COMPARATIVE STUDY OF DIFFERENT CONVERTER TOPOLOGIES FOR GRID CONNECTED PV SYSTEM

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ALTERNATE HYDRO ENERGY SYSTEMS

By

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May 2016

CANDIDATE DECLARATION

I hereby certify that the work which is being presented in this Dissertation, entitled, **"COMPARATIVE STUDY OF DIFFERENT CONVERTER TOPOLOGIES FOR GRID CONNECTED PV SYSTEM"** in partial fulfilment of the requirement for the award of the degree of **Masters of Technology** with specialization in "**Alternate Hydro Energy Systems**", submitted in **Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee** is an authentic record of my own work carried out during the period from July 2015 to May 2016 under the supervision of **Dr. D. K. Khatod**, Assistant Professor, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee India.

I have not submitted the matter embodied in this Dissertation for award of any other degree.

Dated: May, 2016

Place: Roorkee. **(PRASANT KESARWANI)**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Dated: May, 2016 **(PRASANT KESARWANI)**

Place: Roorkee

ABSTRACT

Fossil fuel are depleting at very fast rate so we need to go for other renewable energy sources for the completion of energy demand. Solar energy is considered as one of the promising source of renewable energy. Due to heavy burden on environment because of the prolonged use of fossil fuels electricity generation through solar photovoltaic has emerged as an attractive option for reducing carbon emissions, remote area electrification and also reducing the electricity bills. Solar energy conversion equipments have longer life and need lesser maintenance and hence provide higher energy infrastructure security. Solar energy is available free of cost in whole world so it is the best option for getting electrical energy.

This dissertation work presents work a comparative study of different converter topologies for grid connected PV system. Centralized inverter is used for large PV array system and it is less flexible. String inverter topology and Multi string inverter is used for small PV array and both are very flexible, while in string inverter one inverter is used for each parallel string and in multi string inverter only one inverter used for whole system with DC-DC converter in each parallel string. AC module inverter is the new and best technology because inverter is fitted in the PV modules directly so losses are very less. The MATLAB software has been used for modelling and simulation for different converter topologies for grid connected PV system. On basis of that model, different parameter like efficiency, current, voltage, and power has been calculated and compared. The performance parameters are also discussed with the mathematical expressions that can be used to analyse the performance of the PV system. Pulse width modulation inverter and 180 degree mode voltage source inverter is used for comparison of parameters. PWM inverter gave higher efficiency, less total harmonic distortion in voltage waveform compare to 180 degree mode voltage source inverter.

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CHAPTER 1
INTRODUCTION

1.1 GENRAL

Energy is most important aspect of our life. We need energy for all types of activities like moving, cooking, running, or doing any work. Energy is very important to our existence on earth. Energy is required to fulfill basic need of human being.

The conventional energy sources are diminishing very fast. The reserves of petroleum, coal and natural gas will be exhausted one day. The exhaust rate of this conventional source of energy will create a dreadful condition in future. Awareness of the planners and scientists all over the world has been attracted to this danger. Cost of petrol, diesel and coal has increased in very dramatic manner and made situation very critical and speed up the search for some alternate source of energy. [1]

Energy crisis increased awareness that our total dependence on one form of energy is not a careful step. The best solution of energy crisis will be through the search of different methods for harnessing the non-conventional energy sources. Since non-conventional energy sources provide pollution free energy, it helps to maintain atmosphere and environment clean and safe. Solar energy is best source from non conventional energy sources.

1.2 SOLAR ENERGY SCENARIO

1.2.1 World Solar Energy Scenario

The sun is our nearest star in the universe. Solar energy gives life to all of us by providing almost each form of energy. Sun gives energy to us indirectly by help in plant growing and plant gives energy in form of food material. Plant can be used as biomass fuel. Plant also used as fossil fuel like coal or petroleum products if plant matter compressed underground for several years. Solar energy provides heat energy which can be used as boiling of water, cooking food and due to variable temperature wind generates, which can be for wind turbine for produce power.

The Fig. 1.1 shows where the sun’s energy is distributed among different components. Research Association for Solar Power tells that power is garrulous from renewable energy sources at a rate of 2,850 times more energy than is needed in the world. The sunlight comes to the earth in a single day; generate enough energy to meet the world's current power requirement for eight years.

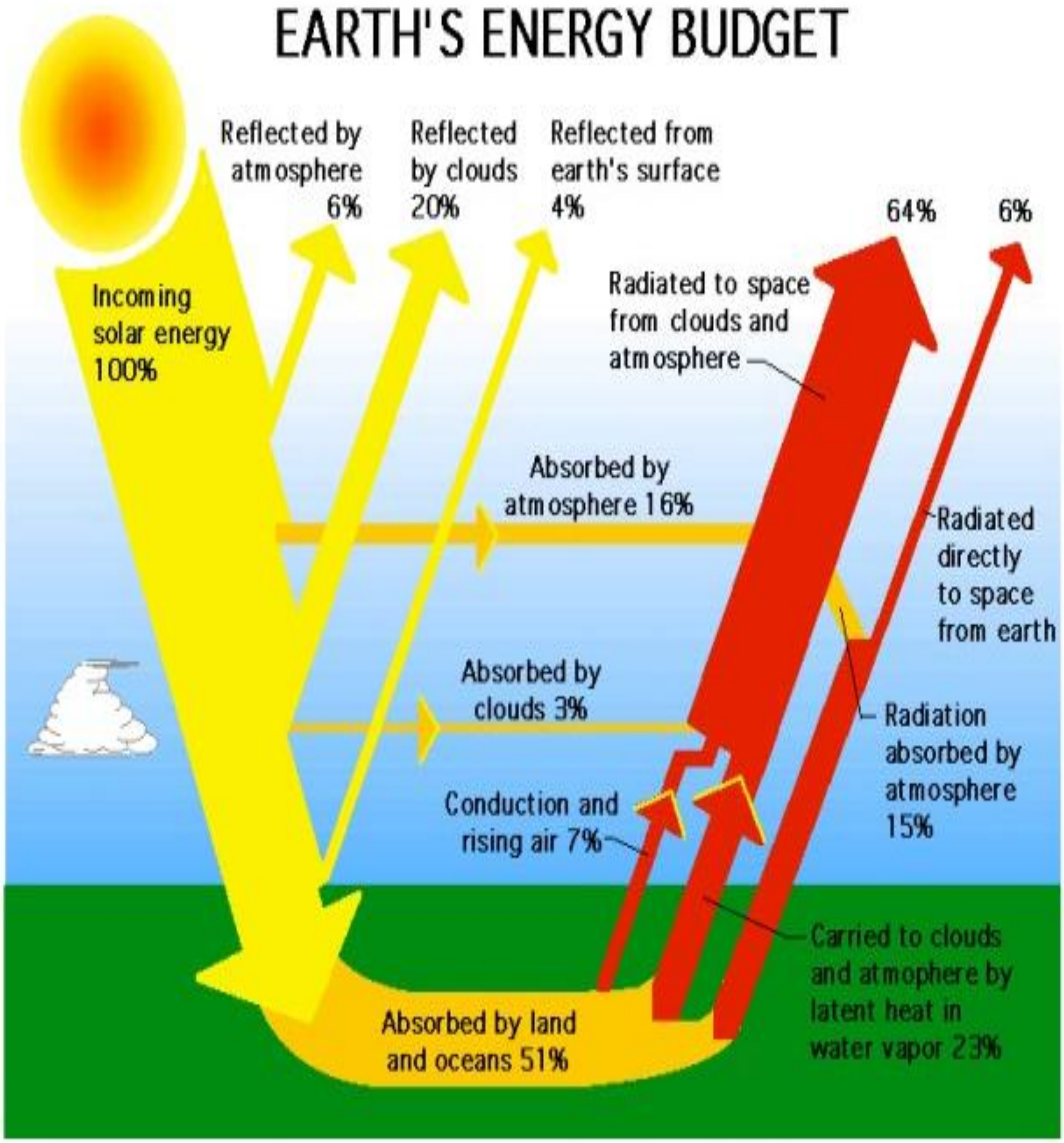

Fig. 1.1 Distribution of Solar Energy [2]

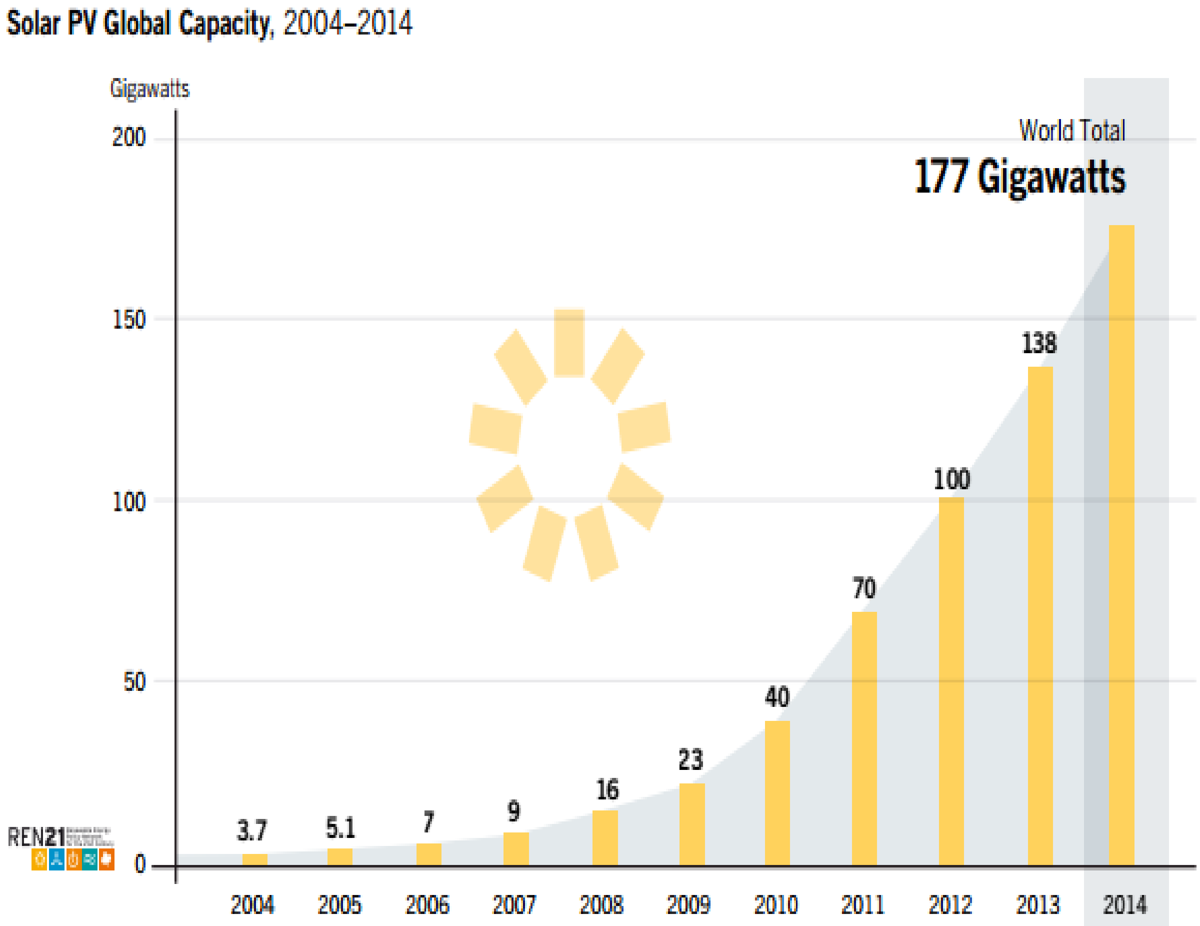

Fig. 1.2 Solar PV Global Capacity [3]

1.2.2 Solar Energy Scenario of India

One of the fastest growing economies in the world is India. India is the fifth largest consumer of energy in the world, and will be the third largest by 2030. Its 70% of primary energy are being met by coal, crude oil. Demand of electricity in India expected to more than double in the next decade. The two main challenges for power sector are: adequately powering the projected economic development and bringing electricity to the 300 million citizens who currently lack access. An inevitable element of economic growth is electricity. Its relative importance increases in relation to technical progress, industrialization and the need for modern comforts. India has electrified more than 571155 villages, and increased installed power capacity from 1362 MW to over 243028.95 MW since independence.

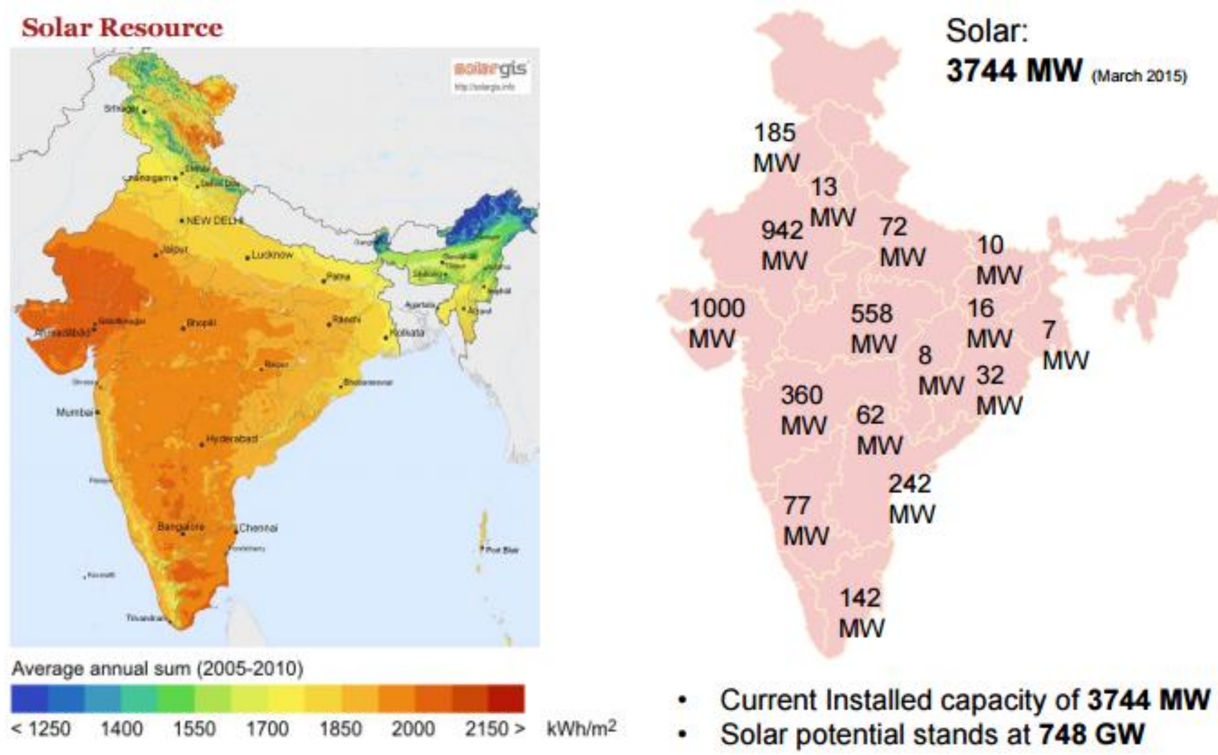

Fig. 1.3 India Solar Energy Potential [4]

1.3 SOLAR PHOTOVOLTAIC SYSTEM

Solar energy comes from the Sun in the form of heat and light. The energy in the heat can have direct application, like warming houses and providing hot water. Indirectly it also provides electrical energy. Weather is affected by heat, which therefore provide the wind for powering wind generators and the rain for powering hydro power stations. The light energy has direct application since we use this light for daily activities but the energy within this light can also be transformed into electrical energy by photovoltaic cell. Photovoltaic is emerging as a major power source due to its numerous environmental and economic benefits and proven reliability.

Photon from solar radiation has energy, when it enters in a photovoltaic material, it transfer his energy to valance electron of the atom. When this photon transfers his energy to valance electron, the energy level of electron is increased by amount of energy of that photon. Now the process has start of conduction, If the transmit power of the photon is more than the semiconductor band gap, electron will jump to the conduction cell of atom and now it can move freely. Solar energy transfers its energy to material by photon [5]. Solar cell is made by diffusing p-type semiconductor and n-type semiconductor, now electrons and holes diffuses at the junction and create an electric field across it. Free electron is created in n-layer by the action of photons.

When solar cell absorbs photon, some of them create electron and hole pairs. Now if these electron-hole pairs are near the junction, its electric field separates the charges, holes and electrons will move towards p-type and n-type side respectively. If the load is connected to solar cell, a current will flow as solar radiation hits the cell.

