PV Fed Off-Grid DC-DC Boost Converter for LED Loads.

A THESIS

is

Submitted in partial fulfillment of the requirements for

the award of the degree of

Bachelor of Technology

in

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

by

Project Batch

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July – 2021

RAGHU ENGINEERING COLLEGE (Autonomous)

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CERTIFICATE

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Date:

DECLARATION

We hereby declare that the project entitled "**PV Fed DC-DC Boost Converter for LED Loads**" submitted for the fulfilment of B. Tech. (EEE) the degree is our original work and the project report has not formed the basis for the award of any other degree, diploma, fellowship or any other similar titles. I also declare that the ideas/sources used in the preparation of the document are adequately cited and referenced the sources.

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ABSTRACT

The switched-mode dc-dc converters are some of the most widely used power electronics circuits for its high conversion efficiency and flexible output voltage. These converters used for electronic devices are designed to regulate the output voltage against the changes of the input voltage and load current. This leads to the requirement of more advanced control methods to meet the real demand. Many control methods are developed for the control of dc-dc converters. To obtain a control method that has the best performances under any conditions is always in demand.

In this study DC-DC boost converter circuit was designed and implemented. The converter input voltage range determined as 5V-9V DC and output voltage of boost converter is created as 25V DC. This converter has potential uses 25V compatible applications. In this circuit design, the implementation of a PWM DC/DC boost converter contains two subsystems – a conventional PWM boost converter and a control circuit. A 555 Timer is used to send the gating signals to a driver which drives the Metal-Oxide-Semiconductor Field Effect Transistors (MOSFET), allowing the converter's output to be kept steady at 25V and 50W through pulse width modulation. A switching frequency of 100 kHz was achieved, and PWM control method was used for switching. The use of a PWM boost converter allows for a variable input and constant output. The output is regulated by the control circuit which adjusts the duty cycle of the gating pulse to maintain a constant output.

The use of photovoltaic panels has become very attractive in distributed power generation systems as they provide a clean and cheap form of energy. There are various converter topologies that are employed in order to connect these sources to the grid but almost always the main component is a DC-DC converter. Most readily available DC-DC converters are designed to work under a (nearly) constant voltage source and therefore their behaviours may not be as expected when connected to a variable current source like a photovoltaic panel. As a case study, this study explores the dynamics and stability of a boost converter that is fed from a photovoltaic panel under an ohmic load

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1.1 Introduction:

DC-DC converter controls dynamic power transfer from the input DC source to the load using power semiconductor switch by connecting the source to the load for predetermined time. These converters occupy applications in high efficiency industrial and aerospace high power supplies, battery bank charging, renewable energy sources, high power LED lighting, DC motor drives and DC micro grid systems. Primarily, DC-DC converter is classified as step down and step-up converter based on the level of DC output voltage with respect to DC input voltage. DC-DC converter is also classified as isolated and non-isolated DC-DC converter. Buck, boost and buck-boost comes under the list of isolated converters. Non-isolated DC-DC converters are cuk, fly back, forward, half bridge, full-bridge and push-pull DC-DC converters. Different topologies are available for specific or multiple applications based on their circuit components interconnections, voltage level and power level. Some topologies have high power capability and input voltage range. Various converter topologies and its input voltage level and power level are represented in**Figure 1. 1**. Isolated full bridge topology DC-DC converter has wide input voltage range and high-power handling capability. But isolated half-bridge topology has wide input voltage range only and has no high-power capacity.

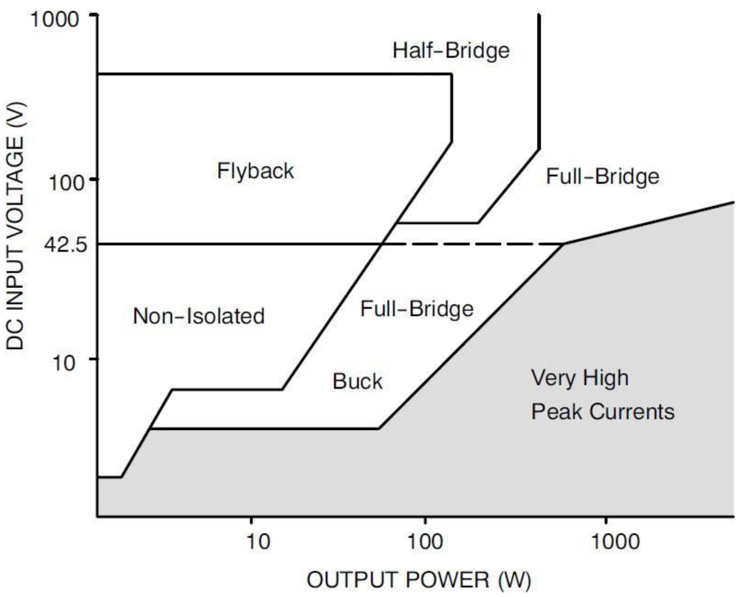


Figure 1-1 : Basic Voltage & Power Topologies

1.2 Basic types of converters:

DC-DC converter is also classified as isolated and non-isolated DC-DC converter. Buck, boost and buck-boost comes under the list of isolated converters. Non-isolated DC-DC converters are cuk, fly back, forward, halfbridge, full-bridge and push-pull DC-DC converters.

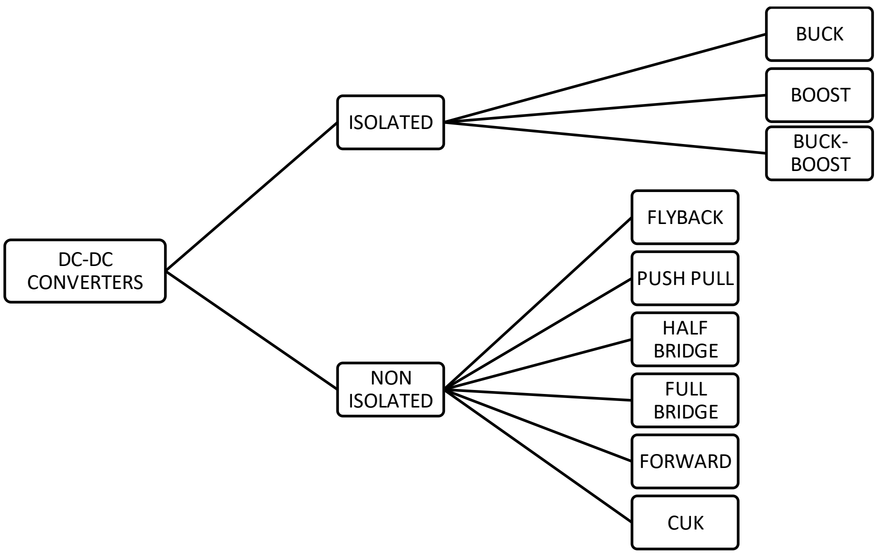


Figure 1-2: Classification of DC-DC Converters

1.2.1 Isolated converter:

In short, an isolated power converter isolates the input from the output by electrically and physically separating the circuit into two sections preventing direct current flow between input and output, typically achieved by using a transformer.

These are of 3 types

i. Buck converters
ii. Boost converters
iii. Buck-Boost converter.

1.2.1.1 Buck Converter

A buck converter is a DC-to-DC power converter which steps down voltage from its input to its output. It is a class of switched-mode power supply typically containing at least two semiconductors and at least one energy storage element, a capacitor, inductor, or the two in combination.

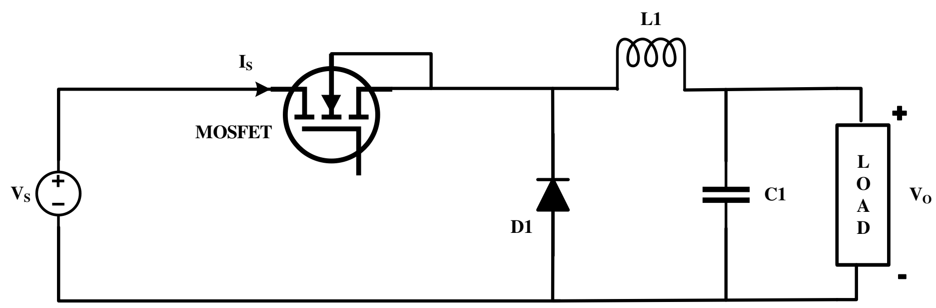


Figure 1-3Basic DC-DC Buck Converter Circuit.

1.2.1.2 Boost Converter:

A boost converter is one of the simplest types of switch mode converter. As the name suggests, it takes an input voltage and boosts or increases it. All it consists of is an inductor, a semiconductor switch (these days it's a MOSFET, since you can get really nice ones these days), a diode and a capacitor. Also needed is a source of a periodic square wave.

1.2.1.3 Buck-Boost Converter:

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a flyback converter using a single inductor instead of a transformer. Two different topologies are called buck–boost converter.

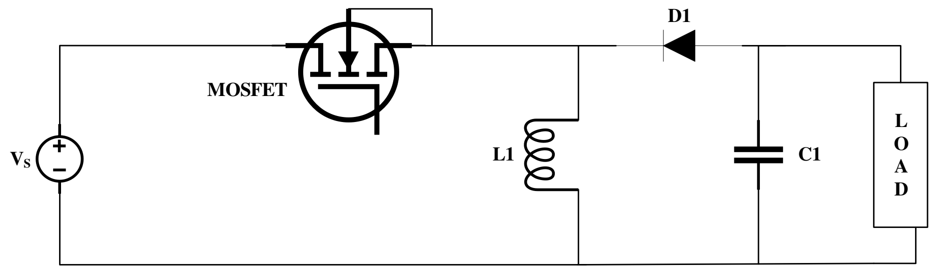


Figure 1-4 Basic DC-DC Buck/Boost Converter.

1.2.2 Non-Isolated converter:

Isolation describes the electrical separation between the input and output of a dc-dc converter.An isolated dc-dc converter uses a transformer to eliminate the dc path between its input and output. In contrast, a non-isolated dc-dc converter has a dc path between its input and output.

These are of six types

1. Fly back Converters
2. Push pull Converters
3. Half bridge Converters
4. Full bridge Converters
5. Forward Converters
6. Cuk Converters

1.2.2.1 Fly back converters:

The flyback converter is used in both AC/DC and DC/DC conversion with galvanic isolation between the input and any outputs. The flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation.

1.2.2.2 Push pull:

A push–pull converter is a type of DC-to-DC converter, a switching converter that uses a transformer to change the voltage of a DC power supply. Push–pull converters have steadier input current, create less noise on the input line, and are more efficient in higher power applications.

1.2.2.3 Half bridge Converters

A half-bridge converter is a type of DC-DC converter that, like flyback and forward converters, can supply an output voltage either higher or lower than the input voltage and provide electrical isolation via a transformer.

1.2.2.4 Full bridge Converters

A Bridge Converter is a DC-DC converter topology (configuration) employing four active switching components in a bridge configuration across a power transformer.A full bridge converter is one of the commonly used configurations that offer isolation in addition to stepping up or down the input voltage.

1.2.2.5 Forward Converters

The forward converter is a DC/DC converter that uses a transformer to increase or decrease the output voltage and provide galvanic isolation for the load. With multiple output windings, it is possible to provide both higher and lower voltage outputs simultaneously.

1.2.2.6 Cuk Converters

The Cuk converter is a type of buck-boost converter with zero-ripple current. Cuk converter can be seen as a combination of boost converter and buck converter, having one switching device and a mutual capacitor, to couple the energy.

