

Simulation & Control Of SPWM Based Three Phase Voltage Source Inverter For Solar System

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This Report Presented in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in the Electrical and Electronic Engineering.

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Dedication

To Our Beloved Parents & Faculties.....

Declaration

We hereby declare that this thesis report on “**Simulation & Control Of SPWM Based Three Phase Voltage Source Inverter For Solar System** “is submitted to Daffodil International University for partial fulfillment of the requirement of the degree of B.Sc. in Electrical & Electronic Engineering. It has not been submitted to any other university or institution for the award of any degree previously. This thesis report does not breach any provision of copy right act.

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Certificate

This is to certify that the thesis book on “**Simulation &Control Of SPWM Based Three Phase Voltage Source Inverter For Solar System**” is done by **Md. Afjal Hossain, ID:142-33-1932 & Faridul Islam, ID: 142-33-1897** partial fulfillment of the requirement of the degree of B.Sc. in Electrical & Electronic Engineering program from the Daffodil International University.

The dissertation has been carried out under my guidance and is a record of bona fide work carried out successfully.

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Abstract

Inverters are used in a large number of power electronics. Inverter is an alternative energy system that converts direct current (DC) into the alternating current (AC) and sometimes used as emergency backup of household electrical appliances and many others in the absence of alternating current (AC). Utility companies and generators produce sine wave alternating current (AC) power, which is used by most commonly available appliances today. This sine wave is not pure; it will be distorted when it passes through electronic device. To remove this unwanted frequency component from the signal filter is used so that we can get pure sine wave. Then this inverter can be controlled by using SPWM to operate a greater efficiency.

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Abbreviation

DC	=	Direct Current
AC	=	alternate Current
IGBT	=	Insulated Gate-Bipolar Transistor
MOSFET	=	Metal-Oxide-Semiconductor Field Effect Transistor
BJT	=	Bipolar junction Transistor
PWM	=	Pulse Width Modulation
SPWM	=	Sinusoidal Pulse Width Modulation
THD	=	Total Harmonic Distortion
PV	=	Photovoltaic Array
EMF	=	Electromotive Force
RMS	=	Root Mean Square

Chapter 1

Introduction

1.1 Introduction

The photovoltaic effect concept was experimentally first by French physicist Edmond Becquerel in 1839. In 1883 Charles Frits built the first solid state photovoltaic cell by coating the semiconductor selenium with a thin layer of gold to form the junctions; the device was only around 1% efficient. In 1905 Albert Einstein proposed a new quantum theory of light and explained photoelectric effect in a landmark paper ^[1]. Today's commodity silicon based solar panels have efficiencies between 16% and 18%; their theoretical limit is thought to be well below 30% and for cadmium telluride it is above 30% ^[2]. Many nations use fossil fuels to produce energy; it is very challenging for coming future because of environment problems and others.

Renewable energy resources (**Such As Wind, Solar and Hydropower**) offer clean, produce little or no pollution or greenhouse gases. In rural areas, 80% people live lack of adequate energy service ^[3]. So renewable energy source is the most important source today's. To utilize this source an inverter is needed.

A voltage source inverter is one that takes in a fixed voltage from a DC power supply and then it converts to a variable frequency AC supply. Solar panel collects radiant energy from the sunlight and then converts it to useable energy. The value of DC power applied in our designed inverter is 874.53V and the output will come 116.67V. This value may be depends upon the application. When SPWM is used to control this inverter then the output is 95.46V.

1.2 Aim of This Project

The aim of this project is implement an inverter with solar panel and controlled this inverter using SPWM. The main aim of this project is to produce electricity for household loads and benefits at low cost, to reduce power loss, to reduce THD, to save energy to reduce greenhouse effect, getting better efficiency within short time, emergency backup for AC when electrical power goes off.

1.3 Problem Statement of Solar Inverter

Solar inverter may run some problems and these issues are easy to solve. Inverter is made of electronic components and sensitive to temperature. So high temperature will lead and that's why operating may be stopped. Adequate cooling technology is the solution of this problem. Isolation fault occurs because of short circuit and the short circuit occurs because of poor connection of DC cables, moisture in the connection part of the PV modules. To solve this problem it is important to ensure the high quality dc cables ^[4] ^[5]. When the inverter has been installed incorrectly such as IGBT connection, filter connection there is a problem occurs.

1.4 Major Components of Our Exhaustive Project

- Solar Cell (874.52V)
- Inductor (0.06H)
- Capacitor (50×10^{-6} F)
- Series RL load (10Ω , 10^{-3} H)
- Pulse Generator
- Saw Tooth Generator
- Logical Gate (NOT)
- IGBT

1.5 Chapterize

Firstly we discuss about photovoltaic effect. Then we discuss about aim of this project, problem statement. Finally we discuss about major components of our exhaustive project.

Chapter 2

Theoretical Study

2.1 Introduction

This chapter discuss about circuit diagram of solar panel inverter, functional description of each block & equipment. In functional description we discuss about how DC to AC works, **IGBT**, filter, resistor, inductor, solar cell.

2.2 Solar Cell

Solar panel (Photovoltaic Cell Carrying Silicon) absorbs sun's light (Photons) from the sun. Then the photons knock some electrons in the silicon to loose and this electron allow to produce DC current ^[6]. Then this DC current works into the inverter. Finally, the inverter converts DC to useable AC power.

The basic unit of power is watt. Larger unit of power is measured in multiples of 1000.

1000 watts = 1 kilowatt (kW) ×1000 = 1 megawatt (MW) ×1000 = 1 Giga watt (GW) ×1000 = 1 Terawatt (TW).

The **I-V** characteristic of an ideal solar cell are given by the Shockley solar cell equation^[7],

$$I = I_L - i_0 \left[\exp \left(\frac{eV}{m k T} \right) - 1 \right]$$

Where,

I_0 = Inverse Saturation Current Of Diode.

e = Electron Charge.

K = Boltzmann Constant.

T = Temperature in (°K)

m = Ideality Factor.

And,

$$V_{oc} = \frac{mkT}{q} \ln \left(\frac{I_{sc}}{I_0} + 1 \right)$$

One way to measure the performance of a solar cell is the fill factor. This is the ratio of maximum power to open circuit voltage and short circuit current ^[8].

$$\text{Fill Factor} = \frac{P_{max}}{P_{in}} = \frac{V_{mpp} \times I_{mpp}}{V_{oc} \times I_{sc}}$$

The Higher The Fill Factor Is Better >0.7.

To calculate the annual solar energy output of a photo voltaic system the equation is ^[9],

$$E = A * r * H * PR$$

Where,

E = Energy (kWh)

A = Total Solar Panel Area (m²)

r = Solar Panel Yield (%), Kw/Area Of A Panel

H = Annual Average Solar Panel Radiation (**Shading Not Included**)

PR = Performance Ratio, Coefficient For Losses (**Range Between 0.5 And 0.9, Default Value 0.75**)

To Calculate How Much Energy Can Be Stored In Battery We Use^[10],

Battery Size In AH × Battery Voltage = Power Available In WH
(V)

The Energy Use By Appliance, 30w = 90WH Battery Needed
×3H

A Solar Panel Can Generate Energy over a Time^[11],

A 20w Panel ×5 Hours Of = 100w Energy Generate.
Sunshine

2.3 IGBT (Insulated-Gate Bipolar Transistor)

IGBT is a three terminal (**Collector, Gate, And Emitter**) power semiconductor device used to get high efficiency & fast switching ^[12]. It is allow to make power flow on the on state & to stop power flow on the off state. From these three terminals collector and emitter are associated with conductance path and the rest terminal 'gate' is associated with its control. It is act as both BJT and MOSFET. It has o/p characteristics of BJT, but it is controlled like an MOSFET. An IGBT has high input impedance like MOSFET (**Metal-Oxide-Semiconductor Field-Effect Transistor**) and low on-state conduction losses like BJT (**Bipolar Junction Transistor**) ^[13].

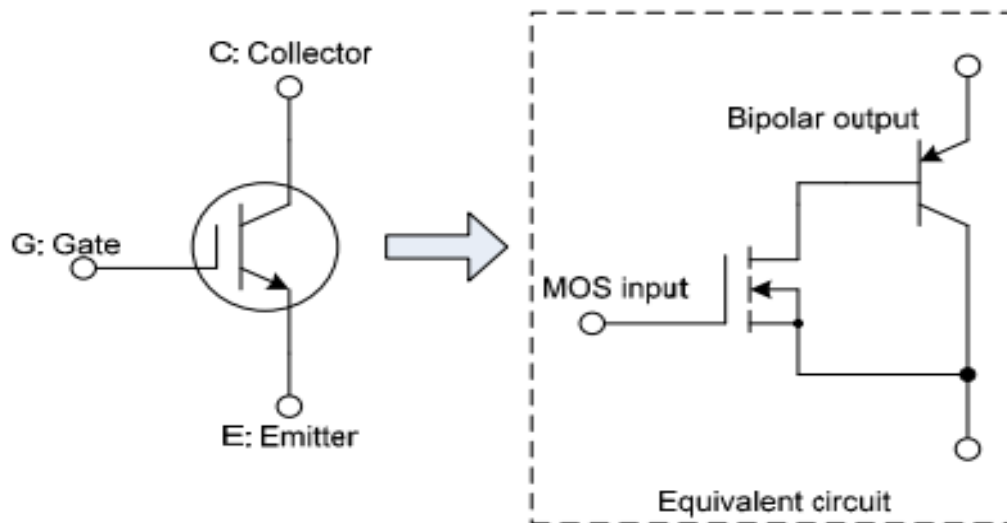


Figure 2.1: General IGBT Diagram

2.3.1 IGBT Working Principle

An IGBT is a voltage controlled device similar to a power MOSFET. Like an MOSFET, when the gate is made positive with respect to the emitter then the circuit will be on state mode, N carriers are drawn into the P channel near the gate region; this result in a forward bias of the base of the NPN transistor which indicate turns on.

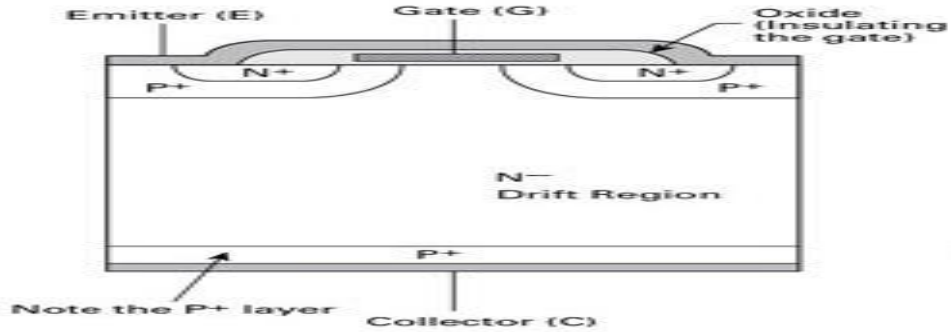


Figure 2.2: IGBT Cross Sectional View

An IGBT is turned on by just applying a positive gate voltage to open the channel and for N carriers. On the other hand the IGBT is turning off by removing the gate voltage to close the channel.

2.3.2 IGBT I-V Characteristics Curve

From the following figure I-v characteristics are shown depending on the different gate voltage. The X axis denotes collector emitter voltage and Y axis represents the collector current. During the off state the current flowing through the collector and the gate voltage is zero. When we change the gate voltage the device goes into the active region. Stable and continuous voltage across gate provides continuous and stable current flow through the collector. Increase of this voltage is proportionally increasing the collector current. $V_{ge3} > V_{ge2} > V_{ge1}$. BV is the breakdown voltage of the IGBT. This curve is identical with BJT's I-V transfer curve. But here Voltage is shown because IGBT is a voltage controlled device.