In this chapter, different components of Solar Photo Voltaic system have been discussed to understand the complete working of Solar Photo Voltaic system.

1.3.1 Components of Solar Photovoltaic System

The Solar photovoltaic system converts available solar energy into useful form of energy i.e. electrical energy. Basic components of typical SPV system are shown in Fig. 1.4.

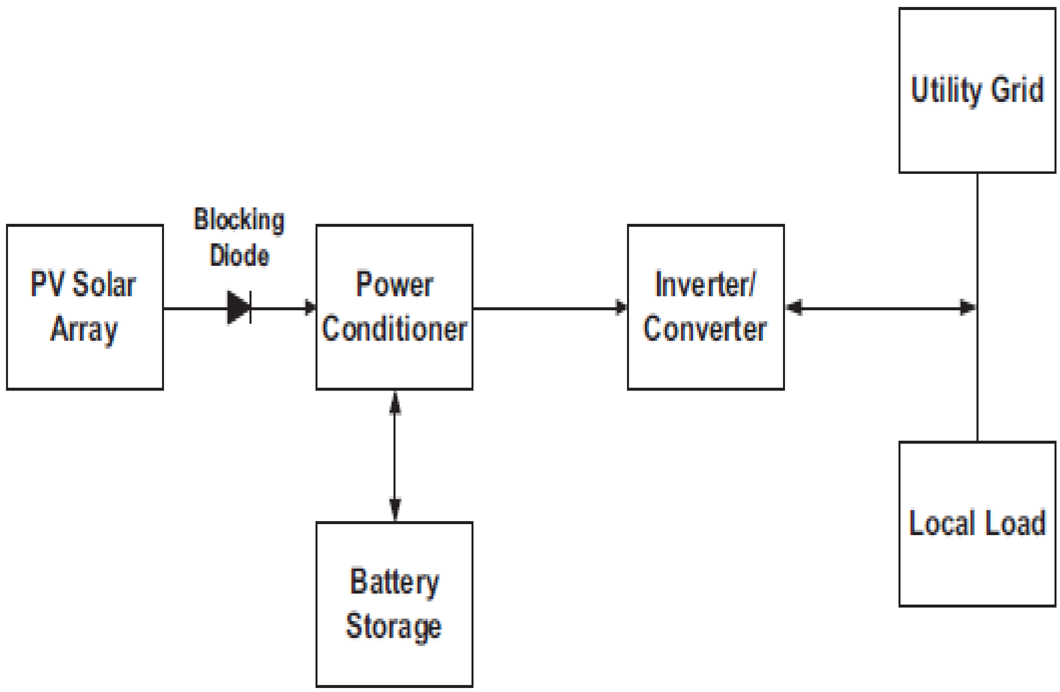

Fig. 1.4 Block Diagram of typical a SPV system [6]

(i) Photovoltaic generator

(ii) Battery

(iii) Charge Regulators

(iv) Inverter

(v) Back-up generator

1.3.1.1 Photo Voltaic Generator

The main unit for the energy generator in the PV system is photovoltaic generator. Solar cell consists of a p-type semiconductor with a less amount of Boron atoms as the substrate. For making the P-N junction, Phosphorus atoms are diffused at high temperature. A barrier potential is generated at the junction to stop motion of electron and holes particles.

When the P-N Generator is irradiated by light, electrons are excited by photons energy which produces electron-hole pairs. This electrical charge is alienated by the voltage barrier at the junction of semiconductor. The electrons and holes will move across the n-type and the p-type concurrently. When an external circuit is connected to semiconductor of a solar cell at this moment, the electrons and holes will generate electric current by moving other side with the help of external circuit to combine with each other. Working of basic solar cell can be understood by Fig. 1.5. [7]

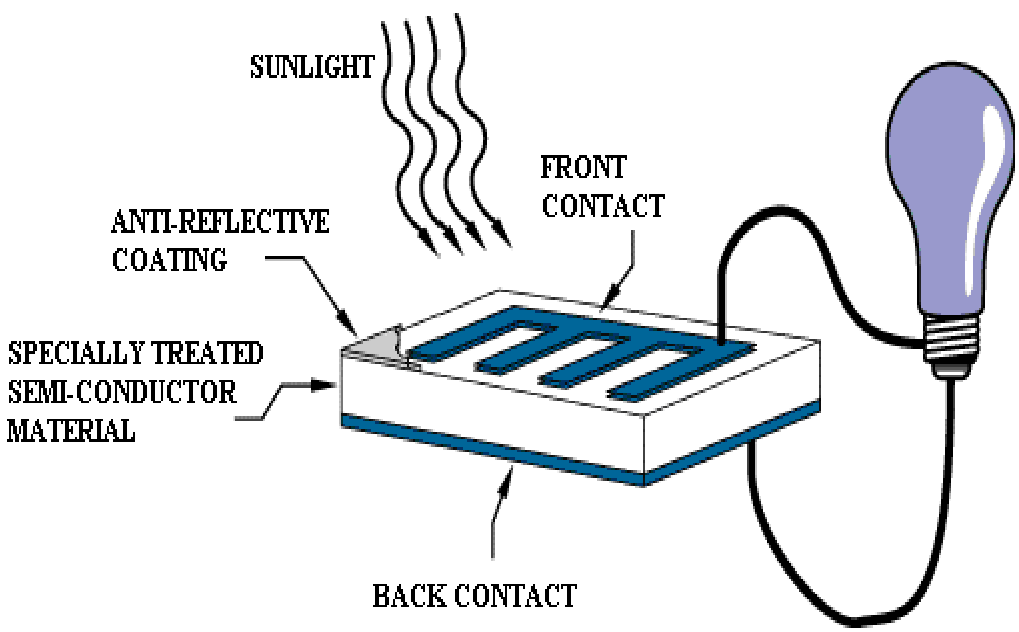

Fig. 1.5 Working of Basic solar cell [8]

The outcome of a solar cell is very less (typically 0.5V), for fulfill the required current and voltage demand solar cells are connected in Series and parallel respectively. These grouping are further known as Module and Arrays as shown in Fig. 1.6, and solar cell model is also explained below:

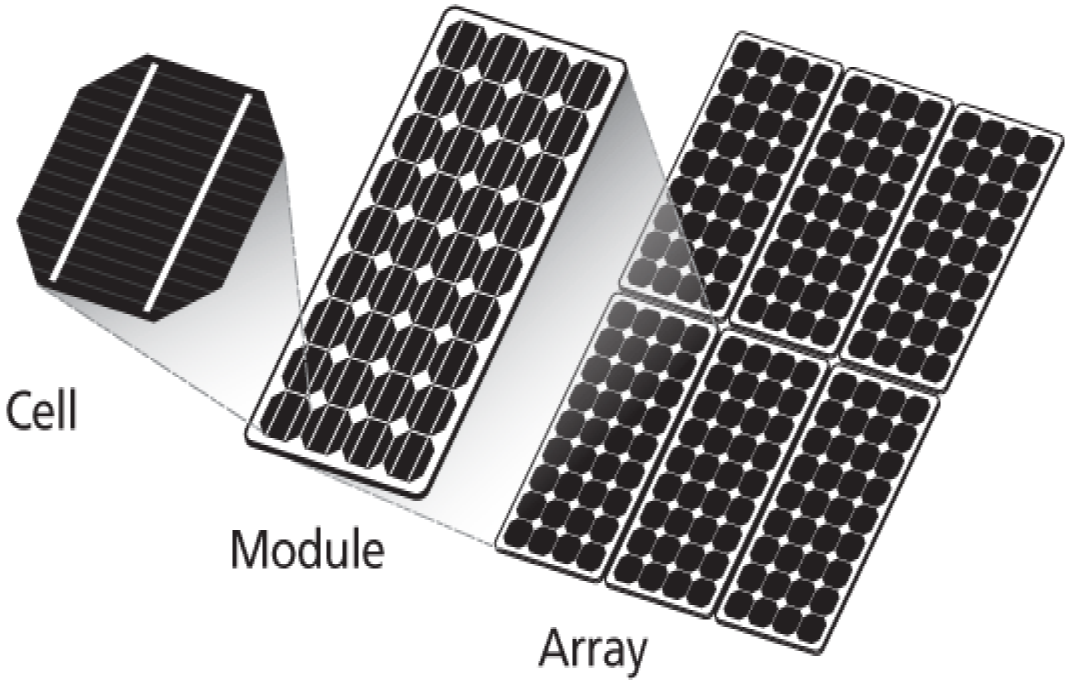

Fig. 1.6 Solar cell, Module and Array [8]

Photovoltaic cell is a device which converts the solar energy into the electrical energy and this phenomenon is known as Photovoltaic effect. By arranging series and parallel combination of photovoltaic cell, solar PV module is created and by arranging PV module into different combination PV array is created according to our power requirement [9]. The solar cell, which is a non-linear device, can be represented by a current source model as illustrate in Fig. 1.7.

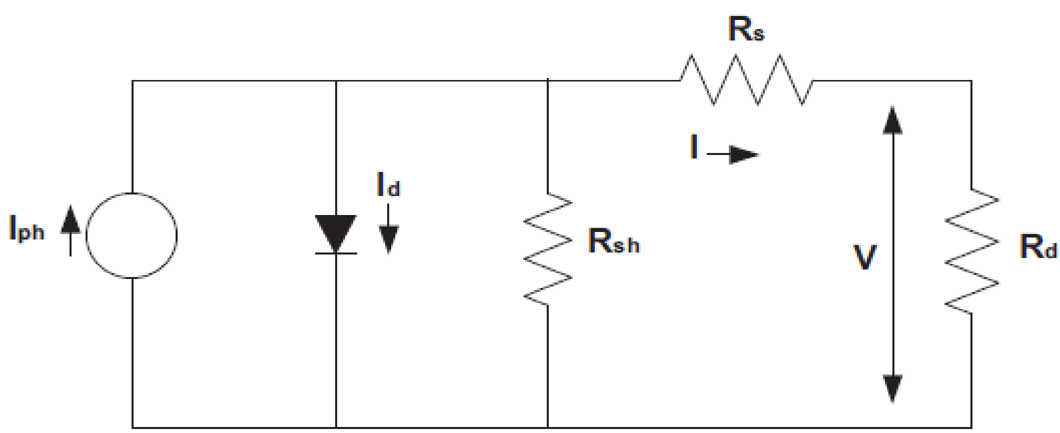

Fig. 1.7 Solar Cell Model [9]

The cell photo current is the source current and represents as $I_{ph,}$ diode reverse saturation current is Id, intrinsic shunt and series resistance is represented as Rsh and Rs respectively. Shunt resistance value is very much than series resistance so it can be neglected for easy analysis. The typical photovoltaic array, I-V characteristics is given by the following equation [10].

$$I = N_p I_{pn} - N_p I_d \left[\exp\left(\frac{qV}{kTAN_s} - 1\right)\right] \tag{1.1}$$

Where,

I = PV array output current (A)

V= PV array output voltage (V)

N_s = Number of cells connected in series

N_p= Number of modules connected in parallel

q = Charge of an electron ($1.6x10^{-19}$C)

k = Boltzmann's constant ($1.38x10^{-23}$J/K)

A = P-N junction ideality factor,

I_d=Cell reverse saturation current,

T = Cell temperature (K)

'A' is a factor which is used to determine the deviation of the cell from the ideal P-N junction characteristic and value varies from 1 to 5, 1 is ideal value [11].

1.3.1.2 Battery

Battery is required for supplying power at the night time and when the PV system cannot fulfill the demand. The type and size selection of battery depends on the load requirements. Batteries should be located in an area with limited temperature area, and proper ventilation must be available. The most commonly available batteries are lead-acid, nickel cadmium, nickel hydride, and lithium. The most common used batteries are Deep-cycle lead-acid. Different sizes flooded batteries are available commercially, but this type of battery requires more maintenance with proper heed can last longer, while less maintenance is required for valve-regulated batteries [12]. The comparison of different commercially available batteries is given in below Table 1.1:

Table 1.1: Comparison of Battery Technologies

Battery Type	Cost	Deep Cycle Performance	Maintenance
Flooded Lead-Acid			
Lead-Antimony	Low	Good	High
Lead-Calcium Open Vent	Low	Poor	Medium
Lead-Calcium Sealed Vent	Low	Poor	Low
Lead Antimony/Calcium Hybrid	Medium	Good	Medium
Captive Electrolyte Lead-Acid			
Gelled	Medium	Fair	Low
Absorbed Glass Mat	Medium	Fair	Low
Nickel-Cadmium			
Sintered-Plate	High	Good	None
Pocket-Plate	High	Good	Medium

The PV system requires battery which should be capable to accept replicate deep charging and discharging without any problem. For large capacity, batteries should be connected in parallel. Generally stand-alone photovoltaic systems require battery to store the electrical power which is generated during the day time, when the photovoltaic systems fulfill the load requirement and excess energy for battery charging. The electrical power is supplied by batteries at night time or when solar radiation intensity is very low.

It is categorized with their nominal capacity (Q_{max}). Nominal capacity is the number of ampere hours (A-h) which is pull out from the battery under determined discharge conditions. The charged proportion takeout (Ah) at discharge time divided by the amount of charge (A-h) is required for restore the original state of charge (SOC) and the efficiency mainly depends on the charging, discharging current and state of charge. The SOC is defined as the relative amount in between the present capacity of the battery and the nominal capacity. State of charge can be represented as:

$$\text{SOC} = \frac{Q}{Q_{max}} \tag{1.2}$$

The State of charge values can be varied from 0 to 1. For fully charge battery SOC value= 1, for complete discharged battery SOC=0.

The many other parameters for battery are battery lifetime and charge or discharge regime. The charge or discharge regime, expressed in hours, can be parameter that shows the relation between the battery nominal capacity and the current at which it is charged or discharged. Battery is represented by a voltage source (E), with a series connected internal resistance R_o as described in Fig. 1.8. For this case, V is terminal voltage and can be showed as

$$V = E - I R_o \tag{1.3}$$

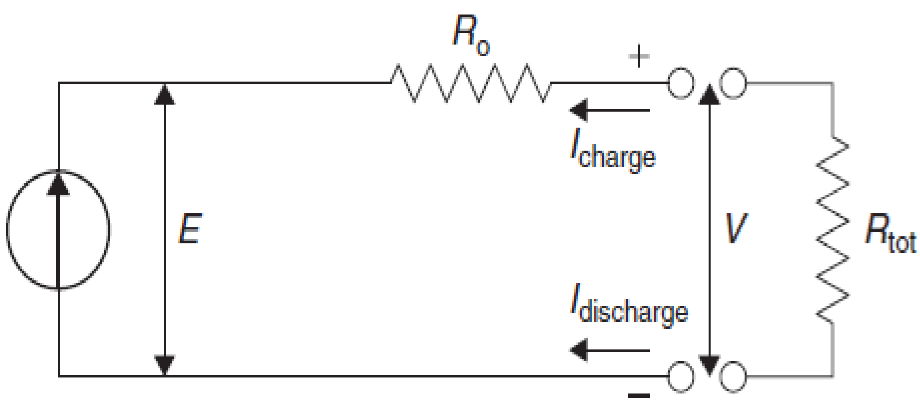

Fig. 1.8 Schematic Diagram of Battery [13]

1.3.1.3 Inverters

An inverter is a device which converts direct current (DC) to alternating current (AC). The inverter is available for single phase as well as for three phases. Total power capacity of inverter is inverter rating, which is ranged from one hundred watt to several megawatts. The inverter is characterized by a power-dependent efficiency, η_{inv}. The inverter main work is maintain a fixed voltage on AC side and transform the input DC power (P_{in}), into the output AC power (P_{out}) with the maximum possible efficiency, which is described as:

$$\eta_{inv} = \frac{P_{out}}{P_{in}} = \frac{V_{ac} I_{ac} \cos\varphi}{V_{dc} I_{dc}} \tag{1.4}$$

Where,

$\cos \varphi$= Power factor.

I_{dc}= DC side current (A)

V_{dc}= DC side voltage (V)

The inverter efficiency mainly depends on rated power on which it operates. A photovoltaic system operate at maximum efficiency either when it has one inverter which is operating with a large load enough to maintain maximum efficiency or an interconnection of the module-integrated inverters or master-slave configuration. When single inverter is used, this gets power from many series-connected photovoltaic modules connected in parallel on a DC bus single inverter is used like in centralized inverter topology. This type of connected system provides maximum efficiency and cost is also less, but need a DC installation. Every PV module has its own inverter which is called as micro-inverter or Module-integrated inverter. This configuration is pricier than a central inverter; but it prevent from use of expensive DC wiring. Micro inverters are fitted in the back side of each module for converting its DC power to AC power. A multi-string type system needs number of inverters connected together and generally can give greater PV output [14].