1.3 Objectives.

- To study about POWER MOSFETS, and to conduct a suitable experiment to determine the threshold voltage of the MOSFET and also to observe the transfer characteristics of the MOSFET.
- To study about different Pulse Width Modulation Techniques & Implement one of the techniques in order to generate the pulsated output at desired frequency and pulse width.
- To study about PV cells, modules in detail and also observe PV-IV Characteristics of a typical PV module.
- To study about boost converters in detail and also the importance of PWM in boost converter.
- To study about importance of inductor in designing a Boost Converter & also to mathematical model an inductor for the constraints/requirements considered.
- To design a fundamental Boost Converter with above constraints considered.
- To integrate the PV module with the boost converter setup & observe the results.

1.4 Organization of Thesis

- So far in this chapter, we discussed about basic DC converter topologies & also gave a fundamental approach towards the same.
- Next up, we will look at literary survey of the thesis where we will discuss about significance of this particular thesis.

- After literary survey, we will look at whole proposed Project including procedural steps, necessary derivations, figures, tables & techniques developed.
- In the penultimate chapter of the thesis, we will be looking at all the experimental proposed in the above section & necessary discussions are made regarding the same.
- Lastly, this thesis shall be concluded with appropriate justifications made throughout this proposed work.

SWITCHED-MODE step-up dc–dc converters originated with the development of pulse width modulated (PWM) boost converters. Step-up dc–dc topologies convert lower dc voltage levels to higher levels by temporarily storing the input energy and then releasing it into the output at a higher voltage level. Such storage can occur in either magnetic field storage components (single inductor/coupled inductor) or electric field storage components (capacitors) through the use of various active or passive switching elements (power switches and diodes). With the introduction of semiconductor switches in the 1950s, step-up dc–dc converters achieved steady performance advancements and their use accelerated through the 1960s when semiconductor switches became commercially available with allied manufacturing technologies. The rise of the aerospace and telecommunication industries further extended the research boundaries of boost converters, especially in applications where efficiency, power density, and weight were of major concern. Efficiency has steadily improved since the late 1980s owing to the use of power field-effect transistors (FETs), which are able to switch more efficiently at higher frequencies than power bipolar junction transistors while incurring lower switching losses and requiring a less complicated drive circuit. In addition, the FET replaces output rectifying diodes through the use of synchronous rectification, whose “on resistance” is much lower than and further increases the efficiency of the step-up dc–dc converter, which requires a higher number of diodes for voltage boosting.

A PWM boost converter is a fundamental dc–dc voltage step-up circuit with several features that make it suitable for various applications in products ranging from low-power portable devices to high-power stationary applications. The widespread application of PWM boost dc–dc converters has been driven by its low number of elements, which is a major advantage in terms of simplifying modelling, design implementation, and manufacturing. The voltage step-up capability of a PWM boost dc–dc converter is enabled by an inductor at the input side that can operate either with a continuous current—in the so-called continuous conduction mode (CCM)—or including a zero current state in the discontinuous conduction mode (DCM). In general, CCM operation is more prevalent owing to the load dependent voltage gain, high current ripple, and low efficiency.

The power converter is the technology which enables the efficient and flexible interconnection of solar source and battery. PV power generation depends on the temperature (T) and solar irradiance (G). P-V characteristics of the solar panel evident that, it can give maximum power at a particular point called maximum power point (MPP). This MPP changes with irradiance level which depends greatly on environmental conditions. So, it is desirable to track this MPP to extract maximum power from the solar panel in all atmospheric conditions. Several power electronic DC-DC converters like Buck, Boost are proposed in the literature to track this MPP of a solar panel. Recent years, more attention has been paid to the renewable energy for the increasing cost of fossil fuel and the regulations of CO2 emissions. The output voltage of these energy sources, such as solar panel and fuel cells, is low and variable. Thus, it needs high-ratio DC-DC converter to get the appropriate output voltage. In order to obtain a high output voltage, the conventional boost converter must operate at extremely high duty-cycle ratios, that is quite difficult to be obtained in practical application for the limitation of semiconductors.

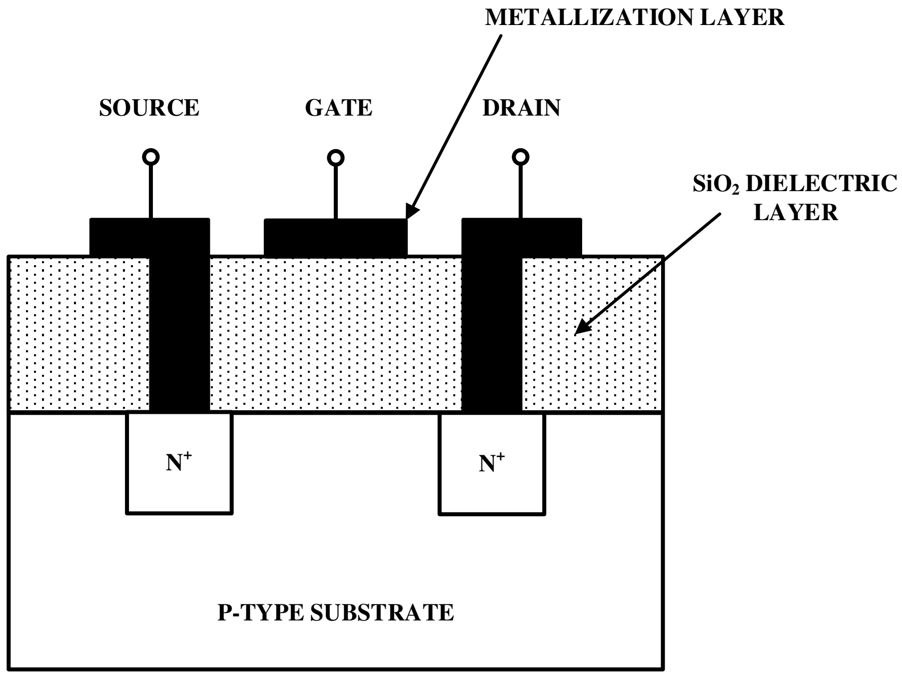
Chapter 3: MOSFET CHARACTERISTICS & PULSE WIDTH MODULATION

3.1 N-channel MOSFETS

The N-Channel MOSFET has an N- channel region located in between the source and drain terminals. It is a four-terminal device having the terminals as gate, drain, source, body. In this type of Field Effect Transistor, the drain and source are heavily doped n+ region and the substrate or body are of P-type.

3.1.1 Construction and Operation Principle

The basic construction of an n-channel enhancement type MOSFET is as shown in the **Figure 31**.



3.1Structure of N-Channel MOSFET.

Two highly doped N+ regions are diffused in a lightly doped substrate of p type silicon substrate. The substrate is sometimes connected to the source otherwise it is brought out as the fourth terminal.The drain and source terminals are connected to the N+ type doped regions through the metallic contact.The channel is absent in this type.The insulating Sio_2 layer is still present which isolates gate terminal from the substrate. This device is called the insulated gate

FET because of the insulating layer of SiO2.This layer gives an extremely highinput resistance.

Operation: The operation can be explained with two operating conditions.

Operation with Vgs = 0

If Vgs is zero and a positive voltage is applied between its drain and source, then due to absence of n-type channel, a zero drain current will present.

Operation with Vgs is positive:

The positive potential at the gate terminal repels the holes present in the p-type substrate. This results in creating a depletion region near the SiO_2 insulating layer. But the minority carriers in the p-type substrate will gate attracted towards the gate terminal gather near Sio2 layer.As the Vgs becomes more positive the number of electrons present at the Sio2 layer will increase. The increasing concentration of electrons creates an induced channel which connects the n-type doped regions. Hence the conductivity increases and current flows from source to drain through the induced channels.Thus, the drain current is enhanced by the positive gate voltage.

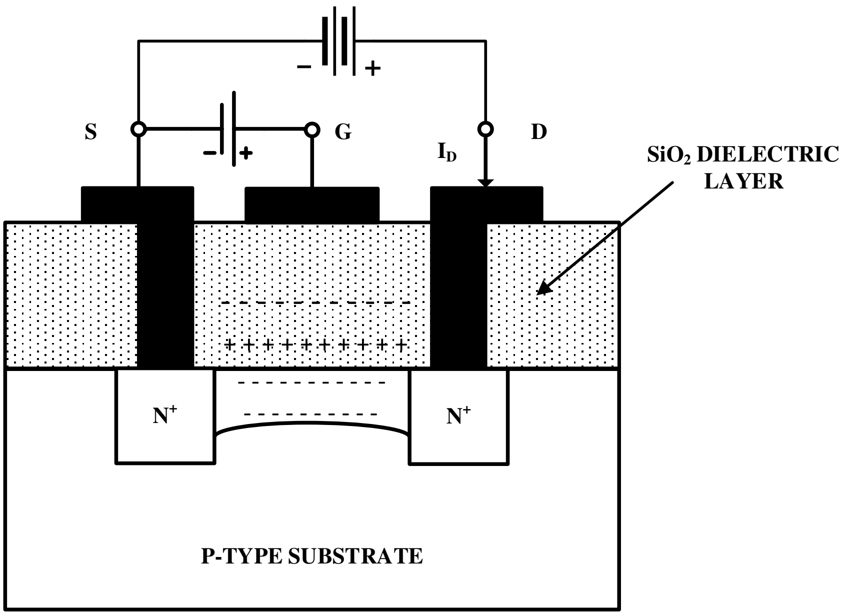


Figure 3.2Operation of N-Channel MOSFET.

3.1.2 Why MOSFETs for Power Converters?

Power MOSFETs are capable of operating at very high frequencies compared with Bipolar Junction Transistors (BJTs) whose switching speed is much slower than for a power MOSFET of similar size and voltage rating. Typical rise and fall times of power MOSFETs are of the order of several nanoseconds which is two orders of magnitude faster than bipolar devices of similar voltage rating and active area. BJTs are limited to frequencies of less than 100kHz whereas power MOSFETs can operate up to 1MHz before switching losses become unacceptably high. Recent advances in the design and processing of MOSFETs are pushing this frequency limit higher.

Power MOSFETs are voltage controlled devices with simple drive circuitry requirements. Power BJTs on the other hand are current controlled devices requiring large base drive currents to keep the device in the ON state. Power MOSFETs have been replacing power BJTs in power application due to faster switching capability and ease of drive, despite the very advanced state of manufacturability and lower costs of BJTs.

BJTs suffer from thermal runaway. The forward voltage drop of a BJT decreases with increasing temperature potentially leading to destruction. This is of special significance when several devices are paralleled in order to reduce forward voltage drop. Power MOSFETs can be paralleled easily because the forward voltage increases with temperature, ensuring an even distribution of current among all components. They can withstand simultaneous application of high current and high voltage without undergoing destructive failure due to second breakdown. However, at high breakdown voltages (>~200V) the on-state voltage drop of the power MOSFET becomes higher than that of a similar size bipolar device with similar voltage rating, making it more attractive to use the bipolar power transistor at the expense of worse high-frequency performance.

Breakdown voltage (BVDSS) is the drain-to-source voltage at which a current of 250µA starts to flow between source and drain while the gate and the source are shorted together. With no bias on the gate, the drain voltage is entirely supported by the reverse-biased body-drain p-n junction. Breakdown voltage is primarily determined by the resistivity of the epitaxial layer.

