“PERFORMANCE EVALUATION OF PHOTOVOLTAIC SYSTEM UNDER PARTIAL SHADING”

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this dissertation titled "**PERFORMANCE EVALUATION OF PHOTOVOLTAIC SYSTEM UNDER PARTIAL SHADING**" is presented on behalf of partial fulfilment of the requirement for the award of the degree of Master of Technology in Electrical Engineering with specialization in Electric Drives and Power Electronics submitted to the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, India in origional, under the supervision and guidance of Dr.S.P.Singh and Dr. Pramod Agarwal, Professor, Electrical Department, IIT Roorkee.

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

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CERTIFICATION

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

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ABSTRACT

Global energy demand is increase rapidly. Major demand is met by fossil fuel. This increases the carbon foot print. So we move towards the renewable energy to reduce carbon foot print. With the increasing growth of renewable energy, photovoltaic (PV) systems are increasingly used to generate electrical energy from solar irradiation. In order to make the PV system can output the maximum power at all times, we can use the maximum power point tracking (MPPT) algorithm more often to reach the achievement that the system can work at the highest efficiency under the different atmosphere. Among all the MPPT methods, Incremental conductance method is used because of its highly accurate at partial shading condition also. It required two sensors, voltage and current. It response time is very fast. It mainly uses P-V characteristic curve to find MPP point. When the slope is zero, it is said that the system works at the MPP.

Shading on PV array cause severe effect on obtaining maximum efficiency by reducing output power. The shading is caused by presence of cloud, shadow of nearby building, dust, damage of cell in the module etc. Under partial shading, it will make the P-V characteristics curve appear multiple peak point. It will lead the conventional P&O misjudge, and make the system work at local maximum power point (LMPP), not at global maximum power point (GMPP).

So in this report first modelling of photovoltaic cell is done in MATLAB simulation according to current equation. Than output of boost converter is connect to inverter and further filtered output is connect to grid. PV power is supplied to grid. This PV cell is used in complete PV system simulation. Tracked the maximum power point under two different partial shaded PV cell. We have done the literature survey on different technique to track Global maximum power point under partial condition. Boost converter is used for matched input impedance to output impedance. Boost converter duty cycle is change to track the maximum power point with change the load. Pulses of inverter circuit is controlled by d-q axis or synchronous reference theory. Complete system is simulated in MATLAB and obtain desired output.

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CHAPTER 1: INTRODUCTION

1.1 NEED OF RENEWABLE ENERGY

Global energy demand increased rapidly in the 20th century and the same trend is continuing in the 21st century as well a major share of the global energy demand has been met with fossil fuels. The extraction, conversion, transmission (transport), distribution and utilization of fossil fuels lead to the release of a variety of environmental pollutants including the CO2 increased concentration of greenhouse gases such as CO2 in the atmosphere has manifested in terms of global warming and many other adverse environmental effects.

It is clear that fossil fuels are unsustainable. Now world is working on reducing the greenhouse emission more than 25 percent by January 2020 and 80 percent by 2050. Large scale harnessing of renewable energy resources and adoption of energy efficiency and other demand-side management measures are expected to solve this problem. A large number of countries in the world have initiated ambitious programs in this direction and considerable success has been achieved in both harnessing the renewable sources of energy as well as in improving the efficiency of energy utilization. As a consequence, the energy mix is changing on the global scale. By the end of 2017, the total electricity generation from renewables accounted for almost 23.7% of global electricity production. In 2018, the worldwide total installed capacity of electricity generation based on renewable sources of energy (excluding large hydropower and pumped storage) reached 2179 GW (IRENA, 2018). In India, the installed capacity for electricity generation based on renewable energy resources reached 49.12 GW in 2016 (95.53 GW excluding large hydro and pumped storage plants) as against a capacity of just 2.31 GW in the year 2000.

Amongst the various renewable sources of energy, solar energy is expected to play a very important role in view of its decentralized availability in most of the countries of the world. Two distinct technological routes have so far been developed for generating electricity from solar energy. One of the options uses solar energy to produce steam at high temperatures and the same is then used to drive a steam turbine to produce electricity. The second option is based on direct conversion of solar energy into electricity using photovoltaic (solar) cells. There has been a substantial cost reduction in producing electricity. To generate power from solar cell is simple. Solar panel collectors collect energy of sunlight which falls on solar module and covert this energy in to power. Solar power is used to power the cities, rural areas, where conventional power is not reached up to or conventional power running cost is more.

1.2 TYPES OF RENEWABLE ENERGY

1.2.1 Solar power

The British astronomer John Herschel, first one who used solar energy to cook food during expedition of Africa. He used solar collector to cook food.

Solar power can be utilized in many ways but broadly used in two ways, first directly use heat of solar to convert in thermal power which can used for heating purpose. Second convert solar heat in the form of electric power by using photovoltaic cell. This method is widely used now a days. Photo voltaic cell is like a current source. Its power depends on solar irradiance and temperature.

Solar power is a clean renewable energy resource with a zero carbon emission. Now a days, solar power is widely used at industries and domestic level due to its low maintenance cost.

1.2.2 Wind power

Wind power is basically airflow power. For extract the power from wind, wind turbines used to harness the energy from airflows. Power output depends on velocity of wind, its increase when velocity of wind increases. Power output of wind depends on function of cube of wind speed. Recent research on this field led to aerofoils wind turbine, their aero dynamic structure is better so this types of wind turbine is more efficient. Now a days, range of wind turbine is 600KW to 5 MW.