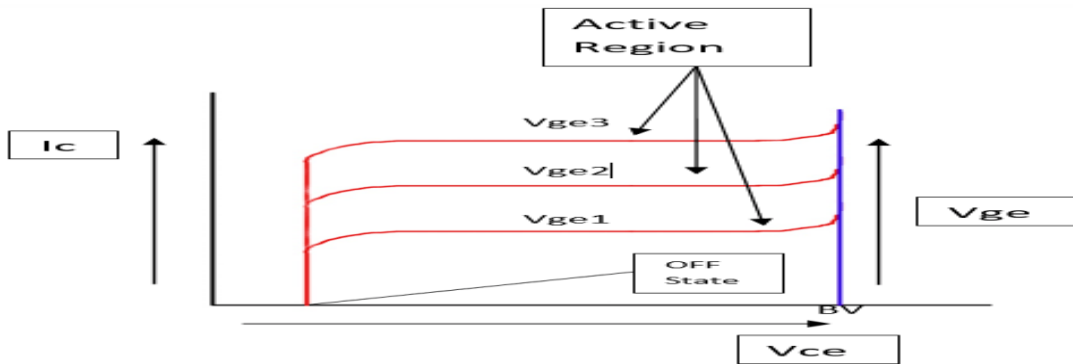


Figure 2.3: I-V Characteristics of IGBT

2.3.3 Transfer Characteristics

The following fig denotes the transfer character of an IGBT where the IGBT will go to the ‘ON’ state after gate voltage is greater than the Threshold value depending on the IGBT specification.

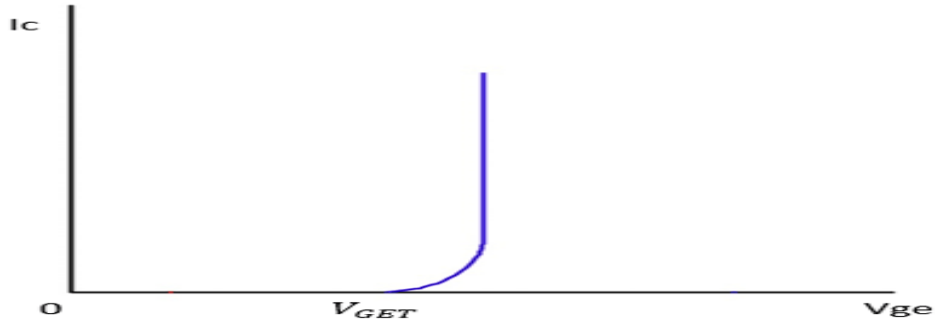


Figure 2.4: Transfer Characteristics of IGBT

2.4 Comparison between IGBT & Other Transistor

A general comparison among IGBT, MOSFET, and BJT is given below:

IGBT Comparison Table [ref]			
Device characteristic	BJT	MOSFET	IGBT
Voltage Rating	High<1KV	High<1KV	Very High>1KV
Current Rating	High<500A	High>500A	High>500A
Input Impedance	Low	High	High
Output Impedance	Low	Medium	Low

From above chart we see that IGBT voltage & current rating is better than BJT & MOSFET. Another we have found that IGBT has high input impedance like MOSFET & low output impedance like BJT, that’s why the IGBT act as both BJT & MOSFET. So for these reason we choose IGBT in our project.

2.5 PWM (Pulse Width Modulation)

It is a modulation technique to encode a message into a pulsing signal. An inverter can't produce power; it only can convert dc voltage to a symmetric ac output voltage of desired magnitude and frequency. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc input voltage is fixed and it is not controllable. A variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse wide modulation (PWM) control within the inverter.

The inverter gain may be defined as the ratio of the ac output voltage to the input dc voltage. The output voltage waveforms of ideal inverter should be sinusoidal. However, the waveforms of practical inverter are no sinusoidal and contain some harmonics. For low- and medium power applications, square wave or quasi square wave voltages may be acceptable; and for high power applications, low distorted sinusoidal wave forms are required. With the availability of high speed power semiconductor devices, the harmonic contents of output voltage can be minimized or reduced significantly by switching techniques. In this system design the Sinusoidal Pulse Width Modulation (SPWM) technique has been used for controlling the inverter as it can be directly controlled the inverter output voltage and output frequency according to the sine functions. PWM basic working diagram given below:

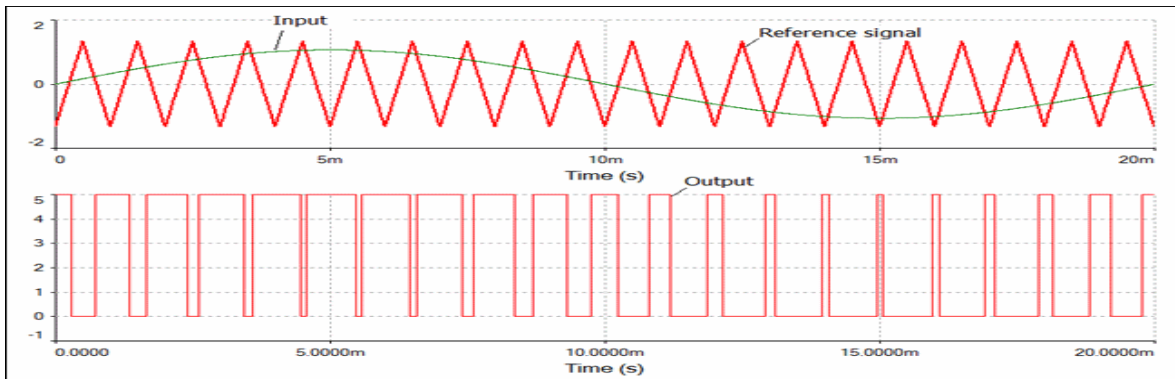


Figure 2.5: Compared To Sine Wave with Carrier Wave & Output Pulses

Here we see, Sine wave > carrier wave, so pulses will be high or 1 & Sine wave < carrier wave, so pulses will be low or 0.

2.6 Using Phase Sequence for SPWM in Mat lab

We have to generate three phase reference waves for three phase inverter. We have to generate three phase reference waves for three phase inverter. Frequency (Hz) converts into radian/s in all phase.

For 1 st phase	For 2 nd phase	For 3 rd phase
F = 50Hz	F = 50Hz	F = 50Hz
Phase delay=0 degree.	Phase delay=120 degree.	Phase delay= -120 or 240 degree.
$\therefore \omega = 2\pi * 50$ rad/s.	$\therefore \omega = 2\pi/3$ rad/s.	$\therefore \omega = -2\pi/3$ or $4\pi/3$ rad/s

2.7 Inductor

In electromagnetism and electronics, inductance is an electrical conductor by which a change occurs in electric current through it makes an electromagnetic voltage in the conductor. It is measured by Henry (H). According to Faraday's Electromagnetic induction law, when the current flowing a conductor changes the time varying magnetic field induces a voltage in the conductor. An electric current flowing through a conductor generates a magnetic field surrounding it. The magnetic flux (ϕ_B) generated by a given current I depends on the geometric shape of the circuit. Their ratio defines the inductance L.

Thus,

$$L = \frac{\phi_B}{I}$$

$$\text{Or } \phi_B = LI$$

An inductor is a component consisting of a wire or other conductor shaped to increase the magnetic flux through the circuit, usually in the shape of a coil. Winding of the wire into a coil increase the number of times the magnetic flux, the more turns; the higher the inductance. The inductance also depends on the shape of the coil. Any change of current through an inductor creates a changing flux, inducing a voltage across the inductor. By Faraday's law of induction, the voltage induced by any change in magnetic flux.

$$\begin{aligned}\epsilon &= -\frac{d\phi_B}{dt} \\ &= -\frac{d}{dt}(LI) \\ &= -L\frac{dI}{dT}\end{aligned}$$

For L is independent of time. So inductance is also a measure of the amount of electromotive force generated for a given rate of change of current. The negative sign indicates that the work is done against the Electromotive force and is not by the EMF.

According to lens law, the direction of induced EMF opposes the change in current that created it. Hence, induced EMF is opposite to the voltage applied across the coil. For example, if the current through the inductor is increasing, the induced voltage will be positive at the terminal through which the current enters and negative at the terminal through which it leaves, tending to oppose the additional current. This is the property of an inductor.

Fixed-value



Iron core



Variable



Variac



Tapped



Figure 2.6: Basic diagram of Inductor

2.8 Capacitor

A capacitor is a two terminal electrical component that stores potential energy or charge in an electrical field & discharge when needed. The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a

capacitor is a component designed to add capacitance to a circuit. The capacitor was known as condenser or condensate. Most capacitors contain at least two electrical conductors, often in the form of metallic plates or surfaces separated by a dielectric medium.

When two conductors experience a potential difference, for example, when a capacitor is attached across a battery, an electric field is develop across the dielectric, causing a net positive charge to collect on one plate and net negative charge to collect the other plate. No current actually flows through the dielectric; however there is a flow of charge through the source circuit. If the condition is maintained sufficiently long, the current through the source circuit ceases. Capacitance is also defined as the ratio of the electric charge on each conductor to the potential difference between them. It is measured by farad (F). Purpose of Capacitor: To keep separated negative and positive charge from each other. In an AC circuit the capacitance changes the phase angle of voltage & current.

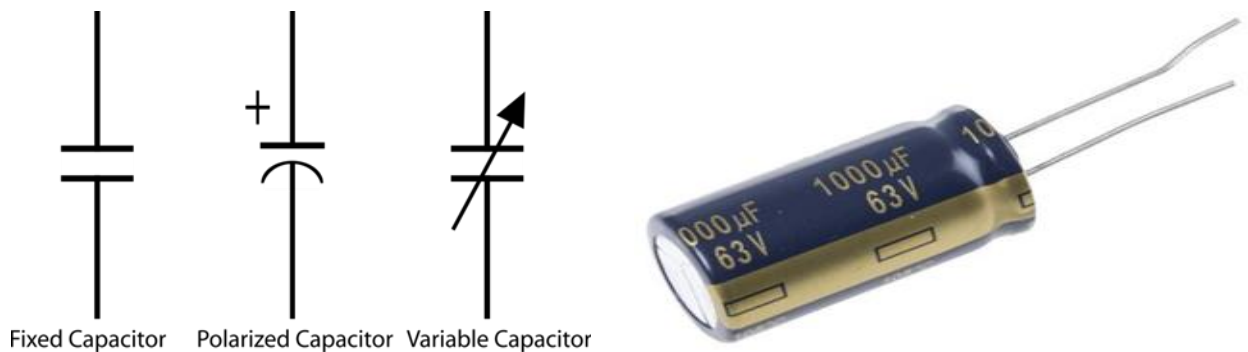


Figure 2.7: Basic Symbol of Capacitor.

2.9 Resistor

A resistor is a two terminal electrical component that works as an electrical resistance of a circuit diagram. The two types of resistors are used in a circuit. One is fixed and another is variable. Fixed resistor has resistances that only change slightly with temperature, time or operating voltage. Variable resistor can be used o adjusts circuit elements or as sensing devices for heat,

light, humidity, force or chemical activity. The behavior of an idea resistor is dictated by the relationship specified by Ohm’s law,

$$V = IR$$

Ohm’s law states that the voltage (V) across a resistor is proportional to the current (I) where the constant of proportionality is the resistance. For example, if a 300 ohm resistor is attached across the terminals of a 12 volt battery, then the current will be $12/300 = 0.04$ amperes flows through the resistor. If 120 ohm resistor is connect instead of 300 ohm then the value of current will be 0.01 amperes. In such way resistor is used to control current flow through a circuit as required. It is measured by ohms (Ω).It is used to reduce current flow, to divide voltage, adjust signal levels, ending transmission line, etc.