All applications of power MOSFET switches require some guard banding when specifying BVDSS rating. It is important to remember that there is a price to be paid for this in the form of either higher RDS(on) or larger die. There may be applications where a reduction of conservative guard banding on BVDSS can be justified by an improved RDS(on) specification or lower cost without jeopardizing performance or reliability.

Bipolar transistors have ratings for maximum current under continuous and pulsed conditions. Exceeding these ratings usually result in device failure. Current ratings on MOSFET transistors have a different meaning because they behave as a resistor when they turn on. This means that the maximum voltage drop or heat generated determines the maximum current. Turning the current on and off at high speeds reduces the average power or heat generated, thereby increasing the maximum allowable current.

3.1.3 List of MOSFETs

IRF150	IRF150 38A 100V N-Channel Power MOSFET
IRF250	IRF250 30A 200V N-Channel Power MOSFET
IRF350	IRF350 14A 400V N-Channel Power MOSFET
IRF510	IRF510 5.6A 100V N-Channel Power MOSFET
IRF520	IRF520 10A 100V N-Channel Power MOSFET
IRF530	IRF530 14A 100V N-Channel Power MOSFET
IRF540	IRF540 30A 100V N-Channel Power MOSFET
IRF610	IRF610 3.3A 200V N-Channel Power MOSFET
IRF620	IRF620 6A 200V N-Channel Power MOSFET
IRF630	IRF630 9A 200V N-Channel Power MOSFET
IRF634	IRF634 8.1A 250V N-Channel Power MOSFET
IRF640	IRF640 18A 200V N-Channel Power MOSFET
IRF644	IRF644 14A 250V N-Channel Power MOSFET
IRF720	IRF720 3.3A 400V N-Channel Power MOSFET
IRF730	IRF730 5.5A 400V N-Channel Power MOSFET
IRF740	IRF740 10A 400V N-Channel Power MOSFET
IRF820	IRF820 2.5A 500V N-Channel Power MOSFET
IRF830	IRF830 4.5A 500V N-Channel Power MOSFET

IRF840	IRF840 8A 500V N-Channel Power MOSFET
IRF1010N	IRF1010N 85A 55V N-Channel Power MOSFET
IRF1404	IRF1404 202A 40V N-Channel Power MOSFET
IRF1405	IRF1405 169A 55V N-Channel Power MOSFET
IRF3205	IRF3205 110A 55V N-Channel Power MOSFET
IRF3315	IRF3315 27A 150V N-Channel Power MOSFET
IRF3415	IRF3415 43A 150V N-Channel Power MOSFET
IRF3710	IRF3710 57A 100V N-Channel Power MOSFET
IRF4905	IRF4905 74A 55V P-Channel Power MOSFET
IRF5210	IRF5210 40A 100V P-Channel Power MOSFET
IRF5305	IRF5305 31A 55V P-Channel Power MOSFET
IRF9520	IRF9520 6.8A 100V P-Channel Power MOSFET
IRF9530	IRF9530 12A 100V P-Channel Power MOSFET
IRF9531	IRF9531 12A 60V P-Channel Power MOSFET
IRF9532	IRF9532 10A 100V P-Channel Power MOSFET
IRF9533	IRF9533 10A 60V P-Channel Power MOSFET
IRF9540	IRF9540 23A 100V P-Channel Power MOSFET
IRF9610	IRF9610 1.8A 200V P-Channel Power MOSFET
IRF9630	IRF9630 6.5A 200V P-Channel Power MOSFET
IRF9640	IRF9640 11A 200V P-Channel Power MOSFET
IRF9Z34N	IRF9Z34N 19A 55V P-Channel Power MOSFET

Table 3.1

3.1.4 Characteristics of MOSFET

A IRF540 N-Channel MOSFET is a type of MOSFET in which channel of MOSFET is compressed of a majority of electrons as current carriers.

These are two types of N-Channel MOSFET

i. Enhancement Type
ii. Depletion Type

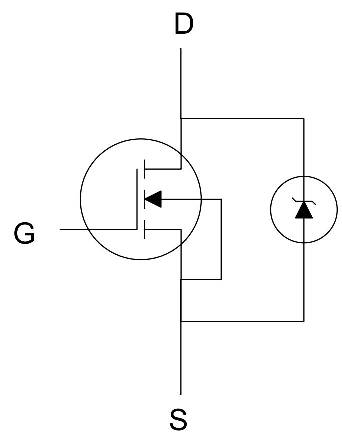


Figure 3.3Internal Schematic of IRF540.

3.1.4.1 Specifications of IRF540:

It is an Enhancement type N-Channel MOSFET

1. Drain-Source Voltage (V_{DS}) = 100V
2. Drain-Gate Voltage (V_{DG}) = 100V
3. Gate-Source Voltage (V_{GS}) = ±20V
4. Drain Current (I_D) = 33A
5. Minimum Threshold Voltage ($V_{GS(Min)}$) = 2V
6. Maximum Threshold Voltage ($V_{GS(Max)}$) = 4V
7. Maximum on Resistance = 0.077Ω
8. Pulsed Drain Current ($I_{D(Peak)}$) = 110A

3.1.4.2 Applications:

1. High Efficiency DC-DC Converters
2. UPS & Motor Control

3.1.4.3 Transfer characteristics of MOSFET

The DC transfer characteristics of a gate describe the output voltage as a function of the input voltage when input is changed slowly enough that the output can keep up. This characteristic curve show variation of output current with respect to input current keeping output voltage constant. The below transfer characteristics curve is drawn for drain current N/S gate to source voltage at constant drain-source voltage.

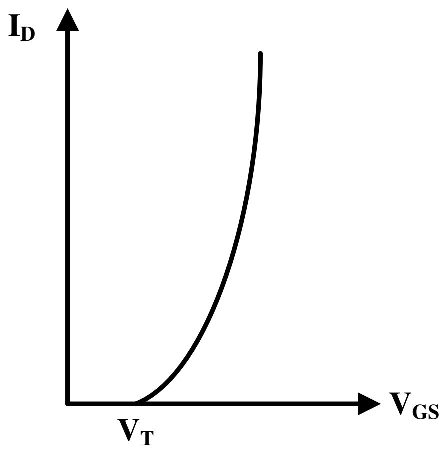
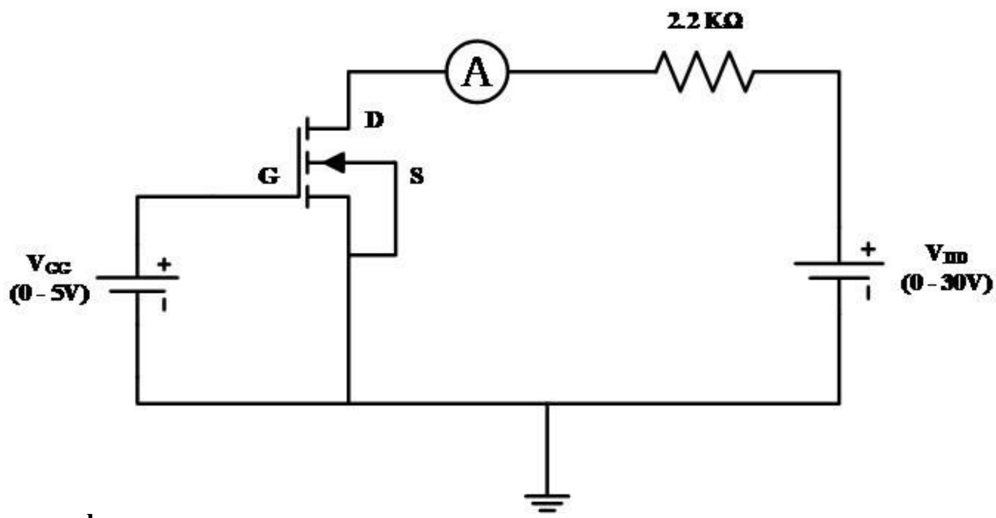


Figure 3. 4Transfer Characteristics of MOSFET



I

rcuit Diagram to obtain Transfer Characteristics of the MOSFET.

3.2 Pulse width modulation

3.2.1 Introduction

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a microprocessor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion.

3.2.1.1 Digital control

By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. What's more, many microcontrollers and DSPs already include on-chip PWM controllers, making implementation easy.

In a nutshell, PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the duty cycle of a square wave is modulated to encode a specific analog signal level. The PWM signal is still digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time is the time during which the DC supply is applied to the load, and the off-time is the period during which that supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

Figure3.7shows three different PWM signals. **Figure 3.7(a)**shows a PWM output at a 10% duty cycle. That is, the signal is on for 10% of the period and off the other 90%. **Figure 3.7(b)** and **Figure 3.7(c)**show PWM outputs at 50% and 90% duty cycles, respectively. These three PWM outputs encode three different analog signal values, at 10%, 50%, and 90% of the full strength. If, for example, the supply is 9V and the duty cycle is 10%, a 0.9V analog signal results.

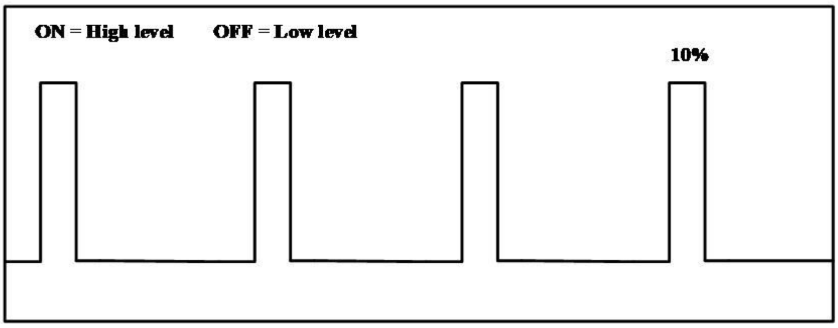


Figure 3. 6(a) : PWM signal 10% duty cycle

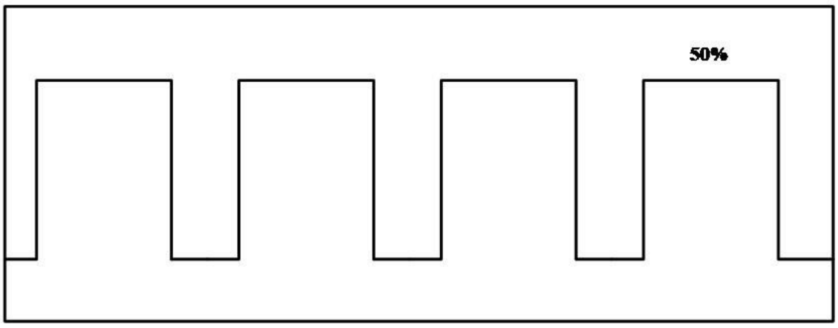


Figure 3. 6(b) : PWM signal 50% duty cycle

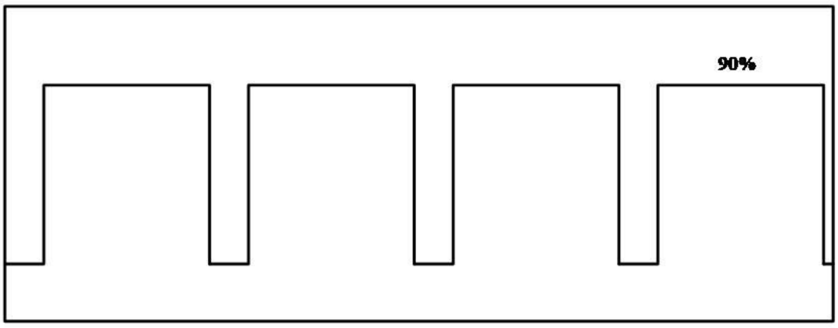


Figure 3. 6(c) : PWM signal 90% duty cycle

Figure 3.6.PWM Signals

3.2.2 PWM Techniques

3.2.2.1 Single pulse width modulation technique

Used for single-phase circuits. Changing the width of the pulse to control the on-time or to control the gate signal of a transistor so that the output voltage of the inverter can be controlled. By changing the width or by changing the width of the courier signal we can definitely change the on-time of the transistor. As we vary the time of the transistor we can vary the inverter output voltage. So, if the width of the gate pulse that we are getting as an output or comparator after pulse width modulation is the width of the output voltage will be getting is d.

