there is no heat dissipation. This means that when the ideal switching elements are turned on, no resistance is present. When they are off, no current flows. But the fact that a switching power supply still has a large advantage over a linear regulator is still present because these ideal components do not exist in real life. The output current flow in an SMPS is determined by the power signal at the input, the storage components and the different circuit topologies utilized, as well as the pattern responsible for driving the switching elements. These switching waveforms have energy concentrated in their spectral density at relatively high frequencies so in order to filter the switching transients and the ripple injected into the waveforms at the output, a small LC filter may be utilized.

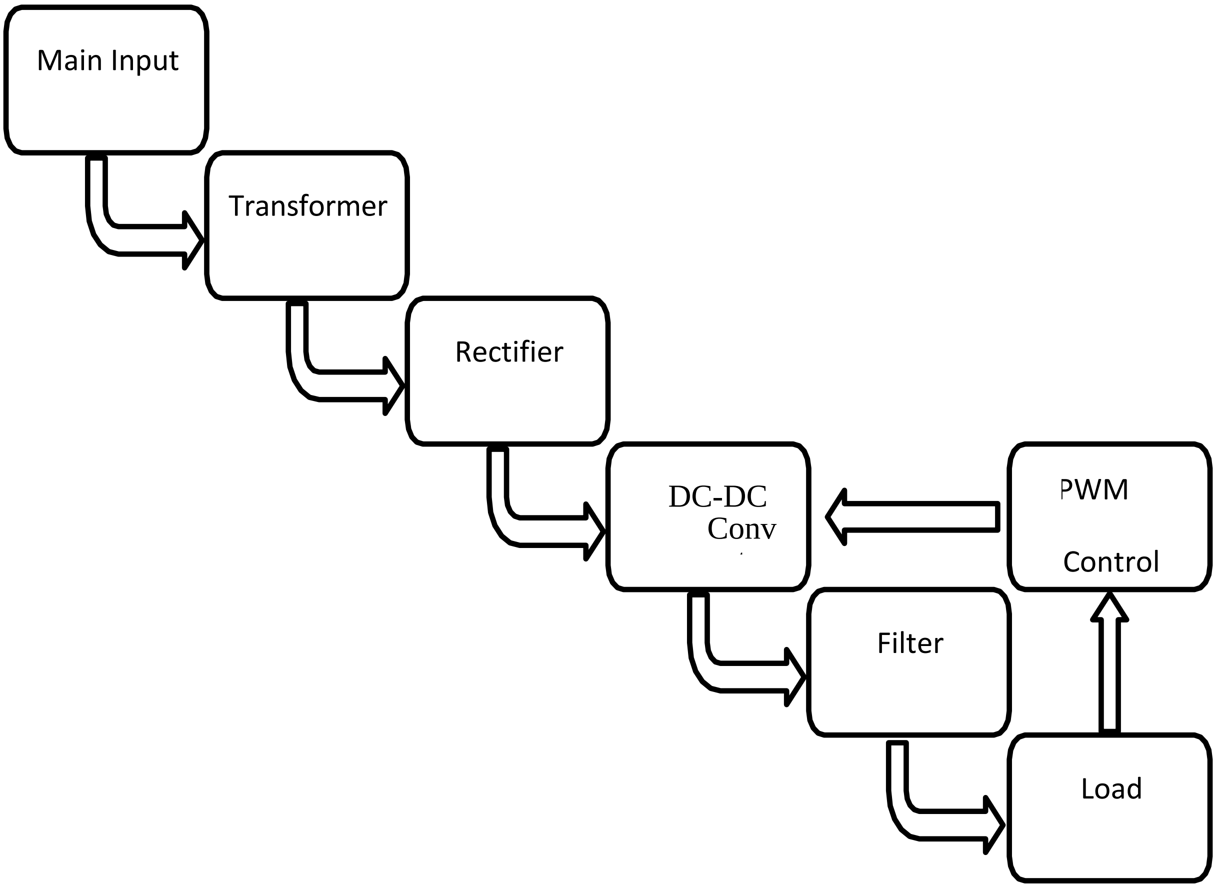

Figure 3 SMPS block diagram

2.3. Advantage and Disadvantage of SMPS

2.3.1. Advantages of SMPS

When acting as a switch, little power is dissipated by the switching transistor, and this is why the SMPS has a higher efficiency (up to 96%) than a non SMPS linear regulator. Additional advantages include reduced size, noise, and weight due to the absence of heavy line-frequency transformers and the heat they generate. The standby power loss is often significantly smaller than that of transformers. A switcher's transformer is also smaller than a regular line frequency transformer, therefore it takes fewer expensive raw materials to build.

2.3.2. Disadvantages of SMPS

These disadvantages include ripple voltage at the switching frequency and its harmonic frequencies, as well as the generation of electromagnetic interference (EMI) at high frequencies, which must be avoided by using a low-pass filter. Electrical switching noise from low-cost SMPS may also re-enter the mains power line, causing issues for equipment linked to it.

2.4. DC-DC Converter

It is an electrical based device which operates on a circuit having a direct source of current labelled as Direct Current, which fluctuates its value from a certain level of voltage to another voltage level in short duration. This is basically a replica of a power converter powered by electricity. The level of power in it ranges from very low value to a very high value.

Electric vehicles, trolleys, maritime hoists, forklifts, and mine movers all employ DC converters to control traction motors. Features such as smooth acceleration and quick dynamic response are included in the package. As DC current sources, DC converters, particularly inverted current sources, can be used. DC-DC converters are key components of the energy conversion process in the emerging field of renewable energy technologies.

There are various types of converters, some of which includes the following:

2.4.1. Buck Converter

In many scenarios, the situation is as such that an overall lower voltage is needed at the output, so a device such as Buck Converter is tended to use, also known as the Step-Down Converter. For example, for a 15V supply but the output application of it required is only of 5V,so in this case the converter used is called the buck converter.

$$P = (V_{in} - V_{out}) * I_{out}$$

Approximately 9Watts of power is squandered by this linear regulator, which is a lot for such a little device. Calculating its efficiency results out to be very ineffective as well therefore the need for a step-down converter heavily arises.

PWM 'dimming' and Buck converters share several characteristics. A PWM signal is required to dim the lights. During periods of low duty cycle, the average voltage is lower than during periods of higher duty cycle.

The voltage that is supplied is the average of the overall voltage, and a very raw pulse width modulated signal is generated and there is nothing such delicacy with load. Although a Resistor Capacitor (RC) based filter is connected here which also depends on the duty cycle of the supplied Pulse Width Modulation (PWM).

Working of Buck Converter:

Step1: The switch is turned on which allows the current to flow through it outside the capacitor, also the value of voltage is limited so that its value does not rise above a specific value.

Step2: Afterwards. the switch is turned off, and the inductor utilizes that voltage value, and thereby the inductor acts as a source now. This power allows the capacitor to charge its value, and the value of diode through it. This maintains the output current even when the cycle is switched.

Step3: Now that the Mosfet has been disabled, no current can flow through this inductor. This inductor is responsible for maintaining a steady current flow and preventing it from spiking unexpectedly. This responds by the creation of a large voltage which has opposite polarity. Because the inductor works as a voltage source, the remaining circuit must be eliminated. An increased charge rate is applied to the output capacitor, making it a better generator of electric current.

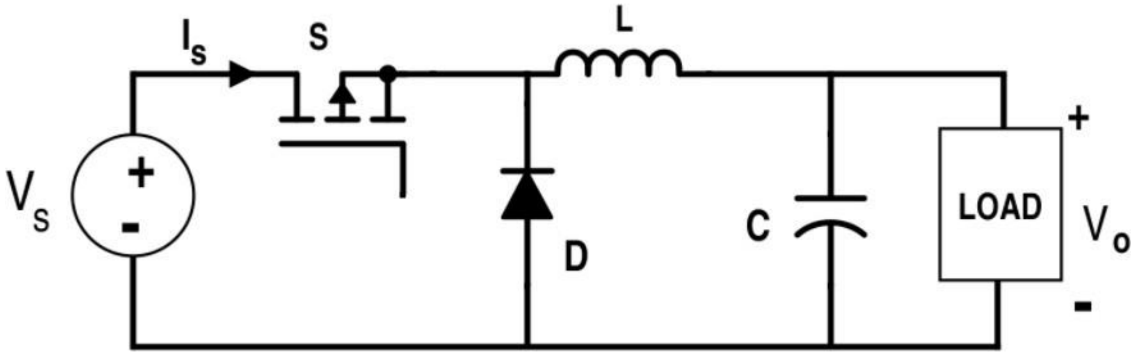

Figure 4 Typical Buck Converter

The inductor current:

Switch Closed:

$$v_L = V_{in} - V_{out} \rightarrow \frac{di_L}{dt} = \frac{V_{in} - V_{out}}{L}$$

Switch opened:

$$v_L = -V_{out} \rightarrow \frac{di_L}{dt} = \frac{-V_{out}}{L}$$

2.4.2. Boost Converter

One of the most basic functions of a boost converter is to boost the input voltage to a higher level. For example, if a supply is 12V but only the application of 24V is needed at the output, at such a situation, a Boost Converter is required.

It is one of the simplest modes of switch- based converter, which have an input voltage which is stepped up in some instant. Its basic construction involves the use of an inductor, a semi-conductor diode and a capacitor.

The simple configuration of a boost converter is as follows:

- When the load is removed, the inductor continues to push power to the right and rapidly charges the capacitor, causing the diode and MOSFET to fail.
- Make sure the duty cycle is set to the lowest setting and that a load is permanently attached before utilising electricity.
- For Boost Converter operation, set a maximum output voltage and alter the MOSFET firing circuit.

Working of boost converter:

Step1: Nothing happens at step1, just the capacitor at output is charged, the input voltage is subtracted at one instant.

Step2: After this the Mosfet is turned on, and the current which is present is divided among the components attached such as inductor. The power does not discharge automatically and the current then paces up its value in some short durations. Also, a phenomenon of magnetic field generation persists in this, and thereby the polarity of the voltage is overall reversed and increased.

Step3: Now that the Mosfet has been disabled, no current can flow to the inductor. The inductor maintains a steady flow of current and resists rapid changes. This responds by the creation of a large voltage which has opposite polarity. The inductor works as a voltage source when the remaining circuit is eliminated. An increased charge rate is applied to the output capacitor, making it a better generator of electric current.

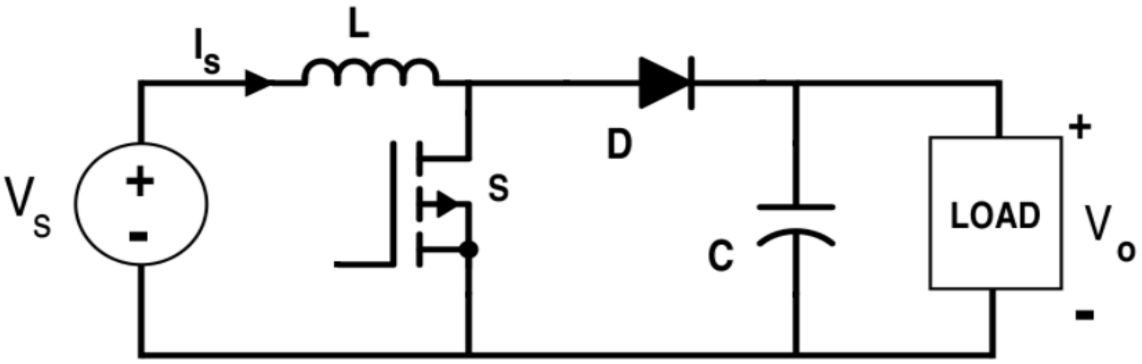

Figure 5 Typical Boost converter

The output is:

$$V_{Lavg} = D \cdot (V_{in}) + (1 - D) \cdot (V_{in} - V_{out}) = 0$$

$$V_{out} = \frac{V_{in}}{1 - D}$$

The Inductor current:

Switch closed:

$$v_L = V_{in} \rightarrow \frac{di_L}{dt} = \frac{V_{in}}{L}$$

Switch opened:

$$v_L = V_{in} - V_{out} \rightarrow \frac{di_L}{dt} = \frac{V_{in} - V_{out}}{L}$$

2.4.3. Buck-Boost Converter

The name "buck–boost" refers to the fact that the output voltage can be lower or higher than the input voltage. The polarity of the output voltage is the opposite of the polarity of the input voltage. The "reluctance" of the inductor is the best way to define the buck-boost function, which allows for rapid changes in current. The current flowing through the inductor is 0 mA while the switch is open, and the inductor is devoid of charge. Due to the blocking diode, no current can travel to the right side of the circuit when the switch is initially closed, so all current must pass via the inductor. A lower source voltage will keep the current low at initially because an inductor can't handle fast fluctuations in current. Allowing the current to rise evenly over time is made possible by decreasing the inductor's resistance. Ideally, the inductor's voltage drop would remain constant. It's important to take into account the intrinsic resistance of cables and switches when calculating voltage loss across inductors. Magnetic energy is also stored in the inductor during this time.