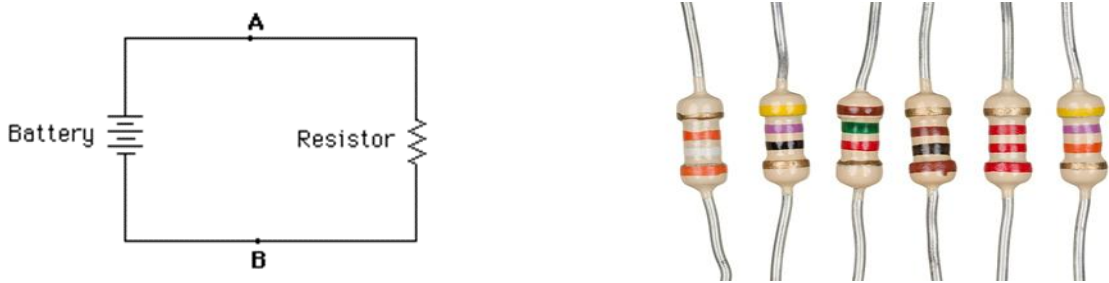


Figure 2.8: Basic Symbol of Resistor

The resistor can be connected in series and parallel. The total resistances of resistors connected in series are the sum of their individual resistance values.

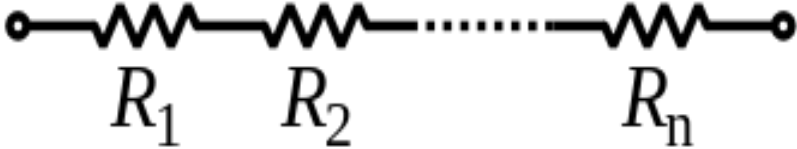


Figure 2.9: Series Resistance

The equivalent resistance will be from the above fig is,

$$R_{eq} = R_1 + R_2 + \dots + R_n$$

The total resistance of resistors connected in parallel is the reciprocal of the sum of the reciprocals of the individual resistor.

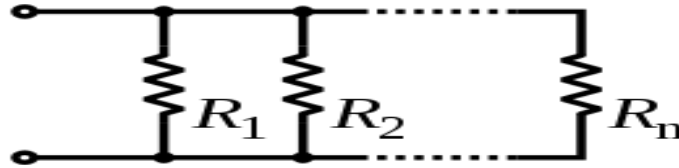


Figure 2.10: Parallel Resistance

The equivalent resistance for parallel connection from the above fig is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

Estimated Resistor Color Code:

For four color band, the first two are rainbow band, third band is decimal multiplier and the last one is tolerance band.

For five color band, the initial three are denoted as rainbow band, fourth is decimal multiplier and the rest one is the tolerance band.

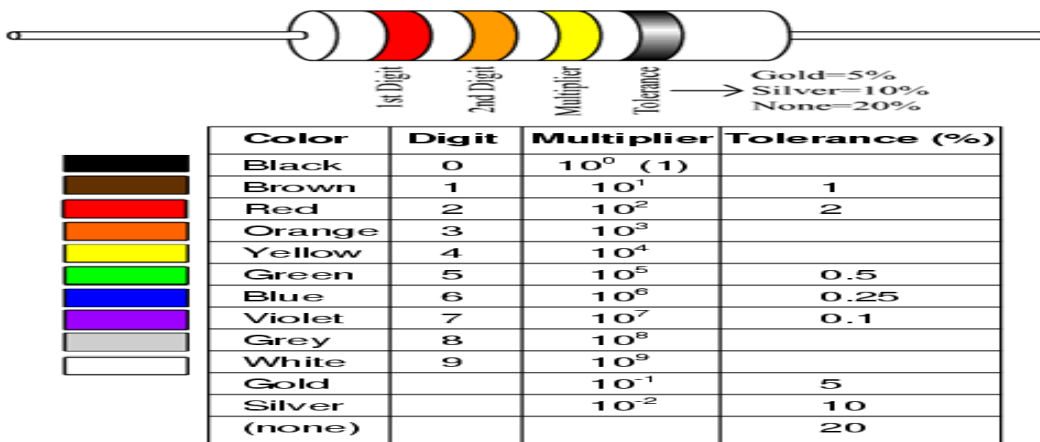


Figure 2.11: Resistor Color Code Value & Tolerance ^[14]

Here, the 1st color is red, for red the digit is 2&the 2nd color is orange, for orange the digit is 3, So the resistance is going to start with ‘23’. The 3rd band is decimal multiplier which is yellow color, for yellow the digit is 4, so we can use four zeros at the end of 23, now the value will be 230000 Ω. Now the final band is tolerance which is silver color, for silver the tolerance is ±10%. So the range of resistance will be at (207000-253000) Ω.

2.10 Filter

In signal processing, a filter is a device or process that removes some unwanted components or features from a signal. Filtering is a class of signal processing, the defining features of filters being the complete or partial suppression of some aspect of the signal. Most often filter removing some frequencies or frequency bands. However filter does not exclusively act in the frequency domain; especially in the field of image processing many other targets for filtering exist. Input filter removes any ripple or frequency disturbances on the DC supply, to provide a clean voltage to the inverter circuit. And the output filter removes high frequency components of the PWM wave, to produce a near sinusoidal output.

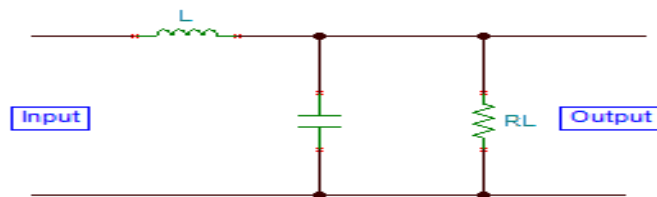


Figure 2.12: LC Filter Des

Electronic filters are generally consisting of resistance, capacitance and inductance. The frequency response can be classified into a number of different band forms describing which frequency bands the filter passes and which are reject,

Low Pass Filter : Low Frequencies Are Passed And High Frequencies Are Attenuated.

High Pass Filter : High Frequencies Are Passed And Low Frequencies Are Attenuated.

Band Pass Filter : Only Frequencies In A Frequency Band Can Pass.

Band Stop Filter : Only Frequencies In A Frequency Band Can Attenuated.

Notch Filter : Reject Just One Specific Frequency.

Comb Filter : Has Multiple Regularly Spaced Narrow Pass Bands Giving The Band Form The Appearance Of A Comb.

All Pass Filter : All Frequencies Are Passed, But The Phase Of The Output Is Modified.

Chapter 3

System Design & Development

3.1 Introduction

In this chapter discuss the schematic diagram of solar cell inverter & the development of this inverter by using SPWM & the THD (Total Harmonic Distortion) of our project as well.

3.2 Inverter

An inverter is an electronics and electrical equipment which provides AC from DC power sources. It is extensively used not only because of their universal function of converting DC power to AC power, but also because of their high efficiency, reduced power cost and versatile applications. It is a good and efficient device for power remedies.

3.2.1 Types of Inverter

The Square Wave Inverter:

A square wave inverter is one of the simplest types which convert a straight DC signal to a phase shifting AC signal. But the output is not pure AC signal. It's formed a pure square wave. It is cheaper than others and simplest construction of a square wave inverter can be get by using on-off switch.

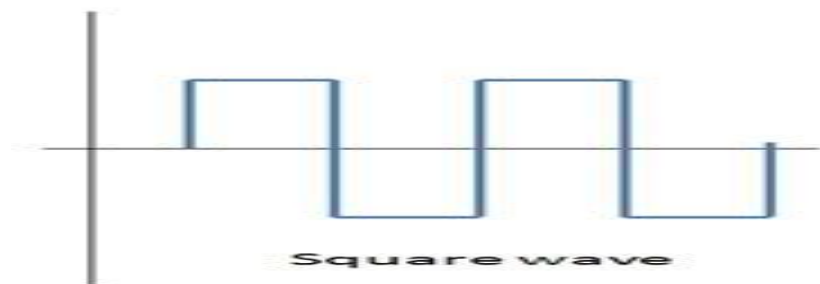


Figure 3.1: Output of A Square Wave Inverter

The Modified Sine Wave Inverter or Quasi Sine Wave Inverter:

The construction of this type of inverter is a bit complex than before inverter but still it is a lot simpler than a pure sine wave inverter. It doesn't shift its phase abruptly from positive to negative or unlike a sine wave, doesn't make a smooth transmission from positive to negative, but takes a brief pauses and then shifts its phase.



Figure 3.2: Output of A Quasi-Square Wave Inverter

Pure Sine Wave Inverter:

The operation of a pure sine wave inverter is far more complex than other two types. Another way to obtain a square wave output from a square wave inverter and then modifies this output to achieve a pure sine wave.



Figure 3.4: Output of a Pure Sine Wave Inverter

3.2.2 Operation of Inverter

For obtain a three phase ac output from dc battery, six IGBT are act as switches with star connected load which has four terminals. The S1, S3 and S5 are upper switches where S4, S6 and S2 are lower switches. There are six modes of operation in a cycle and the duration of each mode is 60°. So the switches are act with firing angle such as (S1=0°, S2=60°, S3=120°, S4=180°, S5=240°, S6=300°), thus this cycle conduct continue.

3.2.3 Circuit Diagram for Regular Solar Cell Three Phase Voltage Source Inverter:

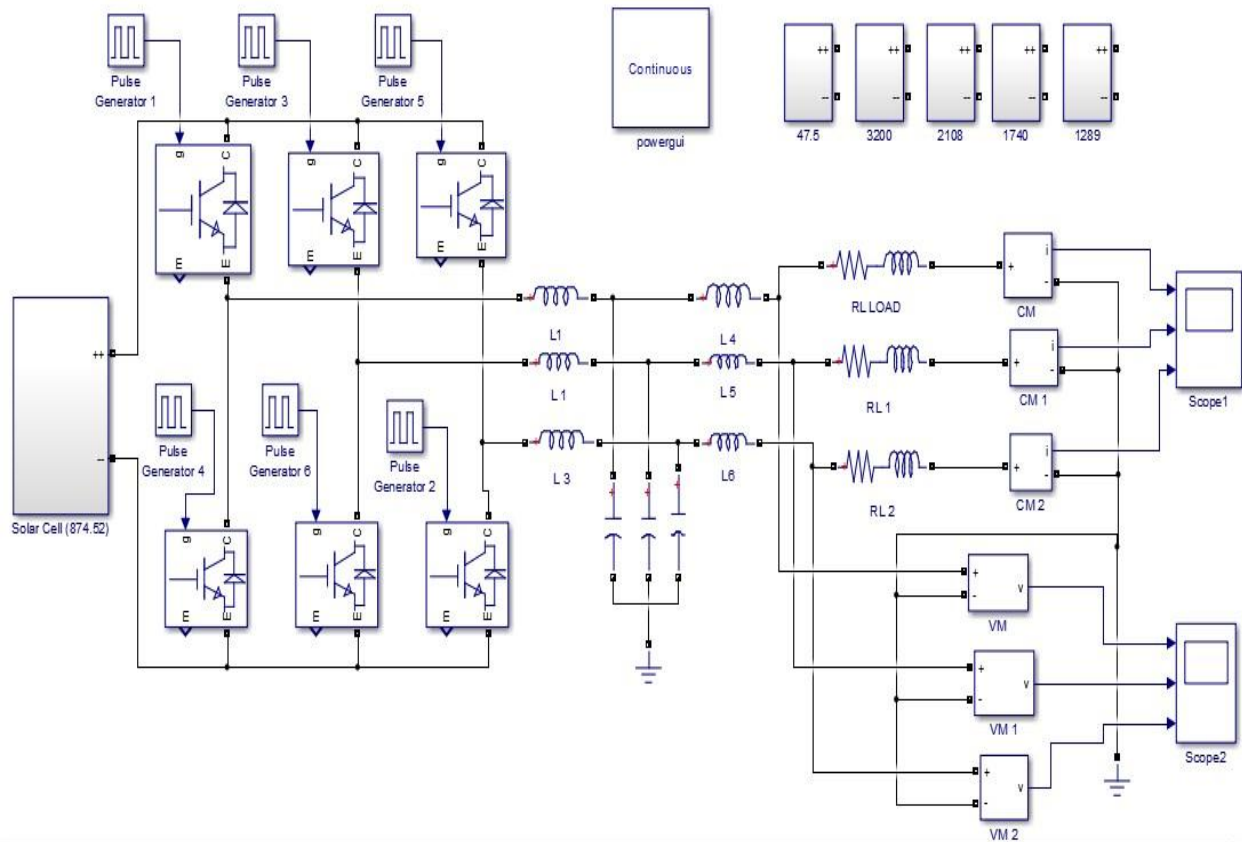


Figure 3.5: Simulation Circuit Diagram of Three Phases Solar Inverter (VSI)

In this inverter we have three lag a, b and c and have eight different combinations such as **(000,001,010,011,100,101,110 and 111)**. When all the upper switches are on state mode then the line-to-line voltage are zero. Even when all the lower switches are on state mode then the line-to-line voltage are also zero. And when two switches: one upper and one lower conduct at the same time then the output voltage is $+V_s$ or $-V_s$.