3.2.2.2 Third harmonic injection pulse width modulation

The third harmonic voltage is not present on the phase voltages and the line to line for a three-phase load with a neutral point which is of floating-point type. Hence, it does not causes any distortion on the phase voltages. By adding a third harmonic signal in a low-frequency sinusoidal reference signal, we can get the amplitude increase in output voltage waveform.

3.2.2.3 Multiple pulse width modulation

Multiple pulse width modulation consists of multiple numbers of pulses per half cycle of the output voltage. Each pulse can be varied by the carrier signal. The frequency of the triangular wave is greater than that used in single pulse width modulation and it decides the number of gating signals per half cycle. By using multiple pulses, the harmonic content can be reduced. The frequency decides the number of pulses per half cycle. The output voltage can be controlled by controlling the modulation index.

3.2.2.4 Sinusoidal pulse width modulation

It indicates that the generation of outputs of the pulse width modulation with a sine wave as the modulating signal. The switching time of a PWM signal can be obtained by comparing a reference sinusoidal wave with a triangular wave of high frequency. This type of pulse width modulation is widely used in industrial applications. The RMS value of the output voltage can be varied by varying the modulation index. This technique improves the distortion factor and eliminates all harmonics less than or equal to 2p-1. By using a filter we can easily remove the higher-order harmonics.

3.2.2.5 Hysteresis band pulse width modulation:-

In this technique, the output is free to oscillate within the predefined error band known as the hysteresis band. The switching frequency of power devices is not fixed constantly and will change depending upon the magnitude and frequency of the reference signal. The main benefit of this control scheme is its ability to respond rapidly to load and line transients.

3.2.2.6 Space vector pulse width modulation:-

Space vector PW modulation (SVPWM) is an algorithm for the control of pulse width modulation (PWM). It is employed for the creation of alternating current (AC) waveforms, it is most commonly to drive 3 phase AC powered motors at varying speeds from DC using multiple class-D amplifiers. The harmonic present at the output is decreased and hence this vector modulation method offers an optimal output current or voltage.

3.2.3 Why 555 Timer?

The basic 555 timer gets its name from the fact that there are three internally connected 5kΩ resistors which it uses to generate the two comparators reference voltages. The 555 timer IC is a very cheap, popular and useful precision timing device which can act as either a simple timer to generate single pulses or long time delays, or as a relaxation oscillator producing a string of stabilised waveforms of varying duty cycles from 50 to 100%.

The 555 timer chip is extremely robust and stable 8-pin device that can be operated either as a very accurate Monostable, Bistable or Astable Multivibrator to produce a variety of applications such as one-shot or delay timers, pulse generation, LED and lamp flashers, alarms and tone generation, logic clocks, frequency division, power supplies and converters etc, in fact any circuit that requires some form of time control as the list is endless.

The single 555 Timer chip in its basic form is a Bipolar 8-pin mini Dual-in-line Package (DIP) device consisting of some 25 transistors, 2 diodes and about 16 resistors arranged to form two comparators, a flip-flop and a high current output stage as shown below. As well as the 555 Timer there is also available the NE556 Timer Oscillator which combines TWO individual 555's within a single 14-pin DIP package and low power CMOS versions of the single 555 timer such as the 7555 and LMC555 which use MOSFET transistors instead.

3.2.3.1 Pin Configuration of 555 Timer

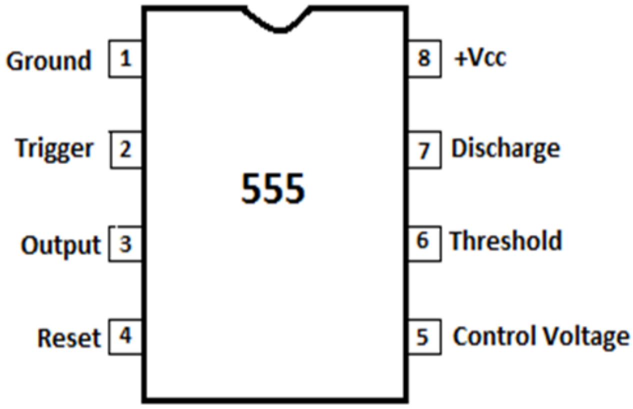


Figure 3.7Pin Configuration of 555 Timer.

Figure 3.7shows pin configuration of 555 timer and description of the same is written below.

Pin 1. Ground, The ground pin connects the 555 timer to the negative (0v) supply rail.

Pin 2. Trigger, The negative input to comparator No 1. A negative pulse on this pin "sets" the internal Flip-flop when the voltage drops below 1/3Vcc causing the output to switch from a "LOW" to a "HIGH" state.

Pin 3. Output, The output pin can drive any TTL circuit and is capable of sourcing or sinking up to 200mA of current at an output voltage equal to approximately Vcc – 1.5V so small speakers, LEDs or motors can be connected directly to the output.

Pin 4. Reset, This pin is used to "reset" the internal Flip-flop controlling the state of the output, pin 3. This is an active-low input and is generally connected to a logic "1" level when not used to prevent any unwanted resetting of the output.

Pin 5. Control Voltage, This pin controls the timing of the 555 by overriding the 2/3Vcc level of the voltage divider network. By applying a voltage to this pin the width of the output signal can be varied independently of the RC timing network. When not used it is connected to ground via a 10nF capacitor to eliminate any noise.

Pin 6. Threshold, The positive input to comparator No 2. This pin is used to reset the Flip-flop when the voltage applied to it exceeds 2/3Vcc causing the output to switch from “HIGH” to “LOW” state. This pin connects directly to the RC timing circuit.

Pin 7. Discharge, The discharge pin is connected directly to the Collector of an internal NPN transistor which is used to “discharge” the timing capacitor to ground when the output at pin 3 switches “LOW”.

Pin 8. Supply +Vcc, This is the power supply pin and for general purpose TTL 555 timers is between 4.5V and 15V.

3.2.4 Pulse Width Modulation Using 555 Timer

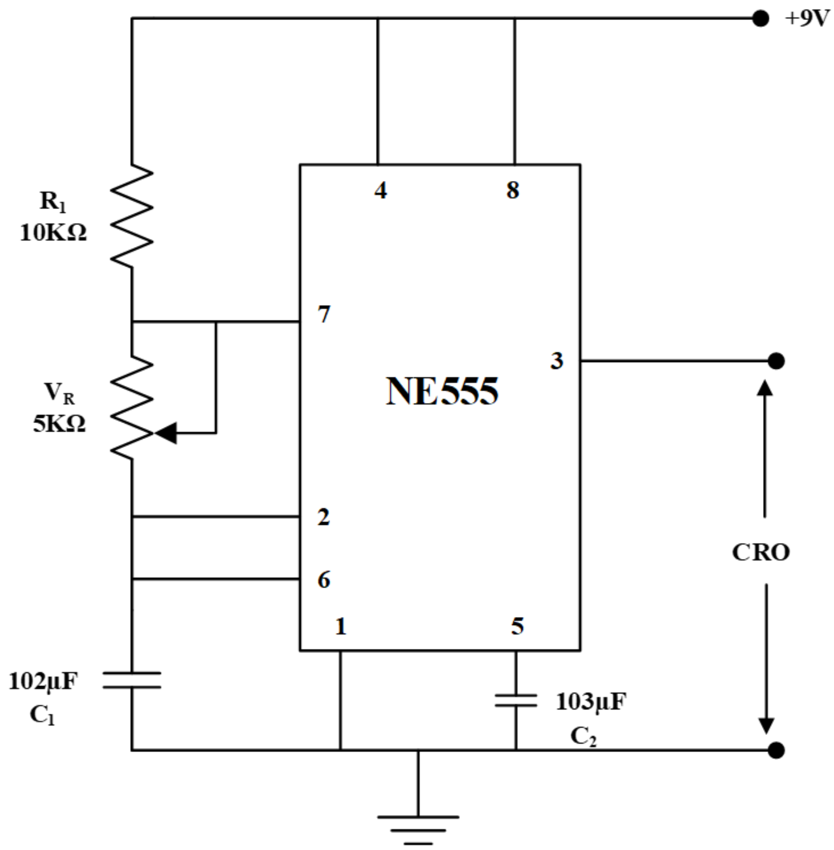


Figure 3.8PWM Using 555 Timer Circuit Diagram.

3.2.5 Hardware Setup

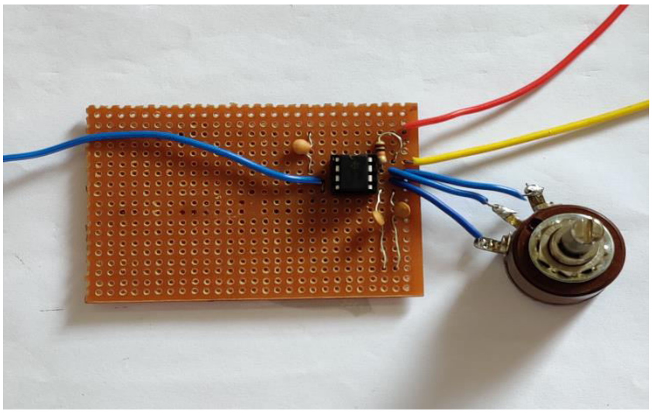


Figure 3.9(a)Practical Circuit of PWM using 555 Timer.

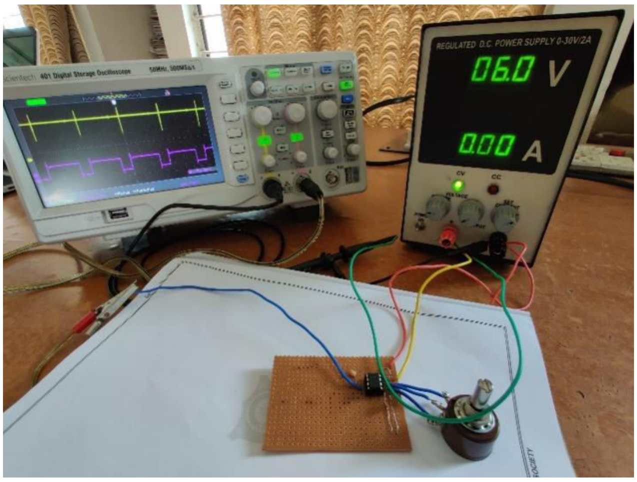


Figure 3.9(b)Complete Hardware Implementation of PWM using 555 Timer.