The inverter performance mainly depends on point at which it is working, threshold point, output waveform of inverter, photovoltaic efficiency, total harmonic distortion (THD), frequency, and maximum power point (MPP). When PV module is shaded by different obstacles, the overall photovoltaic output reduces and it affects inverter performance.

The main work of an inverter are wave-shaping, maintain output voltage, islanding operation. The inverters are of mainly three types, which are classified as sine wave, modified sine wave, and square wave. Most of inverters are of sine wave type inverter because most appliances are made for a sine wave type operation. The Modified sine wave type inverter has a waveform like a square waveform, but by additional step it can also work with most of the appliances. Finally, a square-wave inverter can generally work for only simple devices with the universal motors, it has only one advantage that it is very much cheaper than others and it can give sine waveform by using a power filter.

1.3.1.4 Charge Regulator

A controller is used to regulate the power from photovoltaic modules to the battery to avoid overcharging and cut the supply to prevent the battery from over discharging. It should be chosen to correct capacity and with required features. Some controllers provide facility to optimize the operating voltage of photovoltaic module which is independent of battery voltage for the maximum power point operation of photovoltaic module. Charge controller is required in photovoltaic system for managing the flow of energy from photovoltaic module to battery and load through battery voltage and at acceptable maximum and minimum values. The majority controllers have two different modes of operation:

1. Normal operating condition, where the battery voltage change between the suitable maximum and minimum values.

2. Over-charge or under discharge condition, at the battery voltage attains a critical value.

The operation of second mode is done through a switch by a hysteresis cycle, such as solid-state devices. Switch function is shown in Fig. 1.9. As shown by the Fig. 1.9. (a) when terminal voltage increases above the threshold level $V_{MAX(OFF)}$ and when the current requirement from the load is fewer than the photovoltaic array current, it disconnects the battery to prevent from over charging and photovoltaic system is reconnected when the terminal voltage reduces to below a fixed value $V_{MAX(ON)}$ .Similarly, as shown in Figure 1.9(b), for protect battery from over discharge and when the load current required is higher than current provided by photovoltaic module and when the terminal voltage goes down below the threshold voltage $V_{MIN(OFF)}$, battery is disconnected. System is restored back at the time when terminal voltage reaches above the fixed threshold voltage $V_{MIN(ON)}$.

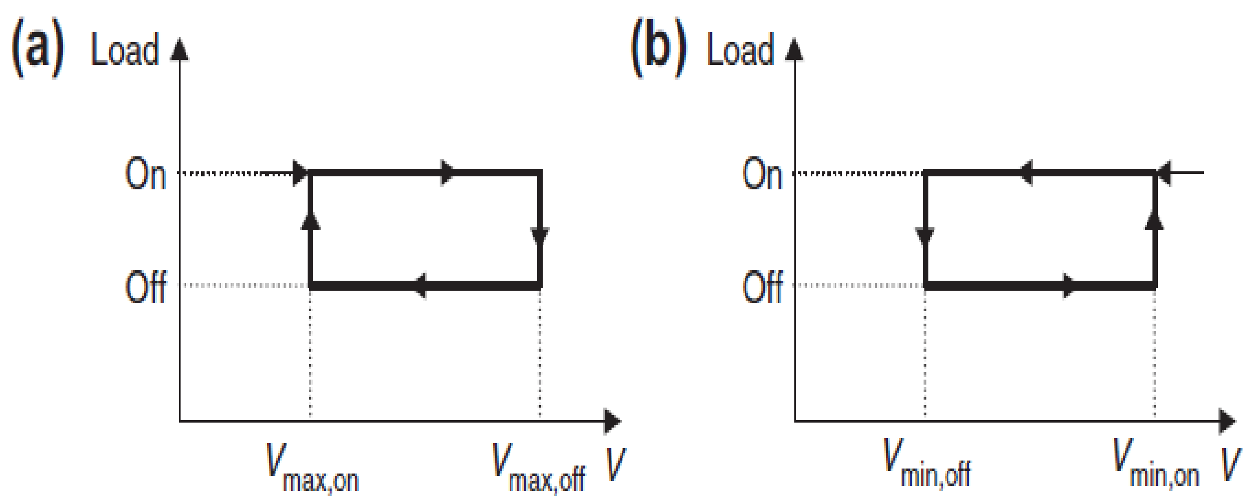

Fig. 1.9 Operating Principle of Over-Charge and Over-Discharge Protection.

(a) Over-charge (b) Over-discharge [15]

1.3.1.5 Back-up Generator

On demand power sources are used as back-up generator such as Diesel, Gasoline, Thermoelectric generator etc. It supplies power when the solar modules cannot supply the power at the requested moment, e.g. during a prolonged period of below average solar radiation.

These all were the basic component of SPV system but the design and type depends on the site conditions where it has to install. Proper selection of component and their sizing is because it affects the cost and system reliability.

1.4 TYPES OF SOLAR PHOTOVOLTAIC SYSTEM

PV power systems are generally classified by their operational and functional requirements, component configurations and on what basis the equipment is connected to other sources of power and electrical loads. This system can be designed for DC or AC power service and it can operate interconnected with or without utility grid. The main classifications are grid-connected photovoltaic system and stand-alone PV systems.

(i) Grid-connected Photovoltaic system

(ii) Stand-Alone Photovoltaic system

1.4.1 Grid-connected Photovoltaic system

Grid-connected photovoltaic systems are designed to operate in parallel with and interconnected with the electric utility grid. The main section of this system is power conditioning unit i.e. inverter. Inverter is used for converting the DC supply from PV module to AC power by taking consideration of voltage level, frequency and power quality needed by the grid and load and stops supply to the grid when the grid is not energized. This system allows a bi-directional interface from photovoltaic system to the AC output/load circuits and the electric utility network, at the on-site distribution panel. Photovoltaic system provides supply power directly to load and back feed to the grid when demand at on-site is less than the supplied power from photovoltaic array. When the electrical load demand is higher or at the night time when solar radiation is not available power is taken from the utility grid. Photovoltaic system should not operate and feedback power to utility grid when the gird is not in service or repair. Power conditioning unit also has controller component to prevent from islanding of inverter [16]. Block diagram is shown in Fig. 1.10.

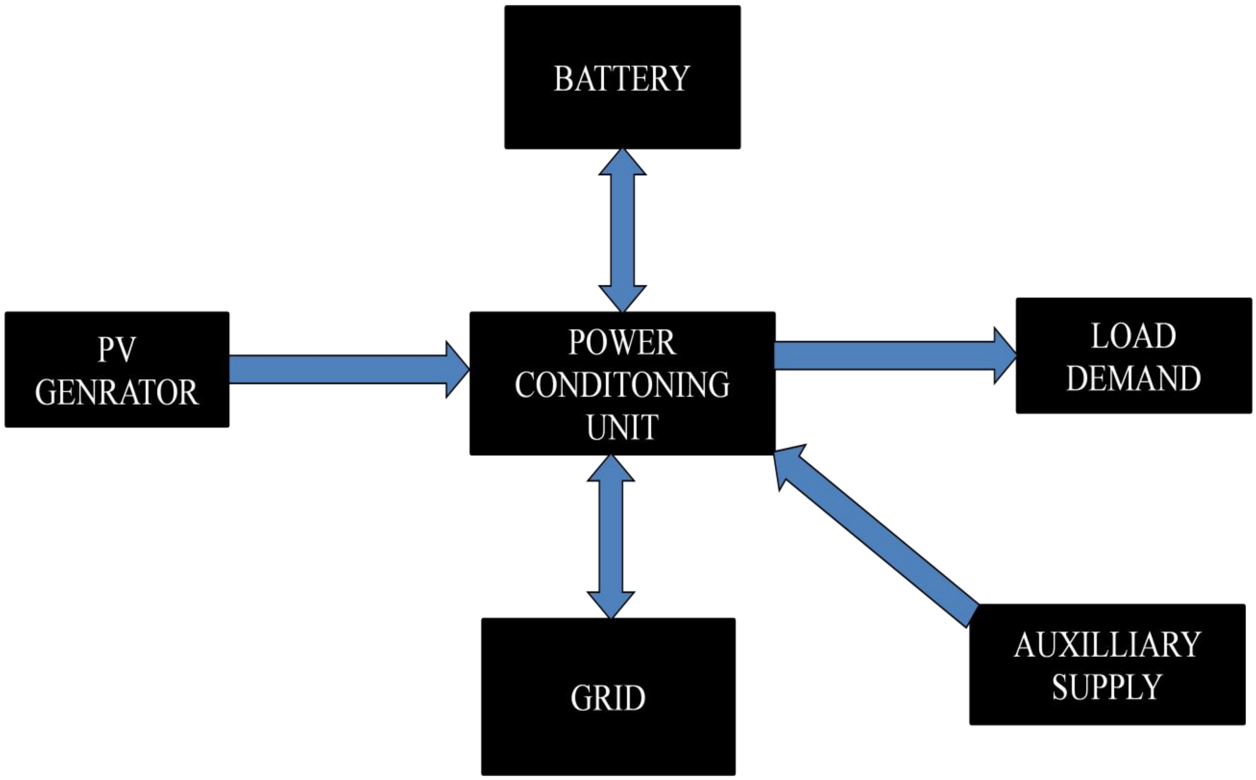

Fig. 1.10 Diagram of Grid-connected PV system

1.4.2 Stand-Alone Photovoltaic System

This type of sytems is operate independently from grid, and are made and sized to generate DC and/or AC electrical load/equipments. This type of system is took supply from photovoltaic array and may us wind, diesel generator or any auxiliary power supply which is known as PV-hybrid system. Direct-coupled stand-alone photovoltaic system is the simple form of stand-alone PV system in which output of a photovoltaic array is directly connected to a DC load. No storing element is available in direct coupled photovoltaic system, so it is used when solar radiation is available during day time. For extract the maximum power from photovoltaic array maximum power point tracking (MPPT) method is used, which is generally inbuilt in the DC-DC converters, is used for amplification of DC voltage.

Batteries are used by most of the stand-alone photovoltaic systems for storage of power. Fig. 1.11 shows a block diagram of a stand-alone photovoltaic system which is powering DC and AC loads and shows a photovoltaic hybrid system configuration.

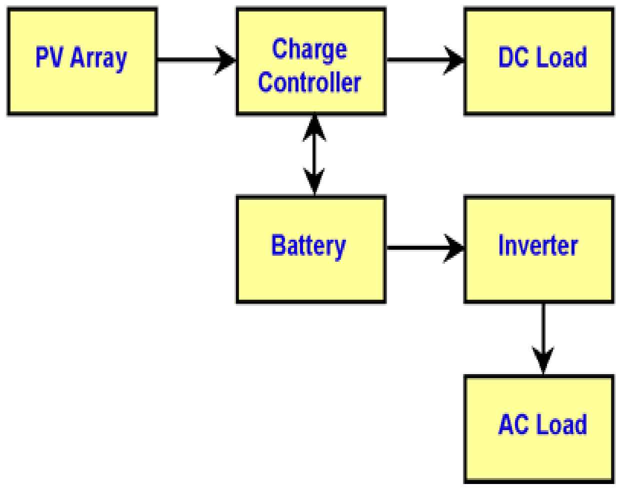

Fig. 1.11 Diagram of stand-alone PV system with battery storage [16]

1.5 OBJECTIVES

1. The main objective of this work is to comparative study of different converter topologies for grid connected PV system.
2. To develop a complete model of grid connected PV system in MATLAB with various inverters.
3. To check output, performance and efficiency of converters by simulation result.

1.6 ORGANISATION OF THESIS

This thesis is organized as follows:

Chapter 1 describes solar energy scenario of the World and India, components, working and types of solar photovoltaic system.

Chapter 2 describes a brief literature review about various converters topologies for grid connected photovoltaic system.

Chapter 3 deals with the theory behind the different converter topologies for photovoltaic system.

Chapter 4 deals with modeling and simulation of grid connected PV system and explanation for used inverter in models.

Chapter 5 presents the result and discussion.

Chapter 6 presents the conclusion and recommendation of the thesis.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Inverter is very important part of solar photovoltaic system. There are different types of inverters available according to their rating, characteristics and connections of PV modules. A lot work has been carried out for improving the efficiency of inverter. In this chapter we will try to summarize the different types of inverter topologies available according to their connections.

2.2 LITREATURE REVIEW

Gawad and Sood [17] presented an overview of a grid connected Photovoltaic systems and different inverters. They discussed different components for the photovoltaic systems and new research for these system components. Then they explored the connection topologies of PV systems and then compared the advantages and disadvantages of all possible connection topology.

Pierquet [18] introduced different inverter topology that uses a block of energy storage in a series-connected path with the line interface block. This design facilitates an independent control over the capacitor voltage and the soft-switching for all type of semiconductor devices. It increases more complexity compare to normal traditional designs, but it provides control for a energy storage voltage and ripple by using electrolytic or film type capacitors. This topology also provides facility for reactive power transfer and maintains high efficiency.

Prasad et al. [19] discussed different type of topologies based on cascaded H-bridge multilevel inverter. They described a multilevel inverter which has two Photo Voltaic Arrays for each and every phase in topology first. In second topology, they introduced a transformer and decreased the number of photovoltaic arrays to one for all three phases. In third topology number of switch has been reduced very much compare to other above described topologies and used number of photovoltaic array is one for all the three phases. They simulated these topologies with RL load. From above topology, the third topology has nice performance with the increase in output voltage and reduction in percentage of total harmonic distortion in comparison with others.

Zia et al. [20] presented grid tie photovoltaic inverter with practical implementation. They performed simulation and practical test for reference voltage fixation method for DC-AC inversion, switching techniques by PIC microcontroller, IGBT gate drive circuit operation with proper filtering and finally power delivery to the grid with proper isolation. The achievements of the practical testing of grid tie inverter lies in successful DC-AC conversion, along with the capability of matching inverter output voltage and frequency with continuous fluctuating grid voltage and frequency.

Bush and Wang [21] presented a new current source converter topology for single phase photovoltaic application. The main principle for this proposed topology is that instantaneous power transfer across the switching bridge is maintained constant. With the help of this topology the low frequency ripple which is common to single-phase inverter has been eliminated and reduction of this absence of low frequency ripple reduce the size of passive components to achieve necessary stiffness. With the less current ripple MPPT performance is readily achieved. They verified modulation and control methods by the use of numerical simulation results obtained from a detailed Saber™ model.

Kjaer et al. [22] focused on inverter topologies for single phase grid connected PV modules. They described some of the standards for photovoltaic and grid application like dc currents injection into grid, power quality, islanding operation detection. They classified the inverter topologies based on no of power processing stages, power decoupling type between the photovoltaic modules and grid, types of grid interfaces, transformers and type of interconnection between stages.

Shimizu et al. [23] described a novel fly back-type single phase inverter circuit which is suitable for ac-module system. They removed the problem of low power from PV array due to partially shadow on few modules with the use of ac module strategy. They described use of small rating film capacitor instead of electrolytic capacitors which is necessary for decoupling and with the help of film capacitor life of inverter increased.

Gonzalez et al. [24] described single phase photovoltaic transformerless inverter. They proposed a new high efficiency topology that generate no varying common-mode voltage and required very less input voltage as the bipolar PWM full bridge. They verified this topology with a 5-kw prototype.

Gu et al. [25] described a transformerless inverter for grid connected photovoltaic system. They designed a very high reliability and efficiency inverter. The proposed inverter utilized two different ac coupled inductors for positive and negative half grid cycles, and superjunction mosfets to achieve high efficiency.

Araujo et al. [26] described a transformerless inverter for grid connected PV system. They proposed two stepdown converters where each converter modulates a half wave of output current. They described different transformerless topologies like H5 and Heric which gave very high level of efficiency and profit ratio is good for low power grid tied system.

Lakwal and Dubey [27] described a multilevel inverter which offers high power capability with lower harmonic losses and lower commutation losses. The proposed multilevel inverter consists of two parts Level and Bridge modules. They described that multilevel inverter is good for unequal dc sources. They introduced Super Imposed Carrier PWM (SICPWM) technique for harmonic reduction, and described that as level module number increases correspondingly voltage waveform improves.