Table Calculation for Three Phase Inverter:

S1	S3	S5	$V_{c0}(t)$	$V_{b0}(t)$	$V_{a0}(t)$	V_{ab}	V_{bc}	V_{ca}
0	0	0	$-\frac{V_s}{2}$	$-\frac{V_s}{2}$	$-\frac{V_s}{2}$	0	0	0
0	0	1	$-\frac{V_s}{2}$	$-\frac{V_s}{2}$	$+\frac{V_s}{2}$	0	$-V_s$	V_s
0	1	0	$-\frac{V_s}{2}$	$+\frac{V_s}{2}$	$-\frac{V_s}{2}$	$-V_s$	V_s	0
0	1	1	$-\frac{V_s}{2}$	$+\frac{V_s}{2}$	$+\frac{V_s}{2}$	$-V_s$	0	V_s
1	0	0	$+\frac{V_s}{2}$	$-\frac{V_s}{2}$	$-\frac{V_s}{2}$	V_s	0	$-V_s$
1	0	1	$+\frac{V_s}{2}$	$-\frac{V_s}{2}$	$+\frac{V_s}{2}$	V_s	$-V_s$	0
1	1	0	$+\frac{V_s}{2}$	$+\frac{V_s}{2}$	$-\frac{V_s}{2}$	0	V_s	$-V_s$
1	1	1	$+\frac{V_s}{2}$	$+\frac{V_s}{2}$	$+\frac{V_s}{2}$	0	0	0

Switching State 001

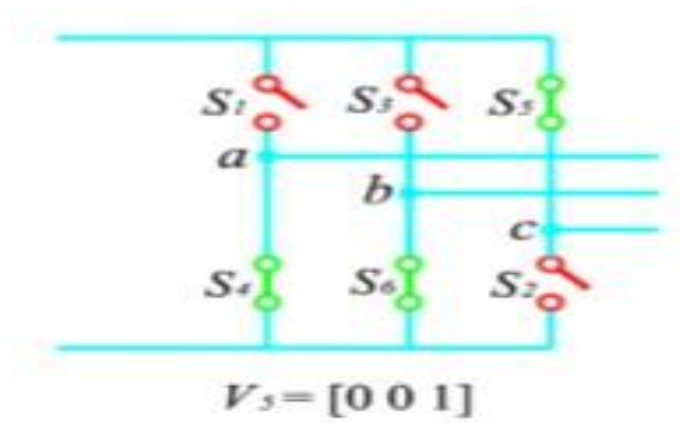


Figure 3.6: Switching State 001

Switching state 001 means S1 and S3 off, S5 on. When S1 and S3 are off it is connecting through the negative voltage. So the voltage of lag a & lag b is negative. Switch S5 is on and it is connected with positive voltage. So lag c is positive.

Switching State 010

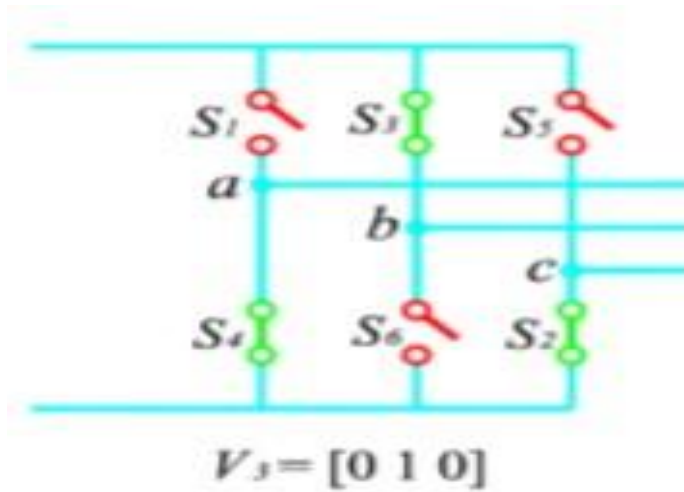


Figure 3.7: Switching State 010

Switching state 010 means S1 and S5 off, S3 on. When S1 and S5 are off it is connecting through the negative voltage. So the voltage of lag a and lag care negative. Switch S3 is on and it is connected with positive voltage. So lag b is positive.

Switching State 011

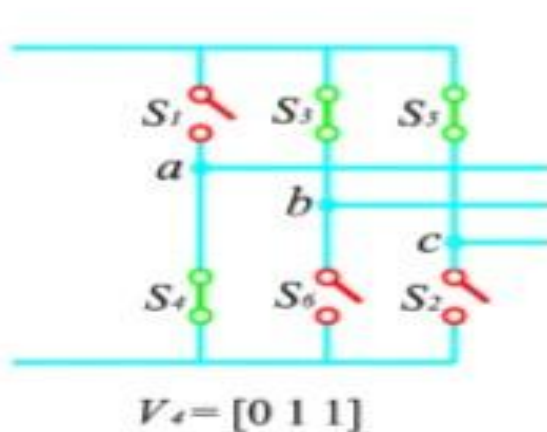


Figure 3.8: Switching State 011

Switching state 011 means S1 off, S3 and S5 on. When S1 is off it is connecting through the negative voltage. So the voltage of lag a is negative. Switch S3 and S5 are on and it is connected with positive voltage. So lag b and lag c are positive.

Switching State 100

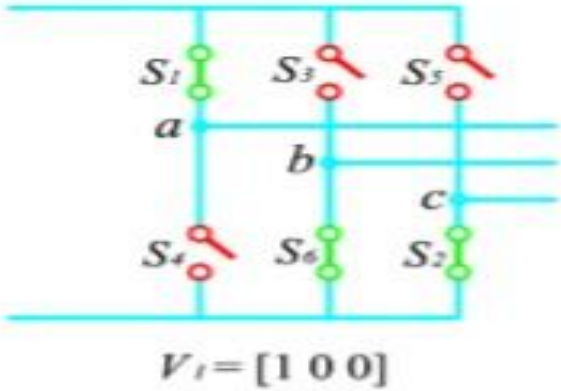


Figure 3.9: Switching State 100

Switching state 100 means S1 on, S3 and S5 off. When S1 is on it is connecting through the positive voltage. So the voltage of lag a is positive. Switch S3 and S5 are off and it is connected with negative voltage. So lag b and lag c are negative.

Switching State 101

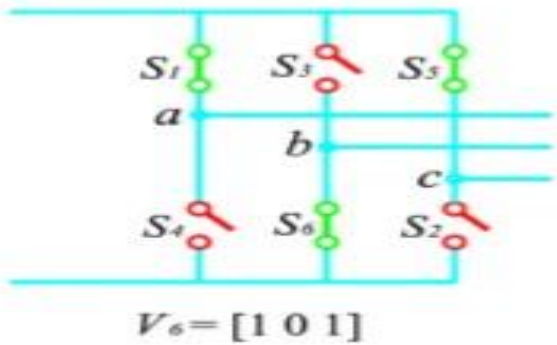


Figure 3.10: Switching State 101

Switching state 101 means S1 and S5 on, S3 off. When S1 and S5 are on it is connecting through the positive voltage. So the voltage of lag a and lag c are positive. Switch S3 is off and it is connected with negative voltage. So lag b is negative.

Switching State 110

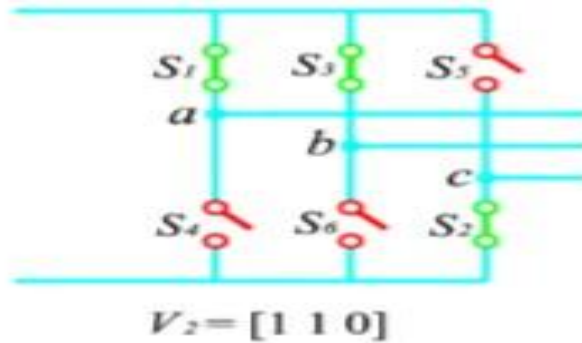


Figure 3.11: Switching State 110

Switching state 110 means S1 and S3 on, S5 off. When S1 and S3 are on it is connecting through the positive voltage. So the voltage of lag a and lag b is positive. Switch S5 is off and it is connected with negative voltage. So lag c is negative.

Switching State for Zero Vector

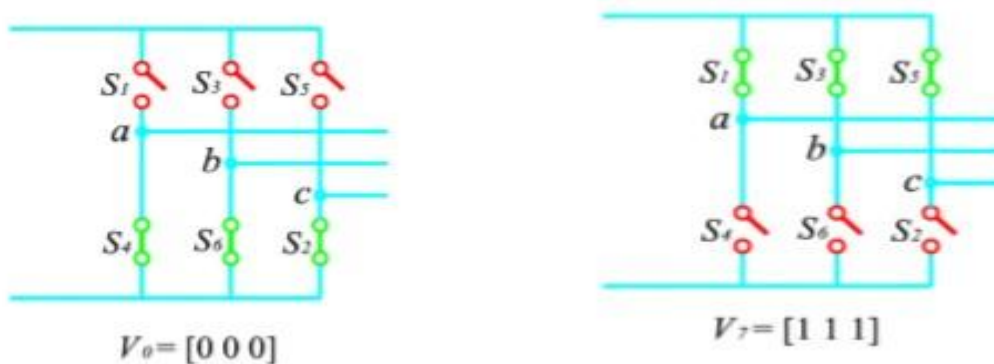


Figure 3.12: Switching State for Zero Vector

Switching state **000** and **111** are called zero vectors. In switching state **111** all upper switches are on and they are connected with each other. So there is no voltage at any lag. Same as switching state **000**.