Chapter 4: Boost Converter

4.1 Boost Converter

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. The minimum oscillator frequency should be about 100 times longer than the transistor switching time to maximize efficiency. This limitation is due to the switching loss in the transistor. The transistor switching loss increases with the switching frequency and thereby, the efficiency decreases. The core loss of the inductors limits the high frequency operation. Control voltage Vc is obtained by comparing the output voltage with its desired value. Then the output voltage can be compared with its desired value to obtain the contol voltage Vcr. The PWM control signal for the dc converter is generated by comparing Vcr with a saw tooth voltage Vr. There are four topologies for the switching regulators: buck converter, boost converter, buck-boost converter, cứk converter.

4.1.1 Basic Boost Converter Model

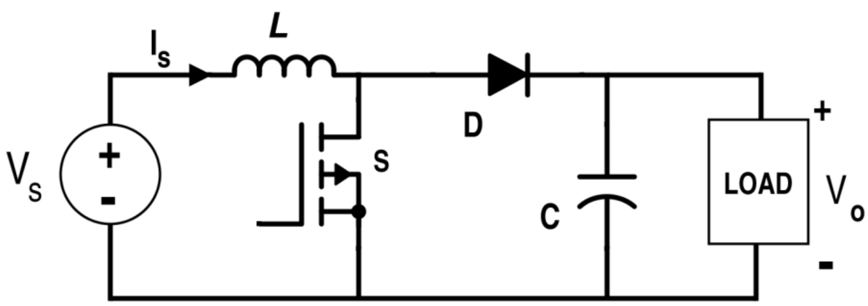


Figure 4.1Basic Boost Converter Circuit.

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by either increasing or decreasing the energy stored in the inductor magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure 3.9.

(a) When the switch is closed, current flows through the inductor in the clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be reduced in energy to maintain the current towards the load. Thus the polarity will be reversed (meaning the left side of the inductor will become negative). As a result, two sources will be in series causing a higher voltage to charge the capacitor through the diode D

4.1.2 Operating modes of Boost Converter

4.1.2.1 Continuous mode

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. Figure 3 shows the typical waveforms of inductor current and voltage in a converter operating in this mode.

In the steady state, the DC (average) voltage across the inductor must be zero so that after each cycle the inductor returns the same state, because voltage across the inductor is proportional to rate of change of current through it (explained in more detail below). Note in Figure 1 that the left hand side of *L* is at V_i and the right hand side of *L* sees the V_s voltage waveform from Figure 3. The average value of V_s is $(1\text{-}D)V_o$ where D is the duty cycle of the waveform driving the switch. From this we get the **ideal transfer function**:

$V_i=(1-D)V_0$

or

$V_0/V_i=1/(1-D)$.

We get the same result from a more detailed analysis as follows: The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behaviour) operating in steady conditions:[2]

During the on-state, the switch *S* is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_l) flowing through the inductor during a time period (*t*) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

Where *L* is the inductor value.

At the end of the on-state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$$

D is the duty cycle. It represents the fraction of the commutation period *T* during which the switch is on. Therefore, *D* ranges between 0 (*S* is never on) and 1 (*S* is always on).

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt}$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)\, dt}{L} = \frac{(V_i - V_o)\,(1 - D)\,T}{L}$$

As we consider that the converter operates in steady state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

Substituting $\Delta I_{L_{On}}$ and $\Delta I_{L_{Off}}$ by their expressions yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0$$

This can be written as:

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

The above equation shows that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with *D*, theoretically to infinity as *D* approaches 1. This is why this converter is sometimes referred to as a step-*up* converter.

Rearranging the equation reveals the duty cycle to be:

$$D =$$

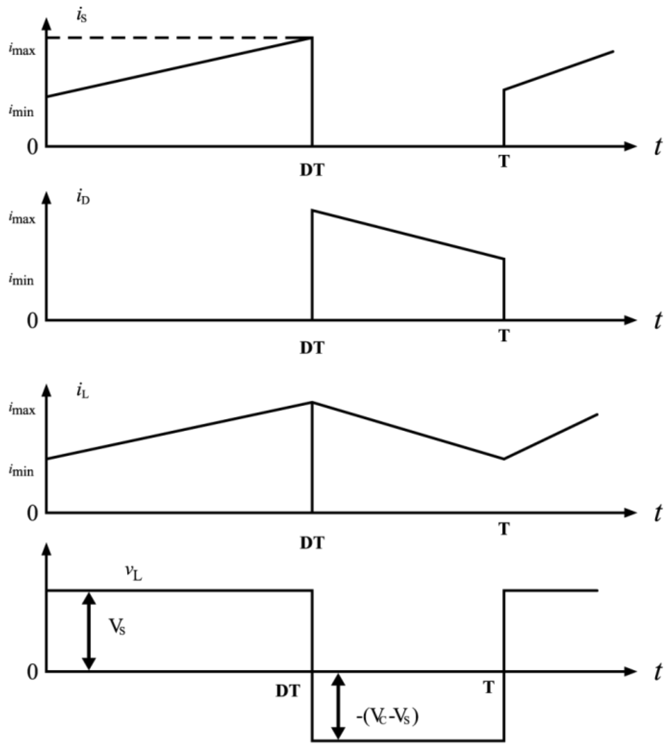


Figure 4.2Waveforms of Currents, Voltages when Boost Converter is in Continuous Conduction Mode.

4.1.2.2 Discontinuous mode

If the ripple amplitude of the current is too high, the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure 4). Although the difference is slight, it has a strong effect on the output voltage equation.

The voltage gain can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$ at t=DT is

$$I_{L_{Max}} = \frac{V_i DT}{L}$$

During the off-period, I_L falls to zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. The average value of I_o can be sorted out geometrically from figure 4. Therefore, the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)}$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o}$$

Compared to the expression of the output voltage gain for continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle (D), but also on the inductor value (L), the input voltage (V_i), the commutation period (T) and the output current (I_o).

$$I_0 = \frac{V_0}{R}$$

Substituting into the equation (R is the load), the output voltage gain can be rewritten as:

$$\frac{V_o}{V_i} = \frac{1 + \sqrt{1 + \frac{4D^2}{K}}}{2}$$

Where,

$$K = \frac{2L}{RT}$$

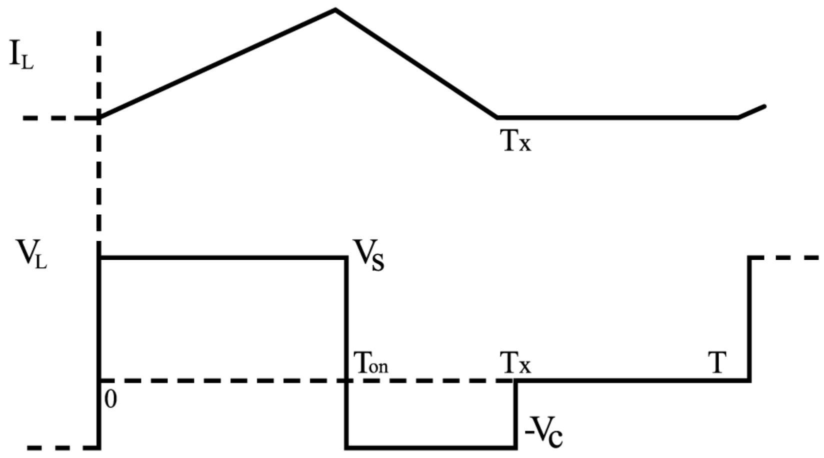


Figure 4.3Waveforms of Currents, Voltage when Boost Converter is in Discontinuous Operating Mode.

4.1.3 Inductor design

Inductors are energy storage elements, which stores the energy from the system source when the source is active and eventually delivers the energy back to the system when the source is inactive. A source is said to be active when it is delivering power, and inactive when it is either not delivering power or sinking power.

Inductors are generally used wherever there is a requirement to smoothen the current flow. In most switching applications, inductors are invariably used in the output filters to smoothen the current flow through the load.

Consider an inductor as shown in figure 1. Let point A be connected to the source side of the inductor and point B be connected to the load side of the inductor.

Let the source be active for a duration DT and the duration for which the source is inactive is(1-D)T where T is the period of action and inaction of the source i.e. 1/T = f is the frequency at which the source becomes active and inactive, and D is the duty cycle.

When the source is active during duration DT, the energy is being stored in the inductor, and the direction of current is as shown in figure1. Point A of the inductor is positive w.r.t. point B, when the source goes inactive, the energy stored in the inductor is released to the load. Now the inductor acts as a generator and hence point B is at a higher potential, than point A. It is assumed that the source side and load side circuits of figure 1 are designed such that there is a path to maintain the current, i, through the inductor, even when the source is inactive, in the direction as shown in figure 1. It is also interesting to note that the average voltage across an inductor is always zero.

4.1.3.1 Determination of Value of Inductance for SMPS.

In all switched mode converters, the inductor will be used as shown in figure 2. When the source is active the volts V_{AC} is a pulsed waveform with duty cycle D. When the source is inactive, there exists a freewheeling path in the source side circuit which causes V_{AC} to become zero. The above configuration applies for forward converter, half bridge, full bridge and push pull converters.

So $V_{AB} = V_{AC} - V_{BC}$

During the period DT, when the source is active,

$$V_{AB} = V_{CC} - V_O = V_L$$

and during the period (1-D)T, when the source is inactive

$V_{AB}=-V_O=V_L$ $\quad\quad\quad$ $V_{AC}=0$

or $\quad V_{BA} = V_O$

Now from Faraday's Law

$V = L\frac{di}{dt}$, We have

$$V_{cc} - V_O = L\frac{\Delta I}{DT} \;\; or \;\; V_O = L\frac{\Delta I}{(1-D)T}$$

Either of the above equations can be used to obtain the L value, so from the 2nd equation we have,

$$L = \frac{V_O(1-D)T}{\Delta I}$$

Where ΔI is the ripple in the inductor current. It is generally in the order of 1% to 10% of I_0.

It should be noted here that T is not the switching period T_S of the converter. For the forward converter, T is same as the switching period T_S, but for half bridge, full bridge and push pull converters T is half of T_S because of the ORing effect of the two halves of the centre tapped secondary. Further D is the duty cycle w.r.t period T and not w.r.t to period T_S. Always D and T should correspond to the waveform at AC (i.e. V_{AC}).

4.1.3.2 Mathematical Modelling of Inductor

The first step towards the inductor design is to find out the value of L for the particular application. The Faraday's equation e = $\frac{Ldi}{dt}$ is used to find the value of L for any circuit. This equation is best suited for switched mode applications. For circuits based on resonant principle, the L value is determined from the resonant frequency and the Q of the circuit etc. So, depending on the type of application and the configuration of the circuit, the value of L has to be arrived at. In Appendix I, we shall derive a method for arriving at the value of the inductor for any switching circuit.