1.2.3 Small hydropower

It can be consider as a renewable energy source because it use run off river flow kinetic energy and potential energy to electrical energy by use of turbine. No need to construct high dams which may led to high cost and harmful for the water species. Small hydropower is useful for local domestic load and industry load, and connect to distributed network in a regional electricity grid.

Upto 10MW of installations of hydropower is come in the category of small hydropower.

1.2.4 Geothermal power

Source of Geothermal energy heat in the different layer of earth. It is a thermal energy which takes heat from earth used for heat water to produce superheated steam, steam falls on steam turbine which produce electricity.

Disadvantage of geothermal energy is low number of region of geothermal source present and reach of this resources is not approachable.

1.2.5 Biomass

Biomass is organic material that comes from plant and animals. Biomass contains sun energy which one extract by plants in the process of photo synthesis.

Combustion of plant release this energy. This energy released in the form of heat of chemical energy of biomass.

1.3 SOLAR POWER IN INDIA

India is a fast developing country in the area of solar power. India has big potential of solar energy. About 4-7 KWh per square meter per day energy received from sun. Over 5000 billion MWh per year energy received by Indian territory. Solar power is a clean renewable energy resource with a zero carbon emission. World is moving towards zero carbon. So India is also willing in it. Solar energy mainly depends on solar irradiance and temperature. Solar radiation converts heat into thermal and electricity. Solar can be provide electricity in less time and faster to distributed network. Perspective of rural electrification off grid power can be provided.

Electricity plays a major role for development of any country. Solar power is most useful for overcome the barrier of various development goals. According to a survey still 3.1 crore home in India living without electricity by December 2018. Many problems occur due to lack of electricity like educational, cold storage for drugs so proper health facility cannot be provided. Most advantage of solar energy is provide pollution free electricity.

As of, March 31, 2019, India had installed 28.18 GW of utility scale solar PV capacity. India set the goal 20GW by 2022. But india achieved 20GW by feb 2018 ahead of 4 years. Now country's new goal is 200GW by 2022 from all renewable sources. In this 100GW will be achieved by solar power as planned. Capacity of solar energy in India is increased by 8 times after 2014.

1.4 RESEARCH OBJECTIVE

Today energy demand is increasing day by day. Uses of conventional energy sources increasing day by day. Because of this carbon emission is increasing rapidly. Conventional energy sources add pollutants in the environment. This is vary hazardous situation. Due to this health issue, increasing temperature of earth and many problem occur. So world is moving towards renewable energy source. India is also play a big role in it. India's mission is generate 200 GW renewable power by year 2022. And in which 100 GW power would be achieved by solar energy. This is a big challenge for India.

So increasing the output power from solar cell is most essential. System should be work on more efficiency. Installing of solar power in hilly area, in city causes shading of part of PV array. Tracking of maximum power point at this time is not possible by conventional MPPT method. Design of most effective MPPT which can track global maximum power point is main research objective. Further system is directly connected to grid.

1.5 DISSERTATION OUTLINE

This dissertation comprised 5 chapter. Each chapter discuss a particular aspects of entire solar PV system.

Chapter 1 is introductory chapter that covers need of renewable energy sources, different types of renewable energy, solar power in India, and research objective.

Chapter 2 provides overview of entire PV system. Mathematical modelling of PV cell, working and conventional MPPT method without partial shading condition. Also discussed change in behaviour of PV characteristics with different irradiance.

Chapter 3 provides working of solar cell under partial shading condition and discussed different types of algorithm which can detect global maximum power point. Also shows how PV output characteristics obtain under partial shading condition.

Chapter 4 is about DC-DC converter. BOOST converter discussed in details. Selection of parameter of boost converter is done in this chapter.

Chapter 5 contains system MATLAB simulation along with simulation result. Control strategy of inverter is also discussed.

At last conclusion of whole dissertation and work is discussed and completed by future scope of this work.

CHAPTER 2: PV SOURCE MODEL

2.1 PHOTOVOLTAIC CELL

Photo voltaic cell is a semiconductor device it directly converts solar radiation energy in to electrical energy. This is done by photovoltaic effect. It is basically a different type of photo diode. Basic principal of photo diode is converts its light energy to current or voltage signal when light falls on n-channel of it. When energy of photon of light is greater than the band gap then electron emits. Due to flow of this electron current generate. Photovoltaic cell is a current source and always forward biased.

2.2 PHOTOVOLTAIC MODULE

When number of PV cell are connected in series and parallel then it is called PV module. Energy output is increased in case of PV module. According to requirement of energy PV module are manufactures in different size. PV module is enough for upto 200W load.

2.3 PHOTOVOLTAIC ARRAY

Large number of photovoltaic module connected in series and parallel at the solar plant. It is called PV array. Series connection gives increase in voltage and parallel connection gives increase in current. So overall capacity of plant increase.

Fig.2.1 Different Solar Modules

2.4 PV MODELLING

Solar cell is basically a current source. It generates current at particular voltage when light falls on it. It shown in fig 2.3 current source is connected with inverted diode and parallel & series resistance. Parallel resistance is due to leakage current and series resistance is due to interruption of the electron in the flow path from n to p junction.