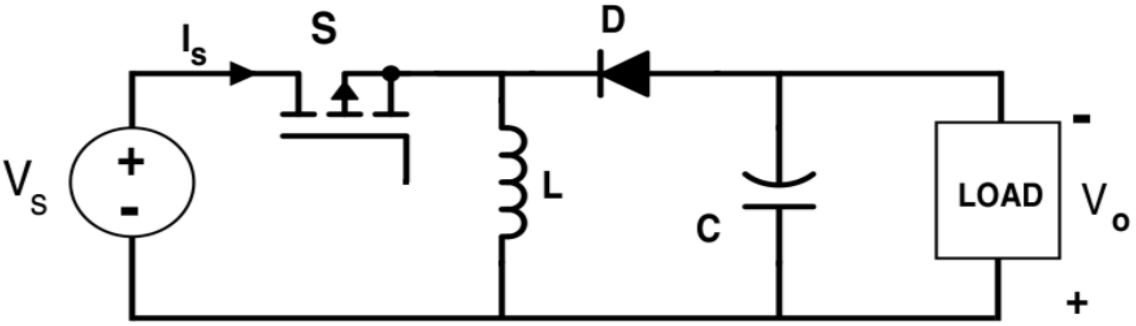

Figure 6 Typical Buck-boost Converter

Working:

- A short circuit will develop if the MOSFET gate driver remains in the ON position, and if the load is unplugged during operation D> 0.5, the inductor will continue to push power to the right
- Rapidly charging the capacitor to a high value (250V), blowing the diode and MOSFET!
- Make sure your duty cycle is set to the lowest setting and that a load is firmly attached before turning on the power.
- Ground is no longer allowed due to the polarity of the voltage being switched.

The output is:

$$V_{Lavg} = D \cdot (V_{in}) + (1 - D) \cdot (V_{out}) = 0$$

$$V_{out} = -\frac{DV_{in}}{1 - D}$$

For Inductor current:

Switch is close:

$$V_L = V_{in} \rightarrow \frac{di_L}{dt} = \frac{V_{in}}{L}$$

Switch is open:

$$V_L = V_{out} \rightarrow \frac{di_L}{dt} = \frac{V_{out}}{L}$$

2.5. Pulse Width Modulation (PWM)

Pulse Width Modulation is a method used to reduce the overall power, which is generated by a signal powered by electricity, which is done by dividing up the signal into different small parts. A switch is used in between which is used simultaneously to flip the load from ON and OFF state which revolves around the average value of voltage. The more time it takes for the switch to turn on, the more power is supplied towards the load. This being one of the most key methods to overall reduce the output that can be utilized better.

Pulse width is usually used in order to run different loads in motors, that are very less appreciated by very small sets of voltage at high switching frequency. This frequency is expected to be high, and it effects the load.

Now it solely depends upon the usage and different rate of its frequency which shows the amount of power which is supplied towards the switch. Giving an example of electric heater which must switch multiple times under a whole minute or any bulb whose light can be dimmed or increased up to a higher frequency. In motor drives, kHz spans from a few thousandths to hundreds of thousands, whereas in audio amplifiers and computer power supplies, kHz ranges from hundreds to thousands. The most important aspect of using this technology is that it uses very less power whenever the switching devices are applicable. This is because the voltage and current are just a product of each other, and they can never be zero under any circumstance. This also works in accordance with all the new AI based systems because usually their main working scheme is the turning on and off nature. This also has been widely used in a lot of communication systems.

Working scheme:

PWM introduces a rectangular wave which is in form of a pulse and has a regulated width with it which outputs into a various form of its value. Any waveform can be considered in this case, just as the following example below:

$$y = \frac{1}{T}\int_0^T f\,(t)\;dt$$

As ***f(t)*** is a pulse wave, its value is **ymax** for 0<t<D.T and **ymin** for D.T<t<T. The above equation then becomes:

$$y = \frac{1}{T}(\int_0^{DT} ymaxdt + \int_{DT}^{T} ymindt)$$

$$y = \frac{1}{T}(D.T.ymax + T(1-D)ymin$$

$$y = (D.ymax + (1-D)ymin$$

2.6. Duty Cycle

The duty cycle is explained as the ratio of time in any circuit which can be turned on or off via a switch. It is also a measure of the time in which the certain system is working up.

The formula of the duty cycle is:

$$D= (PW/T)* 100\%$$

Here D is the duty cycle, PW is the pulse width, T is the total time.

Explanation of the duty cycle is that it basically divides a process into two different parts. One part is the ON part and the other one is the OFF part. Generally, the divide of this is among 50% both cycles, but it can be altered according to needs of the system.

For example, if the duty cycle of ON time is 35% and OFF time is 65%, it means that if this functions in 100 minutes, it means 35 minutes it will be **ON** and the remaining 65 minutes it will be **OFF**.

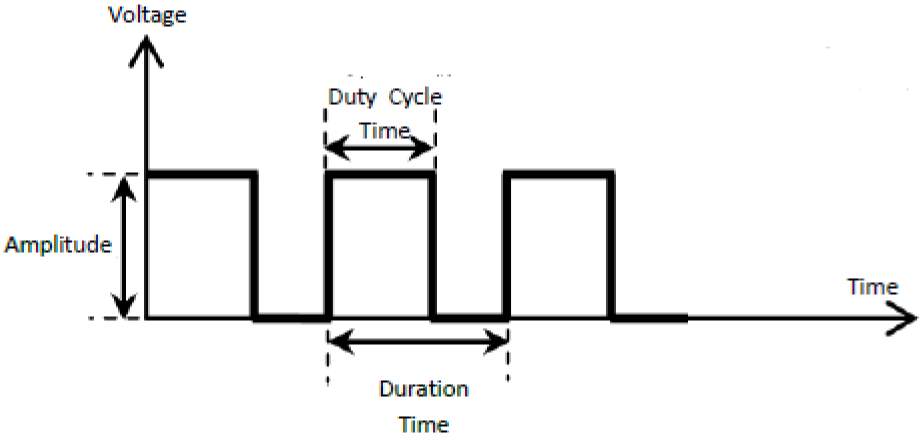

Figure 7 PWM Signal with Duty cycle

Chapter 3: Control Design for Buck Converter in MATLAB/Simulink

3.1. Introduction

In recent years, digitally regulated power supplies have been the hot topic due to rising demands for DC-DC circuit efficiency and power usage. The following diagram depicts the buck converter's analogue circuit. As the name suggests, the Buck controller is made up of several components.

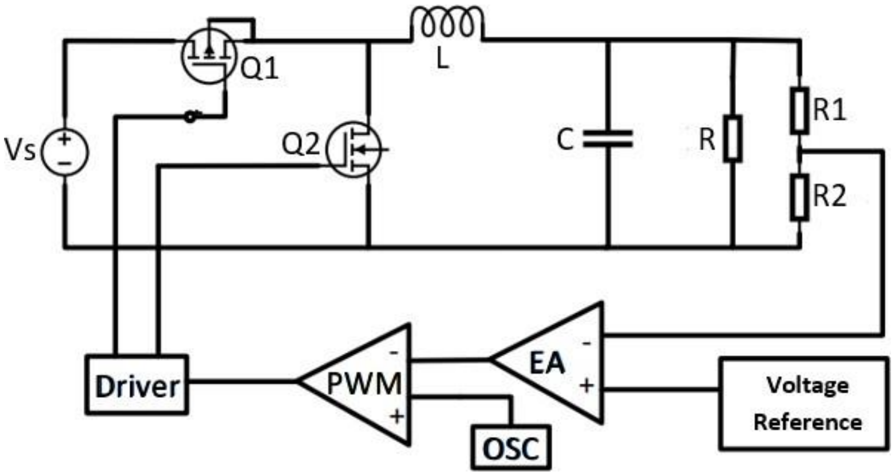

Figure 8 Analog control buck circuit structure

Precision, low power consumption, high efficiency, and a compact physical footprint are just a few of the benefits of a digital power supply. They're used in a range of industries, including new energy vehicle power management, electronic equipment power adaptors, and the communication business. This technique of control is expensive, requires a larger circuit board, and has a low circuit reliability. Only inductors and capacitors are excluded from the digital control power supply given in this study, which reduces chip cost, size, and dependability by consolidating power levels and all digital closed-loop control modules onto a single silicon chip. The advantages of digital circuit control over analogue circuit control include enhanced flexibility, precision, and online tuning. The use of fully integrated digital control chips is becoming more common.

3.2. Digital DC-DC Controller

Figure 9 depicts the design of a digital DC-DC buck converter system. There is an ADC converter, a PID controller, a MOSFET driver, a power stage, and an ADC. Dead time has been introduced to the two PWM signals required to drive the MOSFETs Q1 and Q2. The ADC converter converts the voltage directly into a digital value. PID controllers calculate and output duty cycle values by comparing a digital value to a reference value. The DPWM module then uses the duty cycle value to generate two PWM signals, one for opening and one for closing, which are sent to the switching device.

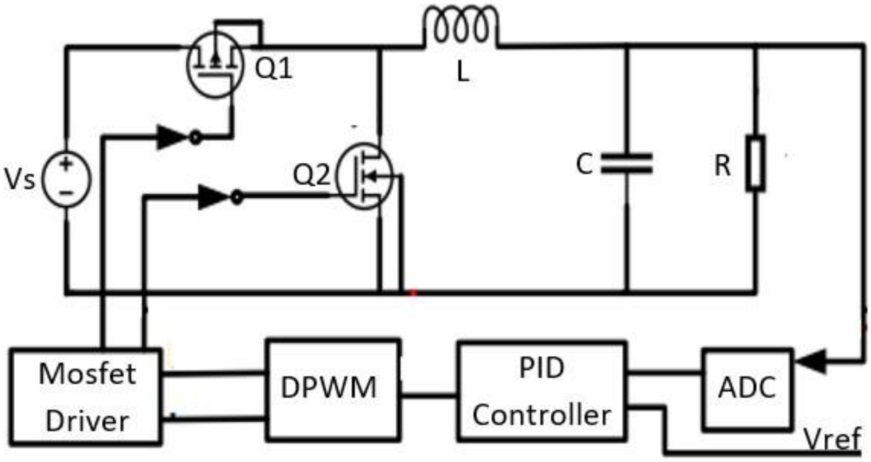

Figure 9 Digital control buck circuit structure

3.3. Modelling of DC-DC Buck Converter

When the chopper switch is on, the output is DC input to the helicopter; when it is off, the output is zero since the Buck Converter output is a series of pulses rather than pure dc. The output voltage of a converter must be averaged by an output filter to convert chopped DC to pure DC.

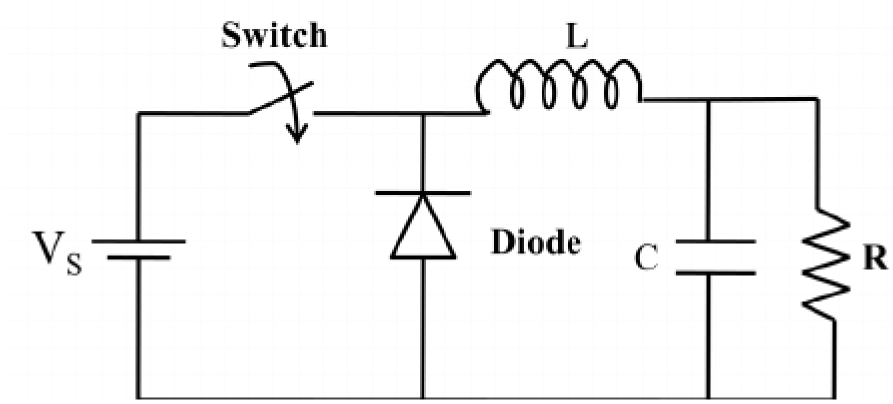

Figure 10 Buck converter Circuit

The above figure shows the buck converter. The large capacitor is added in parallel to the load to control the output ripples but if the inductor and diode are not present in the circuit so the switch will burn out due to huge current spark when then switch closes. An extra inductor can be employed in buck converter circuits to avoid the excessive current spark, however the inductor's current momentum can cause the switch to burn out. The switch can be opened while the inductor current continues to flow by utilising a "freewheeling" diode. The load voltage ripple has been kept to a minimum thanks to high-frequency switching.

The output voltage of a direct current supply is reduced using a buck converter. The buck converter's output voltage is controlled by a polynomial controller. The difference between the actual output and the reference voltage is measured when using a polynomial controller. This voltage difference is fed into a control element, which causes it to adjust its output to a specified reference value. Voltage regulation is the process of controlling the voltage.

The supply voltage is applied to an inductor capacitor, or LC, circuit by the buck converter's transistor and diode. The voltage across the capacitor determines the output voltage. The LC circuit's input voltage is modulated using pulse width modulation, or PWM. Duty cycle range d= [0, 1]

represents the proportion of the cycle duration when supply voltage, i.e., input, is connected to the circuit, as shown. The duty cycle is the Buck converter's control signal.

3.3.1. Capacitor and inductor operating in a steady state

The following equation describes the steady-state current flow via a capacitor:

$$i(t) = C\frac{dv(t)}{dt} \quad \text{which leads to } v(t) = v(t_o) + \frac{1}{C}\int_{t_o}^{t_o+t} i(t)dt$$

Due to the fact that the capacitor is in periodic steady state,

$$v(t_o + T) - v(t_o) = 0 = \frac{1}{C}\int_{t_o}^{t_o+T} i(t)dt$$

Since the integrated term on the right equals zero, the average current flowing through a capacitor in a periodic steady state is zero.