3.2.4 Finding Three Phase Conduction for 180°

The conduction sequence of transistors is **123, 234, 345, 456, 561, and 612**. For a Y connected load, the line-to-neutral voltage must be determined to find the line or phase currents. There are three modes of operation in half-cycle and the equivalent circuit shown below:

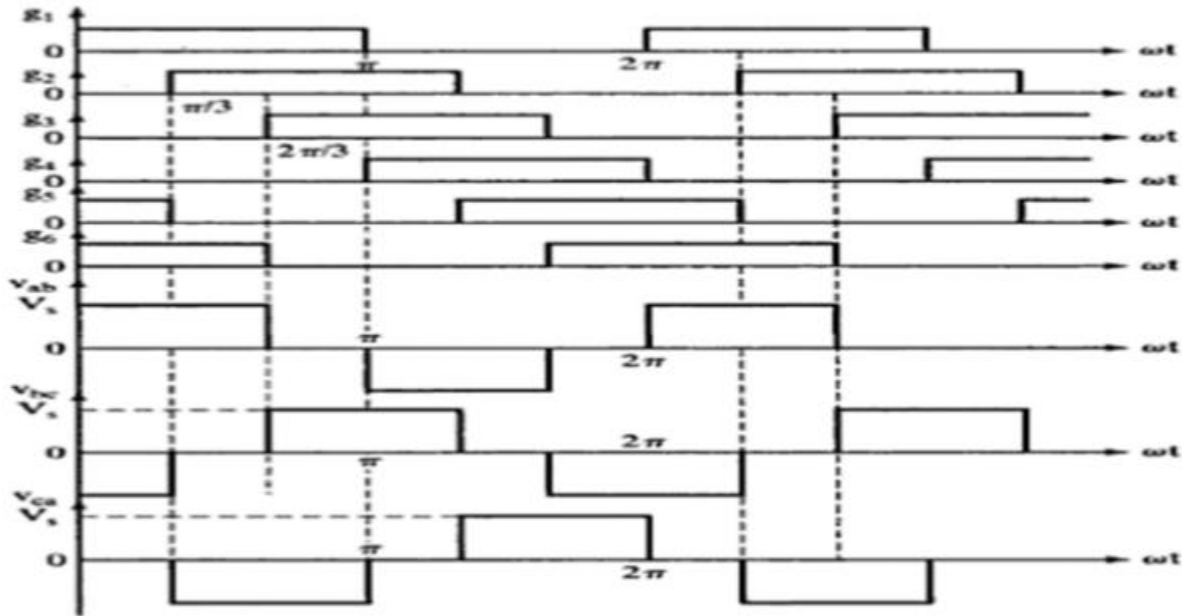


Figure 3.13: Conduction for 180°

Table Calculation for 180° Conduction

Switch	Conduction°
S1	0 +180 = 180
S2	60 to 240
S3	120 to 300
S4	180 to 360
S5	240 to 420
S6	300 to 480

After 360° the S1 switch is repeating thus way.

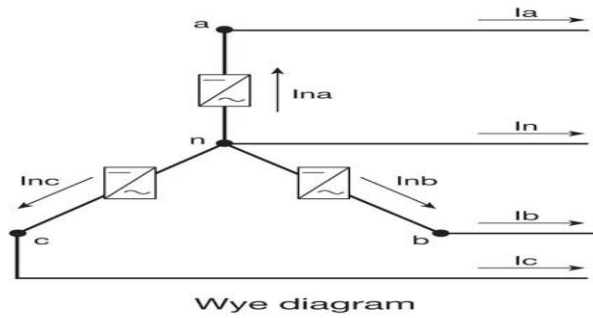


Figure 3.14: Y-connected

During mode 1 for $0 \leq \omega t < 60^\circ$, transistors Q1, Q5 and Q6 conduct.

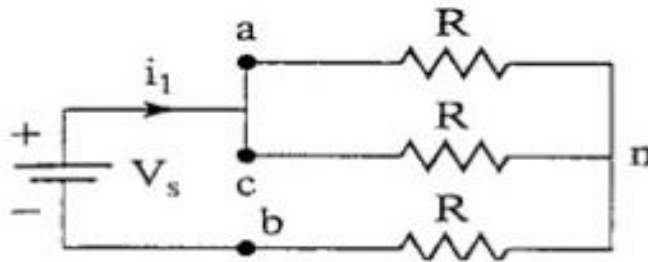


Figure 3.15: Mode 1 for 180 degree

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$I_1 = \frac{V_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = V_{cn} = \frac{i_1}{2} R = \frac{V_s}{3}$$

$$V_{bn} = -i_1 R = \frac{-2V_s}{3}$$

During mode 2 for $60^\circ \leq \omega t < 120^\circ$, transistors Q1, Q2 and Q6 conduct.

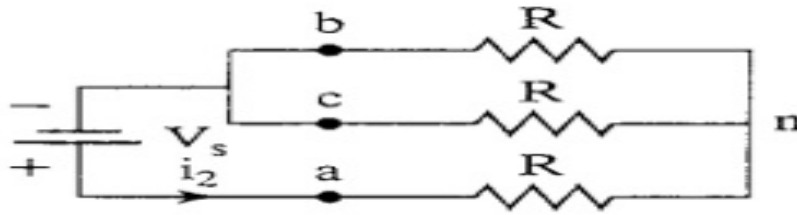


Figure 3.16: Mode 2 for 180 Degree

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$I_2 = \frac{v_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = i_2 R = \frac{2v_s}{3}$$

$$V_{bn} = V_{cn} = \frac{-i_2 R}{2} = \frac{-v_s}{3}$$

During mode 3 for $120^\circ \leq \omega t < 240^\circ$, transistors Q1, Q2 and Q3 conduct

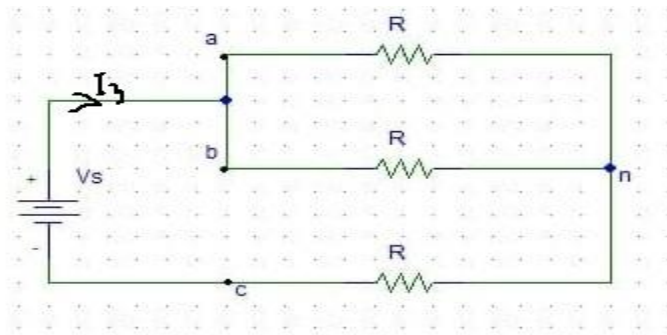


Figure 3.17: Mode 3 for 180 degree

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$I_3 = \frac{v_s}{R_{eq}} = \frac{2V_s}{3R}$$

$$V_{an} = V_{cn} = \frac{i_3 R}{2} = \frac{v_s}{3}$$

$$V_{bn} = -i_3 R = \frac{-2v_s}{3}$$

Phase Voltages for 180° Conduction

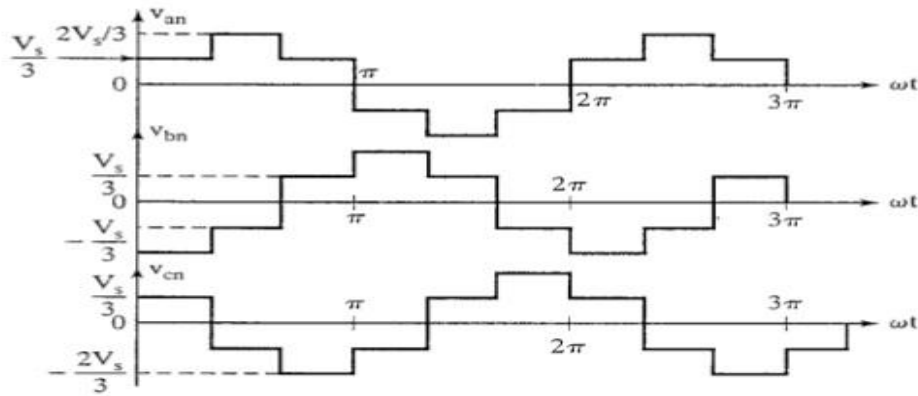


Figure 3.18: Phase Voltages for **180** Degree Conduction

To find out line to line voltage for 180 degree conduction V_{ab} is phase shifted by 30° for Y connected load as

$$V_{ab} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t + \frac{\pi}{6})$$

Similarly, for V_{bc} and V_{ca} phase shift by 120° & 240° according to V_{ab}

$$V_{bc} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t - \frac{\pi}{2})$$

$$V_{ca} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t - \frac{7\pi}{6})$$

Now the line-to-line rms voltage can be found from.

$$\begin{aligned} V_L &= \left[\frac{2}{2\pi} \int_0^{2\pi} V_s^2 d(\omega t) \right]^{0.5} \\ &= \sqrt{\frac{2}{3}} V_s = 0.8165 V_s \end{aligned}$$

From here the rms phase voltage can be found.

$$V_p = \frac{V_L}{\sqrt{3}}$$

The line current i_a is given by.

$$I_a = \sum_{n=1,3,5,\dots}^{\infty} \left[\frac{4v_s}{\sqrt{3}[n\pi\sqrt{R^2+(n\omega L)^2}]} \sin \frac{n\pi}{3} \right] \sin(n\omega t - \theta_n).$$

3.2.5 Finding Three Phase Conduction for 120°

The conduction sequence of transistors is **12, 23, 34, 45, 56, and 61**. For a Y connected load, and the line-to-neutral voltage must be determined to find the line or phase currents. There are three modes of operation in half-cycle and the equivalent circuit shown below:

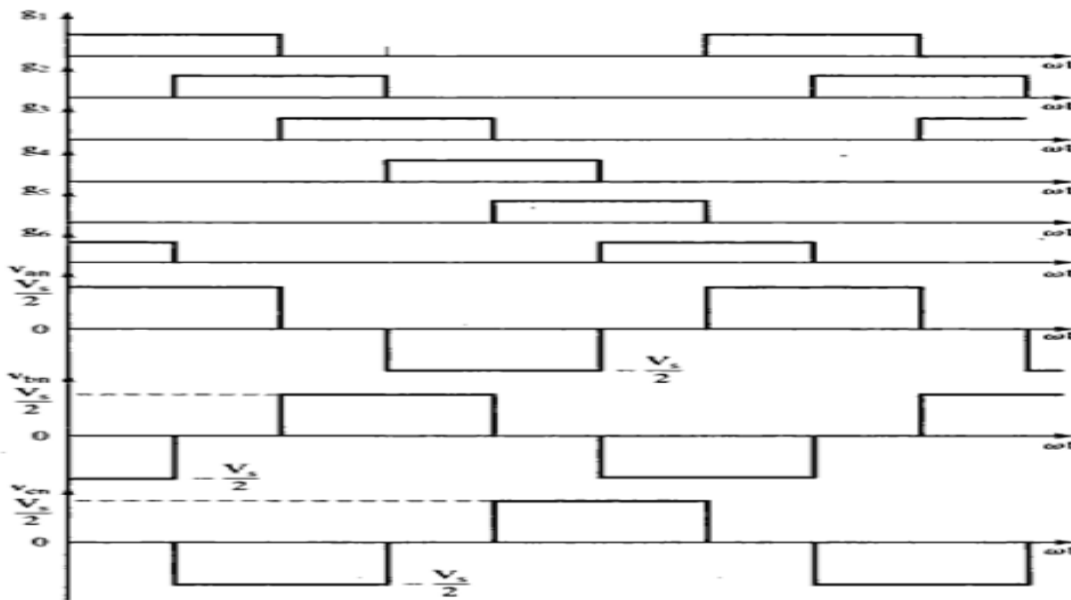


Figure 3.19: Conduction for 120°

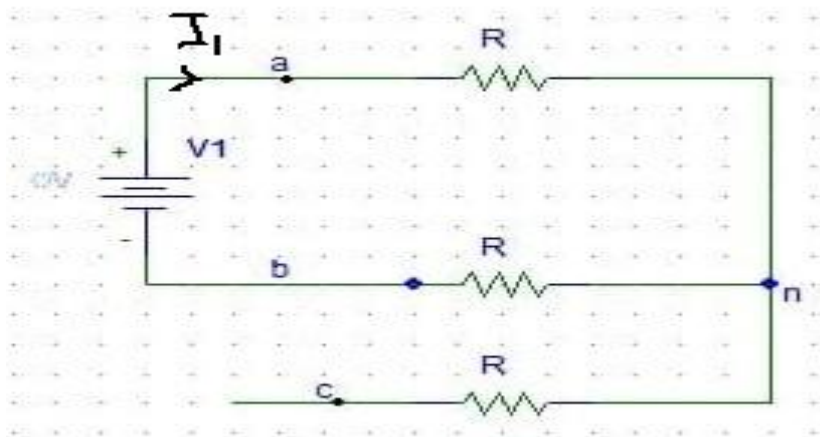


Figure 3.20: Mode 1

During mode 1 for $0 \leq \omega t < 60^\circ$, transistors Q1, Q5 and Q6 conduct.

$$V_{an} = \frac{v_s}{2}$$

$$V_{bn} = \frac{-v_s}{2}$$

$$V_{cn} = 0$$

During mode 2 for $60^\circ \leq \omega t < 120^\circ$, transistors Q1, Q2 and Q6 conduct.