When lights falls on PV cell electric field generates inside the PV cell depletion region like diode shown in fig. 2.2. In n-type semiconductor due to impurities negative charge is carry by free electron and in p-type semiconductor due to impurities positive charge is carry by holes. Therefore free electrons in n-type semiconductor and free holes in p-type semiconductor are called majority carrier in n-type semiconductor and p-type semiconductor respectively. Due to electric field positive and negative charge carriers separated. Flow of electron produce current, when it is connected to any load.

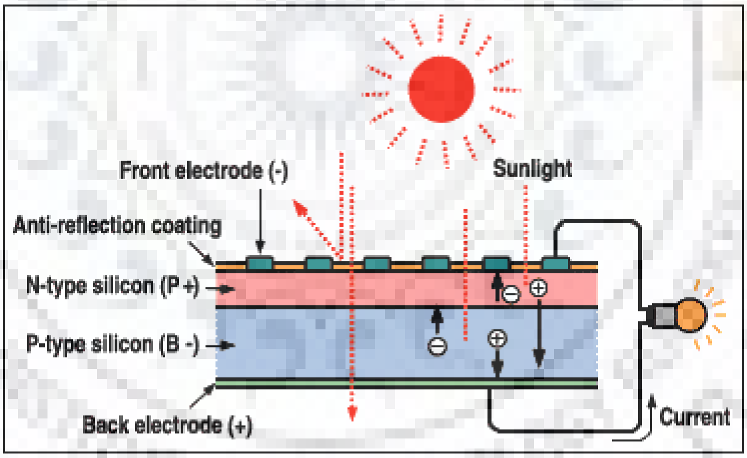


Fig.2.2 Schematic Cross-Section of a Typical Solar Cell

Accuracy of PV cell mainly depends on PV cell modelling. I-V and P-V characteristics are drawn according to various environmental condition. Current of PV cell depends of irradiance and voltage is affect by temperature.

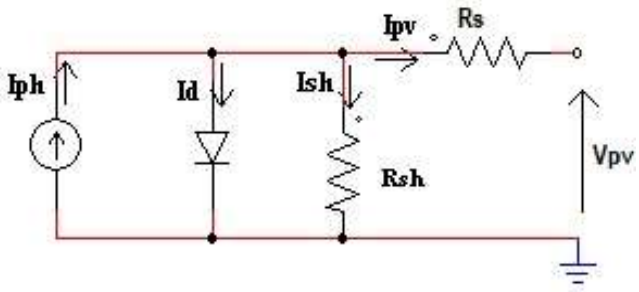


Fig.2.3 Equivalent Circuit of PV Cell [1]

Equations of PV mathematical model that are used for PV array represented [1]:

$$Ipv = Iph - Is\left[\exp\frac{q(Vpv+RsIpv)}{AKTak} - 1\right] - \frac{Vpv+RsIpv}{Rsh} \quad (1)$$

Number of PV cell are connected in series and parallel to meet the energy demand or increase the power. These mathematical equation is given by[1]:

$$NpIpv = NpIph - NpIs\left[\exp\frac{q\left(Vpv+\frac{Ns}{Np}RsIpv\right)}{AKTakNs} - 1\right] \quad (2)$$

$$Iph = [Isc + Ki(Tak - Trk)]\frac{G}{1000} \quad (3)$$

$$Is = Irs\left(\frac{Tak}{Trk}\right)^3 exp\left[\frac{qEg\left(\frac{1}{Trk}-\frac{1}{Tak}\right)}{KA}\right] \quad (4)$$

$$Irs = \frac{Isc}{exp\left(\frac{qVoc}{NsKTakA}\right)-1} \quad (5)$$

Vpv ⟶ output voltage of a PV module (V)

Ipv ⟶ output current of a PV module (A)

Trk ⟶ the reference temperature = 298 K

Tak ⟶ the module operating temperature in Kelvin

Iph ⟶ the light generated current in a PV module (A)

Irs ⟶ module reverse saturation current (A)

Is ⟶ the PV module saturation current (A)

A ⟶ an ideality factor

K ⟶ Boltzmann constant = 1.3805 × 10^{-23} J/K

q → Electron charge = 1.6×10^{-19} C

Rs → the series resistance of a PV module

Isc →the PV module short-circuit current at 25°C and 1000W/m2 = 2.55A

Ki →the short-circuit current temperature co-efficient at Isc = 0.0017A /°C

G → the PV module illumination/ irradiance (W/m2) = 1000W/m2

Eg→ the band gap for silicon = 1.1 Ev

Ns→ the number of cells connected in series

Np→ the number of cells connected in parallel

From the equation 1to eq. 5 I-V and P-V characteristics of PV module is shown in fig.2.4 without partial shading:

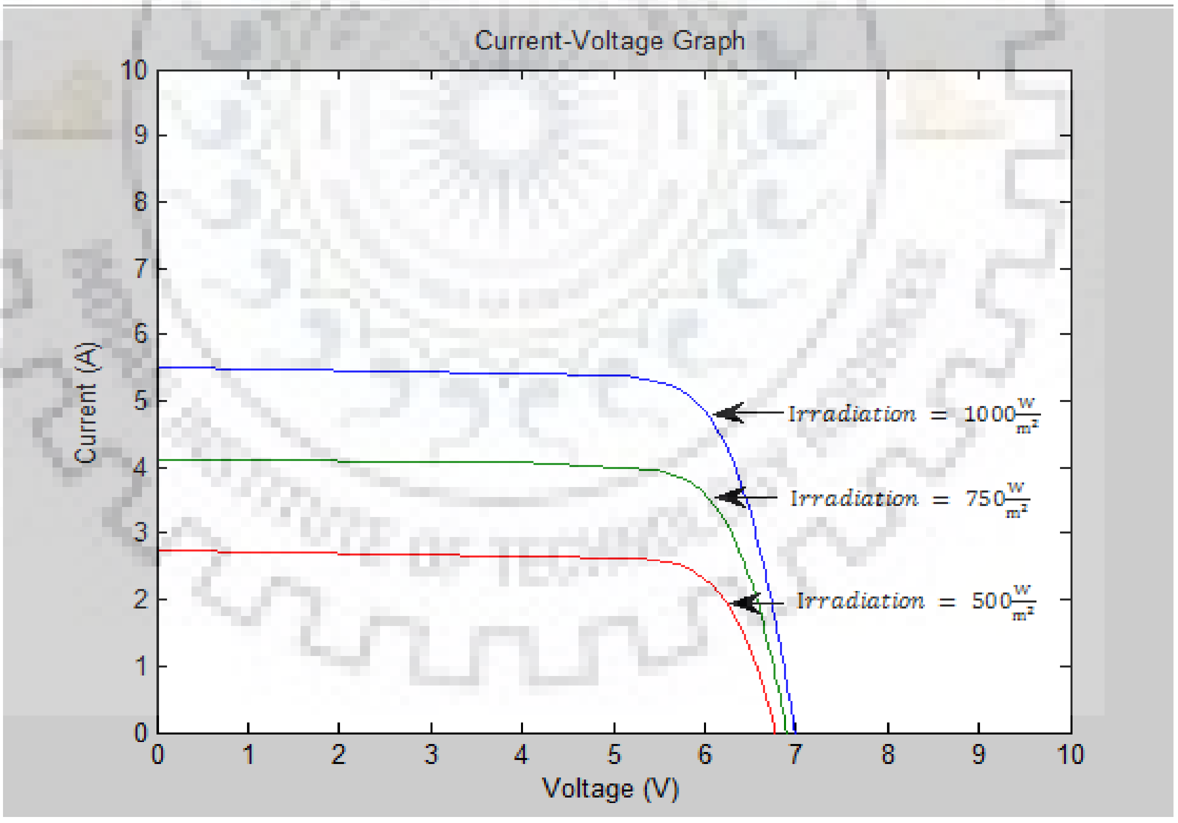


Figure 2.4. I-V graph at 1000 W/m^2, 750 W/m^{2}and 500 W/m^{2}respectively [2].

$$Ppv = Vpv * Ipv \qquad (6)$$

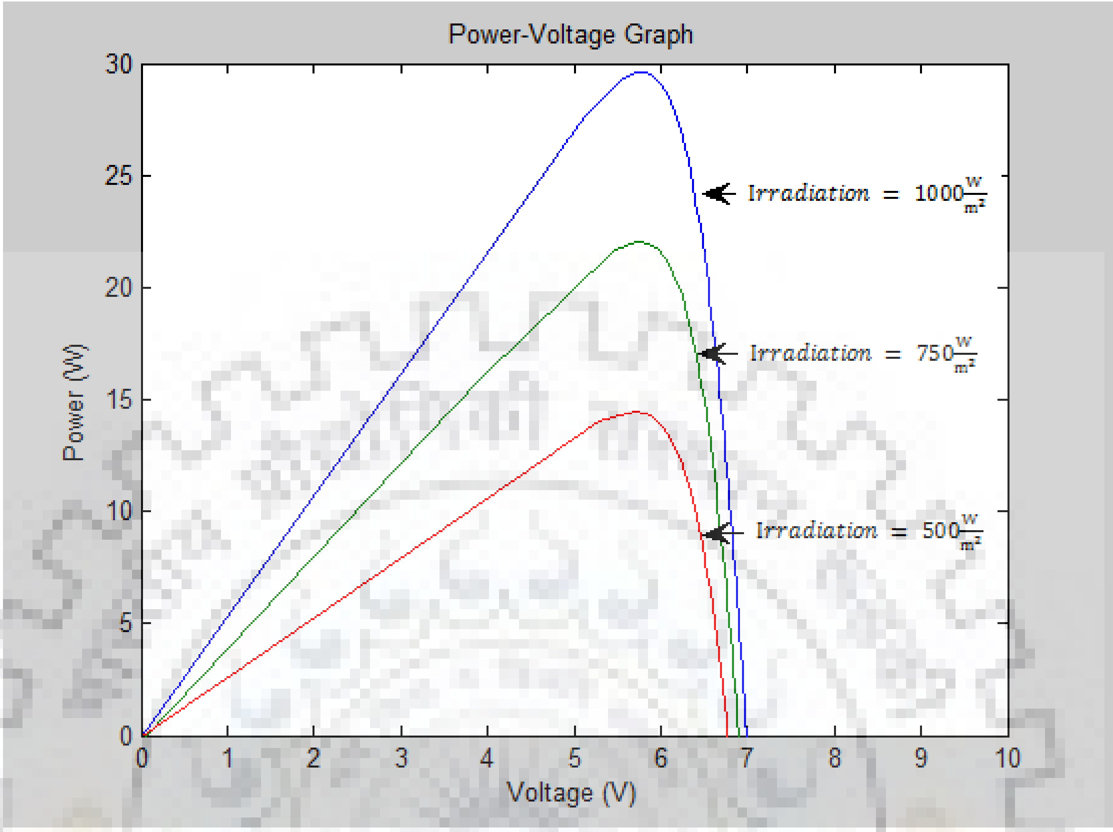


Figure 2.5. P-V graph at 1000 W/m^2, 750 W/$m^2$and 500 W/m^2 respectively [2].