A periodic steady-state inductor's core voltage is determined by the following equation:

$$v(t) = L\frac{di(t)}{dt} \text{ which leads to } \; i(t) = i(t_o) + \frac{1}{L}\int_{t_o}^{t_o+t} v(t)dt$$

The inductor is in a steady state because it is in a periodic mode.

$$i(t_o + T) - i(t_o) = 0 = \frac{1}{L}\int_{t_o}^{t_o+T} v(t)dt$$

The average voltage across a steady-state inductor is zero since the integrated term on the right equals zero.

3.3.2. Capacitor and inductor behavior in a Buck converter

Voltage can't be changed instantly in capacitors:

$$i(t) = C\frac{dv(t)}{dt}$$

Voltage "inertia" is a feature of capacitors. A constant voltage source is an ideal capacitor with infinite capacitance. This is why you can't connect a capacitor to a power source or a switch in parallel (otherwise KVL would be violated, i.e., there will be a short-circuit).

Inductors do not allow for instantaneous current changes:

$$v(t) = L\frac{di(t)}{dt}$$

Inductors are frequently used to maintain a steady current (current "inertia"). A constant current source is a perfect inductor with infinite inductance. As a result, a current source or a switch cannot be linked in series with an inductor (otherwise KCL would be violated).

3.3.3. Design of Buck converter

While examining the inductor current, when the switch closed

$$v_L = V_{in} - V_{out} \rightarrow \frac{di_L}{dt} = \frac{V_{in} - V_{out}}{L}$$

When the switch opens:

$$v_L = -V_{out} \rightarrow \frac{di_L}{dt} = \frac{-V_{out}}{L}$$

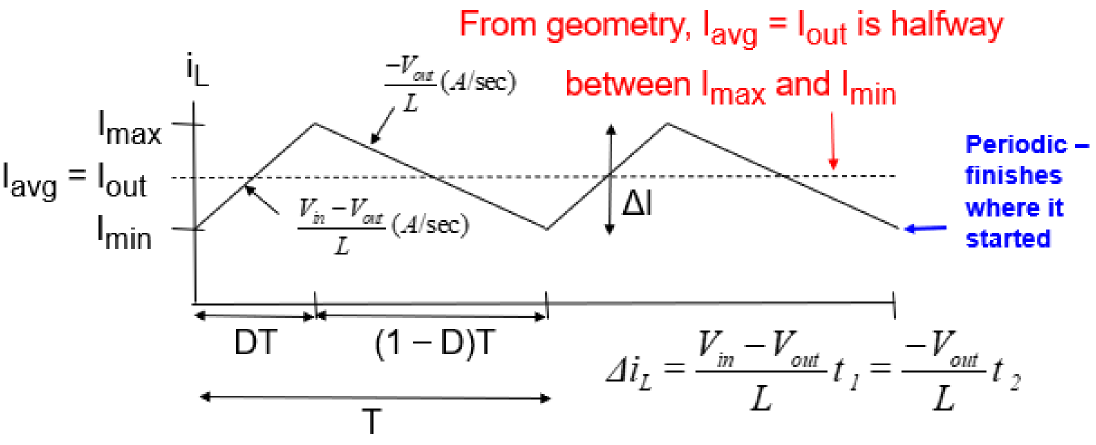

Figure 11 Graph of Inductor voltages in Buck converter

Because the inductor's average voltage is zero,

$$V_{Lavg} = D \cdot (V_{in} - V_{out}) + (1 - D) \cdot (-V_{out}) = 0$$

$$DV_{in} = D.V_{out} + V_{out} - D.V_{out}$$

The input/output equation becomes

$$V_{out} = DV_{in}$$

From power balance

$$V_{in}I_{in} = V_{out}I_{out}$$

$$I_{out} = \frac{I_{in}}{D}$$

Because Vin has no harmonics, the input power is just Vin • Iin, even though Iin is not constant.

3.3.4. RMS of common periodic waveform

Sawtooth:

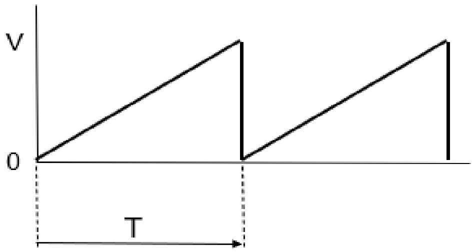

Figure 12 Graph of Periodic Voltage Waveform

$$V_{rms}^2 = \frac{1}{T}\int_0^T \left[\frac{V}{T}t\right]^2 dt = \frac{V^2}{T^3}\int_0^T t^2 dt = \frac{V^2}{3T^3}t^3|_0^T$$

$$V_{rms} = \frac{V}{\sqrt{3}}$$

A common DC-DC converter current waveform is used as an example. The following is a breakdown of the waveform's ripple and minimum value:

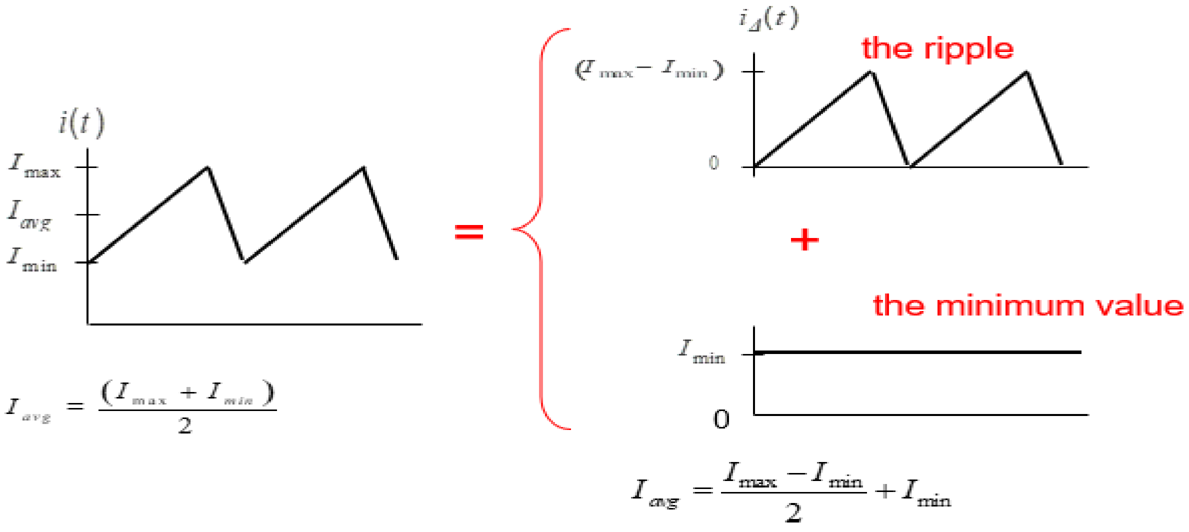

Figure 13 Graph of Periodic Voltage Waveform and Minimum value Voltage of Waveform

$$I_{rms}^2 = Avg\{(\Delta i(t) + I_{min})^2\}$$

$$I_{rms}^2 = Avg\{\Delta i^2(t) + 2\Delta i(t).I_{\mathrm{min}} + I_{min}^2\}$$

$$I_{rms}^2 = Avg\{\Delta i^2(t)\} + 2\mathrm{I_{min}}Avg\{\Delta i(t)\} + I_{min}^2$$

$$(Avg\{\Delta i^2(t)\} = \frac{\Delta i(t)}{\sqrt{3}} \cdot \frac{\Delta i(t)}{\sqrt{3}})$$

$$I_{rms}^2 = \frac{(I_{\mathrm{max}} - I_{\mathrm{min}})^2}{3} + 2\mathrm{I_{min}}\frac{(I_{\mathrm{max}} - I_{\mathrm{min}})}{2} + I_{min}^2$$

Define $I_{PP} = I_{max} - I_{\mathrm{min}}$

$$I_{rms}^2 = \frac{I_{PP}^2}{3} + I_{min}I_{PP} + I_{min}^2$$

Recognize that $I_{\mathrm{min}} = I_{avg} - \frac{I_{PP}}{2}$

$$I_{rms}^2 = \frac{I_{PP}^2}{3} + I_{min}I_{PP} + I_{min}^2$$

$$I_{rms}^2 = \frac{I_{PP}^2}{3} + \left(I_{avg} - \frac{I_{PP}}{2}\right) I_{PP} + \left(I_{avg} - \frac{I_{PP}}{2}\right)^2$$

$$I_{rms}^2 = \frac{I_{PP}^2}{3} + I_{avg} I_{PP} - \frac{I_{PP}^2}{2} + I_{avg}^2 - I_{avg} I_{PP} + \frac{I_{PP}^2}{4}$$

$$I_{rms}^2 = \frac{I_{PP}^2}{3} - \frac{I_{PP}^2}{4} + I_{avg}^2$$

$$I_{rms}^2 = I_{avg}^2 + \frac{I_{PP}^2}{12}$$

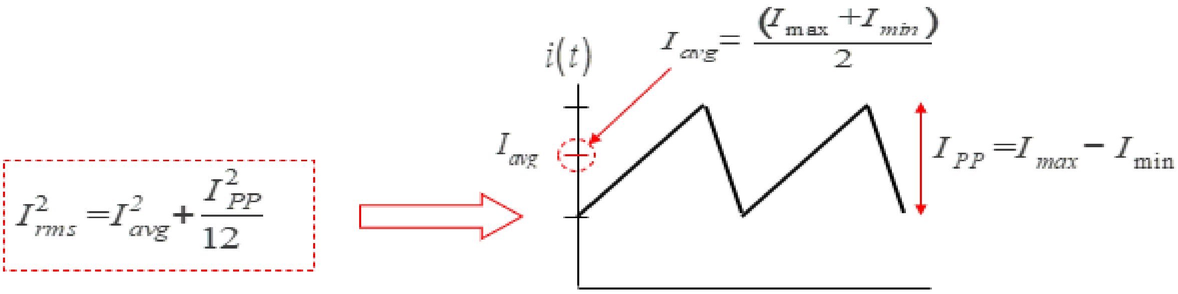

Figure 14 Graph of Periodic Current Waveform and Minimum value of Current Waveform

3.3.5. Inductor current ratting

$$I_{Lrms}^2 = I_{avg}^2 + \frac{1}{12} I_{pp}^2 = I_{out}^2 + \frac{1}{12}(\Delta I^2)$$

$\Delta I = 2I_{out.}$, It has the greatest effect on the rms current. The intersection of continuous and discontinuous conduction is where Iout occurs.

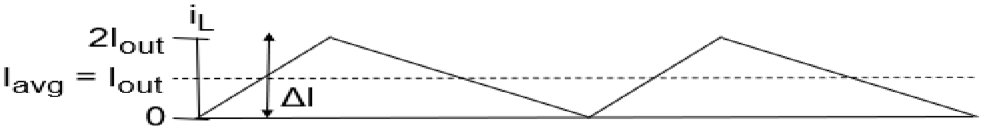

Figure 15 Graph of Inductor Current Ratings Graph

$$I_{Lrms}^2 = I_{out}^2 + \frac{1}{12}(2\mathrm{I}_{out})^2 = \frac{4}{3} I_{out}^2$$

$$I_{Lrms} = \frac{2}{\sqrt{3}} I_{out}$$

3.3.6. Capacitor current and current rating

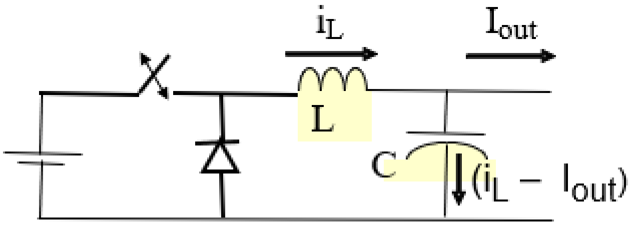

Figure 16 Circuit of Capacitor Current Ratings Circuit

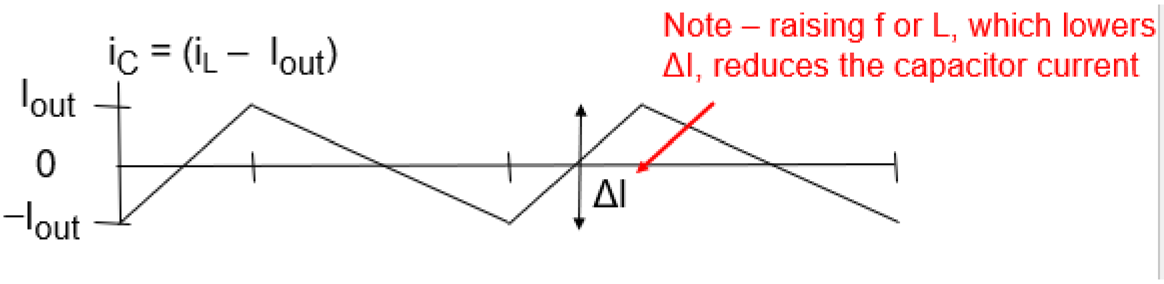

Figure 17 Graph of Capacitor Current Ratings

Continuous and discontinuous conduction are separated by a maximum rms current, where $\Delta I = 2I_{out}$