Chen and Smedley [28] presented a three phase Boost-Type grid connected inverter. They proposed one-cycle control (OCC) method and the pulse width modulation (PWM) method. They described a single power stage conversion with the help of Current source inverter (CSI) with shorted inductor. The proposed method is simple and stable, and the system provides fast dynamic response.

Wang [29] proposed full-bridge series-resonant buck-boost inverter. This inverter included a full-bridge topology and a LC resonant tank without auxiliary switches. The proposed inverter provided the main switch for turn-on at Zero current switching (ZCS) by a resonant tank. This inverter gave a very high efficiency.

Chen et al. [30] presented a three-phase two-stage gird connected module integrated converters (MICs). Generally for MICs single stage conversion is required but here they proposed zero voltage switching in two stage operations for the grid connected photovoltaic system. In first stage they interfaced a high efficiency full-bridge LLC resonant DC–DC converter which is interfaced to the photovoltaic array which produce a dc-link voltage and in the second stage considered a three phase DC to AC inverter circuit which employed a easy soft-switching method without any auxiliary components. This inverter reduced per watt cost and improved reliability.

Mastromauro et al. [31] presented a single-phase Grid connected PV system with power quality conditioner. They used incremental conductance method for MPPT and shunt controller for voltage support.

2.3 GAPS IDENTIFIED

Based on literature review, the following gaps have been identified:

1. Though many active filter controller are working like PI, PID controller, Hysteresis Controller, but still more research work is needed for smooth controlling,
2. More research work is required for islanding inverter.
3. More research work is required for comparative study of inverter for grid connected photovoltaic system on the basis of performance, efficiency and output.

CHAPTER3

INVERTER TOPOLOGIES

3.1 GENERAL

An inverter is an electrical power converter that changes direct current (DC) to alternating current (AC) of desired voltage and frequency with the use of appropriate switching and control circuits.

The inverter works opposite to function of rectifier. The electrical inverter is a high power electronic oscillator. Inverters are generally used for supply AC power from DC supply like solar panels and batteries. Inverters used for solar system has to fulfill different requirement like maximum power point tracking (MPPT), conversion of AC to DC, inject a sinusoidal current into grid.

3.2 STANDARDS REQUIREMENT OF INVERTER

There are two major tasks involved for inverter interfacing solar photovoltaic module with the grid. First is PV modules should be operated at MPP and second is to sinusoidal current injection into the grid.

3.2.1 Grid Requirement

The standards given by utility companies must be followed because inverter is connected to grid. EN61000-3-2, IEEE1547 and the United State National Electrical Code (NEC) 690 are some standards on grid requirement. These standards address issues like grounding, power quality and islanding operation problem. The inverters should be capable to address an islanding situation and take right action for prevent the person and equipment. [32]

These standards put limitations on highest possible dc current injection into the grid. The main cause for limitation is to avoid distribution transformers saturation. The NEC 690 standard give criteria that the photovoltaic modules should be system grounded and sensible for ground faults.

3.2.2 Requirement by the Photovoltaic Module

Now days monocrystalline and multicrystalline –silicon modules are the most common PV technology which is based on microelectronic manufacturing process [33]. The MPP voltage is in range of 23 to 28 V at a power of 160 W, and the Open circuit voltage (OCV) is less than 45

-V The inverters should take care that PV module is working at MPP, which is that point where the most power is withdrawn. Ripple should be low at terminal of PV module to operate at MPP without much fluctuation. Magnitude of ripple voltage should be less than 8.5% of MPP voltage to get utilization ration of 98%.

3.2.3 Requirement by Operator

According to operator inverter cost should be less, it is easily achieved by the similar circuit as these are used nowadays with single phase power factor improvement circuits and changeable speed drives. Inverter must have very good efficiency on a high range of input voltage and power because these parameters are variable and depends on solar irradiation and ambient temperature. It should be high life time, generally most photovoltaic producer offers 25 years warranty on initial efficiency of 80% [34].

The main part of inverter which limits the life is electrolytic capacitor which is used for power decoupling in between the photovoltaic array and grid. The operational lifetime is given by for electrolytic capacitors.

$$Lop= (L_{op})_0 * 2^{[(To-Th)/ (\Delta T)]} \quad (3.1)$$

where,

L_{op} = operational lifetime

$(L_{op})_0$ = lifetime at a hotspot temperature of T_o

T_h = hotspot temperature

3.3 Photovoltaic Inverters Topology

Photovoltaic inverters are categories in four different forms-

(1) Centralized Inverters

(2) String Inverters

(3) Multi-String Inverters

(4) AC–Module Inverters

3.3.1 Centralized Inverters

The past technology is based on centralized inverters which connect a large number of PV modules to grid. In centralized inverter PV modules are divided into series to avoid further voltage amplification. Series connections are arranged in parallel by string diode to attain enough power level. This type of connection has some brutal limitation like; it needed high DC voltage cables in between the photovoltaic array and inverter, power mismatch due to centralized maximum power point tracking, string diode losses, photovoltaic module mismatch losses and a nonflexible design. Centralized inverter should use where large no of photovoltaic array is available. This topology is best suited for large power requirement by the load or electric utility grid. In centralized inverter topology system, cost per unit is very low comparing to others inverter topology. The main problem for centralized inverter topology is that complete system become fail at one point fault.

Centralized inverter has several advantages like: it is easy to monitor, much easy to maintain and cost of this inverter is very low because of centralized system. This type of inverter is available in MW range of rating. The connection diagram of centralized inverter is shown in fig 3.1 below.

3.3.2 String Inverters

In String Inverter topology, every string has its own separate inverter. This system is very flexible and reliable in nature. It is a small version of Centralized inverter. There is no need of further voltage amplification for each string. Each string has separate MPPT so improved efficiency also. This type of topology is most common topology used in the home and commercially. String inverter topology is the robust system. This system can be used for single phase as well as three phase. This type of topology has a separately voltage and current monitoring device which is helpful for easy monitoring of the system compared to other centralized inverter topology. In the string inverter topology, the overall plant performance can be monitored easily at string level. String inverter can be mounted on photovoltaic structure so no need of any foundation like in centralized inverter topology. The overall performance of the system is good.

String inverter has several more advantages compare to Centralized inverter like; there is no loss of energy due to partial shading of modules, no string diode losses. It has some disadvantage also like; costlier than centralized inverter and used for low power rating. It is available generally for 3-5 kW rating for per string. The connection diagram of String inverter is shown in fig 3.1.

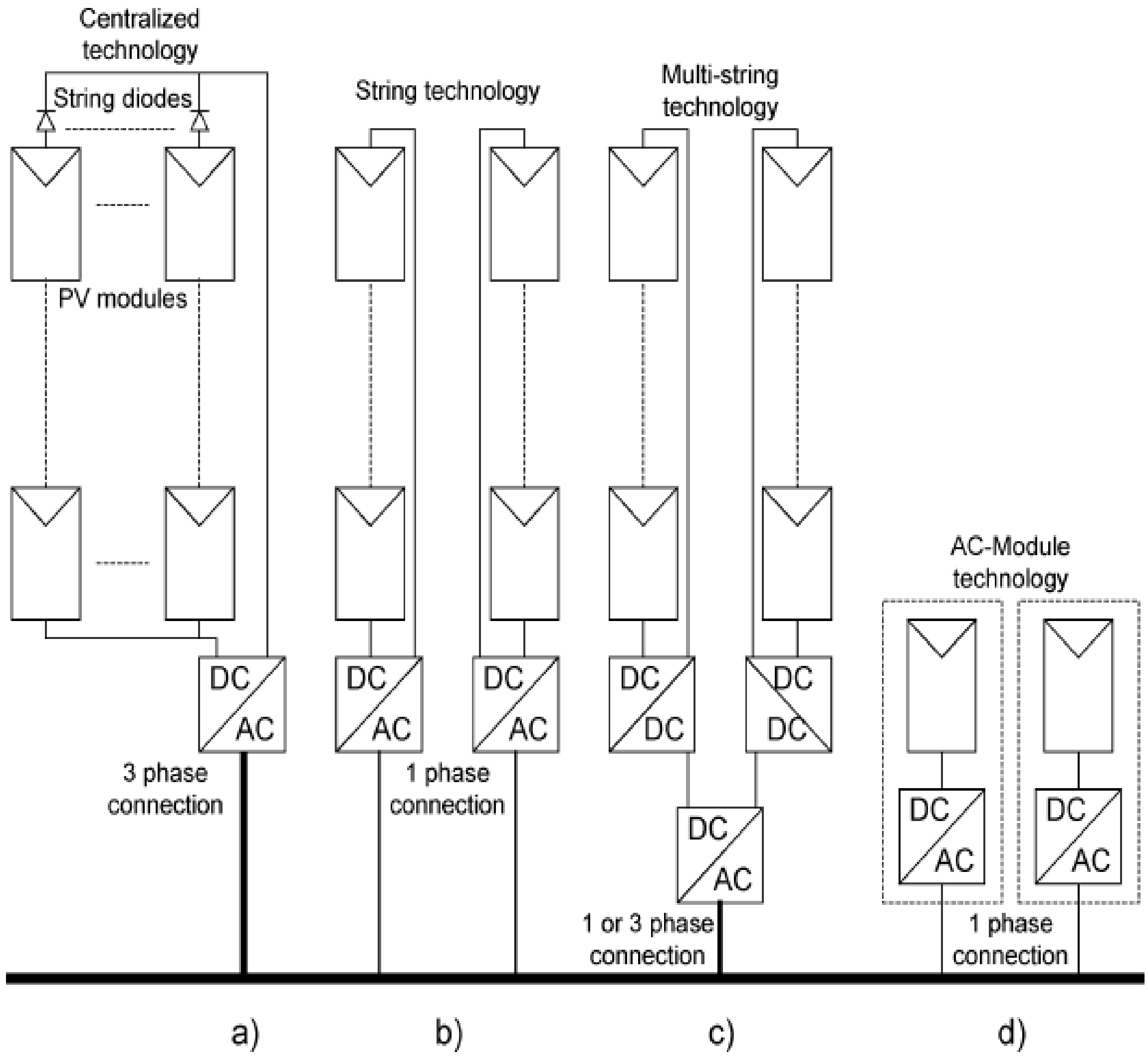

Fig. 3.1 Connection Topology of Photovoltaic Inverters (a) Centralized Inverter (b) String Inverter (c) Multi-String Inverter (d) AC-Module Inverter [32]

3.3.3 Multi-String Inverter

Multi-String inverter is next stage of String inverter in which many strings are connected with their own DC-DC converter with the common DC-AC inverter. In this topology each string can be controlled separately so this system is very much reliable compare to Centralized inverter. This topology is very much flexible in nature because it can be start with few modules and further changes can be easily done; since a new string can be add on existing with DC-DC converter.

Multi-String topology has several advantages like, no loss of energy due to partial shading of module, no string diode loss. There is separate voltage amplification facility available for each string, so voltage can be maintained constant. There is some limitation also with this topology like, costly than Centralized topology, extra losses inside the DC-DC converter. The topology diagram is shown in fig 3.1.

3.3.4 AC-Module Inverters

AC-Module Inverters is the integration of photovoltaic-cells and the inverter [35]. The main aim for this inverter is boost the very low voltage of PV cell to a right level for the grid. This topology is very much flexible in nature and less power loss due to partial shading. There is easily detection of module failure and no mismatch losses between modules.

There is several limitation also like; inverter replacement is not easy in case of faults, due to extra thermal losses life of power electronic element reduced and cost is also high.

CHAPTER 4

MODELLING AND SIMULATION OF PV INVERTER CONNECTED WITH GRID

4.1 GENERAL

This chapter describes the simulation model of grid connected PV system. First is photovoltaic system model which has two constraint irradiance and temperature, for this model these two constraints has taken variable. Secondly it describes inverters model used for conversion of DC-AC. After that complete model of grid connected PV system has given**.** Complete model is described below.

4.2 PHOTOVOLTAIC ARRAY MODEL

This photovoltaic array has 14 series connected module per string and 35 parallel strings With a rating of V_{mp} (voltage at maximum power point) 26.6V and I_{mp} (current at maximum power point) 7.7096A per module. Other parameters are shown in given Fig. 4.1

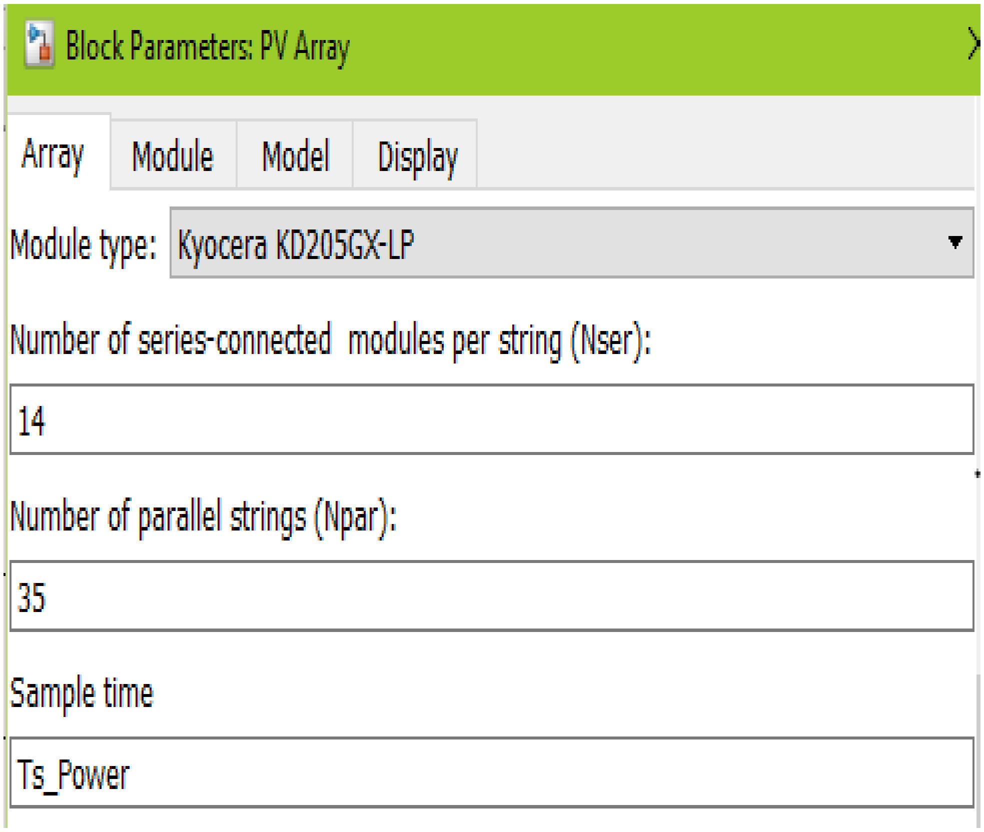

Fig. 4.1. PV array parameters

PV array contains number of module as described above, module parameter like open circuit voltage, short circuit current, maximum power point voltage, maximum power point current, temperature coefficient of maximum power point voltage and current is given by manufacturer. For this model all these parameters are shown in Fig. 4.2.