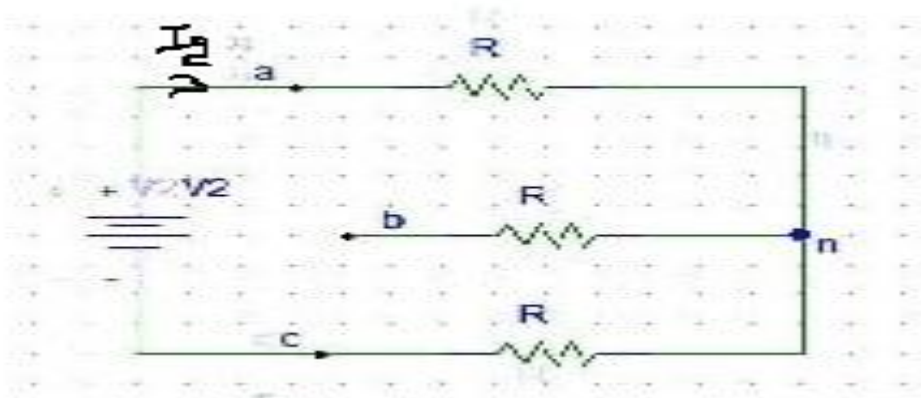


Figure 3.21: Mode 2

$$V_{an} = \frac{v_s}{2}$$

$$V_{bn} = 0$$

$$V_{cn} = \frac{-v_s}{2}$$

During mode 3 for $120^\circ \leq \omega t < 240^\circ$, transistors Q1, Q2 and Q3 conduct

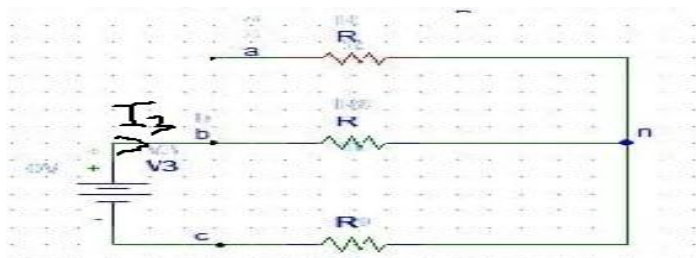


Figure 3.22: Mode 3

$$V_{an} = 0$$

$$V_{bn} = \frac{v_s}{2}$$

$$V_{cn} = \frac{-v_s}{2}$$

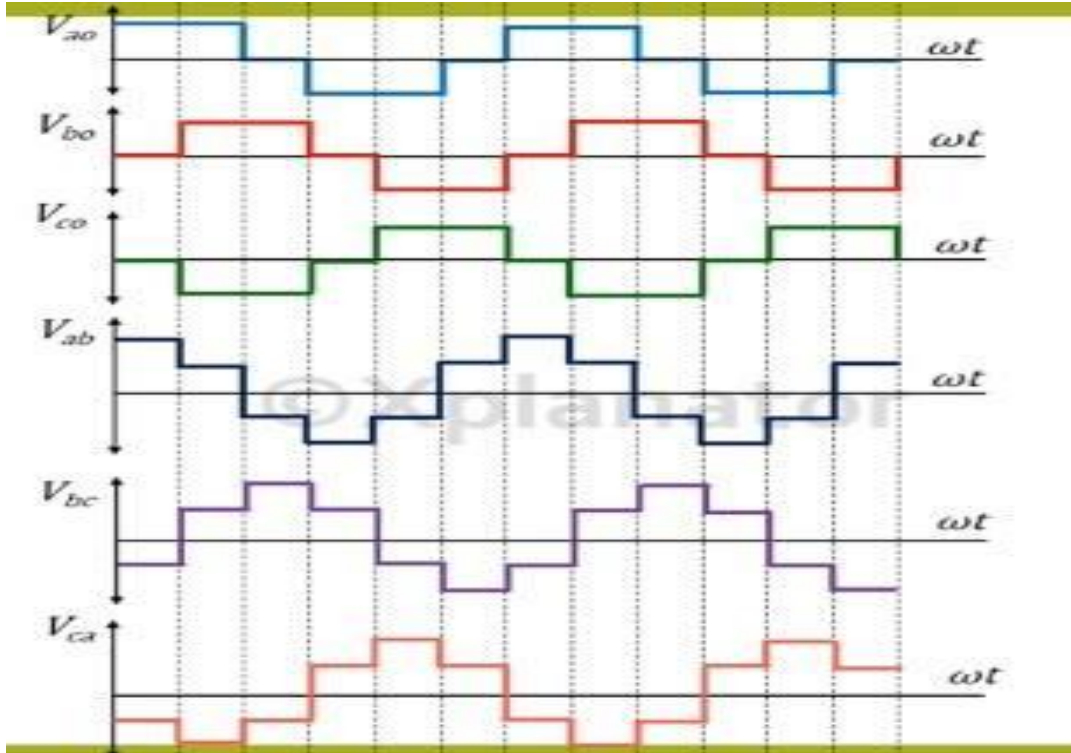


Figure 3.23: Line-To-Line Voltage for 120 Degree Conduction

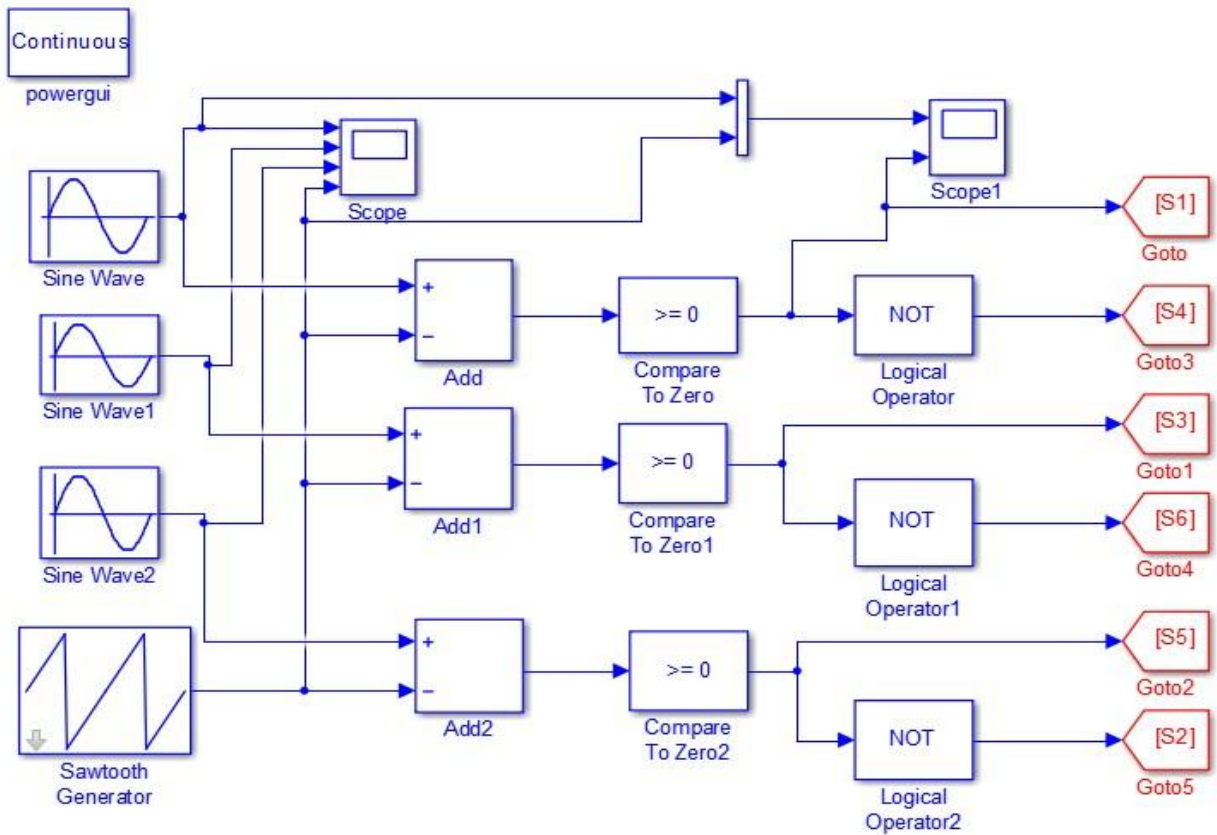
Line-to-line voltage equation for 120 degree conduction,

$$V_{ab} = \sum_{n=1,3,5,\dots}^{\infty} \frac{2\sqrt{3}V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t + \frac{\pi}{3})$$

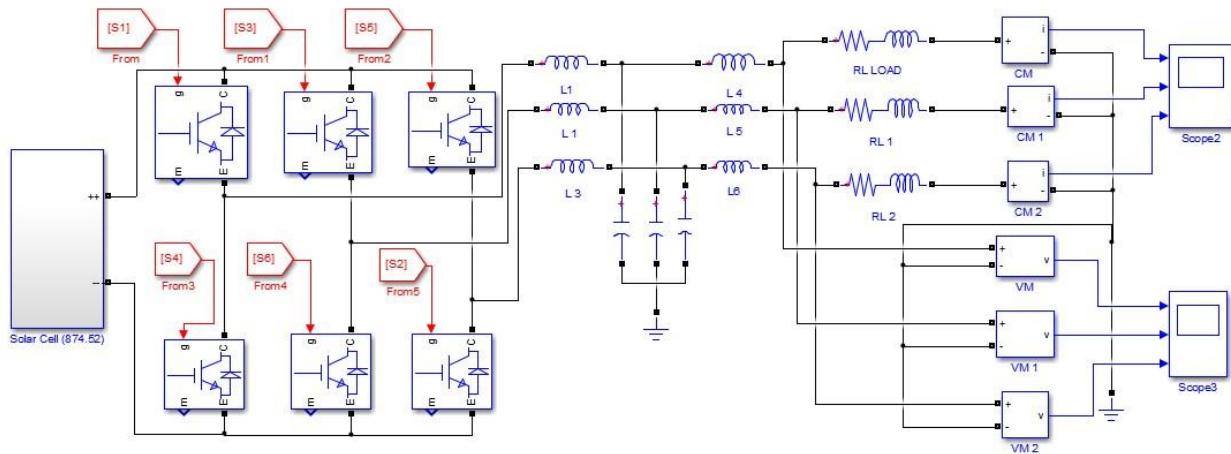
$$V_{bc} = \sum_{n=1,3,5,\dots}^{\infty} \frac{2\sqrt{3}V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t - \frac{\pi}{3})$$

$$V_{ca} = \sum_{n=1,3,5,\dots}^{\infty} \frac{2\sqrt{3}V_s}{n\pi} \sin \frac{n\pi}{3} \sin n(\omega t - \pi).$$

3.2.6 Circuit Diagram for Three Phases Solar Inverter after Controlling By SPWM:



a. part 1



b. part 2

Figure 3.24: Simulation Circuit Diagram of This Inverter Controlling By SPWM (a. part 1, b. part 2)

Here For Comparison 'Add Block Sign' Should Be '+ -'.

Sine wave connected at '+' of add block so it should be ' $> = 0$ ' for generate 'high' when sine wave is greater than carrier wave.

Set tags of each 'Go to': S1, S3, and S5. These are given to upper switches of the inverter respectively, resulting positive part of the waves.

Now add 'Go to' lower switches of the inverter S4, S6, and S2. It is complementary of upper switches in the same structure. For making complementary add 'logical operator' block and set it to 'NOT'. Then add 'From block' to the inverter.

3.2.7 Using Blocks for Simulating of SPWM

Sine Wave Block : Used For Generating Sine Wave.