Area Product:

The energy to be handled by the inductor core is given by

$$E = \frac{1}{2}LI_m^2 \quad ..(3.1)$$

Where, E is the energy in joules, L is the inductance in Henrys and I is the peak inductor current in amps. The window area of the core should accommodate 'N' turns of wire cross-section area 'a'. Thus,

$$K_w A_w = N.a \quad ..(3.2)$$

But, a $=\frac{I}{J}$, where I is the rms current through the inductor in amps. and J is the current density in A/mm^2. So, equation (3.2) can be rewritten as

$$K_w A_w = N\frac{I}{J} \quad ..(3.3)$$

Defining crest factor K_c as

$K_c \equiv \frac{I_m}{J} = \frac{(peak)}{(rms)}$ and substituting for I, we have,

$$K_w K_c A_w J = N I_m \quad ..(3.4)$$

From the Faraday's equation, we have

$e = \frac{Ldi}{dt} = N\frac{d\emptyset}{dt} = NA_c\frac{dB}{dt}$ and

$$LI_m = NA_c B_m \quad ..(3.5)$$

Substituting equation (5) in equation (1), we have

$$E = \frac{1}{2} N I_m A_c B_m \quad ..(3.6)$$

Substituting for I_m in equation (3.6) from equation (3.4) and rearranging, we have the Area Product for the core given by,

$$A_p = A_c A_w = \frac{2E}{K_w K_c J B_m} \quad ..(3.7)$$

As there is only winding K_w can be chosen as 0.6. The core can be chosen by comparing the area product value obtained from equation (3.7) with the appendix-II.

No. of Turns:

The number of turns can be calculated from the below equation

$N = \frac{LI_m}{NA_c}$ ..(3.8)

Gauge of Wire:

The cross-section area of the wire can be calculated from the formula,

$a = \frac{I}{J}$ ..(3.9)

The gauge of the wire can be decided by comparing the calculated wire cross section from equation (3.9) with Appendix-II.

Air gap,I_g : As per section 4.1, air gap, I is used to reduce the core size.

From the Faraday's equation, we have,

e $= \frac{Ldi}{dt} = N\frac{d\emptyset}{dt}$, we have

$B = \frac{LI}{NA_c}$ ..(3.10)

Where $B = \frac{\emptyset}{A_c}$

From Ampere's Law, we have

$mmf = NI = \int H.dl$, which gives rise to

$$H = \frac{NI}{l_m}$$

Where l_m is the mean magnetic path length,

So,

$B = \mu\frac{NI}{l_m}$ ..(3.11)

Equating equations 3.10 and 3.11, we have,

$\frac{l_m}{\mu A_c} = \frac{N^2}{L}$ ..(3.12)

$\frac{l_m}{\mu A_c}$ is the reluctance of the magnetic path which can be split into

$$\frac{l_c}{\mu_0\mu_r A_c} + \frac{l_g}{\mu_0 A_c}$$

Where,

l_c is the mean magnetic path in the magnetic material, m

l_g is the air gap length, m

A_c is the core section, m^2

If the material is of high permeability one, then the reluctance is contributed mainly by the air gap, so

$$\frac{l_c}{\mu_0\mu_r A_c} \ll \frac{l_g}{\mu_0 A_c}$$

$$l_g = \frac{\mu_0 N^2 A_c}{L} \quad ..(3.13)$$

In calculating N, B_m is assumed, which may not be the exact B_m in the core, so the air gap calculated may not be exact. So in many cases, value of L may have to be trimmed by slightly adjusting the airgap.

4.1.3.3 Theoretical Calculations of the Inductor

Considering,

Output Voltage, V_{out} = 20V,

Input Voltage, V_{in} = 5V,

Switching Frequency, F= 40KHz

The L for this converter is given by

$$L = \frac{V_0(1 - D_{min})}{\Delta I f_s}$$

ΔI Is the current ripple in the inductor. Usually 10 to 25% of I_0 is taken . Here,

$\Delta I = 10\%$ I_0 of , is taken.

Where, $D_{mm} = \frac{V_0}{V_{gmax}}$

Substituting the appropriate values in the above equations, we find that

L=0.1553 mH

Area Product:

The energy and area product calculations are as follows:

$$E = \frac{1}{2} L I_m^2$$

Where,

$I_m = I_0 + \frac{\Delta I}{2}$

Substituting the values in the above equations, we have E = 2.14 x10 joules

$A_P = A_W A_C = \frac{2E}{K_w K_c J B_m}$

Take B_m = 0.2T for ferrite, J = 3A/mm^2(3 x 10° A/m), K_c = 1 (for square wave) and

K_w = 0.6.

Substituting the values in the area product equation, we have

$A_p = 1.18888 \times 10^{-8} m^4 = 11888.8\ mm^4$

Now choose the core from Appendix-I which has a A_p higher than the value calculated above

P 36/22 is proper choice - (A_c = 201 mm^2, A_w = 101 mm^2, A_W = 20100 mm^4).

No. of Turns: The equation for the number of turns is given by

$$N=\frac{L I_m}{A_c B_m}.$$

Substituting the values for the variables, we have N=34 turns (taking the next higher integer if the calculation does not give an integer value).

Wire Gauge: The gauge of the wire can be calculated from the equation given below, taking

J = 3 A/mm^2

a = $\frac{I}{J}$, where I = I_0

Substituting the values of the variables in the above equation, we have,

$$a= 1.6666\ mm^2$$

Now choose the wire gauge from Appendix-II, which has a cross section area greater than the value calculated above.SWG 16 is a proper choice (a = 2.075 mm).

Air Gap Length:

Air Gap Length l_g is given by the equation,

$l_g = \frac{\mu_o N^2 A_c}{L}$, where H, = $4\pi\times10^{-7}$ H/m.

Substituting the variable values to the above equation, we have,

$l_g = 0.717 \times 10^{-3} m = 0.717m$

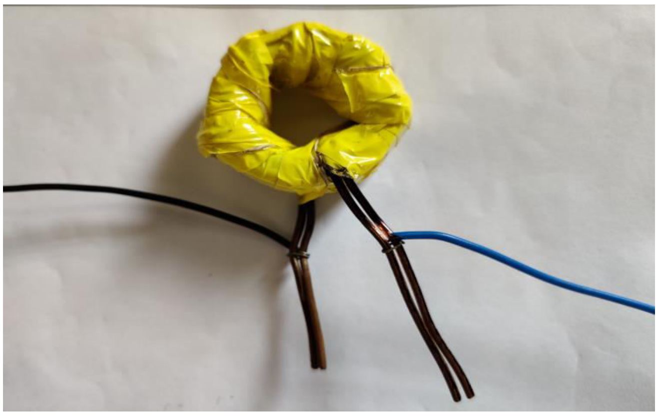


Figure 4.4Inductor Designed for Boost Converter.

4.1.4 MATLAB/Simulink Modelling.

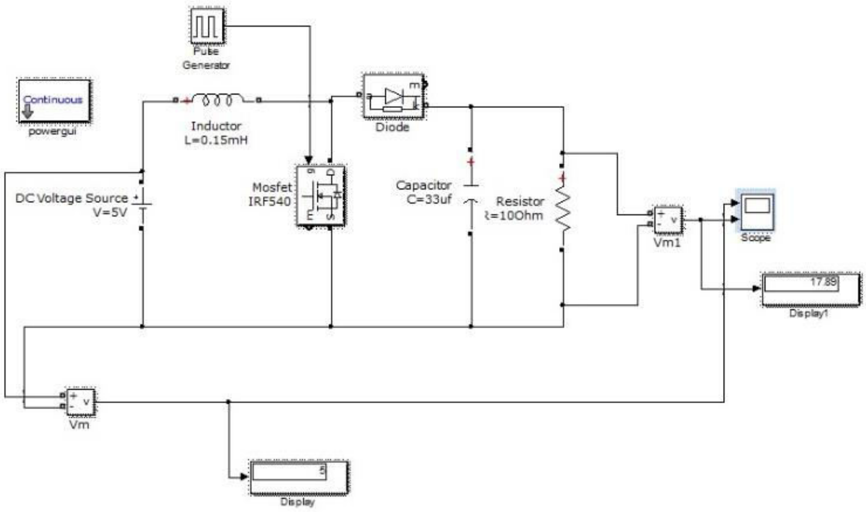


Figure 4.5Simulink Model of Basic DC-DC Boost Converter.

5.1 PV Cells

A photovoltaic (PV) cell, also known as a solar cell, is an electronic component that generates electricity when exposed to photons, or particles of light. This conversion is called the photovoltaic effect, which was discovered in 1839.

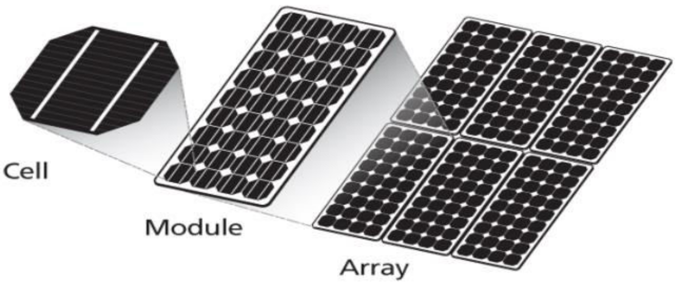


Figure 5.1Illustration of Basic Difference PV Cell, Module, Array.

5.1.1 Working of PV cell

A photovoltaic cell is made of semiconductor materials that absorb the photons emitted by the sun and generate a flow of electrons. Photons are elementary particles that carry solar radiation at a speed of 300,000 kilometres per second.When the photons strike a semiconductor material like silicon, they release the electrons from its atoms, leaving behind a vacant space. The stray electrons move around randomly looking for another “hole” to fill.

To produce an electric current, however, the electrons need to flow in the same direction. This is achieved using two types of silicon. The silicon layer that is exposed to the sun is doped with atoms of phosphorus, which has one more electron than silicon, while the other side is doped with atoms of boron, which has one less electron. The resulting sandwich works much like a battery: the layer that has surplus electrons becomes the negative terminal (n) and the side that has a deficit of electrons becomes the positive terminal (p). An electric field is created at the junction between the two layers.

When the electrons are excited by the photons, they are swept to the n-side by an electric field, while the holes drift to the p-side. The electrons and holes are directed to the electrical contacts applied to both sides before flowing to the external circuit in the form of electrical energy. This produces direct current. An anti-reflective coating is added to the top of the cell to minimize photon loss due to surface reflection. (See diagram.)

5.1.2 Different Types of Photovoltaic Cells

There are three main types of PV cells. Their conversion efficiencies are being improved all the time.

5.1.2.1 Crystalline Silicon Cells

Silicon is extracted from silica. The latter has many forms, including quartz, which is found in large quantities in sand. Silicon cells account for more than 95% of the solar cell market. In commercial applications, their efficiency ranges from 16.5% to 22%, depending on the technology used.

5.1.2.2 Thin-Film Cells

Instead of cutting silicon wafers of around 200 microns3, it is possible to deposit semiconductor material in thin layers only a few microns thick on a substrate such as glass or plastic. Commonly used substances are cadmium telluride and copper indium gallium selenide (CIGS), whose laboratory efficiencies are close to that of silicon, at 22.1% and 23.3%, respectively. Amorphous (non-crystalline) silicon can also be used for making thin-film cells. This technology has long been applied in small calculators but is less efficient than silicon.

5.1.2.3 Organic cells

Organic solar cells that utilize organic molecules or polymers rather than semiconducting minerals are starting to be commercially applied. The cells continue to have a low conversion efficiency and a short lifetime but are potentially a low-cost alternative in terms of production. Another technology, dye-sensitized solar cells with photosensitive pigments, inspired by photosynthesis, is beginning to attract attention.