$$I_{Crms}^2 = I_{avg}^2 + \frac{1}{12}(2\mathrm{I}_{out})^2 = 0^2 + \frac{1}{3} I_{out}^2$$

$$I_{Crms} = \frac{I_{out}}{\sqrt{3}}$$

3.3.7. Mosfet and diode current ratings

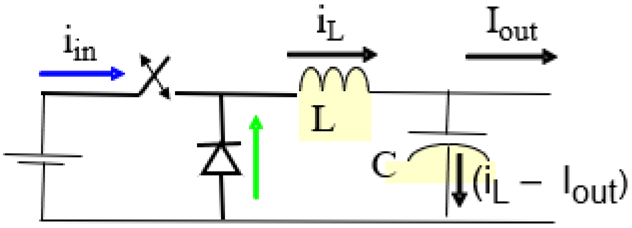

Figure 18 Circuit of MOSFET and Diode Current Ratings

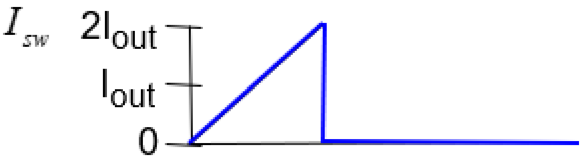

Figure 19 Graph of MOSFET (Switch) Current Ratings

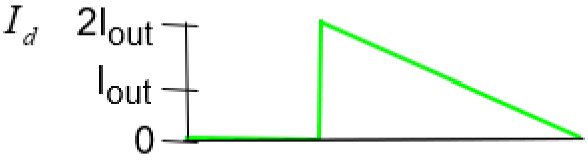

Figure 20 Graph of Diode Current Ratings

Take worst case for each:

$$I_{rms} = \frac{2}{\sqrt{3}} I_{out}$$

3.3.8. Boundary of continuous/discontinuous state

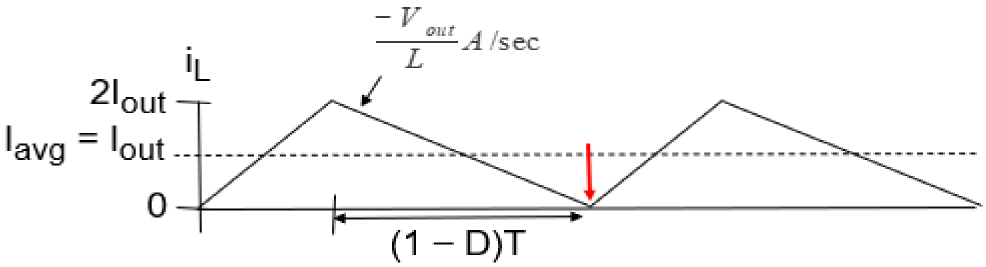

Figure 21 Boundary of continuous/discontinuous state

Worst case:

$$2\mathrm{I}_{out} = \frac{V_{out}}{L}(1-D)T = \frac{V_{out}(1-D)}{Lf} = \Delta I_L$$

$$L_{crit} = \frac{V_{out}(1-D)}{2\mathrm{I}_{out}f}$$

3.3.9. Worst-case load ripple voltage

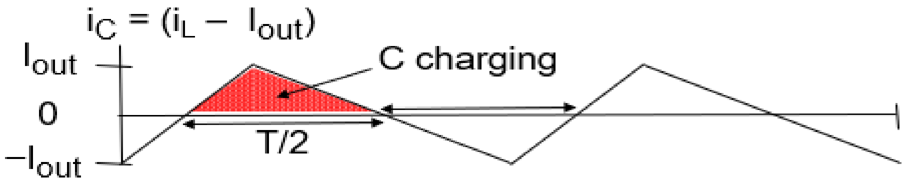

Figure 22 Worst case Load Ripple voltage

Based on the current waveform of a common DC-DC converter. The ripple and the waveform's minimum value can be decomposed as follows:

$$\Delta V = \frac{\Delta Q}{C} = \frac{\frac{1}{2}\frac{T}{2} I_{out}}{C} = \frac{T I_{out}}{4C} = \frac{I_{out}}{4Cf}$$

As $I_{out} = i_{c,max}$

For worst case: $\Delta V = 2V_o$,

$$C_{crit} = \frac{I_{out}}{8V_o f}$$

The rising of frequency and capacitance reduces the load voltage ripple.

3.3.10. Voltage ratings

The Diode and Mosfet uses: 2Vin

The capacitor uses: 1.5Vout

Worst-Case Component Ratings Comparisons for DC-DC Converters

Converter Type	Input Inductor Current (Arms)	Output Capacitor Voltage	Output Capacitor Current (Arms)	Diode and MOSFET Voltage	Diode and MOSFET Current (Arms)
Buck	$\frac{2}{\sqrt{3}} I_{out}$	1.5 V_{out}	$\frac{1}{\sqrt{3}} I_{out}$	2 V_{in}	$\frac{2}{\sqrt{3}} I_{out}$

3.3.11. Design of buck converter in MATLAB

The DC-DC buck converter's transfer function is as follows:

$$G(s) = \frac{R}{RLCs^2 + Ls + R}$$

$$W = \frac{1}{\sqrt{Lc}}$$

Experimentation is used to determine the values of inductors and capacitors. For maximum load current, make sure the inductor is safe before purchasing it. Use 10% to 20% of the output ripple current as an inductor value, and then use the filter break frequency to figure out how much capacitance you need.

$$fr = \frac{1}{2\pi\sqrt{Lc}}$$

Low output ripple is achieved by making the converter's switching frequency significantly greater than the output filter's break frequency.

3.4 Design of PID Controller

The PID controller requires the plant transfer function to be built. The SMPS plant's only components are the modulator and the second-order filter. In the equation, the second-order output filter's transfer function is denoted. As a result, the modulator transfer function must be calculated in order to determine the plant's overall transfer function. The output voltage is represented as follows since the converter in use is a Buck Converter:

$$V_{out} = DV_{in}$$

$$D = \frac{T_{on}}{T}$$

Vin = Converter input DC voltage

Table 1 illustrates the buck converter components that are under consideration.

Parameters	**Value**
Output Capacitor C	200 uF
Output Capacitor Resistance R$_c$	0.01 Ω
Inductor L	600 uH
Winding Resistance of Inductor R$_L$	0.01 Ω
Resistance Load R	20 Ω
Switching frequency	31.38 kHz

Table 1: Parameters of Buck Converter

Overall transfer function of the PID controller is as:

$$G(s) = \frac{Vo}{u} = Vin\left(\frac{R}{R+Rl}\right)\left(\frac{\frac{s}{Wzero}+1}{\Omega(s)}\right)$$

Where

$$\Omega(s) = \frac{s^2+}{Wo^\wedge 2} + \frac{s}{QWo} + 1$$

$$Wo = \frac{1}{\sqrt{Lc((\frac{R+Rc}{R+Rl})}}$$

$$Wo = \frac{1}{CRc}$$

$$Q = \frac{1}{Wo(\frac{L}{R+Rc} + \frac{R}{R+Rl} + RcC}$$

The MATLAB code of the transfer function is provided in appendix I.

Using the result of the MATLAB code, the generated transfer function is:

$$G = \frac{0.0029999s + 299.9}{0.00028s^2 + 299.9 + 1}$$

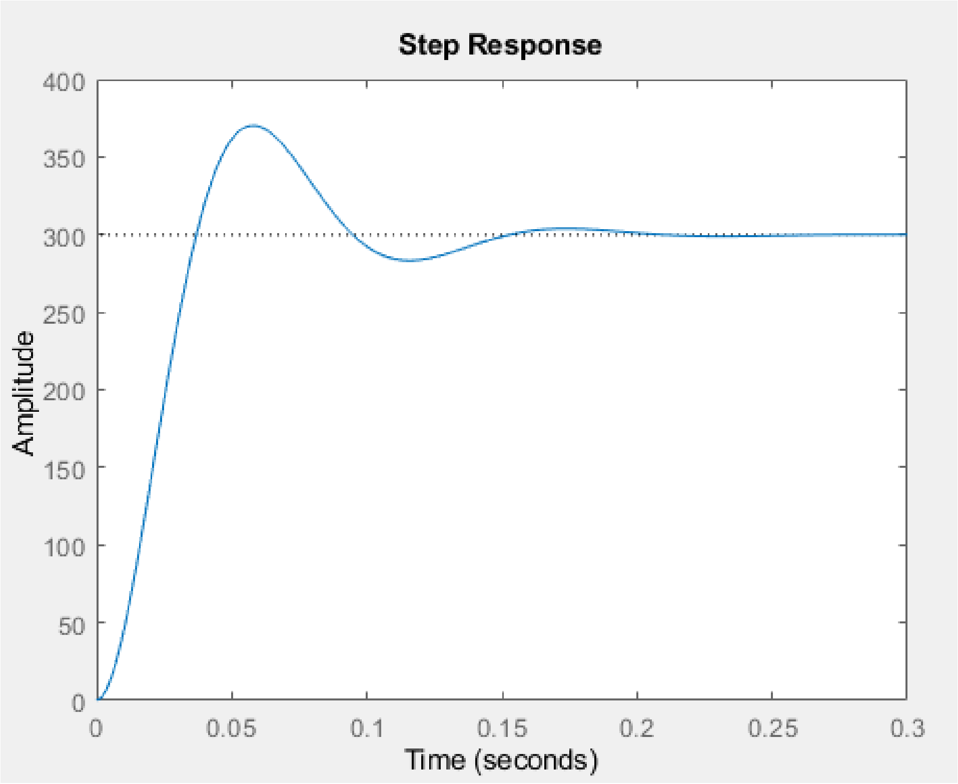

Figure 23 Step Response before tunning

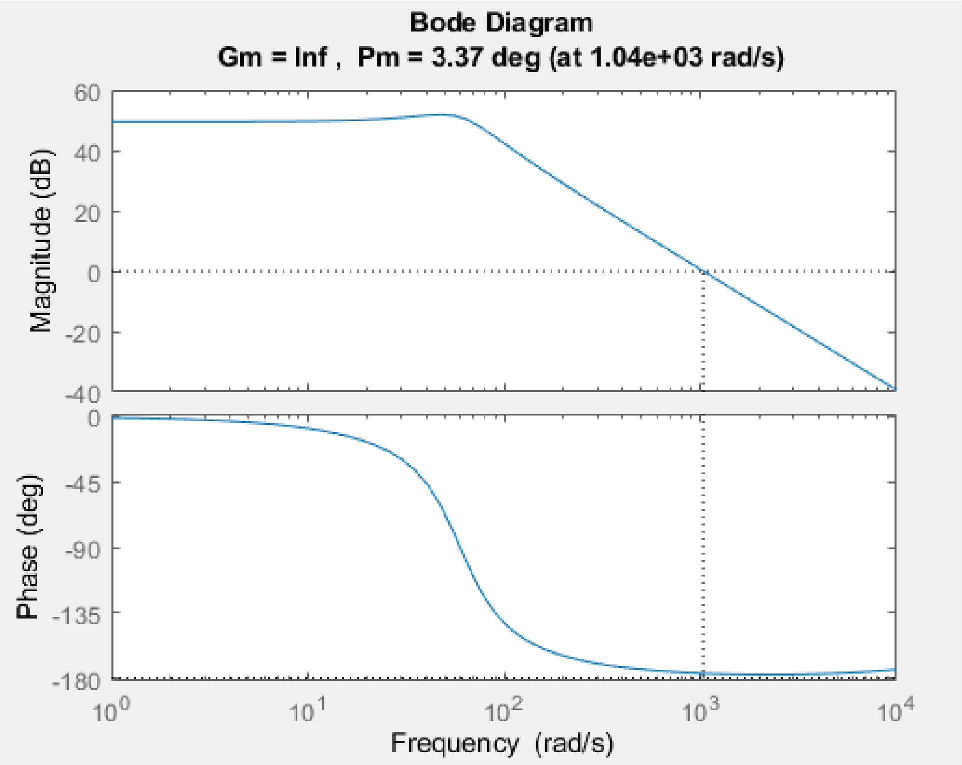

Figure 24 Bode Plot before Tunning

The PID Controller expression is given as:

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

Control signals are denoted by **u(t),** while error signals are denoted **by (et).** There are three sorts of gains: derivative, proportional, and internal.