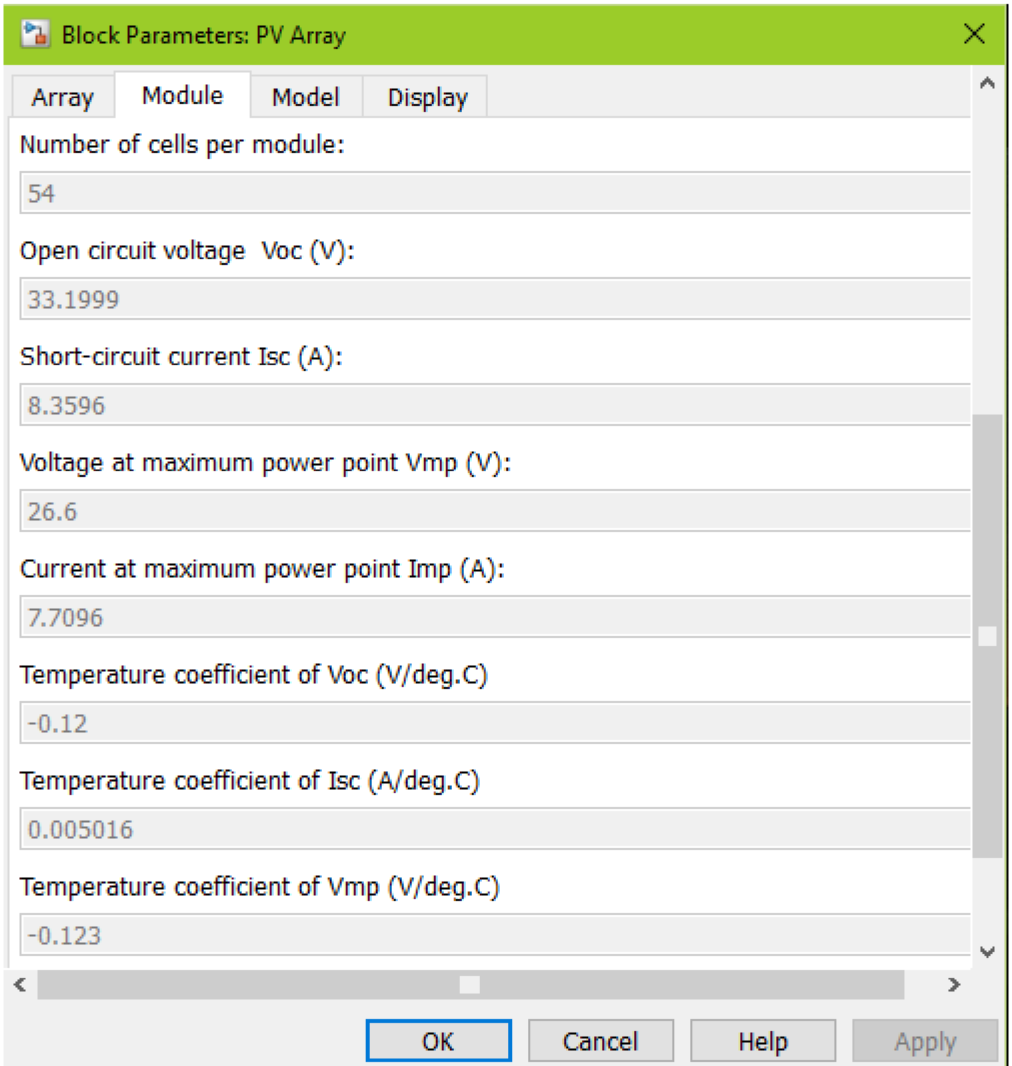

Fig. 4.2. PV Module parameters

PV array model has flexibility to change irradiance and temperature. PV model and constraint diagram has shown in fig 4.2 and fig 4.3 respectively and formula used in also given in equation 4.1, 4.2 and 4.3.

$$I_d = I_{sat} \times e^{(\frac{V_d}{V_T} - 1)} \tag{4.1}$$

$$V_d = V + R_S \times I \tag{4.2}$$

$$V_T = \frac{k \times T}{q \times Q_d \times N_{cell} \times N_{ser}} \tag{4.3}$$

where,

I_d = diode current (A)

V_d = diode voltage (V)

I_{sat} = diode saturation current (A)

V_T = temperature voltage

T = cell temperature (K),

k = Boltzman constant = 1.3806e-23 J.K^-1

q = electron charge = 1.6022e-19 C

Q_d = diode quality factor

N_{cell}= number of series-connected cells per module

N_{ser} = number of series-connected modules per string

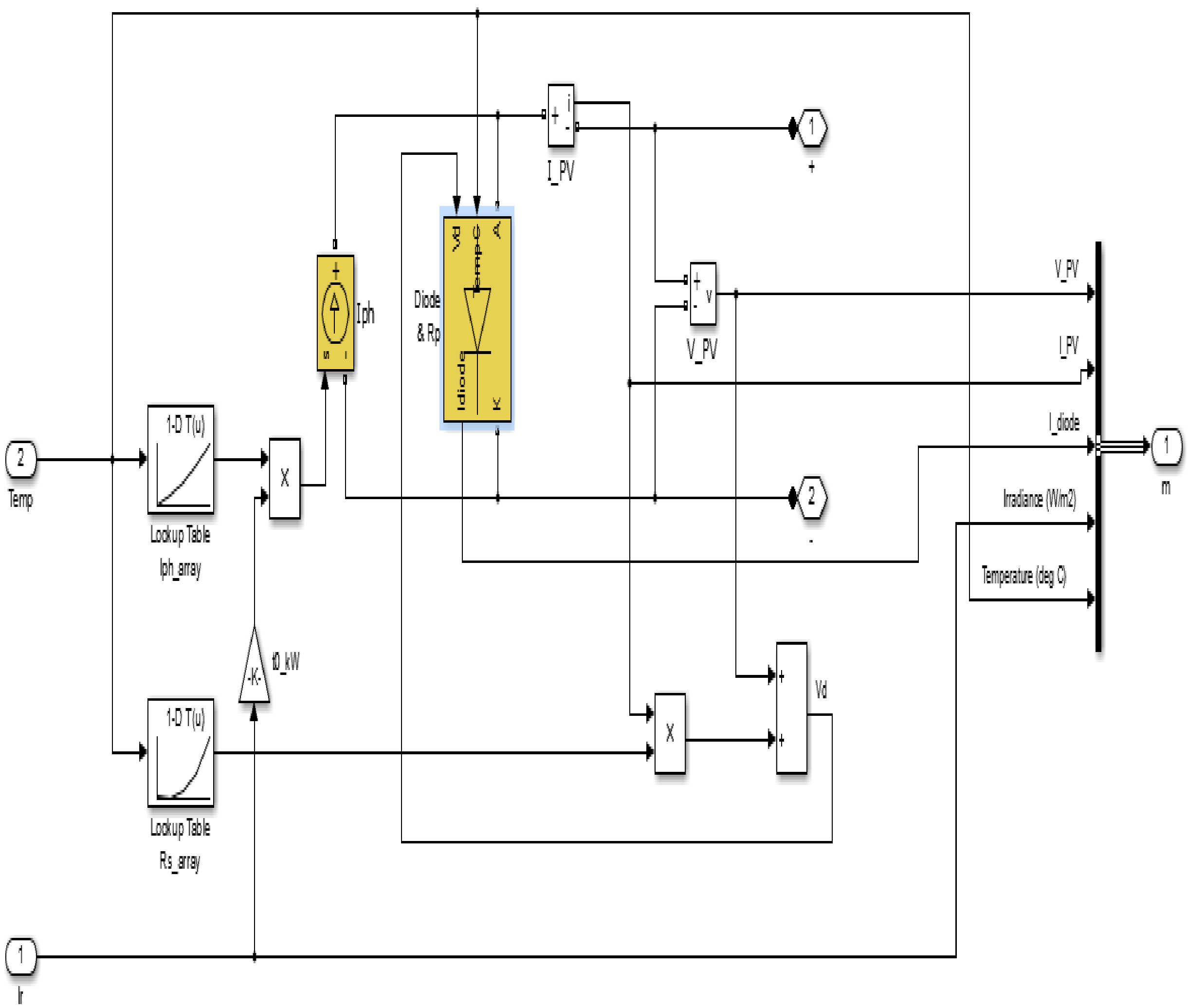

Fig. 4.3. Photovoltaic Array Model

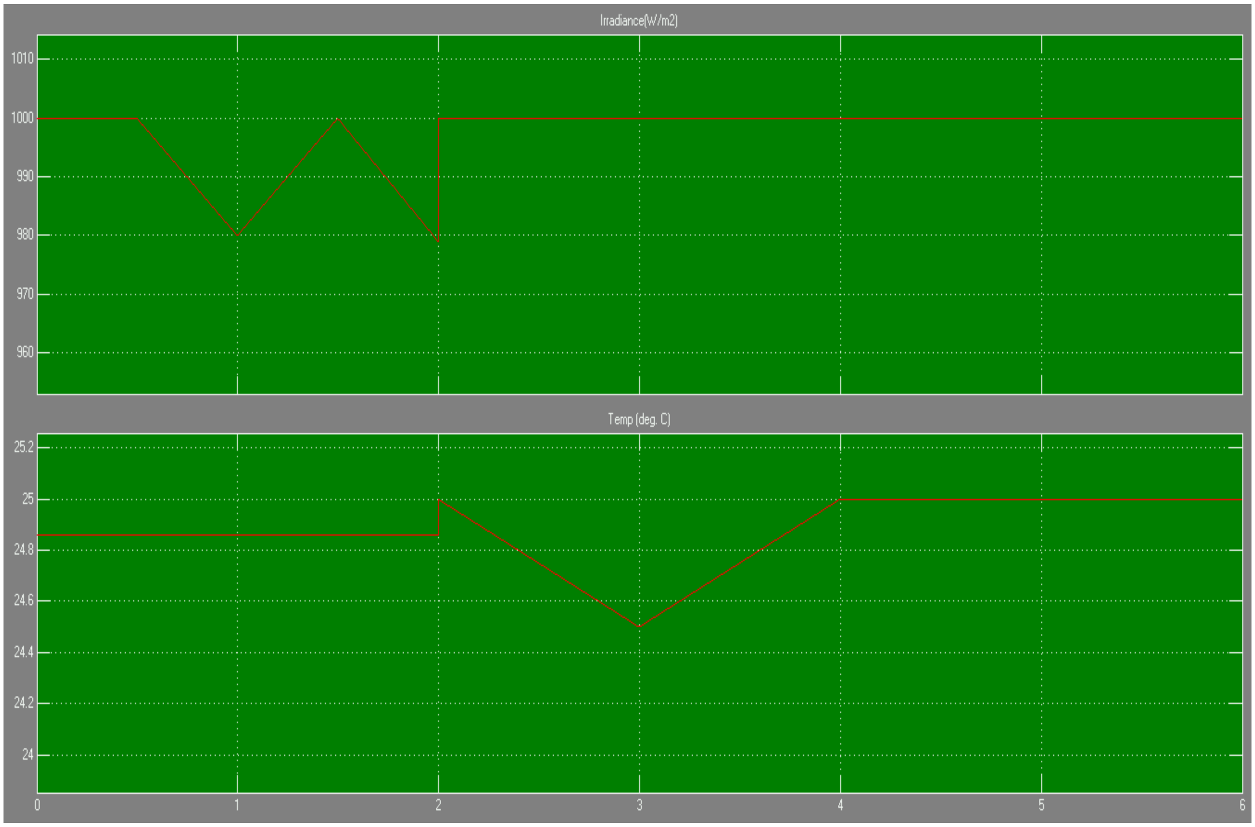

Fig. 4.4. Irradiance and Temperature signal

4.3 BOOST CONVERTER

A boost converter is DC-DC converter, which is used for amplification of voltage at input side of inverter. When voltage on input side of inverter or output of PV module is less, boost converter is used. Boost converter is a type of switch mode power supply in which storage element like inductor or capacitor is used for boosting the voltage. Boost converter principle can be used for regenerative braking of DC machine. In order to improve the performance of converter, filters should be used. The equation used by boost converter is shown below:

$$P = V_a \times I_a = V_{dc} \times I_{dc} \tag{4.4}$$

$$I_{dc} = \frac{V_a \times I_a}{V_{dc}} \tag{4.5}$$

where,

V_{dc}= output voltage from boost converter

I_{dc} = output current from boost converter

V_a = input voltage to boost converter

I_a = input current to boost converter

Boost converter used duty cycle concept for boosting the voltage. Duty cycle value in this model is 0.25.Boost converter model has shown below in fig 4.4:

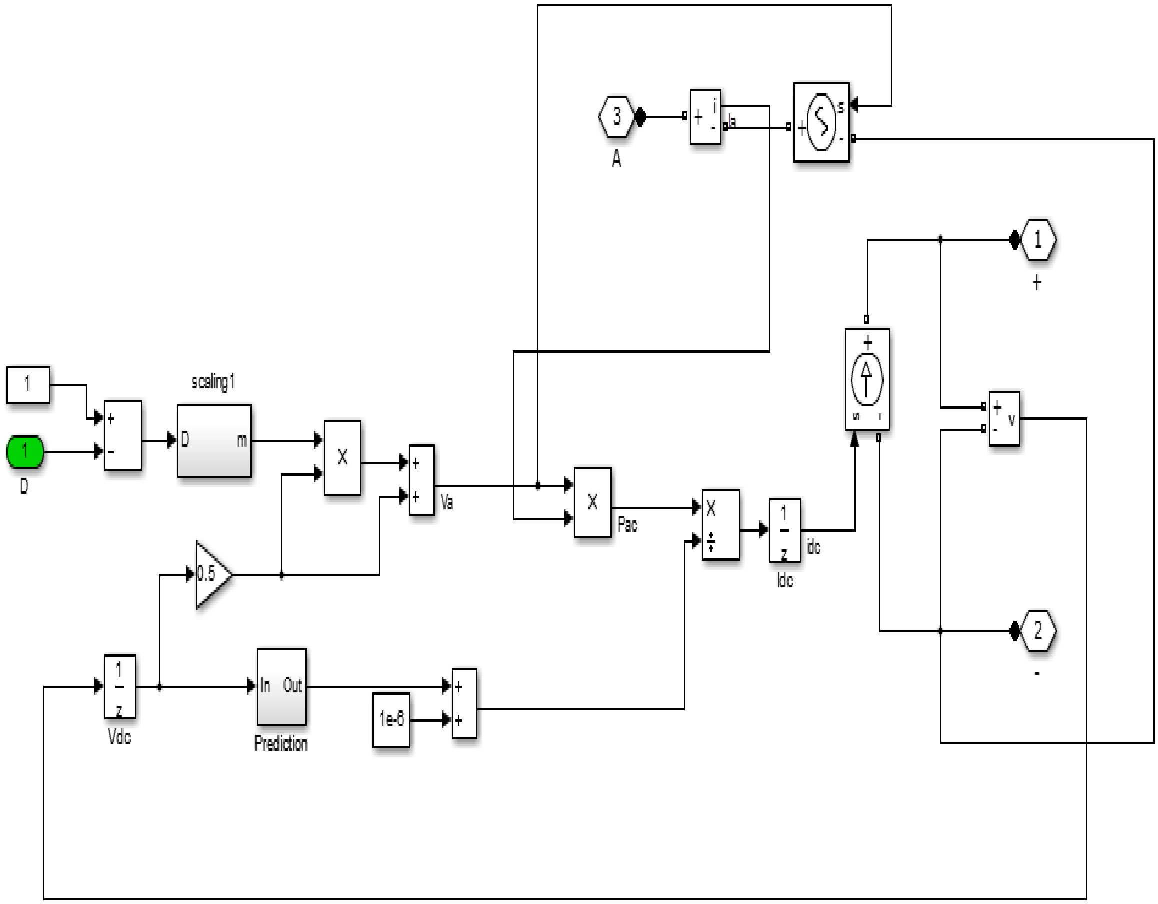

Fig. 4.5. Boost Converter Model

4.4 INVERTERS

Inverter is used for conversion of DC power to AC power. There are two type of inverter used for models, Pulse width Modulation (PWM) inverter and 180 Degree Mode Voltage Source Inverter (VSI).