From fig 2.4 & 2.5 it is clearly shown that change of irradiance level will change current and voltage of PV array. Change in short circuit current is proportional to change in irradiance, but open circuit voltage shows minor change because of logarithmic relation with the irradiance.

Output power of PV array is also decrease with decrease in irradiance. PV curve characteristics is nonlinear at specific temperature and irradiance.

As per fig 2.3 up to the voltage 5.4V short circuit current is nearly constant. Afterward it drops to zero rapidly at open circuit voltage. That point is the maximum power point of PV array. Efficiency will be increased if we track this point. Tracking of this point is called maximum power point tracking.

2.5 MAXIMUM POWER POINT TRACKING TECHNIQUE

Track of voltage and current that makes power maximum at that point is called maximum power point. 20 to 30 percent of total energy fall on PV array can converter in output power of PV cell. Efficiency is increased by keeping voltage and current according to maximum power point.

Maximum power point tracking technique is basically follows maximum power transfer theorem, according to this theorem input resistance should be equal to load resistance. When it comes to equal then maximum power will be transferred.

Generally DC-DC converter is connected to the PV cell for increase the output voltage. Duty cycle of converter changed according to make source impedance equal to output resistance or load impedance.

There are so many technique is used for maximum power point tracking. Some technique which are popular are:

1. Perturb and observe method
2. Incremental conductance method
3. Fraction short circuit current
4. Fraction open circuit voltage
5. Fuzzy logic based
6. Neural networks based

2.5.1 Perturb and observe method

Perturb and observe method is one of the simplest and cost effective method. For calculating the maximum power point this method is required only sensor. That is voltage sensor. So it is cost effective and easy to implement. Basic concept of this method is from starting of the voltage increase voltage by a small amount. By increasing the voltage if power is increasing then it is a right direction and further increase the voltage with the help of duty ratio of DC-DC converter. If reverse happen then decrease the voltage with the help of duty ratio of DC-DC converter.

Disadvantage of this method is it oscillate around the maximum power point. And other one is it cannot track maximum power point in the case of sudden change in irradiance. When sudden change occur it track wrong maximum power point in state of correct one. In this condition system will run on wrong MPP. Which can be neglect by introducing the error limit or wait function but it will increase system time complexity. Also, by using incremental conductance method it can be avoided. Advantage of this method is easy to implement and time complexity is less.