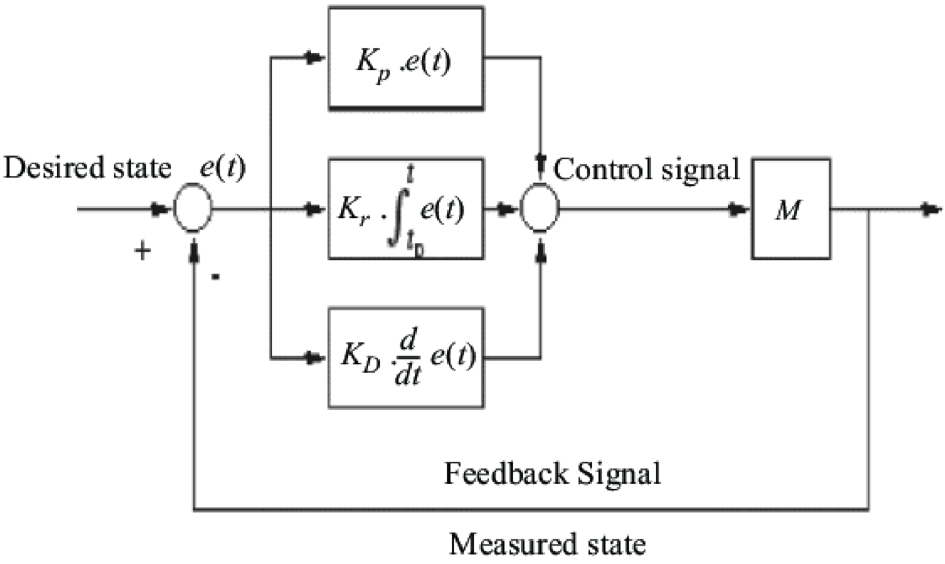

Figure 25 Parallel PID controller diagram

The discrete-time PID Controller can be written as:

$$u_k = K_p e_k + K_i \sum_{n=1}^{k} e_k + K_d (e_k - e_{k-1})$$

After that the PID tuner tool of MATLAB is used to tune the controller for better performance and extracted the values of Kp, Ki, and Kd.

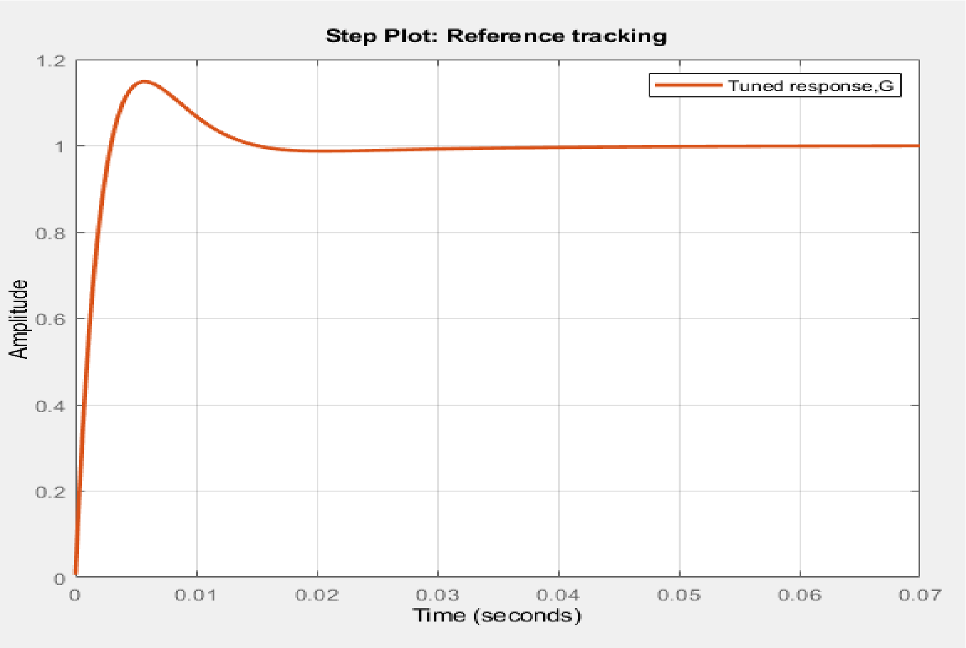

Figure 26 Step Response after Tunning

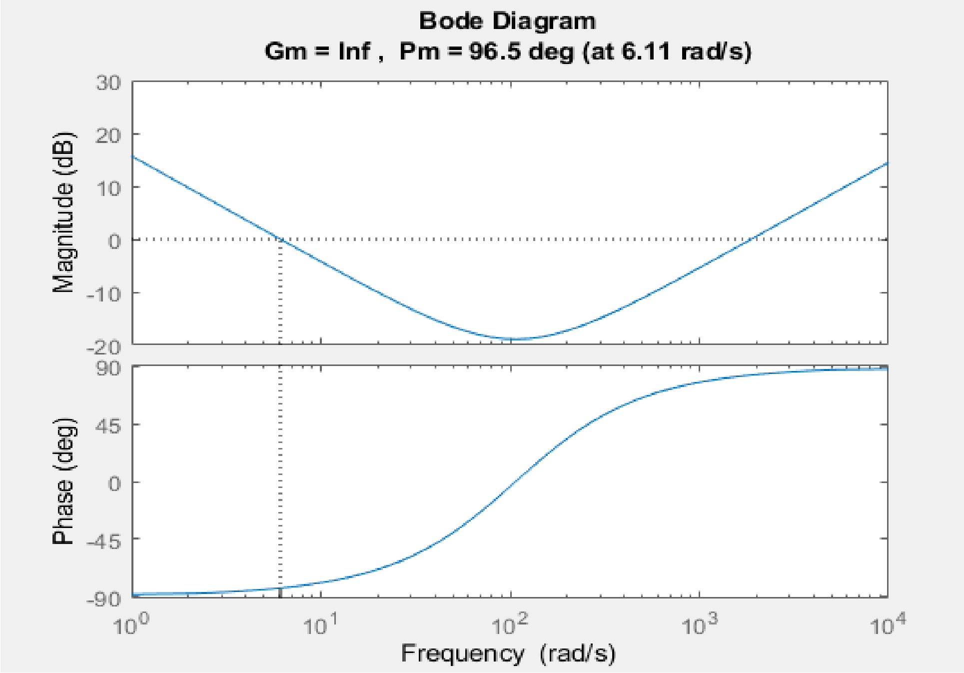

Figure 27 Bode Plot after Tunning

And the value of Kp, Ki and Kd are:

$$Kp = 0.07$$

$$Ki = 12.726$$

$$Kd = 0.005$$

3.5 MATLAB Results

Using the overall architecture illustrated in the figure for the reference voltage Vref = 300V, a numerical simulation test is built to validate the controller's validity and efficiency,where input voltage is set as V_{in} = 220V rms. The following figures shows the response of the output current, outputvoltage, input voltage, error, and PWM signal, respectively.