4.4.1 Pulse width Modulation (PWM) Inverter

Pulse width modulation inverters are gradually taking over other types of inverters in industrial applications. Pulse width modulation techniques are characterized by amplitude pulses of constant magnitude. To obtain control output voltage and to reduce its harmonic content in pulse width modulation inverter width of the pulse should be modulated. The PWM inverter can also eliminate some of lower order harmonics and improve the quality of output waveform.PWM inverter model is shown in Fig. 4.5

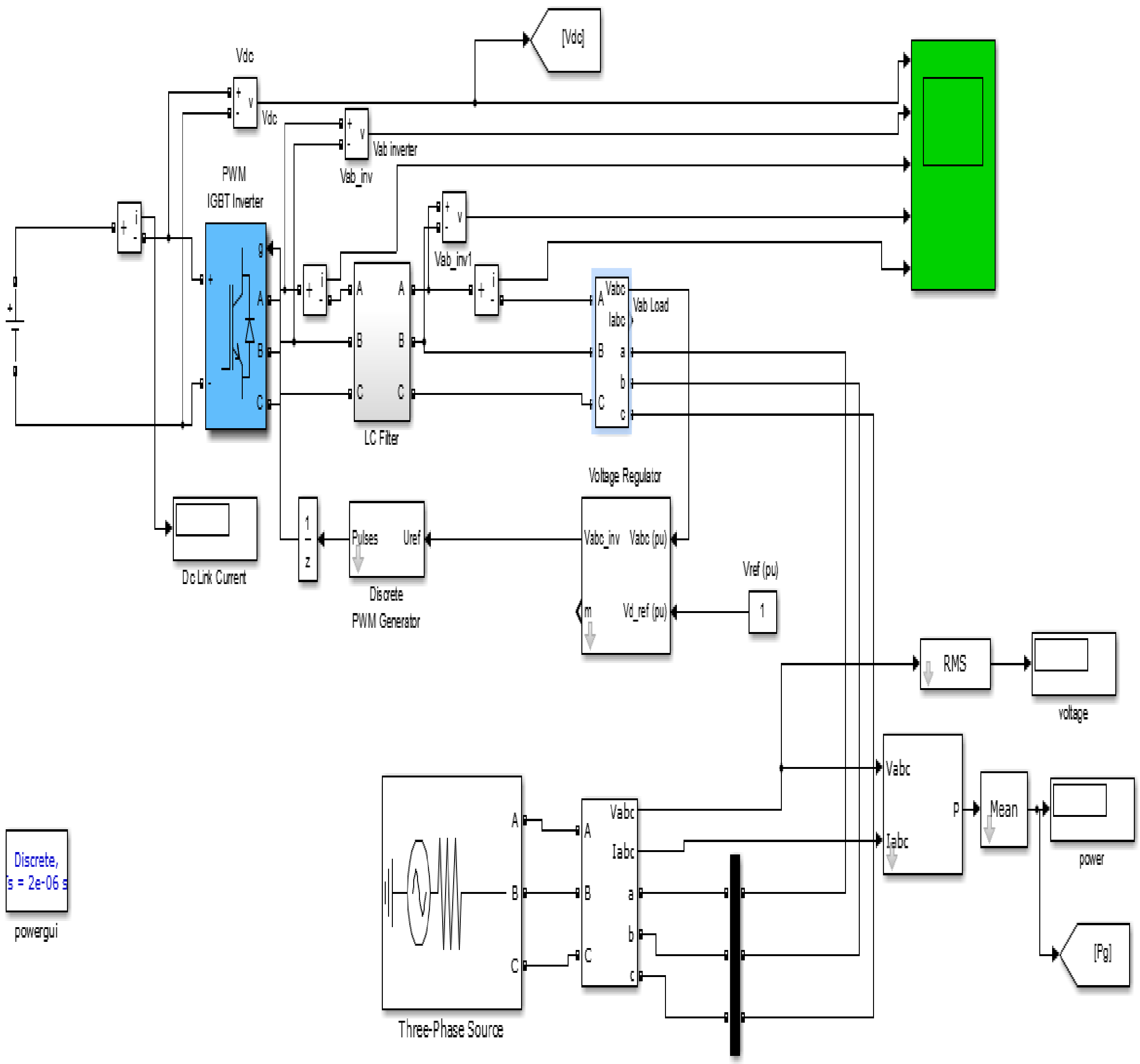

Fig. 4.6. PWM Inverter Model

4.4.2 180 Degree mode Voltage Source Inverter (VSI)

In this type of inverter each mosfet is conducted for 180 degree of a cycle. Mosfet pair in each arm is switch on with a interval of 180 degree. It means T_1 conducts for 180 degree and T_4 for another next 180 degree of a cycle. Mosfet in upper group i.e. T_1, T_3, T_5 conduct at interval of 120 degree. Same is true for lower group mosfet i.e. T_4, T_2, T_6. One drawback of 180 degree mode VSI is, a possibility of short circuit across the supply, when the incoming switch starts conducting before the outgoing switch belong to same phase stops conducting. For 180 degree mode voltage source inverter even and triple harmonics are not present. The 180 degree VSI model is shown in Fig. 4.6.

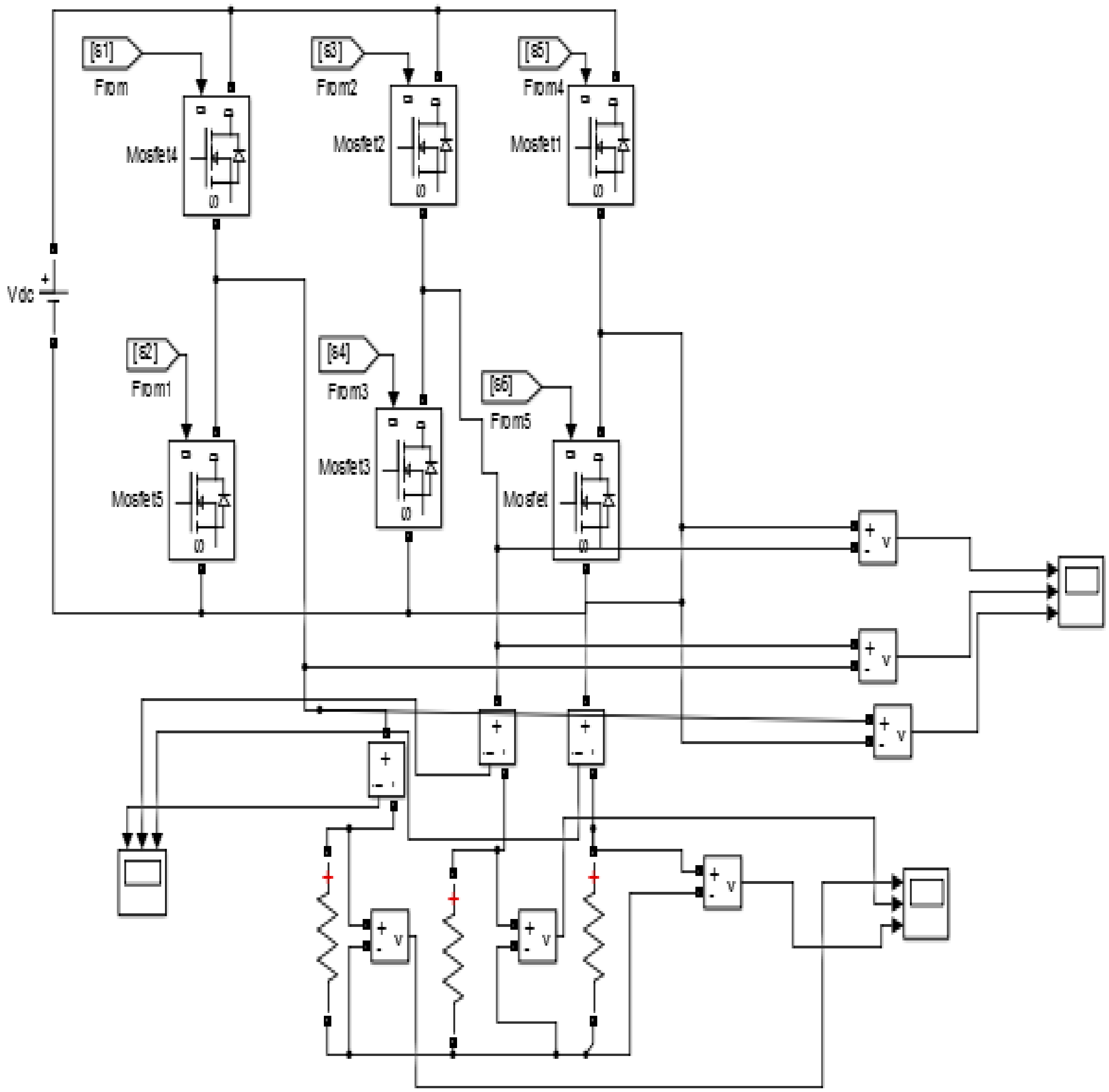

Fig. 4.7 180 degree mode voltage source inverter Model

4.5 MODELS DESCRIPTION

Two models have shown below in Fig. 4.7 and 4.8, which shows PV array, inverter and grid. Firstly PV array give supply DC power to inverter, inverter transforms Dc into AC which is supplied to the grid. In first model PWM inverter is used with the IGBT switch. LC filter is used to remove the harmonic in the system, with the help of three phase VI measurement block power is given to grid and with 3 phase VI instantaneous block active power is calculated. FFT analysis has done for calculating harmonics in voltage waveform. This system provides 400V L-L (line to line), 50 HZ supply to grid.

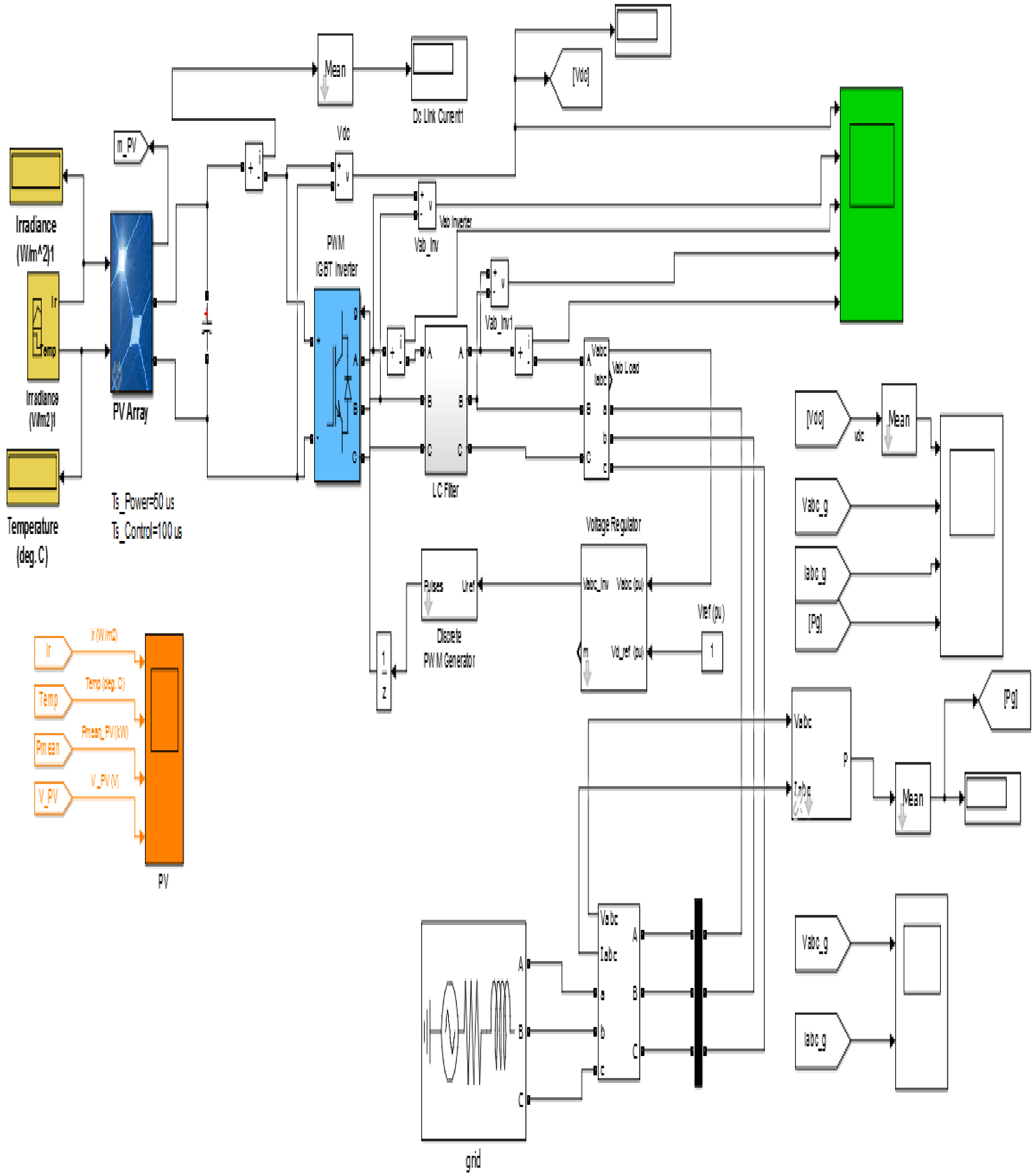

Fig. 4.8 Complete Grid connected PV Model with PWM Inverter

In the second model 180 degree VSI is used. All block is used is here same as describe above model for power, voltage, and harmonic calculation. For inverter, mosfet switch is used. Boost converter is used for step-up the voltage by varying duty cycle, in this model duty cycle value is

0.25. N channel type mosfet swich is used here. Gate signal for mosfet is switched on at 180 degree phase. The model is shown below in Fig. 4.8.

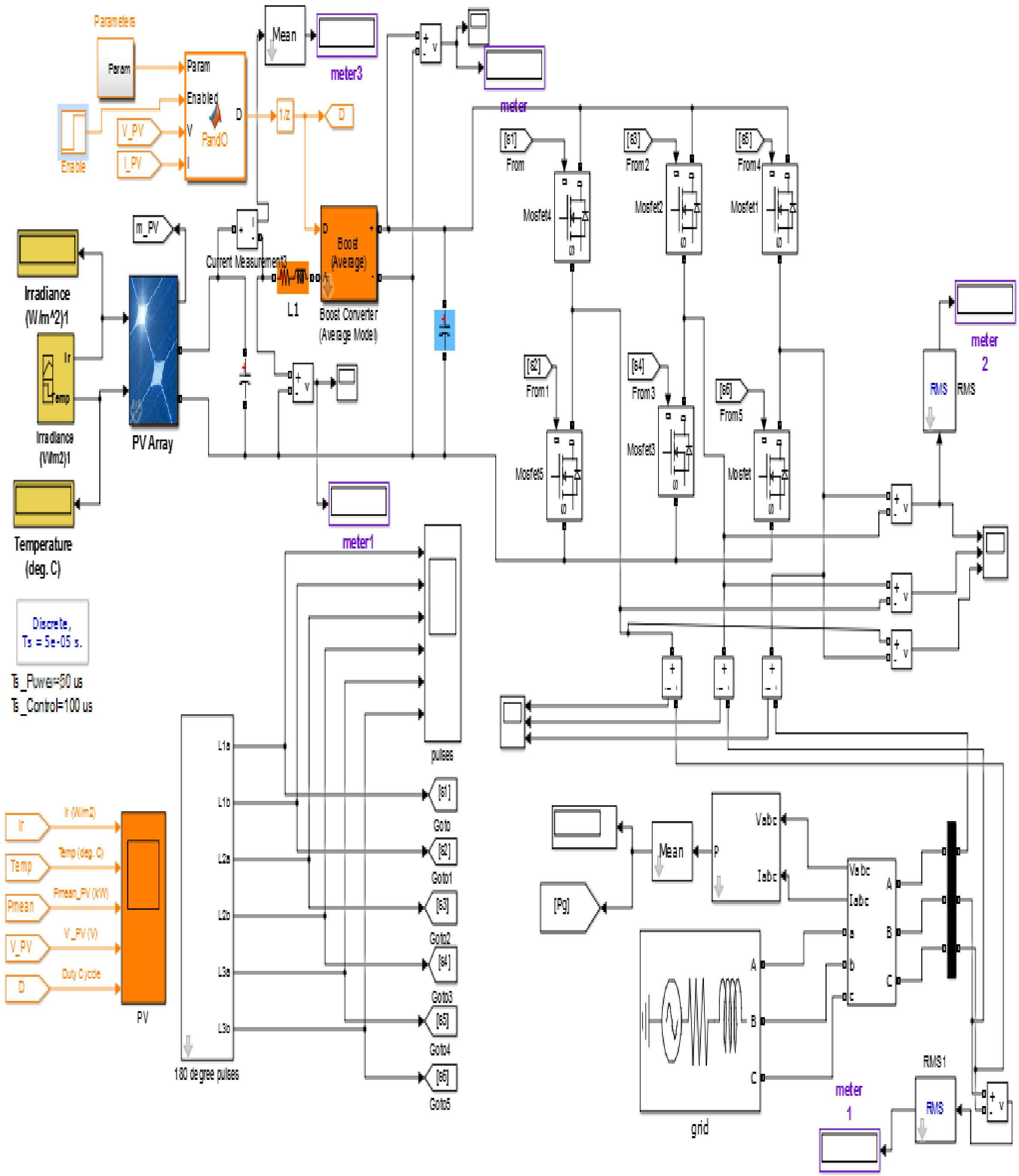

Fig. 4.9 Complete grid connected PV model with 180degree mode VSI

CHAPTER 5

RESULTS AND DISCUSSION

5.1 GENERAL

This chapter contains all the results obtained from simulation by using different inverter in a comparative manner. Different parameter has been compared for both inverters.

5.2 OUTPUT OF PV ARRAY

PV array gives DC voltage to the inverter and according to their capacity it supplies power. Here PV array has 14 number of series module per string and 35 parallel string , with one module rating of Vmp (voltage at maximum power point)=26.6 V and Imp (current at maximum power point) = 7.70A. According to our power requirement we can add more no of parallel module. Same PV array is used for PWM inverter as well as for 180 degree mode VSI.