5.1.3 I-V and P-V Characteristics

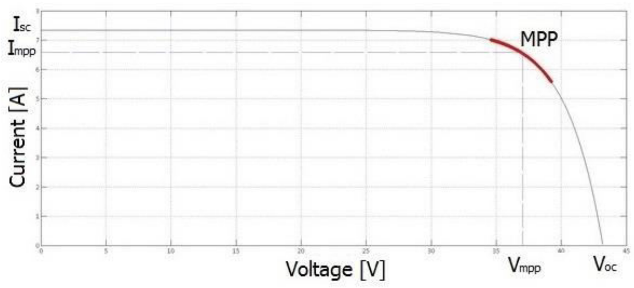


Figure 5.2I-V Characteristics of PV Module.

The above figure shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited that is not connected to any load the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells open circuit voltage, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current, or Isc.

Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

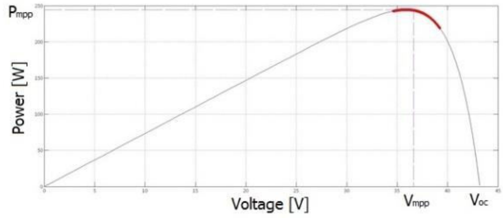


Figure 5.3P-V Characteristics of PV Module.

Another way to visualize the I-V curve is to convert it to a relationship between power and voltage. In this case, we can call it (P-V) curve of PV module, as shown in Figure 2.2. Similar to an I-V curve, the highest voltage occurs at the open-circuit condition and the current is zero and the short-circuit voltage is zero at the origin of the curve, but the current is maximum. Since the power is nothing but the voltage times the current (P=VxI), the power at both the short-circuit and open-circuit conditions is equal to zero since either voltage or current equals zero at each of these points. If we observe the power and voltage starting at the open-circuit condition (where the voltage is maximum and power is zero), and as we increase the load of the circuit, the power starts increasing and the voltage falls down until it reaches the value at MPP (where power is maximum). If we increase the load further, the voltage keeps falling down. However, the power will decrease as well until it reaches the value of zero at short-circuit condition (where the both voltage and power are zero). It can be seen that it is much easier to find the peak power on the P-V curve in comparison to the I-V curve, as it resembles a hump. The power at MPP is referred to as "Pmpp."

5.1.4 Series and parallel connections of panel

The solar cell is a two-terminal device. One is positive (anode) and the other is negative (cathode). A solar cell arrangement is known as solar module or solar panel where solar panel arrangement is known as photovoltaic array.

It is important to note that with the increase in series and parallel connection of modules the power of the modules also gets added.

5.1.4.1 Series Connection of Modules

Sometimes the system voltage required for a power plant is much higher than what a single PV module can produce. In such cases, N-number of PV modules is connected in series to deliver the required voltage level. This series connection of the PV modules is similar to that of the connections of N-number of cells in a module to obtain the required voltage level. The following figure shows PV panels connected in series configuration.

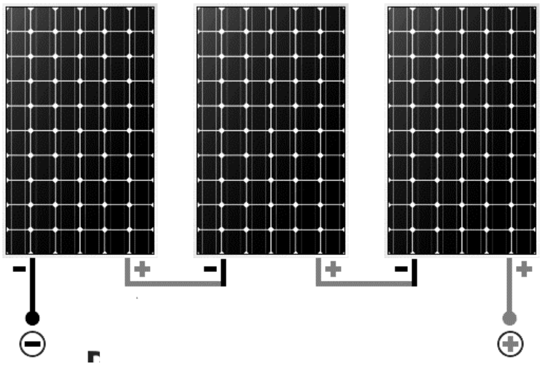


Figure 5.4Series Connection of PV Module.

With this series connection, not only the voltage but also the power generated by the module also increases. To achieve this the negative terminal of one module is connected to the positive terminal of the other module.

If a module has an open circuit voltage V_{OC1} of 20 V and other connected in series has V_{OC2} of 20 V, then the total open circuit of the string is the summation of two voltage.

$V_{OC} = V_{OC1} + V_{OC2}$

$V_{OC} = 20\text{ V} + 20\text{ V} = 40\text{ V}$

It is important to note that the summation of voltages at the maximum power point is also applicable in case of PV array.

5.1.4.1.1 Calculation of the Number of Modules Required in Series and their Total Power

To calculate the number of PV modules to be connected in series, the required voltage of the PV array should be given. We will also see the total power generated by the PV array. Note that all the modules are identical having the same module parameters.

Step 1: Note the voltage requirement of the PV array:

Since we have to connect N-number of modules in series we must know the required voltage from the PV array

- PV array open-circuit voltage V_{OCA}
- PV array voltage at maximum power point V_{MA}

Step 2: Note the parameters of PV module that is to be connected in the series string:

PV module parameters like current and voltage at maximum power point and other parameters like V_{OC}, $I_{SC,}$ and P_M should also be noted.

Step 3: Calculate the number of modules to be connected in series:

To calculate the number of modules "N" the total array voltage is divided by voltage of individual module, Since the PV module is supposed to be working under STC the ratio of array voltage at maximum power point V_{MA} to module voltage at maximum power point V_M is taken.

A similar calculation for open-circuit voltage of PV can also be done i.e., ratio of array voltage at open circuit V_{OCA} to module voltage at open circuit V_{OC}. Note that the value of "N" can be a non-integer so we have to take next higher integer and so the value of V_{MA} and V_{OCA} will also increase than what we desired.

Step 4: Calculating the total power of the PV array:

The total power of the PV array is the summation of the maximum power of the individual modules connected in series. If P_M is the maximum power of a single module and "N" is the number of modules connected in series, then the total power of the PV array PMA is $N \times P_M$.

5.1.4.2 Parallel Connection of Modules:

Sometimes to increase the power of the solar PV system, instead of increasing the voltage by connecting modules in series the current is increased by connecting modules in parallel. The current in the parallel combination of the PV modules array is the sum of individual currents of the modules.

The voltage in the parallel combination of the modules remains the same as that of the individual voltage of the module considering that all the modules have identical voltage.

The parallel combination is achieved by connecting the positive terminal of one module to the positive terminal of the next module and negative terminal to the negative terminal of the next module as shown in the following figure. The following figure shows solar panels connected in parallel configuration.

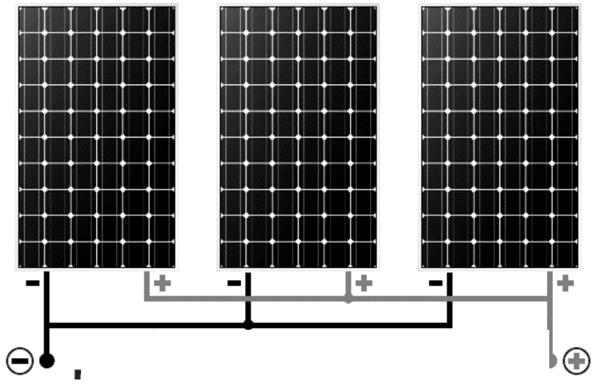


Figure 5.5Parallel Connection of PV Module.

If the current I_{M1} is the maximum power point current of one module and I_{M2} is the maximum power point current of other module then the total current of the parallel-connected module will be $I_{M1} + I_{M2}$. If we keep on adding modules in parallel the current keeps adding up. It is also applicable for short-circuit current Isc.

5.1.4.2.1 Calculation of the Number of Modules Required in Parallel and their Total Power

To calculate the number of PV modules to be connected in parallel, the required current of the PV array should be given. We will also see the total power generated by the PV array. Note that all the modules are identical having the same module parameters.

Step 1: Note the current requirement of the PV array:

Since we have to connect N-number of modules in parallel we must know the required current from the PV array

- PV array short-circuit current I_{SCA}
- PV array current at maximum power point I_{MA}

Step 2: Note the parameters of PV module that is to be connected in parallel:

PV module parameters like current and voltage at maximum power point and other parameters like V_{OC}, I_{SC}, and PM should also be noted.

Step 3: Calculate the number of modules to be connected in parallel:

To calculate the number of modules N the total array current is divided by the current of an individual module, Since the PV module is supposed to be working under STC the ratio of array current at maximum power point I_{MA} to module current at maximum power point I_M is taken.

A similar calculation for short-circuit current of PV can also be done i.e., ratio of array short-circuit current I_{SCA} to module short-circuit current I_{SC}.

Note that the value of N can be a non-integer so we have to take next higher integer and so the value of I_{MA} and I_{SCA} will also increase than what we desired.

Step 4: Calculating the total power of the PV array:

The total power of the PV array is the summation of the maximum power of the individual modules connected in parallel. If P_M is the maximum power of a single module and "N" is the number of modules connected in parallel, then the total power of the PV array P_{MA} is $N \times P_M$. we can also calculate the array power by the product of PV array voltage and current at maximum power point i.e.

$V_{MA} \times I_{MA}$.

5.2 Integration of PV Module with DC-DC Boost Converter.

Integration of PV Module can be done for ON/OFF grid applications in order to feed the power back to grid or for normal household applications respectively.

5.2.2 MATLAB/Simulink Modelling.

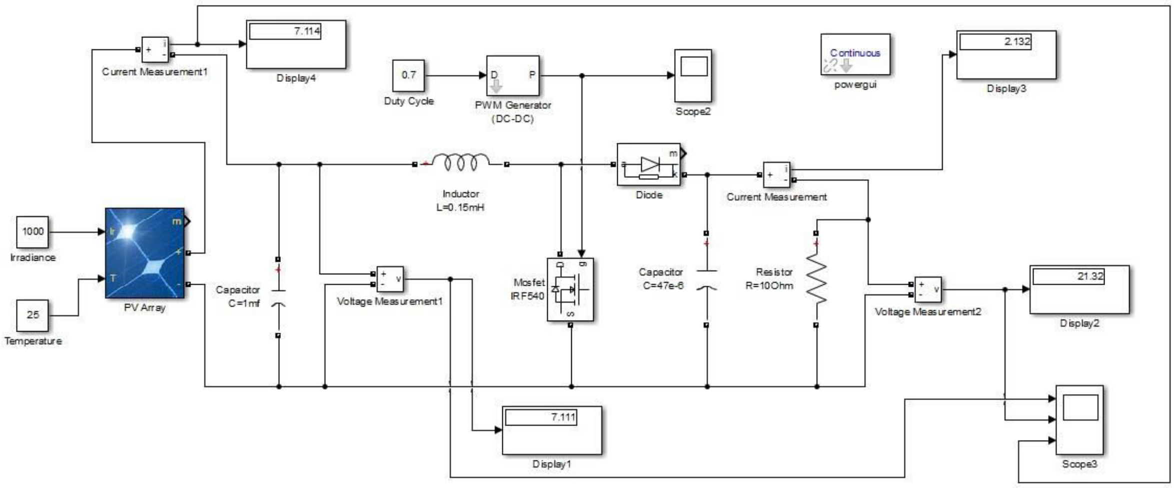


Figure 5.6Complete Simulink Model of PV Fed DC-DC Boost Converter.