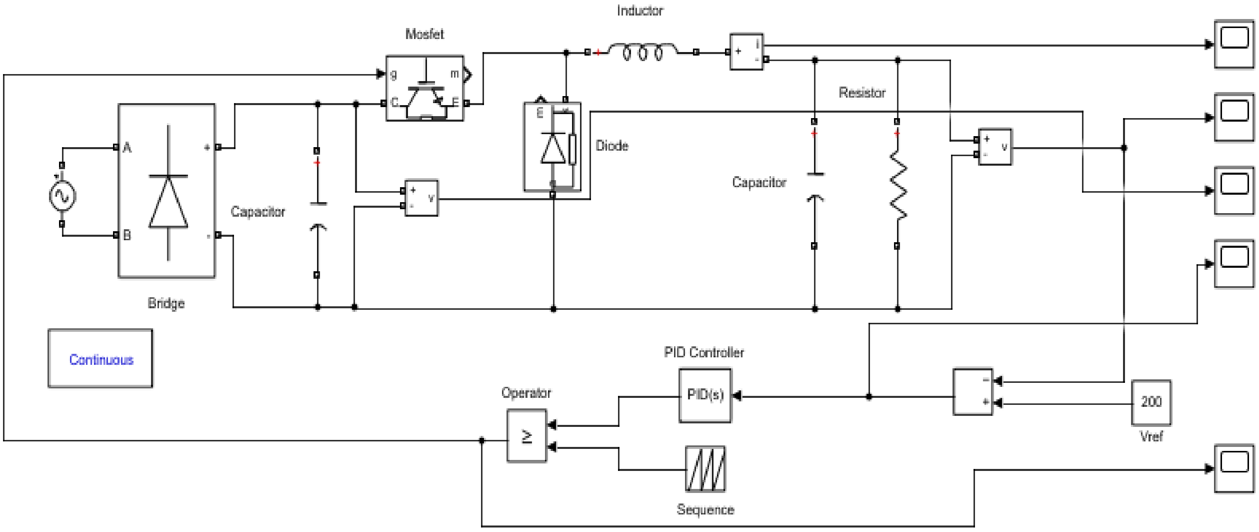

Figure 28 Simulink model control

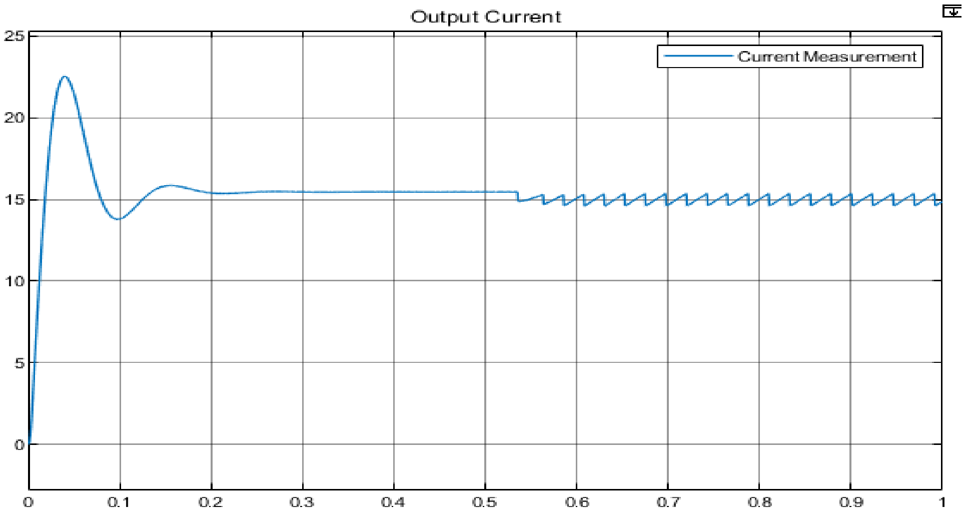

Figure 29 Output Current response in MATLAB

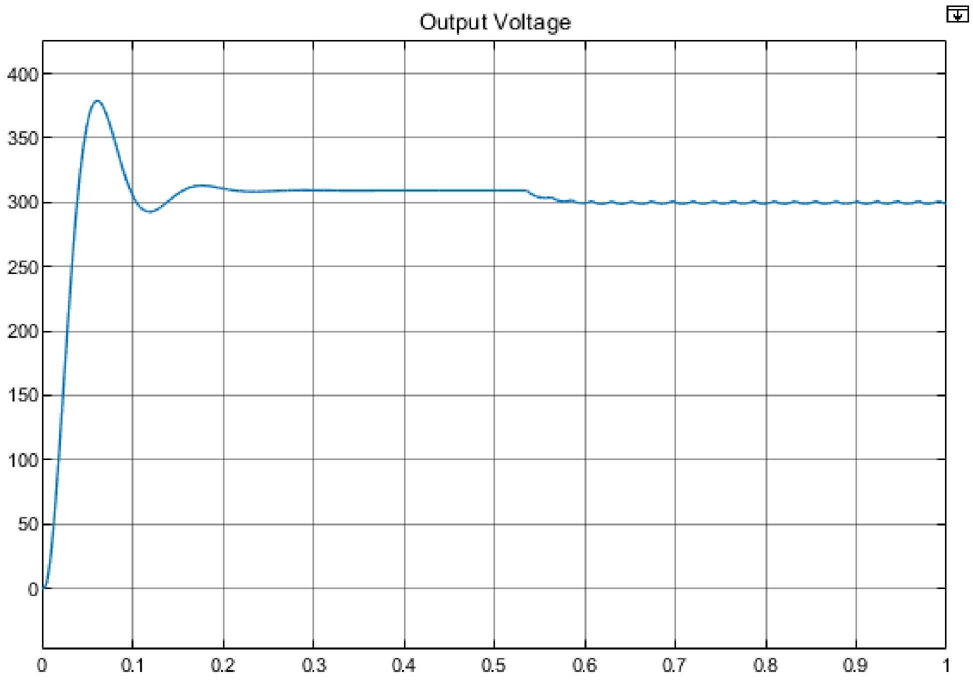

Figure 30 Output voltage response in MATLAB

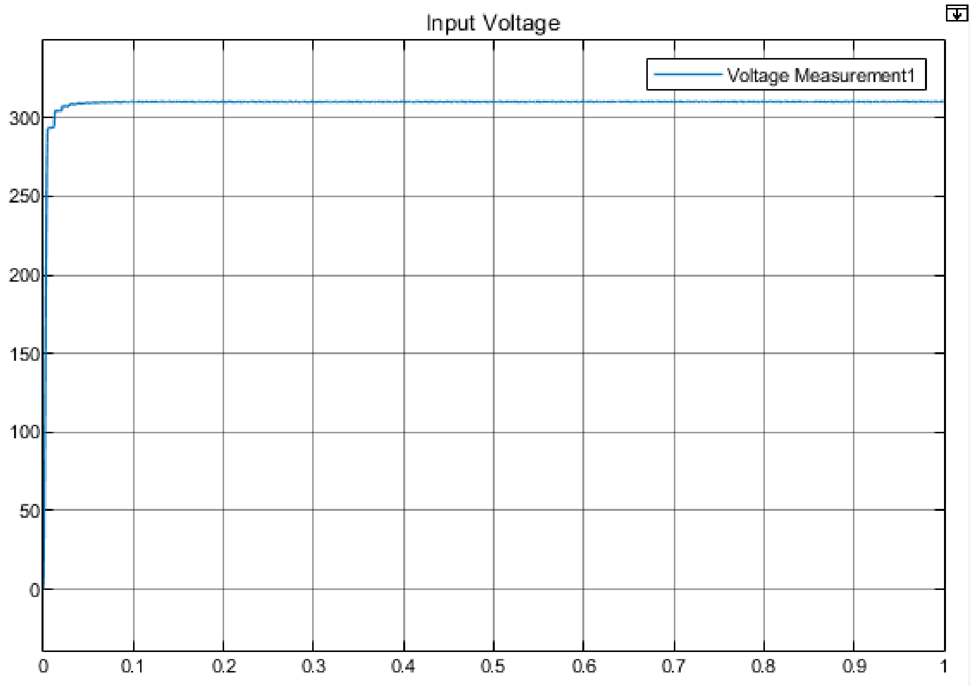

Figure 31 Input Voltage response in MATLAB

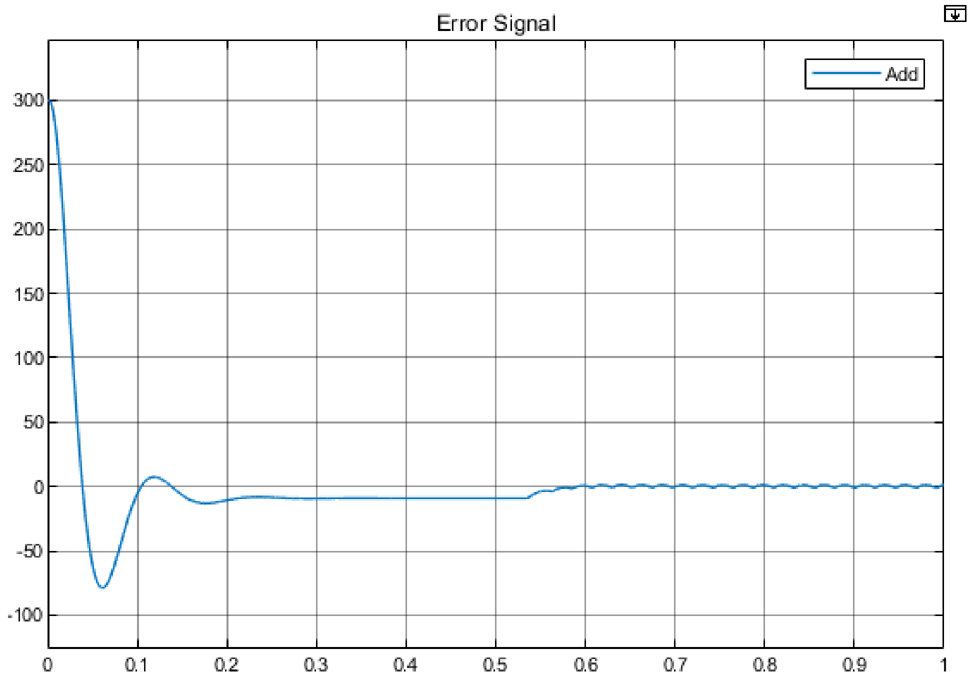

Figure 32 Error Signal / Feedback Signal response in MATLAB

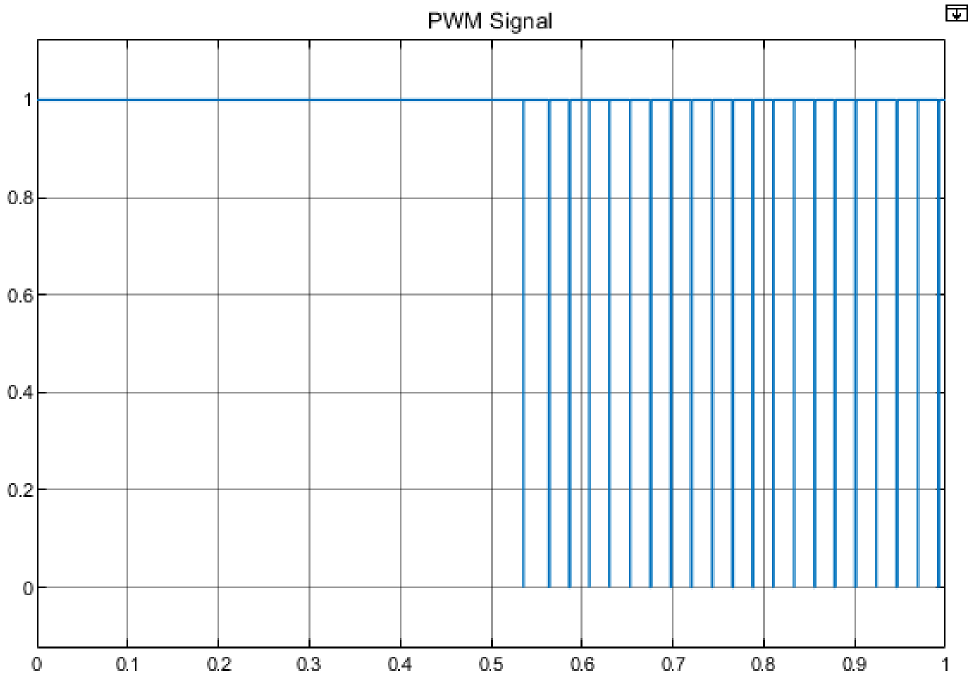

Figure 33 PWM Generated Signal

Chapter 4: Hardware Design Using Proteus Simulation

4.1. Introduction

Using the above results and PID controller values the hardware simulation is designed in Proteus Professional 8.10, software. The PID controller parameters are used in the Arduino UNO code and results are also verified. The complete design structure is given below.

4.2. Rectifier

Rectifiers convert alternating current (AC) to direct current (DC) by oscillating in both directions (DC). Half-wave rectifiers allow only one path of electricity to pass through by eliminating one side of the alternating current. Half-wave rectifiers are inefficient because they squander half of the incoming AC power. For more efficient conversion, full-wave rectification uses both sides of the AC waveform.

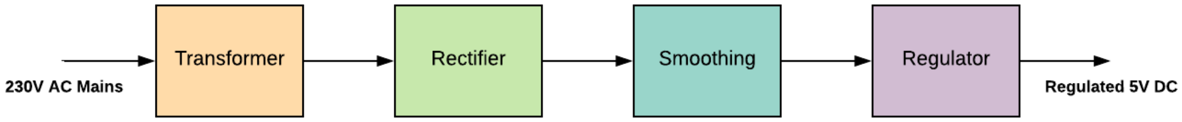

Figure 34 Rectifying Process.

GSIB1580 bridge IC

In the project (circuit) GSIB1580 bridge IC is used as it can have the voltage from 200-800V and the current of 15A.

The IC is frequently used in switching power supply, household appliances, office equipment, and industrial automation applications for AC/DC bridge full-wave rectification.

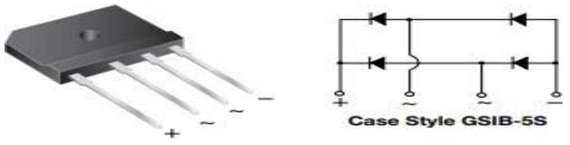

Figure 35 GSIB1580 Bridge Rectifier

4.3. IC7805

Circuits based on voltage regulators are extremely prevalent. Regardless of the fluctuating input voltage, these devices produce a consistent output voltage. As a well-known regulator, the 7805 IC is employed in this project. Almost any project will contain this IC. The 7805 IC is a good choice because it has a +5V output voltage and a 1.5A output current. For projects that demand more current, a heat sink is recommended due to the IC's high rate of heat loss.

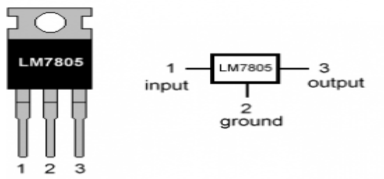

Figure 36 LM7805 IC Pin configuration

4.4. IC7812

1. To get 12V at 1A with an input voltage of 14 to 35V, you'll need a linear regulator like the IC7812.
2. Input
3. GND
4. Output

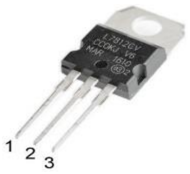

Figure 37 LM7812 IC Pin configuration

4.5. Arduino UNO

The ATmega328 microcontroller is used on the Arduino UNO board (datasheet). A USB connector, an ICSP header, and a reset button are among the 14 digital I/O pins available, six of which can be PWM outputs and six of which can be analogue inputs. There's also a USB port, an ICSP header, a power jack, and a reset button. The microcontroller is ready to use once you connect it to a computer via USB or power it with an AC-DC converter or battery.

Microcontroller	**Atmega328**
Clock Speed	16 MHz
DC current for 3.3V pin	50mA
Digital I/O pins	14 (6 provide PWM output)
Flash Memory	32 kB
Input Voltage	7-12V
Operating Voltage	5V
SRAM	2 kB

Table 2 Arduino UNO Parameter

Power:

The board can be powered by the Arduino Uno's USB port or an external power supply. The power source is automatically selected. External power can be provided by an AC-to-DC converter or a battery. Use a 2.1mm center-positive connection to attach the adaptor to the power connector. Batteries should be connected to the POWER connection's Gnd and Vin pins. External power supplies ranging from 6 to 20 volts can be used to power the Arduino. If a voltage regulator receives more than 12V, it may overheat and kill the Arduino board. 7 to 12 volts is the recommended voltage range. The following are the power connectors:

When the Arduino is powered by an external source, VIN is the voltage it receives.

- **VIN**. This pin, through the board's regulator, provides 5V to the system. The DC jack, the USB connector (5V), and the VIN pin are all options for powering the board.
- **5Volt.** The board can be destroyed if power is delivered via the 5V or 3.3V pins.

- **3.3V.** The on-board regulator generates a 3.3V supply, which your gadget requires. The maximum current draw is 50 milliamperes (mA).

- **GND.** It's down at the bottom.

While designing the power supply the Arduino is given 5v power to turn it ON using the voltage obtained by 7805 IC (voltage regulator).

The build in libraries of Arduino is used for LCD display and PID controller that are:

#include <LiquidCrystal.h>

#include <PID_v1.h>

The pins 5, 8, 10, 11, 12, and 13 is used to interface with LCD, whereas pin 6 is used for PWM output obtained using the PID parameter given in Chapter3.

The PWM frequency of PWM pins of Arduino is changed by using simple code for PWM frequency of 31372.55 Hz:

➔ TCCR2B = TCCR2B & B11111000 | B00000001

PID()

Connect the PID controller to the given Input, Output, and Setpoint. The PID algorithm in parallel form is employed.

- Input: variable that is trying to control.
- Output: variable that would be adjusted by the controller.
- Setpoint: values to maintain the input.
- Kp, Ki, Kd: The controller's output can be altered by adjusting the tuning parameters.
- Direction: When a mistake occurs, the output will either shift forward or backward (direct or reverse). The direct method is used by the vast majority of people.

SetMode()

Specifies whether PID Controller should be automatic or Manual. In default PID is in manual mode.

SetTunings()

The dynamic behavior of a controller is determined by the parameters that are tuned. Will it oscillate or will it not? Will it go rapidly or slowly? When a controller is set up, it comes with a default set of Tuning parameters. For the vast majority of users, this is sufficient in most cases. Some tunings, however, must be modified in real time. The above function can be used for this purpose.

SetSampleTime()

The frequency at which the PID algorithm analyses itself is set here. The default value is 200 mS.

Compute()

The PID algorithm has been included. For each loop, it must be called once (). It will usually just return without taking any action. SetSampleTime specifies the rate at which the new Output will be computed.

Serial.begin()

Bits per second is the unit used to specify the data transfer rate for serial data. In order to communicate with Serial Monitor, select one of the baud rates in the lower right corner of the screen. If you need a higher baud rate, such as for communication with the component via pins 0 and 1, you can use it. The data, parity, and stop bits are all controlled by a second, optional input. There are eight bits of data, no parity, and one stop bit by default.

Serial.print()

Prints data to the serial port as ASCII text that can be read by humans. There are various variations of this command. Each digit is represented by an ASCII character when the numbers are printed. Single characters are used to send bytes. The whole set of characters and strings is supplied.

analogRead()

Returns the current value of the analogue pin specified. A 10-bit multichannel A/D converter is included in the Arduino boards. An integer value between 0 and 1023 will be returned for inputs between zero and the working voltage (5V or 3.3V).

analogWrite()

The pin is written to with a PWM wave. The brightness of the LED or the speed of the motor can be controlled by this.

4.6. IRF830 MOSFET

The IRF830 N-Channel MOSFET has a drain current of 4.5A and can switch loads up to 500V. The Gate and Source pins have a 10V gate threshold voltage, and the on-state resistance is 1.5 ohms. Switching high current and high voltage loads necessitates the use of MOSFETs. The gate voltage is too high to use with the CPU's I/O directly. The on-resistance (RDS) of the IRF830 MOSFET is roughly 1.5, which is a significant drawback. The transistor can be used to build the simplest basic driver circuit, which supplies 10V to the gate pin of the MOSFET. Because MOSFETs are inexpensive, have low thermal resistance, and switch quickly, they are helpful in DC-DC converter circuits.