5.2.1 Output of PV Array for PWM Inverter

DC output voltage from PV array is 395.5V and output power from PV array is approximately 93kW. Waveform of DC voltage and power is shown in Fig.5.1.

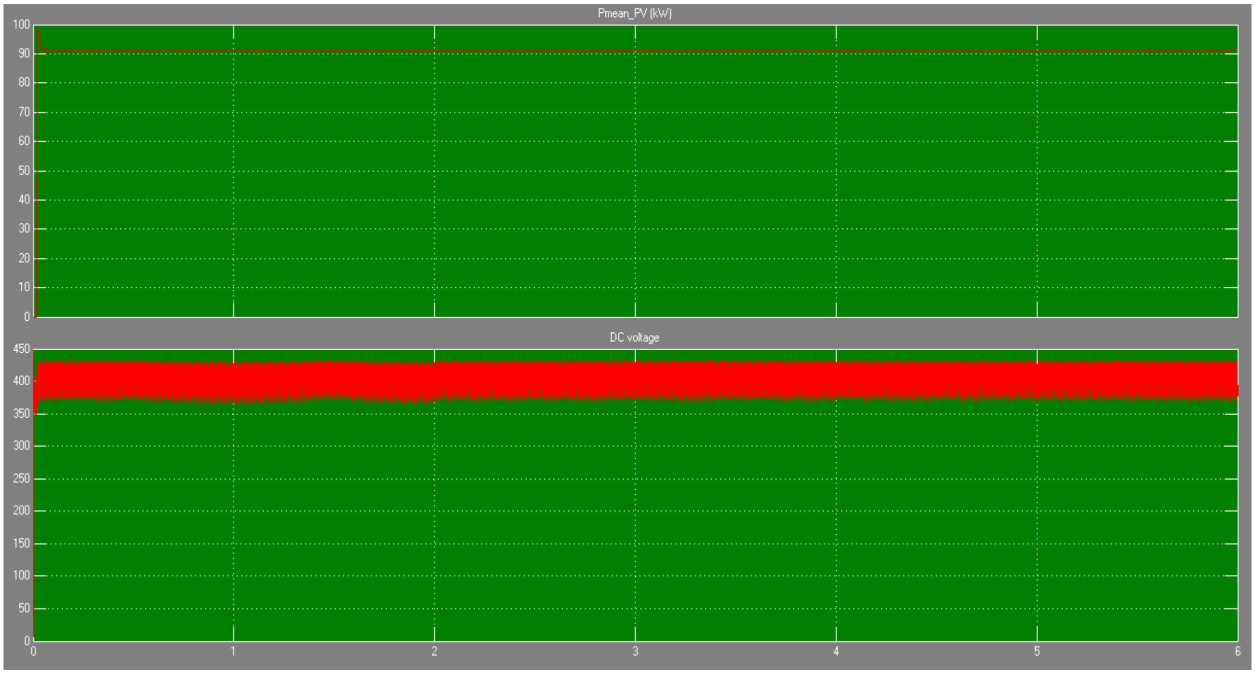

Fig. 5.1 Waveform of PV Array Output for PWM inverter

5.2.2 Output of PV Array with duty cycle for Boost Converter for 180 degree mode VSI

180 degree mode VSI requires boost converter with a duty cycle of 0.25, boost converter is required for meet the voltage level of grid 400V line to line. DC voltage before boost is 407V and after boost converter 542V and power from PV array is 91.97kW which is lee than PV array output of PWM inverter. Waveform of DC voltage, amplified DC voltage and PV array is shown in Fig.5.2.

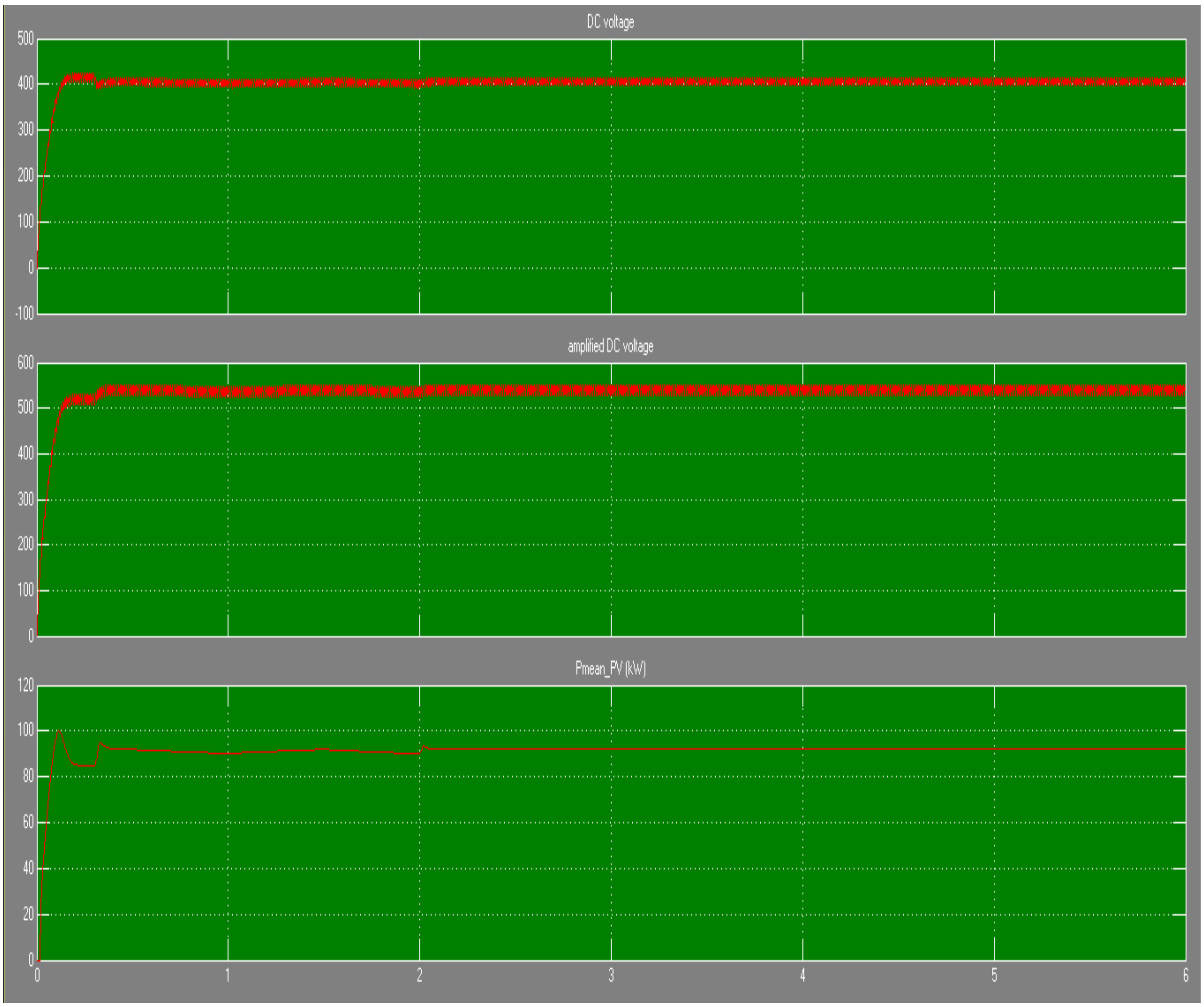

Fig. 5.2 Waveform of PV Array Output with Duty cycle for 180degree mode VSI

5.3 OUTPUT VOLTAGE FOR INVERTERS AND FFT ANALYSIS OF WAVEFROM

Output voltage should meet grid voltage level of 400 V line-line. For synchronization with the grid output voltage should be same as the grid voltage.

5.3.1 PWM Inverter Output voltage and FFT Analysis

Output voltage of PWM inverter is almost same as grid requirement (400V line to line) and waveform has shape of sinusoidal so it contains very less harmonics. Output voltage waveform should not change with load. Output voltage of this PWM inverter is 399.86 V, with frequency of 50 Hz. Line Voltage waveform Vab is shown in Fig.5.3.

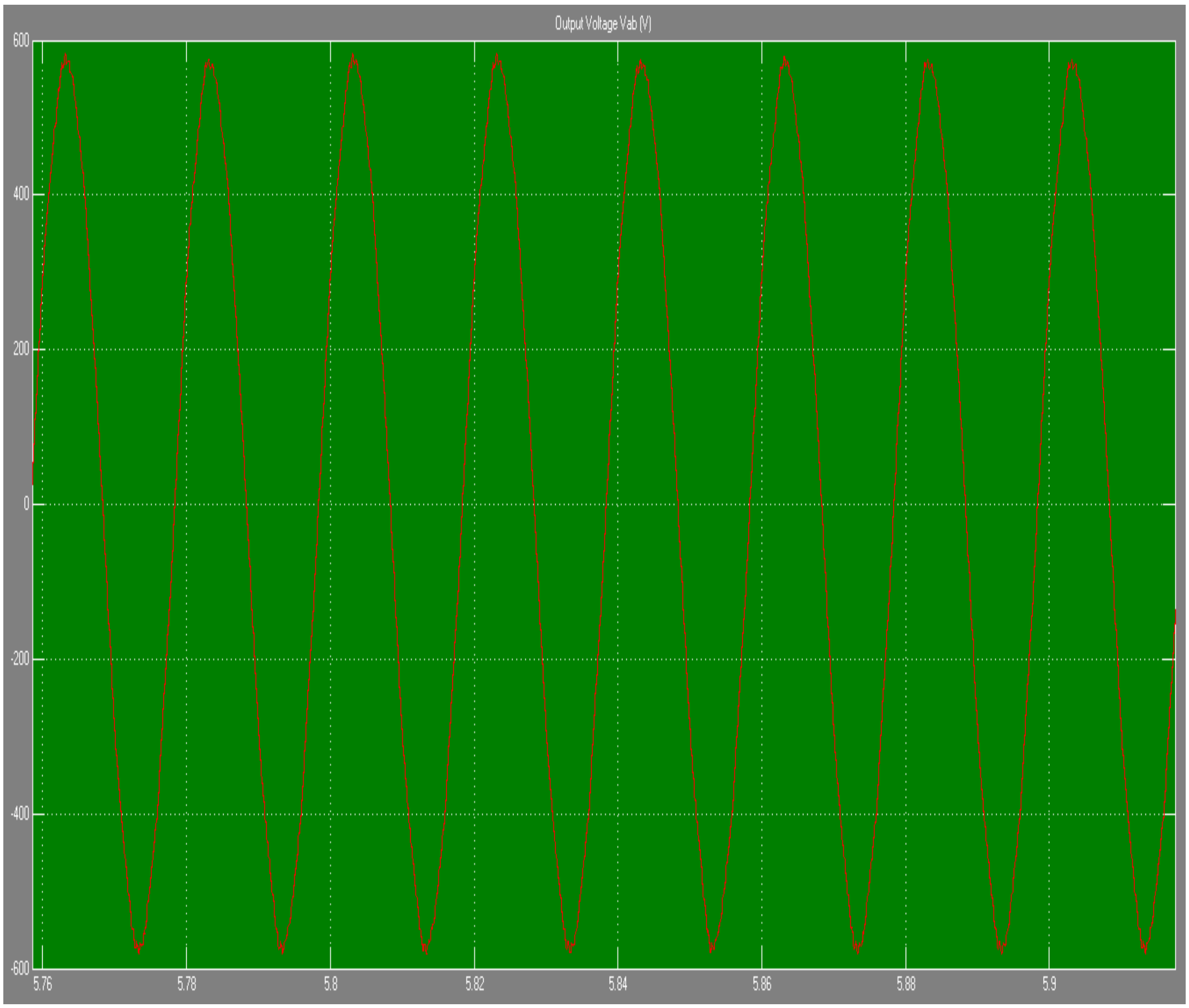

Fig. 5.3 Voltage Output waveform for PWM Inverter

Fast fourier transform (FFT) analysis is done for percentage of harmonic content in waveform. For this we have to calculate total harmonic distortion. For analysis we have taken 5 cycles of waveform at 50 Hz. In this PWM inverter voltage waveform the total harmonic distortion (THD) is 1.9%. FFT analysis calculation is shown in Fig.5.4.

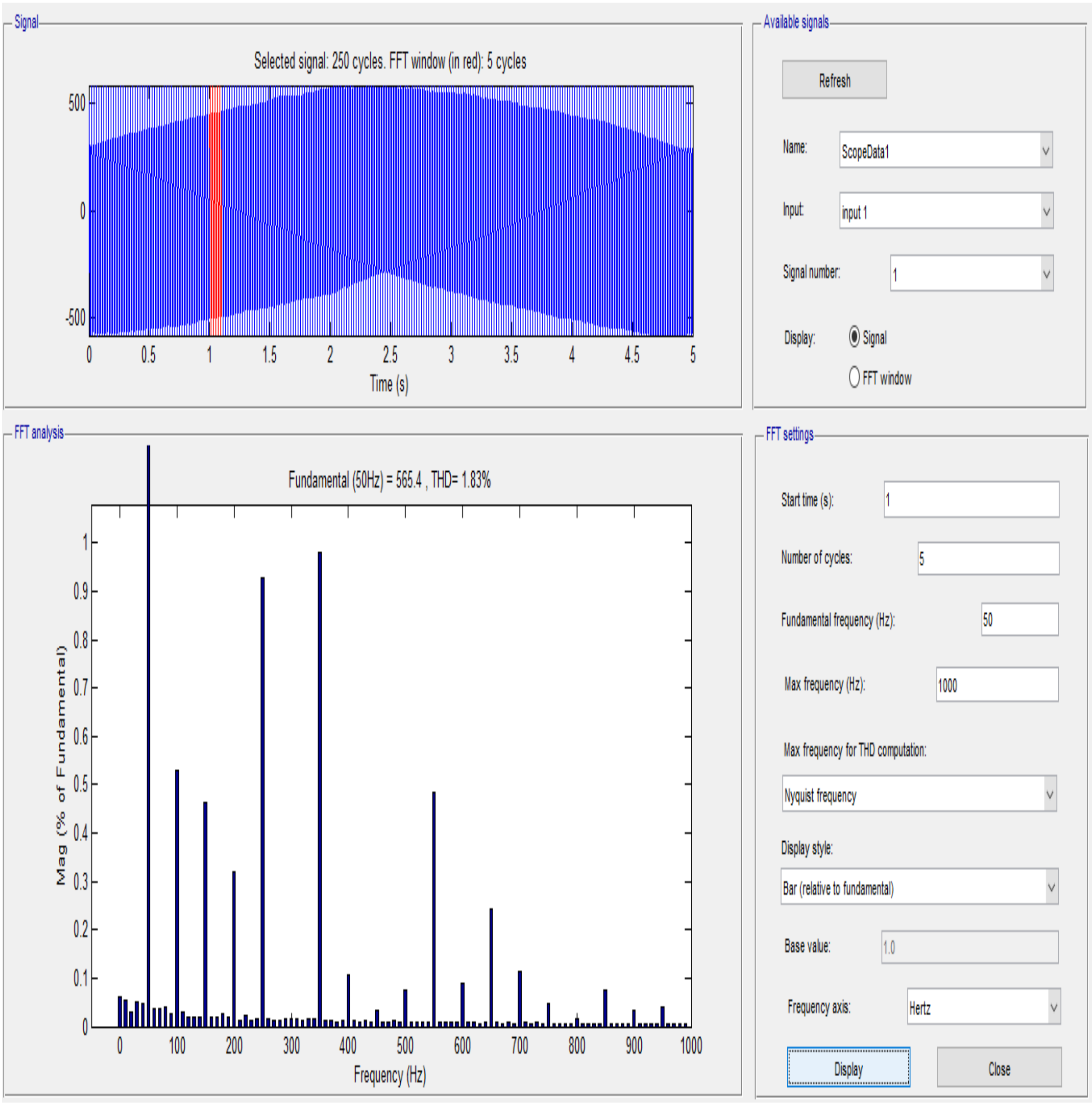

Fig. 5.4 THD Analysis for PWM Inverter voltage waveform

5.3.2 Output Voltage for 180degree mode VSI and FFT Analysis

Output voltage of 180 degree VSI gives 397.8 V line-line at 50 Hz frequency which is almost equal to grid voltage**.** Waveform of this inverter needs some filter for harmonics reduction. Voltage source inverter requires boost converter for boosting the DC voltage. In this system duty cycle of 0.25 is used for boost converter. Output voltage Waveform is shown in Fig.5.4.