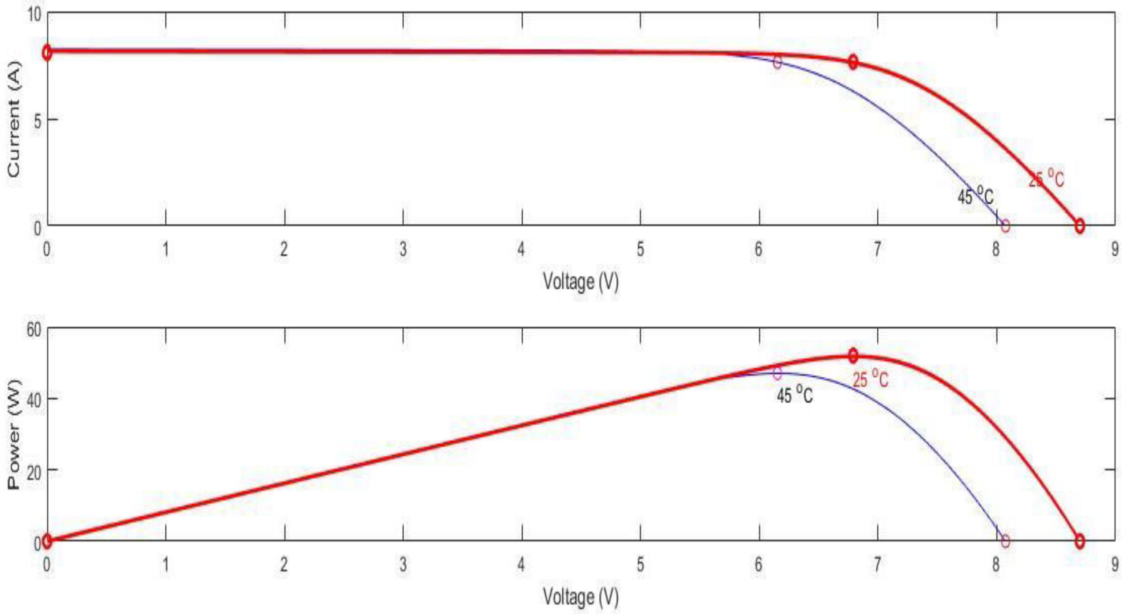


Fig 5.7. PV/IV simulation Results

6.1 Results Obtained.

6.1.1 MOSFET Transfer Characteristics.

S.no.	$V_{DS} = 10V$		$V_{DS} = 20V$	
	$V_{GS}(V)$	$I_D(MA)$	$V_{GS}(V)$	$I_D(MA)$
1.	0.9	0	0.5	0
2.	1.2	0	1.1	0
3.	1.4	0.14	1.5	1.06
4.	1.8	1.24	2	1.40
5.	2.0	1.46	3.0	2.05
6.	2.6	1.83	3.5	2.36
7.	3.0	2.04	4.1	2.79
8.	3.5	2.37	4.6	3.12
9.	4.0	2.69	5.0	3.50
10.	4.6	3.14	6.0	4.02

Table 4.1

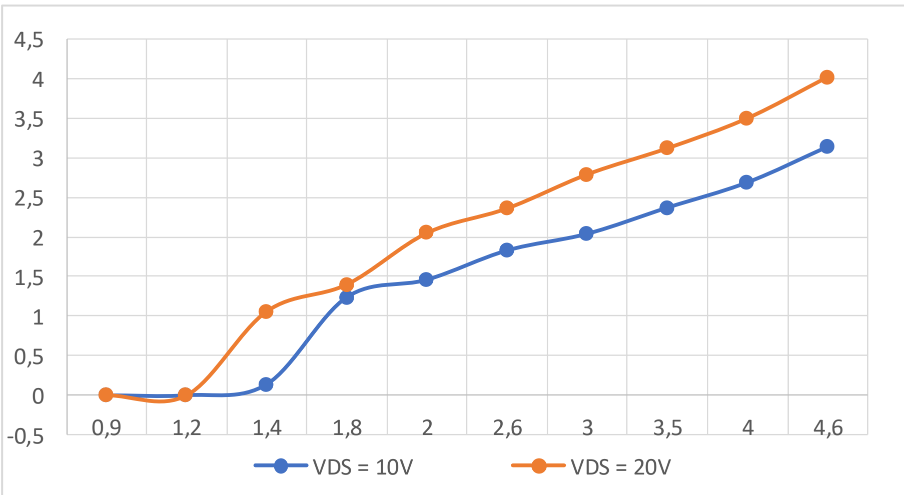


Figure 6.1 MOSFET Transfer Characteristics.

6.2 Pulse Width Modulation Using 555 Timer

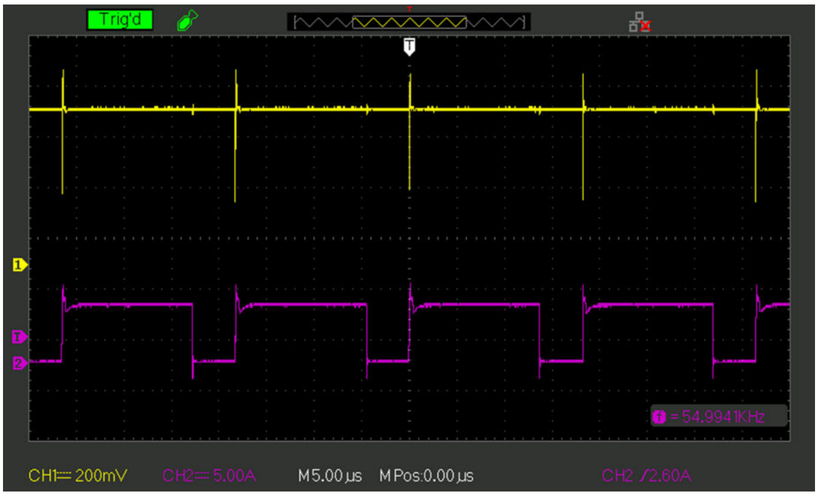


Figure 6.2(a)Minimum Duty Cycle obtained in PWM using 555 Timer.

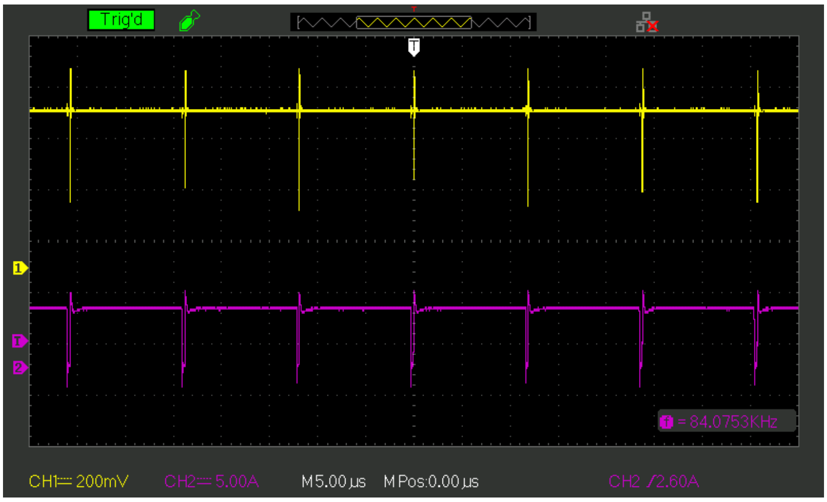


Figure 6.2(b)Maximum Duty cycle obtained in PWM using 555 Timer.

6.3 Basic DC-DC Boost Converter

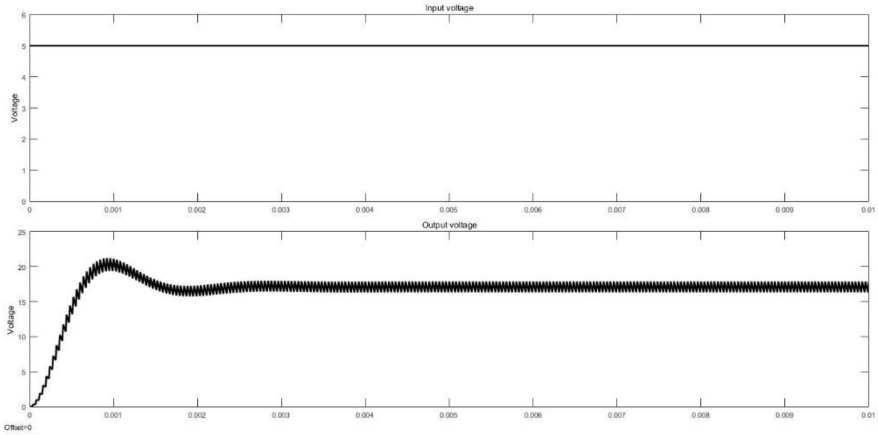


Figure 6.3Output of Basic DC-DC Boost converter Simulink Model.

6.4 PV Fed DC-DC Boost Converter.

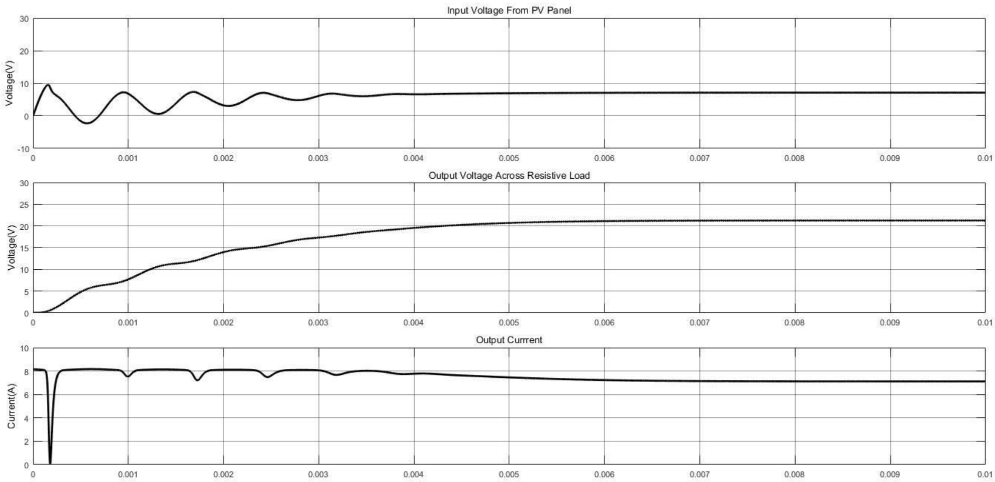


Figure 6.4 Output of PV Fed DC-DC Boost Converter Simulink Model.

6.5 Discussion

- It is determined that the Threshold Voltage of the Power MOSFET (IRF540) is 4V from the transfer characteristics of MOSFET.
- The 555 Timer produced square wave pulses with a good range of variability of the pulse width of the signal with the minimum duty cycle being 73% & maximum being 97%.
- The fundamental DC-DC Boost converter model for the constraints considered gave an output voltage of 17V for a given input of 5V at 50KHz.
- The PV fed DC-DC Boost Converter Model gave an output wattage of 45W for an input power wattage of 9W.

Chapter 7: Conclusion and Future Scope

This thesis presents an overview of boost converters, and considers their efficiency in photovoltaic applications that operate under a wide range of changeable weather conditions. From this, it is clear that each boost converter circuit has its own disadvantages and advantages, and the choice is decidedly application dependent. When using PV systems in destitute residential locations, the objective is to have low cost of PV systems that offer high efficiency under all operation conditions. To do so, it is necessary to combine the advantages of interleaved boost converter circuit and conventional boost converter circuit. Importantly, the proposed topology with its control scheme extends the range whereby the circuit operates in continuous conduction mode with very low irradiance conditions. The simulation results have confirmed that the circuit of interleaved boost converter with novel switch adaptive control has good features of low ripple of the current and voltage at the output and input stages, low stress on devices. It promises to operate in continuous current mode over a wider range of operating conditions, and offers optimised high efficiency under all weather conditions. In general, the circuit is a good choice for all PV systems that requires high efficiency operation in unpredictable weather conditions.

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