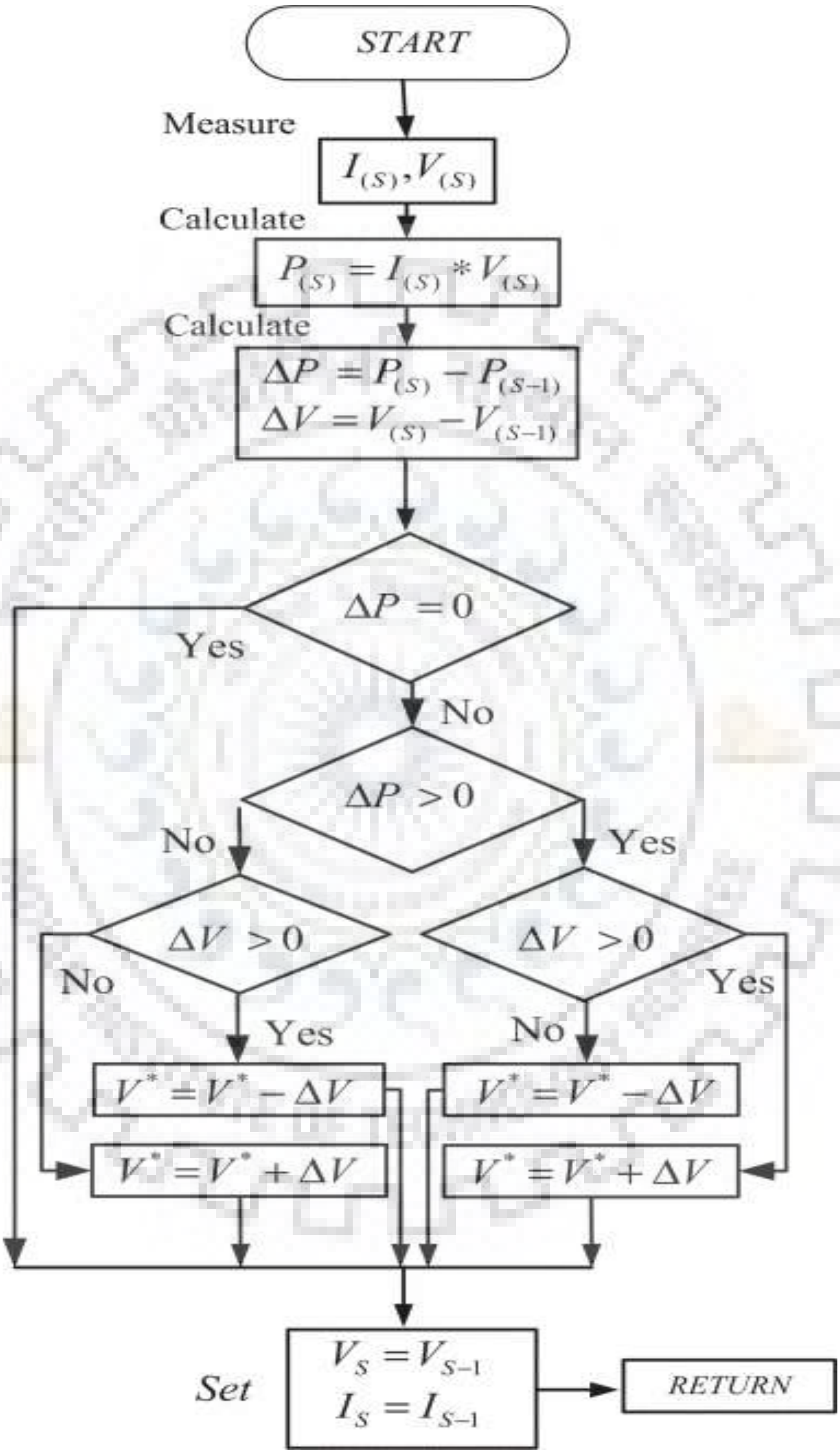


Fig.2.6. Flow Chart Of Perturb and Observe Method [3]

2.5.2 Incremental Conductance

Incremental conductance method work on slope of PV characteristics at the point of maximum power. From fig 2.5 it is clearly shown slope of the PV curve is zero at the point of maximum power point. That’s why this method required is two sensor, voltage and current sensor.

$$\left.\frac{dp}{dv}\right|_{mpp} = \left(\frac{d(vi)}{dv}\right)$$

$$0 = i + V\frac{di}{dv}$$

$$\left.\frac{di}{dv}\right|_{mpp} = -\frac{i}{v}$$

This method contains comparison of incremental conductance (dP/dV) to PV array conductance (I/V). When both conductance become equal that is maximum power point. It can be verified by equations also. This method uses voltage and current sensor so change in irradiance is immediately identifies. This method can be use when rapidly change in irradiance occur. Time complexity of this method is more than perturb and observe method. Incremental conductance method is widely use due to its high accuracy and cost effective. In our dissertation also we used this method to improve the efficiency.

Advantage of this method is, it will not oscillate around the maximum power point like perturb and observe method. It became stable at point of maximum power.

Disadvantage is, its cost and complexity is more than perturb and observe method. When we further discuss about algorithm cost and complexity keep increasing.

Algorithm of incremental conductance method is as follow:

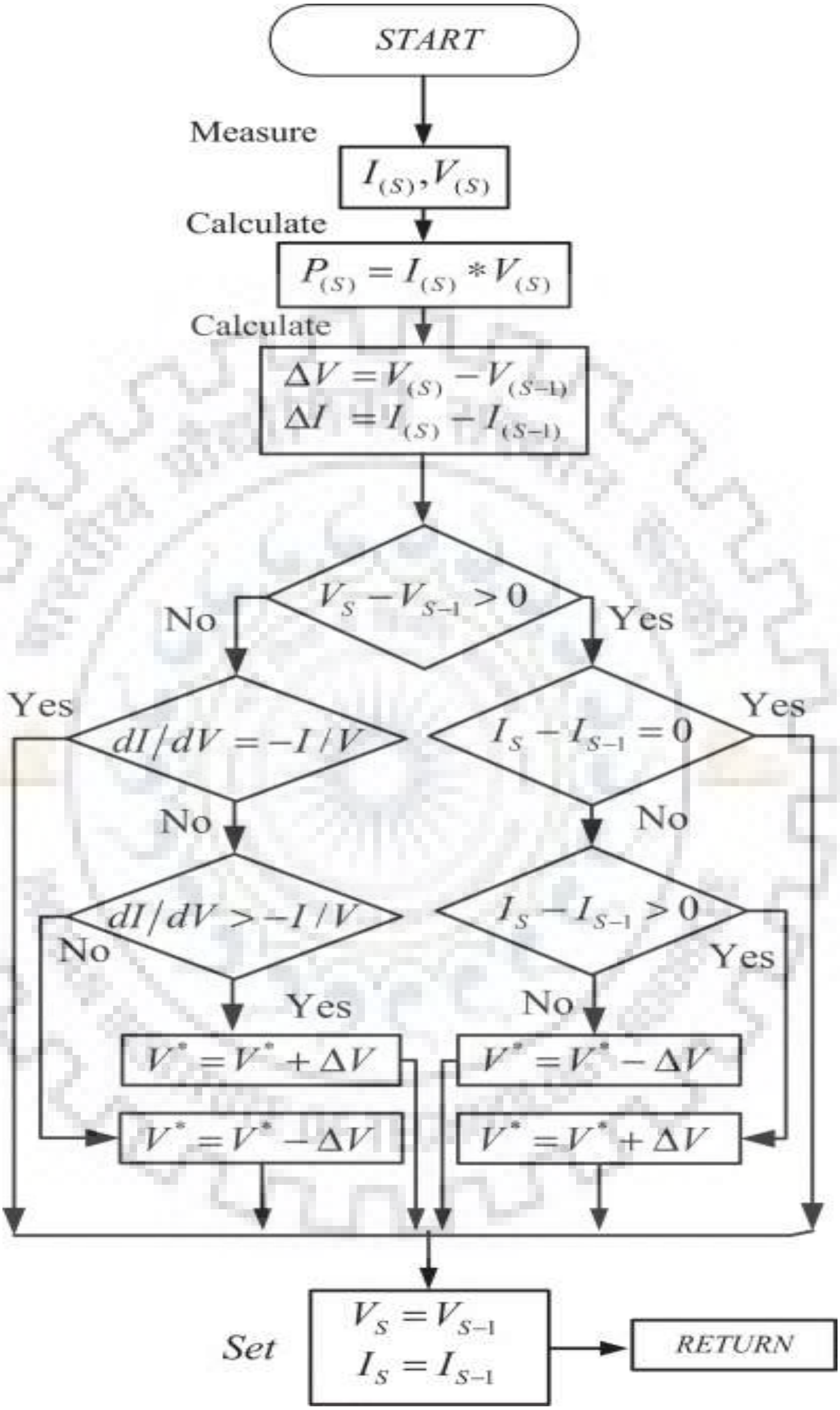


Fig 2.7 Flow Chart of Incremental Conductance Method [3]

2.5.3 Fuzzy Logic Based MPPT

Now a days use of fuzzy logic based controller increased due to microcontrollers. This is a rule based controller

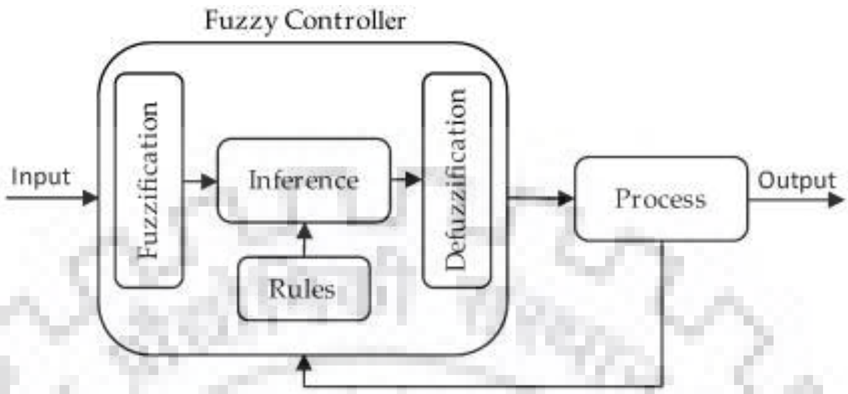


Fig 2.8 fuzzy logic controller

According to block diagram first it change its input value to fuzzification. Afterward according to rules it changes its value then followed by defuzzification of signal.

Advantages of fuzzy logic is, it can handle non-linearity, not required exact mathematical model, and able to do work with imprecise input.

2.5.4 Artificial Neural Network (ANN):

ANN also microcontroller based MPPT technique. Neural network has basically three layer (1) input layer (2) hidden layer (3) output layer

There are many node in each layer. Which are user dependent. In the case of PV array input layer parameters is short circuit current and open circuit voltage, irradiance and temperature. In the hidden layer their some function that solve according to input parameter and convert signal accordingly. Output layer contains signal for duty ratio which drive the system at point of maximum power.

2.5.5 Fractional Open Circuit Voltage

From the fig 2.4 it is clearly shown voltage of PV at maximum power is some fraction of open circuit voltage. At this point current is nearly short circuit current. So voltage at maximum power point is linearly relationship with open circuit voltage.

So we can write:

$$V_m = KV_{oc}$$

Where k is proportionality constant

Vm is voltage at maximum power

Voc is open circuit voltage

Value of k is depends on characteristics of the PV array. Value of k is computed according to different irradiance and temperature beforehand for particular PV array. Value of k is been reported between 0.71 to 0.78. Once value of K determine Vm computed easily and maximum power can be traced. Disadvantage of this method is temporary power loss.

2.5.6 Fraction Short Circuit Current

From the fig 2.4 it is clearly shown current of PV at maximum power is some fraction of short circuit current. So current at maximum power point is linearly relationship with short circuit current.

So we can write:

$$I_m = KI_{Sc}$$

Where k is proportionality constant

Im is current at maximum power

Isc is short circuit current

Like fraction voltage method here also value of k determine beforehand according to PV array being used. Value of k is been reported between 0.77 to 0.91.

CHAPTER 3: MPPT TECHNIQUE UNDER PARTIAL SHADING

3.1 GENERAL

Sometime the irradiance of PV array is not uniform due to many reasons like neighbouring building shadow, telephone pole, towers, cloud passing, trees, in hilly area shadow of hill. So at that time track the maximum power point is not so easy. Conventional maximum power point tracking technique are fails. In this condition multiple peaks occur on the PV characteristics. So conventional method cannot determine global peak. Track the maximum power point in this condition is difficult and make the system more complicated.