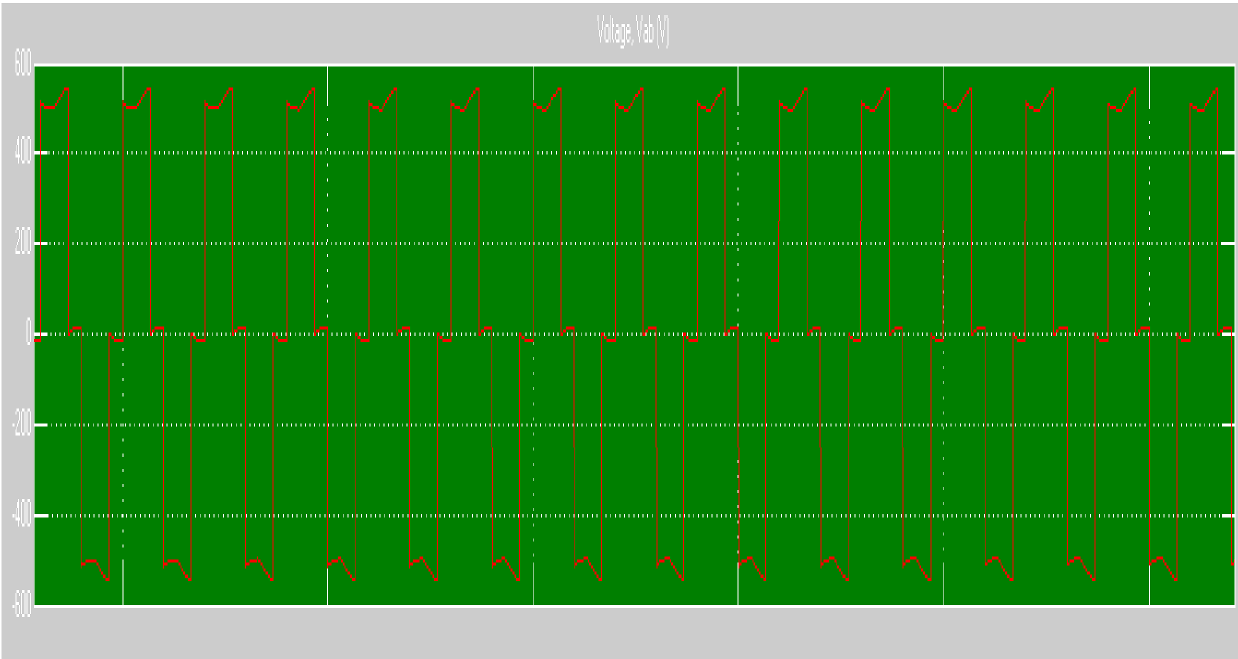

Fig. 5.5 Voltage Output waveform for 180 degree mode VSI

In case of 180 degree mode VSI, FFT analysis of voltage waveform gives 32.57% total harmonic distortion. FFT analysis calculation is shown in Fig. 5.5

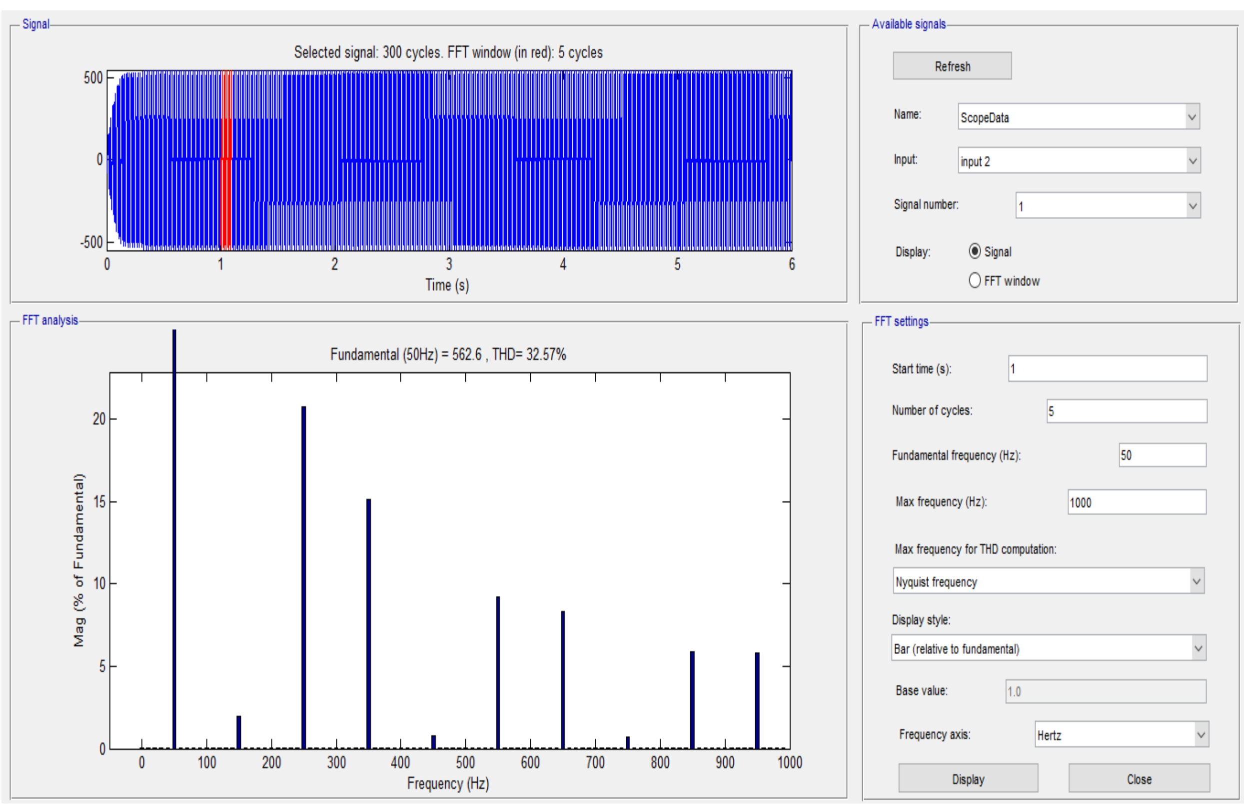

Fig. 5.6 Waveform for THD Analysis for 180degree mode VSI voltage

5.4 OUTPUT POWER WAVEFORM

Output power from inverter is power, which is either supplied to grid or directly to the load. In our model we are supplying power to the grid directly.

5.4.1 Output Power for PWM Inverter

In case of PWM inverter output power is 88.79 kW and efficiency of inverter is 97.91%. Output power waveform is shown in Fig. 5.7.

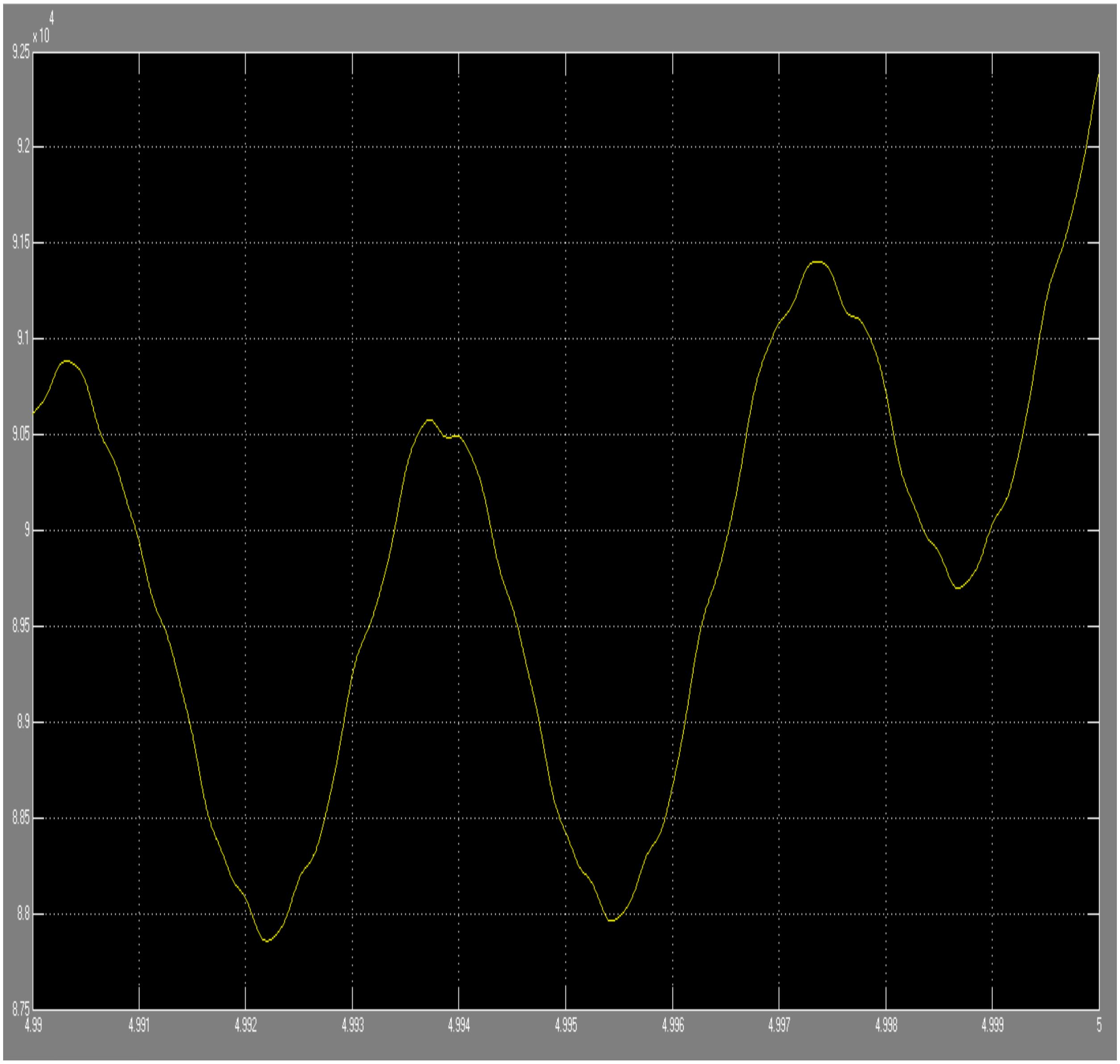

Fig. 5.7 Output Power Waveform for PWM Inverter

5.4.2 Power Output Waveform For 180 degree mode VSI

Output power for 180 degree mode VSI is 84.94 kW and the efficiency of inverter is 92.05 %, which is less than the PWM inverter. Output power waveform is shown in Fig. 5.8.

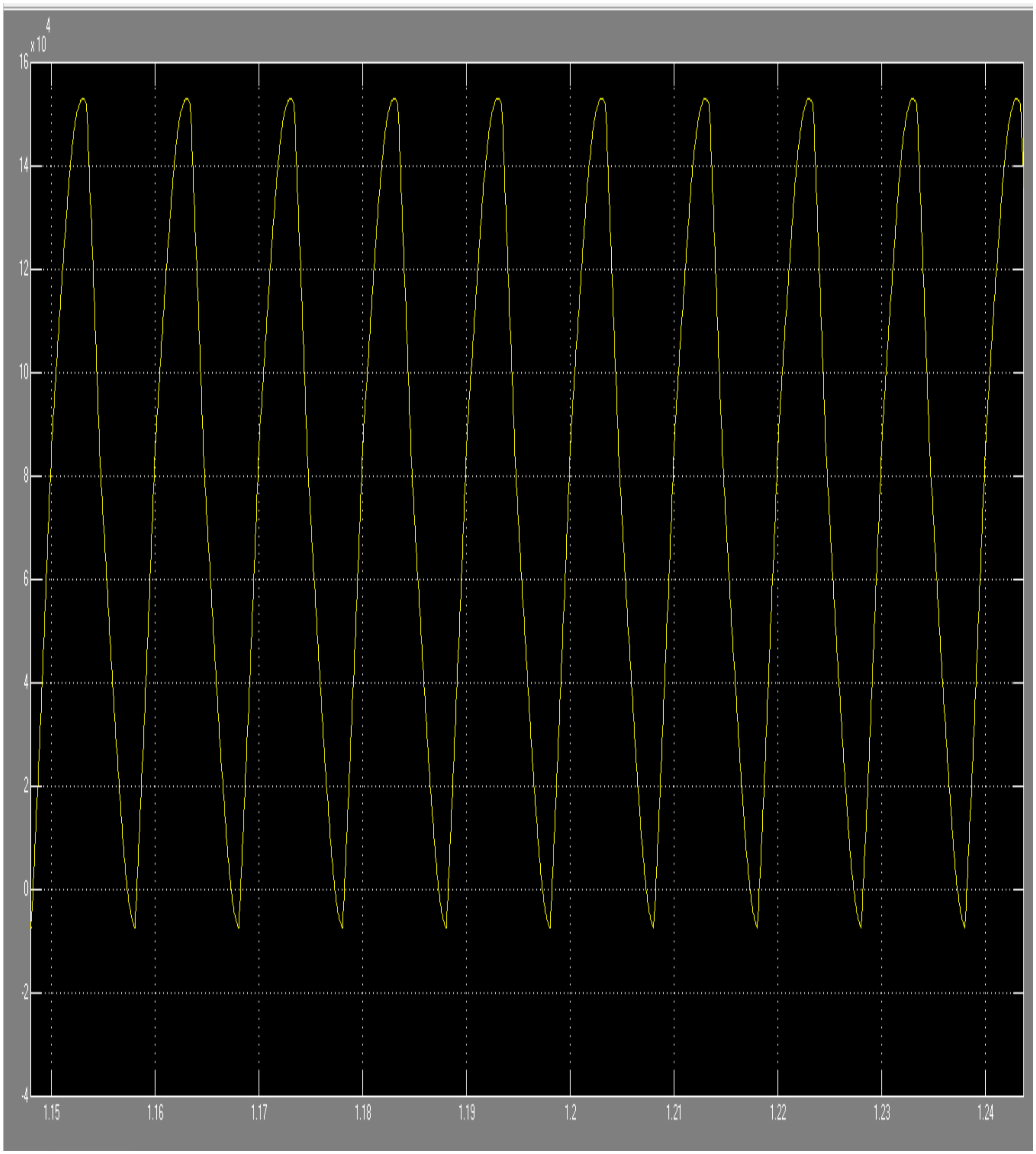

Fig. 5.8 Output Power Waveform for 180 degree mode VSI

5.5 COMPARASION OF DIFFERENT PARAMERETR FOR GIVEN TWO INVERTER

Efficiency and power value came better in PWM inverter compare to 180 degree mode VSI. THD value is less in PWM inverter compared to 180 degree mode VSI. Voltage level is almost same in both the inverters as required by the grid. Comparison of parameters is done in Table 5.1.

Table 5.1 Comparison of parameter for Inverters

PARAMETERS	**PWM INVERTER**	**180DEGREE mode VSI WITH BOOST CONVERTER**
VOLTAGE(DC) (V)	395.5	407
CURRENT (DC) (A)	238.6	226.6
POWER (Input) (kW)	94.36	92.22
VOLTAGE(line to line) (V)	400	401.48
VOLTAGE (line to line) peak (V)	565.5	567.7
POWER (OUTPUT) (kW)	92.4	84.94
EFFICIENCY (%)	97.92	92.1
TOTAL HARMONIC DISTORTION IN VOLTAGE WAVEFORM(THD) (%)	1.9	32.56

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

On the basis of present study and results reported in the thesis, the following conclusions are drawn:

1. A MATLAB/SIMULINK model for a grid connected PV system by using different inverters has been developed. This developed model can be used to predict the performance of different three phase inverters.

2. Centralized inverter topology is preferred for large no of PV modules, when input voltage is sufficient to high to avoid further amplification. But it is not flexible. For flexibility purpose Multi string Inverter topology should used and some time in this type amplification is needed.

3. Pulse Width Modulation (PWM) Inverter should be preferred for conversion of DC to AC because it gives very low Total Harmonic distortion (THD).

4. The efficiency of PWM Inverter is 97.9%.

5. The efficiency of 180 Degree mode Voltage Source Inverter (VSI) is 92%.

6.2 FUTURE SCOPE

Based on the present work following future works are recommended:

1. Present work is done by using only two type of inverter PWM Inverter and 180 degree mode Voltage Source Inverter. It is therefore recommended to use other type of inverter like Current Source Inverter and Fly-back Inverter and check their performance.

2. The modeled system should be able to detect the islanding operation.

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