Saw tooth Generator : Used For Generating Saw tooth Wave.

Add & Compare : Used For Comparison To Zero Block Of Waves.

Mux : For Multiplexing Signals.

Scope : For Displaying.

Go To & From : For Giving Pulses To The Inverter 'Go To' & 'From' Is Used.

3.3 THD (Total Harmonic Distortion)

The total harmonic distortion is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the power of all harmonic components to the power of the fundamental frequency.

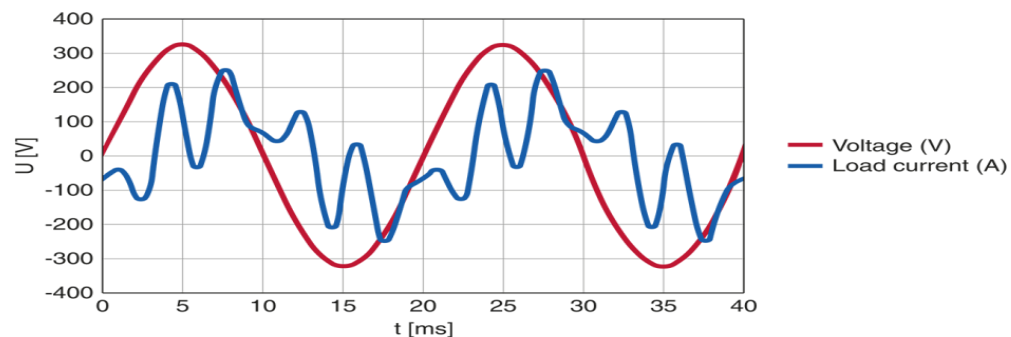


Figure 3.25: Harmonic Distortion

THD is defined as the ratio of the equivalent root mean square (RMS) voltage of all the harmonic frequencies (from the 2nd harmonic) over the RMS voltage of the fundamental frequency. The equation is

$$\mathbf{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} v_{n_rms}^2}}{v_{fund_rms}}$$

Units : Unit Less

Limits : $THD \geq 0$.

Chapter 4

Result & Discussion

In this chapter introduce the simulation output for current & voltage of solar cell inverter & the result after controlling that solar inverter by SPWM & the result of THD of both as well.

4.1 The Result for Regular Solar Cell Three Phase Voltage Source Inverter

In our work we used 874.53V DC from solar cell & after simulate we get peak voltage 165V & peak current 17A. The calculated value & total harmonic distortion given below

4.1.1 Output for Voltage & Current



Figure4.1: Mat Lab Simulation Output for Current (a. Phase 1, b. Phase 2, c. Phase 3)

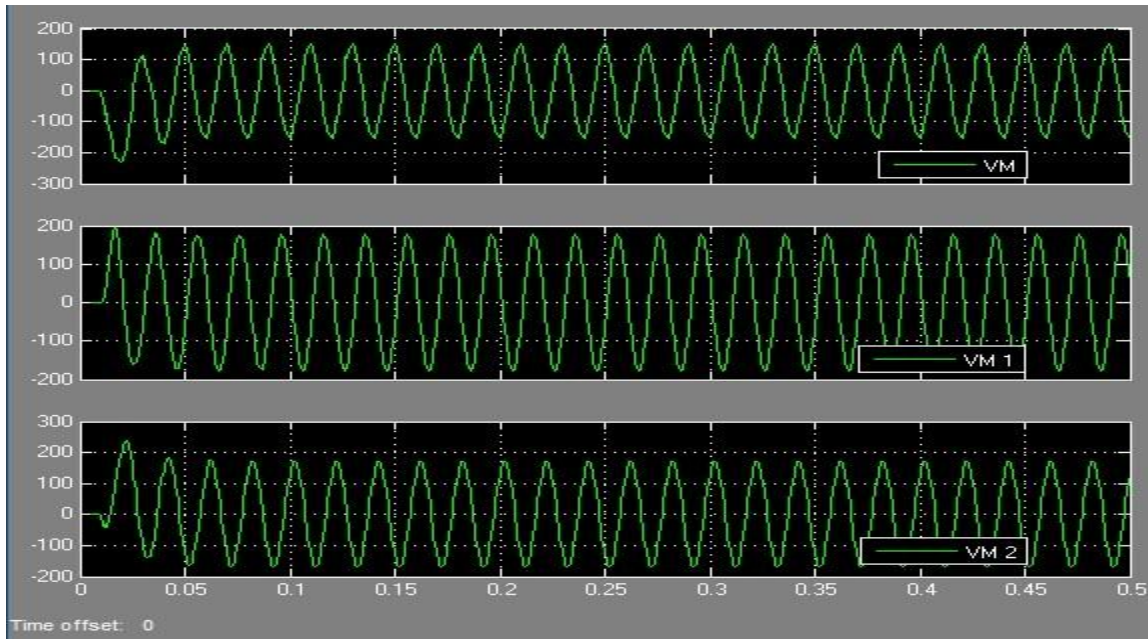


Figure 4.2: Mat Lab Simulation Output for Voltage (a. Phase 1, b. Phase 2, c. Phase 3)

4.1.2: THD (Total Harmonic Distortion):

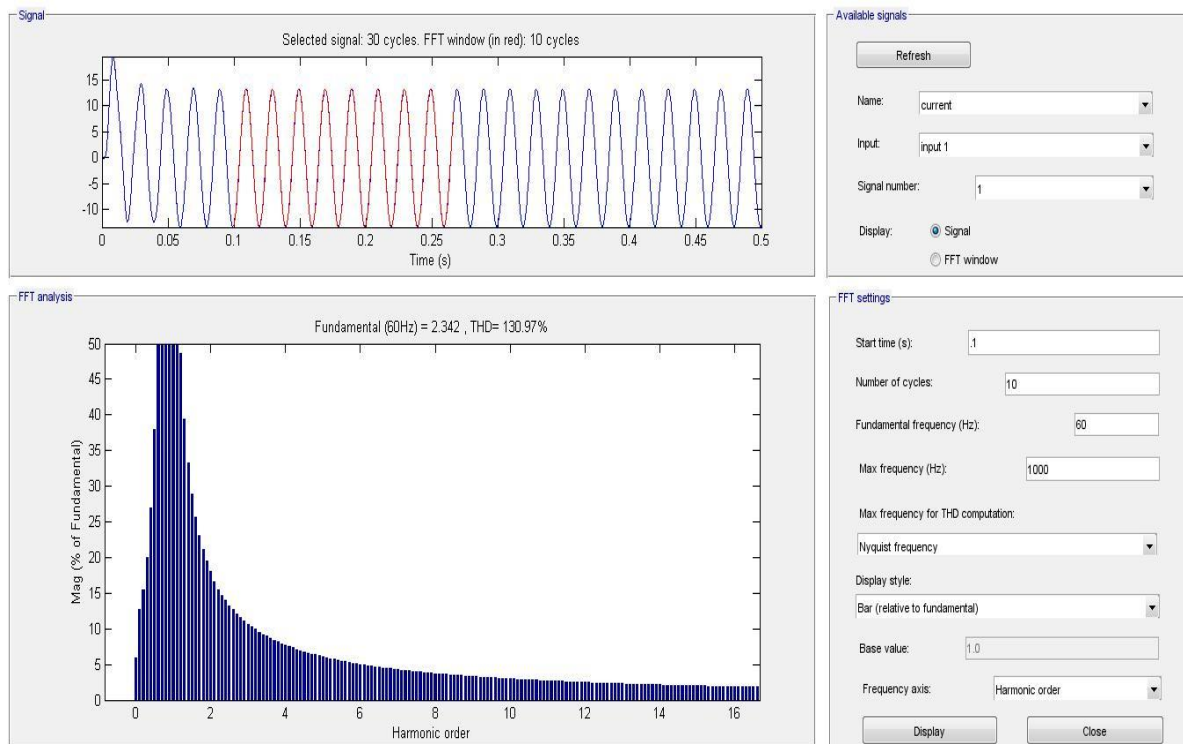


Figure 4.3: THD (Total Harmonic Distortion) For Current

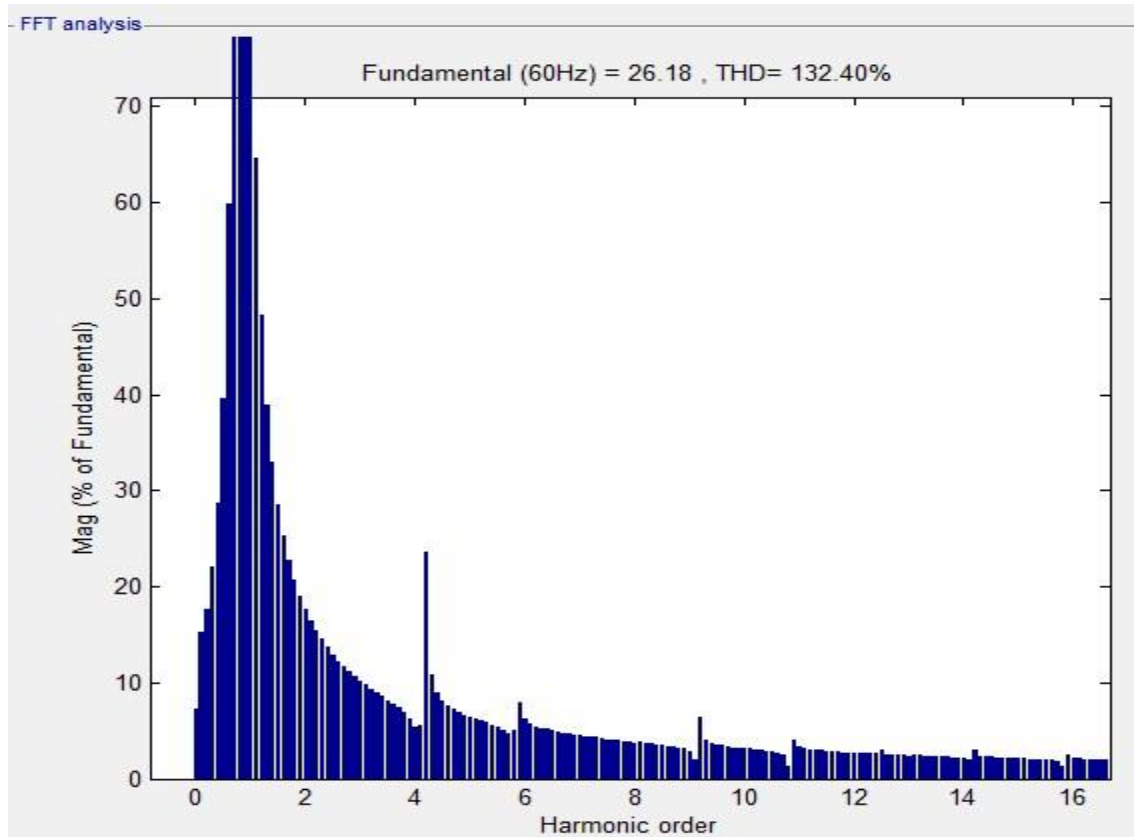


Figure 4.4: THD for Voltage

4.1.3 Calculation

Calculated Value For Regular Solar Inverter:

Current (I_{RMS}) = $(0.707 \cdot 17) = 12.02A$

Voltage (V_{RMS}) = $(0.707 \cdot 165) = 116.67V$

For Current THD (Total Harmonic Distortion):

THD = 130.37 % (60Hz)

Magnitude:

X = -0.8333 to 16

Y = 0 to 50

Z = -1 to 1

For Voltage THD (Total Harmonic Distortion):

THD=132.40%

Magnitude:

X = -0.8333 to 16

Y = 0 to 50

Z = -1 to 1

4.2 The Result for Three Phase Solar Cell Inverter after Controlling By SPWM

Here we get the peak current 13A & the peak voltage 135V. The calculated value & total harmonic distortion given below