Applications of IRF830:

- Switching of high-power devices
- Inverter Circuits
- DC-DC Converters
- Manage motor speed
- dimmers and flashers for LEDs
- applications requiring high-speed switching

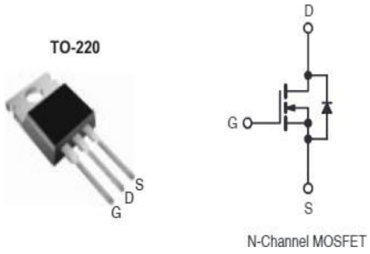

Figure 38 IRF830 NPN MOSFET

4.7. MOSFET Driver IC IR2112

The IR2112 is the high voltage IC that acts as the MOSFET driver and IGBT driver. 600 V is the threshold voltage of the independent high and low side referenced output channels. Bootstrap feature makes it compatible for high side driver applications. Additionally, it has Schmitt triggered inputs that are compatible to the standard CMOS and LSTTL outputs. Low- and high-side driver IC, IR2112 operates in the 10–20volt range.

Features of IR2112 MOSFET driver:

- It is high-low side Driver IC with a source-current 0.25A and the sink-current 0.5A
- It can tolerate negative transient voltage.
- Range of the voltage supply is from 3.3V to 20V and supply range of the gate driver is from 10 to 20V.
- It has a feature of floating, channel which can perform the bootstrap operation.
- Inputs and outputs are in phase.
- Threshold voltage is +600V.
- Cycle by cycle edge-triggered shutdown logic

The IC IR2112 is turned by giving 12V voltage supply obtained by IC 7812 at pin 3. The PWM output of Arduino is given at pin 10 of the IC and its inverse is given to pin 12 using the NOT gate IC. Pins 2 and 11 are ground. Pin 6 is given 220V rms. Pin 1 and 7 are attached to MOSFET gate IRF830.

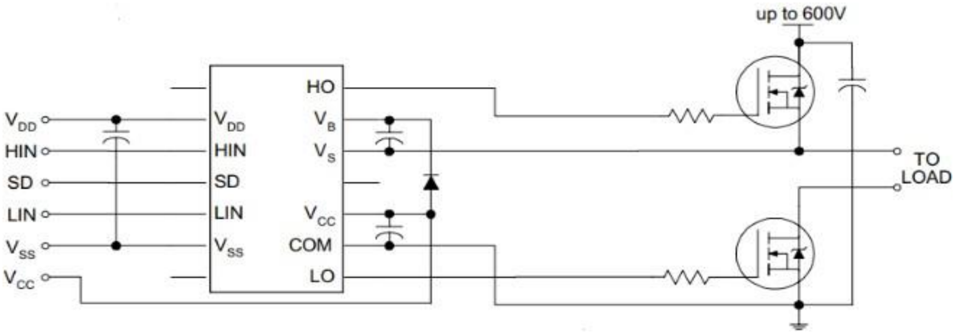

Figure 39 High bridge MOSFET driver typical connection

4.8. Buck Converter Design

The buck converter is designed with filter elements like inductor and capacitor. When converter is in working state, the MOSFET and the diode worked in complimentary to one another i.e., when diode is ON, MOSFET is OFF and when MOSFET is ON, diode is OFF. This happens at the rate of switching frequency.

Design Specifications:

Input voltage = 220V rms
Output voltage = 300 V

Switching frequency = 31 kHz
Duty ratio = 0.88

Output power = 4.5 kW

- $P_o = V_o * I_o$

$$I_o = output\ current = 15\ A$$

- $R = \frac{V_0}{I_o}$

$$R = load\ (resistance) = 20\ \Omega$$

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

$$L_{min} = 38.2\ uH$$

- $C = \frac{(1-D)}{8L\left(\frac{\Delta V}{V}\right)f^2}$

$$C = 27.2\, uF$$

Circuit Design:

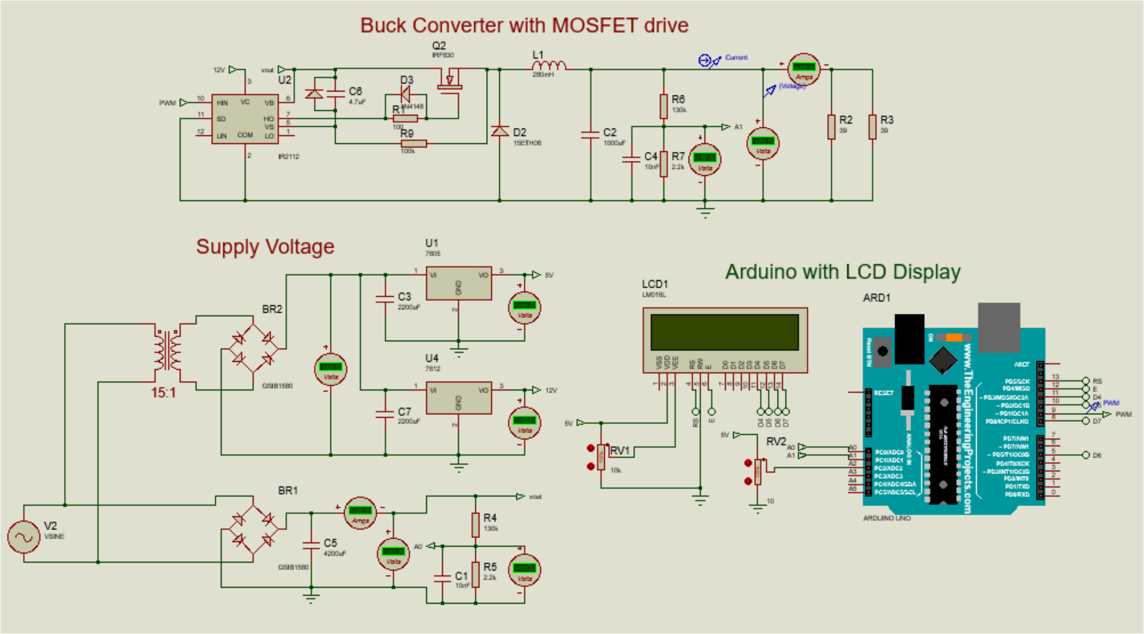

Figure 40 Proteus circuit design

For a **load of 20Ω** we get the voltage varying from 2.93V-295.3V.

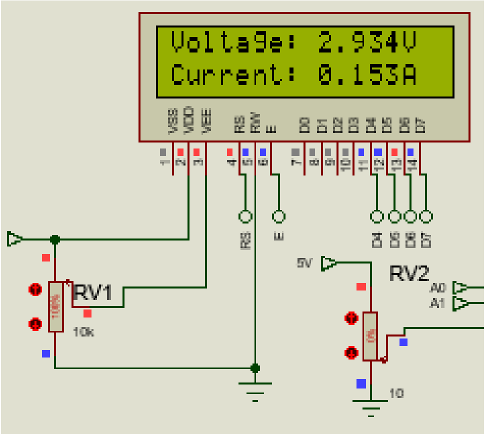

Figure 41 Minimum Voltage Obtained

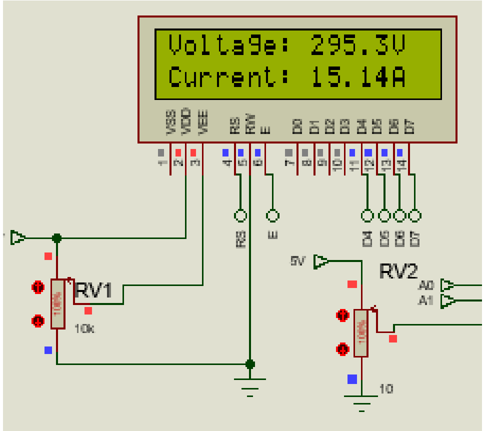

Figure 42 Maximum Voltage Obtained

For a **load of 100Ω** we get the voltage varying from 2.93V-295.3V.

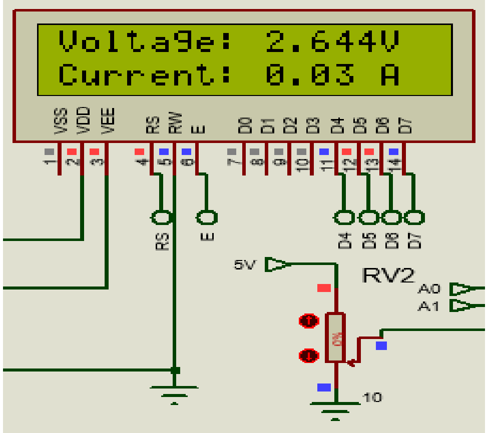

Figure 43 Minimum Voltage Obtained

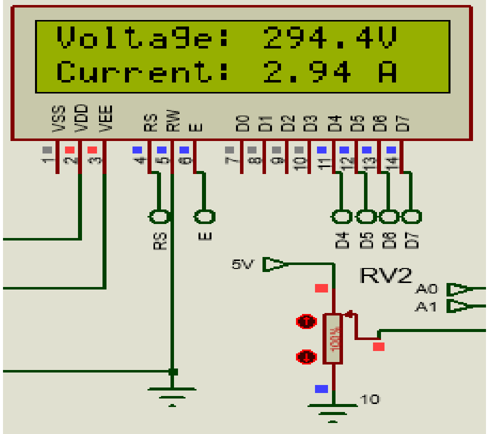

Figure 44 Maximum Voltage

4.9. Graphical plots

The results obtained by the simulation of the circuit are as follow:

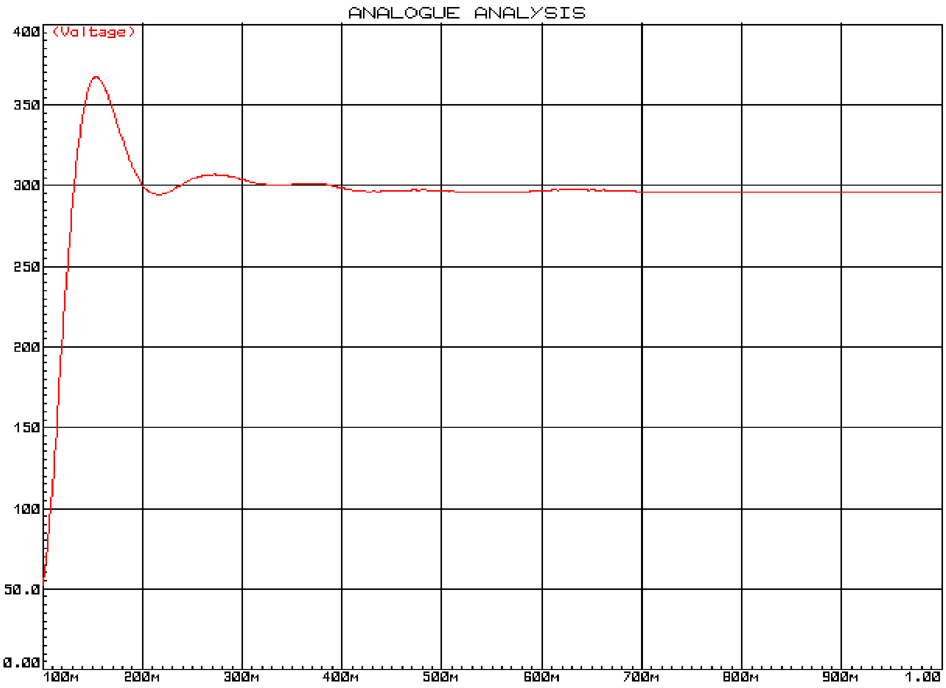

Figure 45 Output Voltage

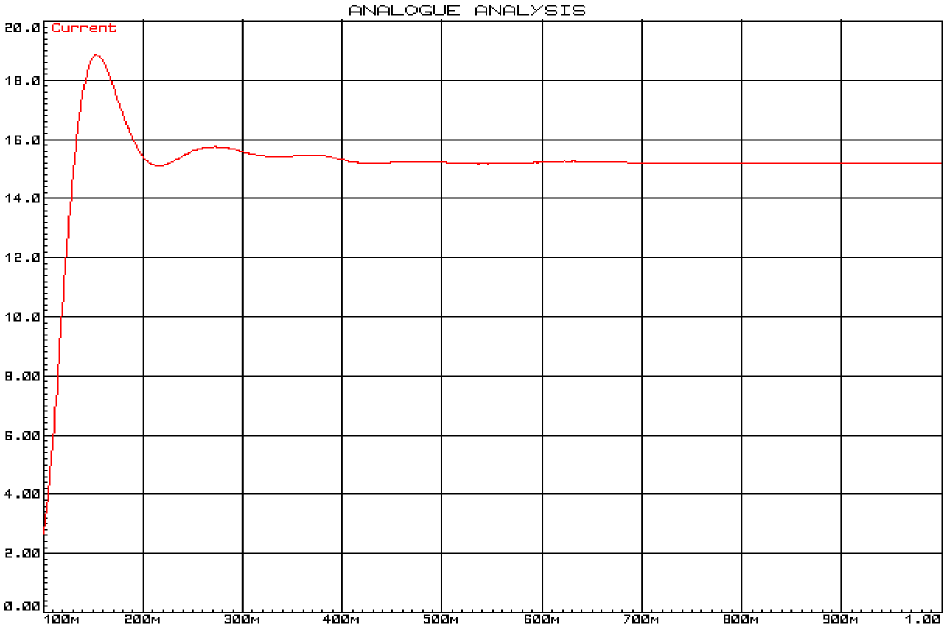

Figure 46 Output Current

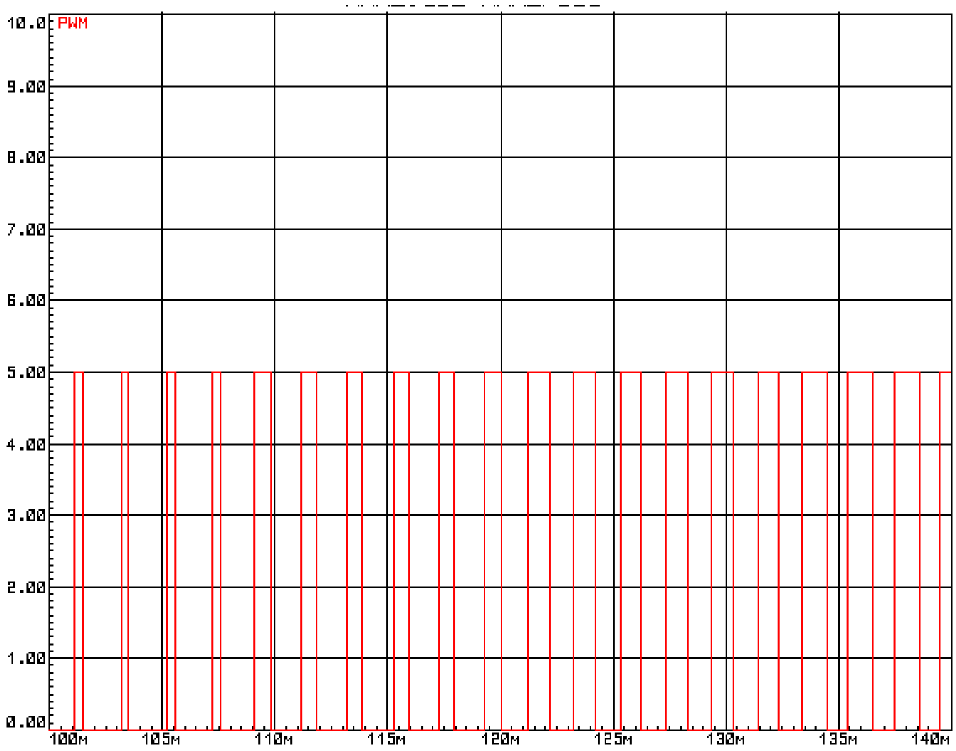

Figure 47 PWM Signal

4.10. PCB Design

The PCB is also designed using proteus software using the above simulated circuit.

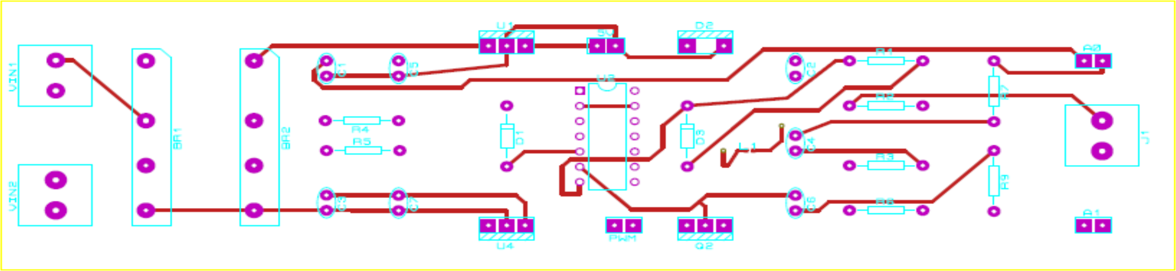

Figure 48 PCB Top Layer

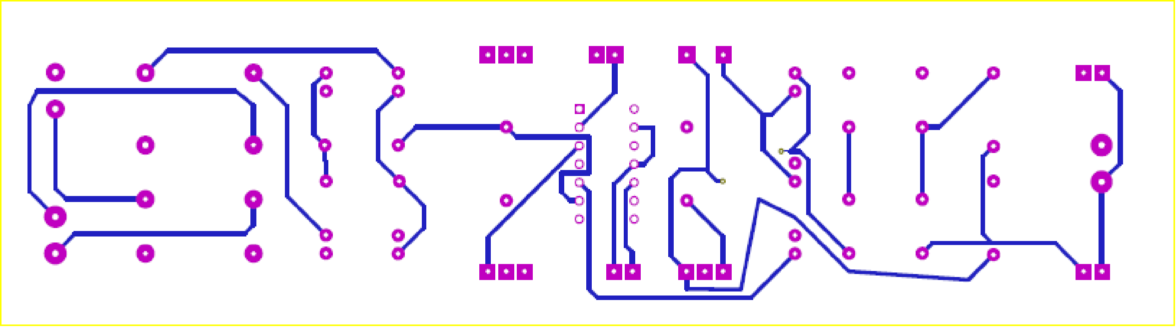

Figure 49 PCB Bottom Layer

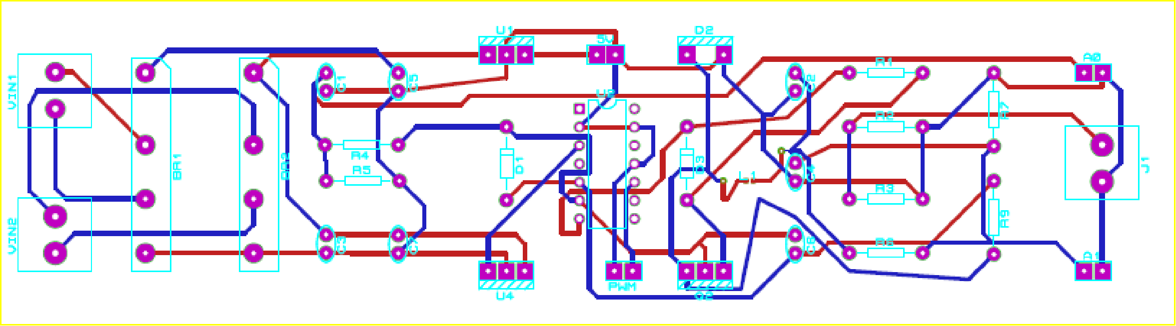

Figure 50 Overall PCB Design

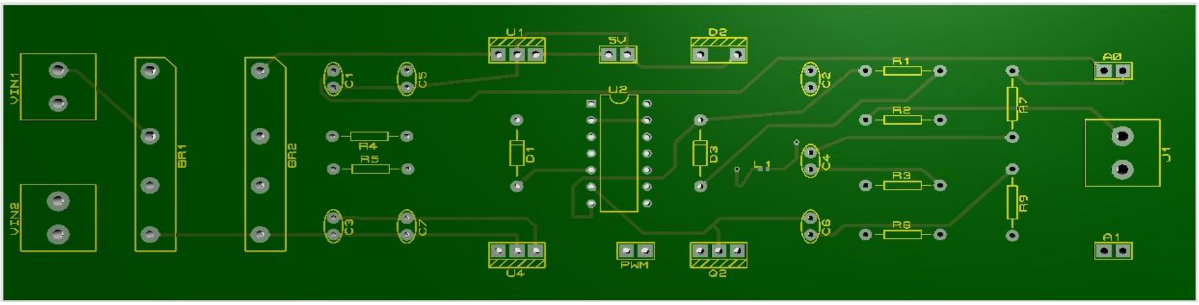

Figure 51 PCB design without components

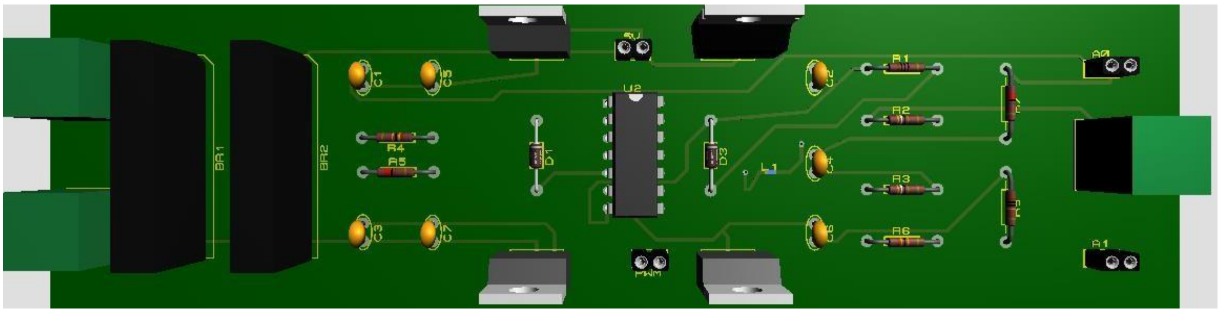

Figure 52 PCB design with components

Chapter 5: Future Work

Power supply, which is designed, is not a final product yet, it is working for voltage control only. It can be continued further for current control and power factor correction as they are also important parameters of power supply.

As a result, the voltage mode control feedback signal is a scaled output voltage. This method provides a feedback architecture that is simple to comprehend. This strategy, however, has a number of drawbacks that must be considered. A change in output voltage must be noticed and propagated through the entire feedback signal and filter before the appropriate compensation can be applied to the output. For systems that require a lot of regulation, this might lead to unduly long response times. In order to deal with the two poles introduced by the output low-pass filter, feedback supply compensation necessitates a higher level of analysis. The overall loop gain is affected by different input voltages, necessitating changes to the feedback component values. In current mode, the limitations of voltage mode control are overcome by utilising the inductor's current waveform for control. In the output voltage feedback loop, a second, faster response control loop controls this signal. Because adding another feedback loop might increase the complexity of a circuit or feedback system, the advantages of doing so should be carefully considered during the design process.

PFC circuits and their input filters must be manufactured as a unit due to space and cost constraints. Although the filter requirements are heavily influenced by the circuit's mode of operation and management approaches, a typical SMPS front end produces less noise than a PFC circuit. The use of a frequency control mechanism in conjunction with a continuous current mode of operation results in the smallest size and cost conceivable.

Chapter 6: Conclusion

A DC power supply is designed that can produce an output voltage of 3-300V and max current of 15A has achieved, making the power output up to 4.5kW. This design is cheapest of all the available power supplies in the market. Mostly high voltage power supplies are expensive but, in this power, supply such topologies are used which minimize the cost. However, after doing the current control and power factor correction (PFC) the product will be finalized and will be available for market production.

Appendix

MATLAB Function

```
L = 280e-3;

R = 20;

R1 = 0.01;

C = 1000e-6;Rc=0.01;

Vin = 300;

Vout = 150;

 fs = 31.38e3;

%% Transfer Function

w0 = 1/sqrt(L*C*((R+Rc)/(R+R1)));

wzero = (1/(Rc*C));

Q = 1/(w0*((L)/(R+R1)+((R*R1*C)/(R+R1))+Rc*C));

P1 = Vin*(R/(R+R1));

N = [P1/wzero P1];
D = [1/w0^2 1/(Q*w0) 1];

G = tf(N,D);

bode(G)

margin(G)

stepinfo(G)
```

Arduino Function:

```
int PWM = 9;
#include <LiquidCrystal.h>
#include <PID_v1.h>
// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(13, 12, 11, 10, 5, 8);
double Setpoint ;
double Input;
double Output ;
double Kp = 0.07, Ki = 12.726, Kd = 0.0005;

PID myPID(&Input, &Output, &Setpoint, Kp, Ki, Kd, DIRECT);
void setup()
{  Serial.begin(9600);
  // set up the LCD's number of columns and rows:
  pinMode(PWM, OUTPUT);
  TCCR2B = TCCR2B & B11111000 | B00000001;    // 31372.55 Hz
  lcd.begin(16, 2);
  myPID.SetMode(AUTOMATIC);
  myPID.SetTunings(Kp, Ki, Kd);
  myPID.SetSampleTime(90);
}
```

```
void loop()
{
  lcd.setCursor(0, 1);
  // print the number of seconds since reset:
  double resister = 19.5;
  double current;
  resister = 19.5;

  float  Out = (300.0*analogRead(A1))/1024.0;
  float  Inp = (300.0*analogRead(A0))/1024.0;
  Setpoint = 300.0*(analogRead(A2))/1023.0; //(voltage_m*300)/1023;
  Input = Out;

  current = Out/resister;
  Serial.print(Setpoint);
  Serial.print(":");
  myPID.Compute();
  Serial.println(Setpoint);
  analogWrite(PWM,Output);
  lcd.setCursor(0,0);
  lcd.print("Voltage: ");
  lcd.setCursor(9,0);
  lcd.print(Out);
```

```
  lcd.setCursor(14,0);
  lcd.print("V");
  lcd.setCursor(0,1);
  lcd.print("Current:  ");
  lcd.setCursor(9,1);
  lcd.print(current);
  lcd.setCursor(14,1);
  lcd.print("A");
 }
```

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