4.2.1 Output for Voltage & Current



Figure 4.5: Output for Current (a. Phase 1, b. Phase 2, c. Phase 3)

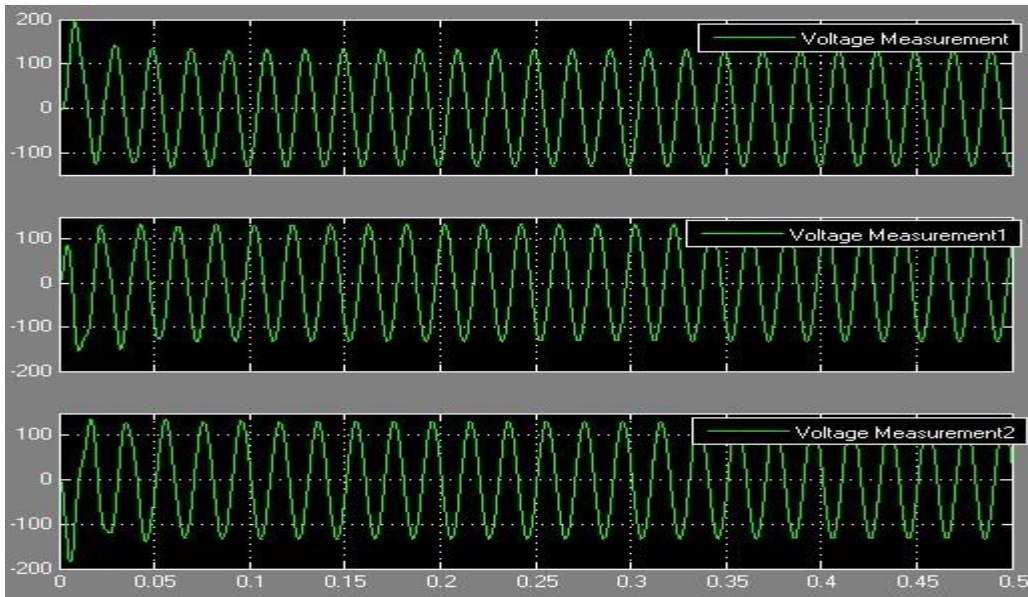


Figure 4.6: Output for Voltage (a. Phase 1, b. Phase 2, c. Phase 3)

4.2.2: THD (Total Harmonic Distortion):

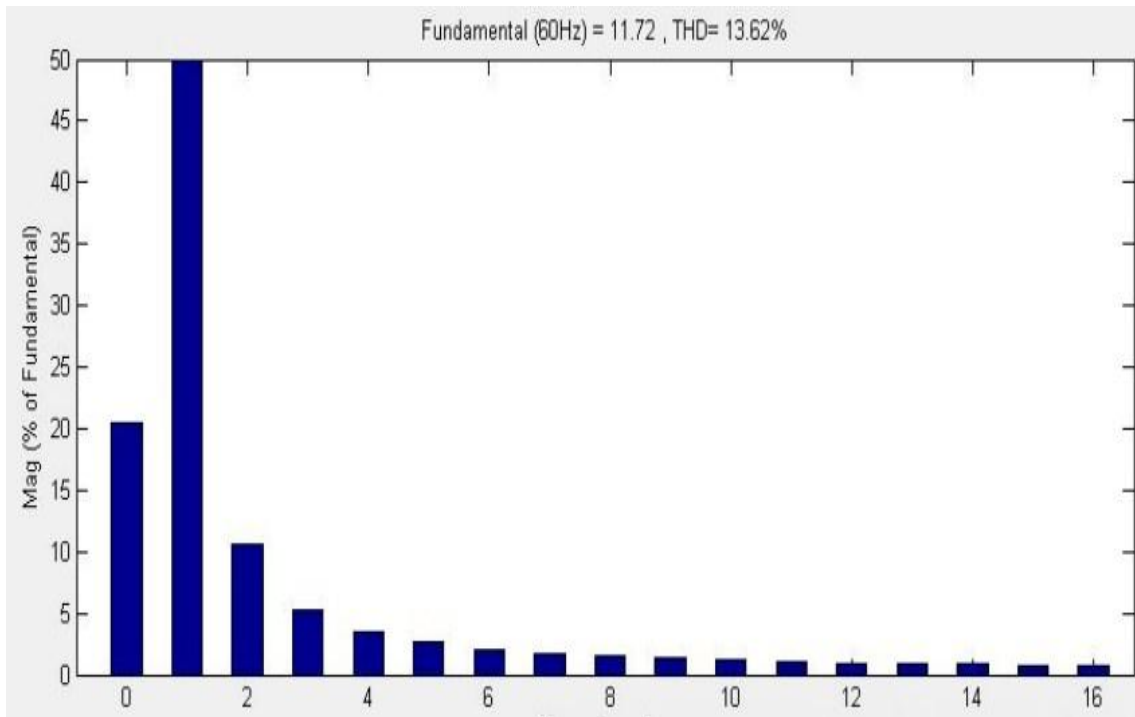


Figure 4.7: THD for Current

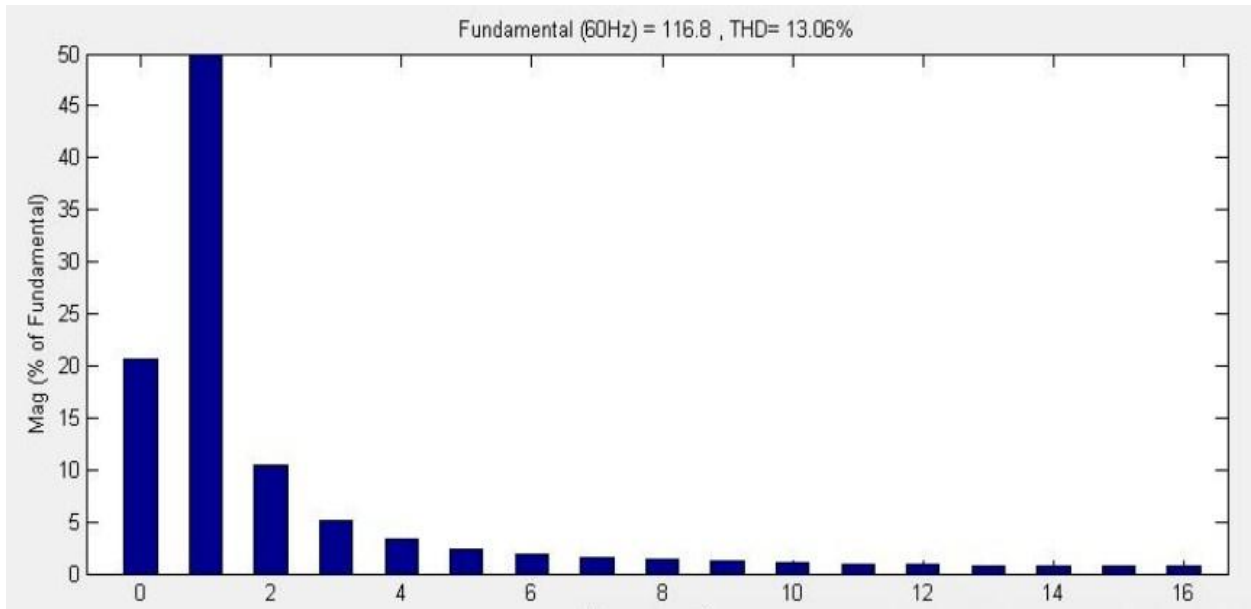


Figure 4.8: THD for Voltage

4.2.3 Calculation

Current (I_{RMS}) = $(0.707 * 13) = 9.19A$

Voltage (V_{RMS}) = $(0.707 * 135) = 95.46V$

For Current THD (Total Harmonic Distortion):

THD=13.62 % (60 HZ)

Magnitude:

X = -.8333 to 16

Y = 0 to 50

Z = -1 to 1

For Voltage THD (Total Harmonic Distortion):

THD=13.06%

Magnitude:

X = -.8333 to 16

Y = 0 to 50

Z = -1 to 1

4.3 Final Output Listed

	Calculated Value For regular Solar Inverter	Calculated Value For Inverter After Controlling By SPWM
Current (I_{RMS})	12.02A	9.19A
Voltage (V_{RMS})	116.67V	95.46V
THD (for Current)	130.97 %	13.62 %
THD (for Voltage)	132.40%	13.06%

4.4 Discussion

Inverters can provide single phase and three phase AC voltages from a fixed or variable DC voltage. There are various voltage control techniques and they produce a range of harmonics on the output voltage. The SPWM is more effective for modulation technique. With a proper choice of switching patterns for power devices, certain harmonics can be eliminated. The aim of this project was controlling this solar inverter by SPWM to reduce power loss, decreasing total harmonic distortion. So here we see that for regular inverter the total harmonic distortion for current is 130.97% & for voltage is 132.40%. After controlling this circuit by SPWM the total harmonic distortion decreases pleasant, for current that is 13.63% & for voltage 13.06%.

Chapter 5

Conclusion

5.1 Conclusion

We successfully complete our project. This project is choosey and suitable for rural areas, camping, and household appliances such as (fan, light motor etc.) The output of this project is not pure sine wave. The output is modified and for this case some power may be loss there. IGBT connection is the main in the inverter set up. If any connection cannot be sated properly, it may be damaged circuit board or may be short circuit. So the connection set carefully. Focusing the switch of IGBT, phase to ground voltage set up, sine wave phase delay, logical operator connection for sequence switched to get the output better and to save the work.

5.2 Limitation of This Work

DC to AC inverter is a one kind of renewable energy source and used it different types of load. In this work here facing some limitation:

- The output of this project is not pure sine wave. The output is modified and for this case some power may be loss there.
- The manufacturing of solar cells involves several toxic, flammable and explosive chemicals which has a bad impact on environment by the distance of time.

5.3 Future Scope of Our Work

High quality of solar inverter is able to handle more DC energy than max output AC we are designed. So when the inverter is maximized, it will raise the output voltage and inverter can be maximized by more improving circuit element (capacitor, resistor & inductor) for appropriate value.

REFERENCES

- [1] Peter Gevorkian, McGraw Hill Professional, 2007 'sustainable energy systems engineering: the complete green building design resource' & 'the Nobel Prize in Physics 1921: Albert Einstein'
- [2] Richard Martin, March 3, 2016, MIT Technology Review 'first solar cells efficiency records'
- [3] S. Rehman & I. El-Amin, 2015, volume 33-number 4, pp 591-620, 'study of a solar/pv/wind/diesel power system for a remotely located population area, Saudi Arabia'
- [4] Green Solver Blog, May 10 2017, 'the 5 most common problems with solar inverter' & Do-it-yourself, 'troubleshooting-common-problems-with a solar inverter'
- [5] Green Solver Blog, May 10 2017, 'the 5 most common problems with solar inverter' & Do-it-yourself, 'troubleshooting-common-problems-with a solar inverter'
- [6] Conserve Energy Future, 'How do solar panels work'
- [7] Afshin Izadian & Arash Pourtaherian, September 2012 IEEE 'basic model and governing equation of solar cell'
- [8] [Steven McFadyen, July 11th 2013 'Photovoltaic\(PV\)-electrical calculation'](#)
- [9] Administrator, July 12 2016 'Basic math solar calculation' blog5/2016/07/12/basic-math-behind-solar-calculations
- [10] Solar Technology International, 'calculating your solar power requirements'
- [11] Solar Technology International, 'calculating your solar power requirements'
- [12] Basic Electronics Tutorial, 'Insulated-Gate Bipolar Transistor' insulated-gate-bipolar-transistor.
- [13] Muhammad H. Rashid (3rd edition), Power Electronics, August 14 2003 'power transistors, IGBTs'
- [14] Study Electronics, 17 July 2017, 'How To Know Resistor Color Code'