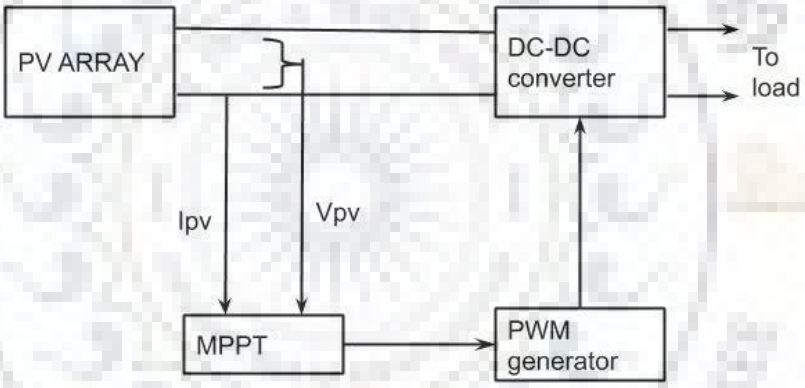


Fig3.1 System block diagram

3.2 EQUIVALENT CIRCUIT UNDER PARTIAL SHADING

In a advancement of PV cell, current in every cell of PV is same. However one of PV cell or module is shaded due to any reason then this shading makes low current cell. Dou to this all other cell also forced to flow this low current because of series connection. It can make the reverse biased shaded cell as a sink instead of a source of solar power which cause local hot spot and can even damage the module, for example, cell or glass splitting, softening of weld. A diode should be connected in parallel to PV panel To protect the shaded panel form dissipating power. When the panel is not shaded the diode will be reverse biased and it will not have any effect. When a panel is shaded it will make the diode forward biased and bypass the shaded panel.

The hazardous impacts of problem is warming the area might be avoided using a sidestep diode. A sidestep diode is basically a parallel connected diode. However with inverse limit, to a sun oriented cell. Under unshaded time, each PV cell whose irradiance is same will be forward one-sided and in this way the parallel diode will be reverse biased and will successfully behave like an open circuit. Be that as it may, if a sun oriented cell is turn around one-sided because of a bungle in short out current between a few arrangement associated cells, then the parallel diode conducts, in this way permitting the current from the higher irradiance cells to stream in the outside circuit as opposed to forward biasing every shaded cell. The most extreme switch inclination over shaded people cell is weakened to about a solitary diode drop, consequently restricting the current and forestalling problem area warming.[5]

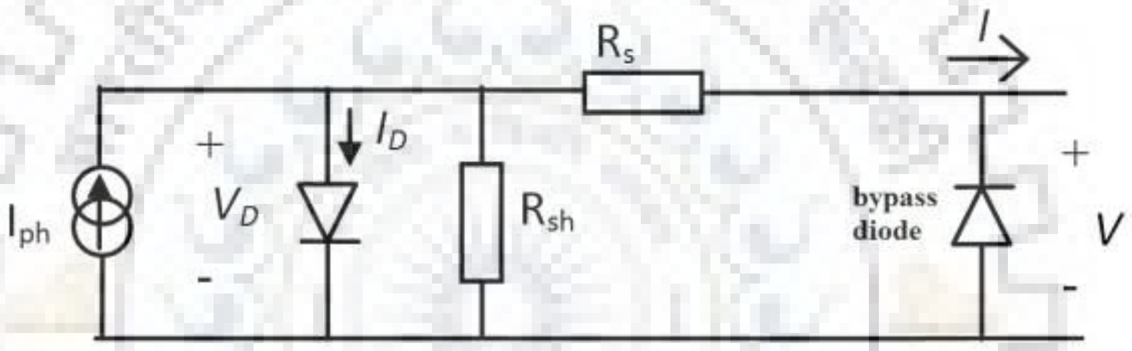
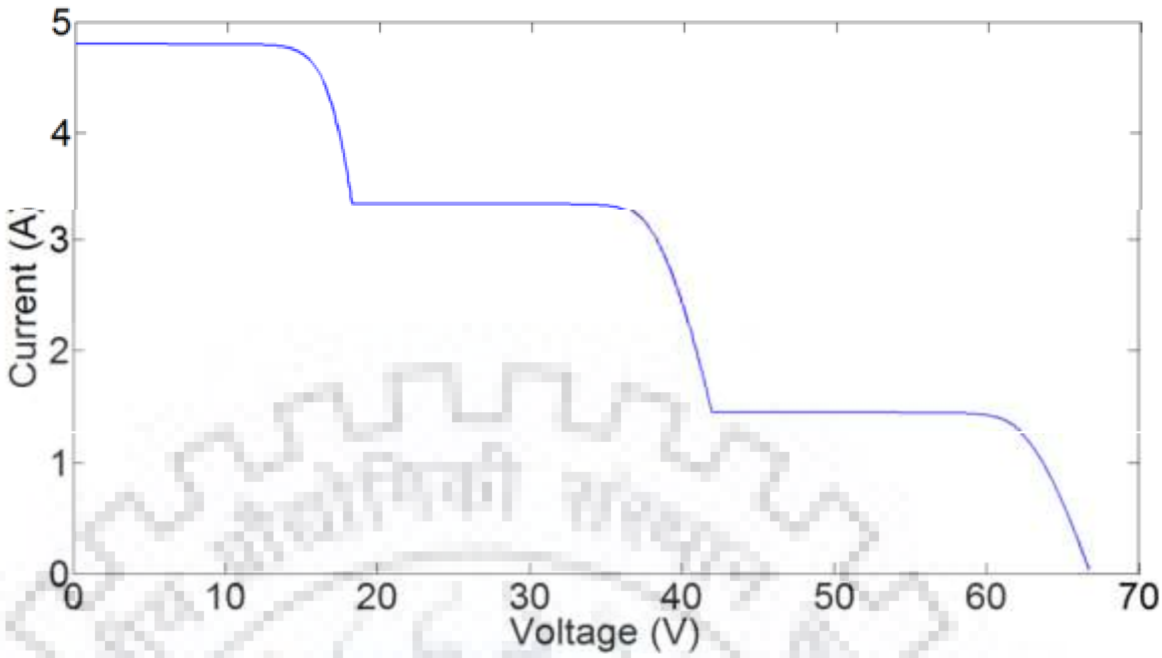
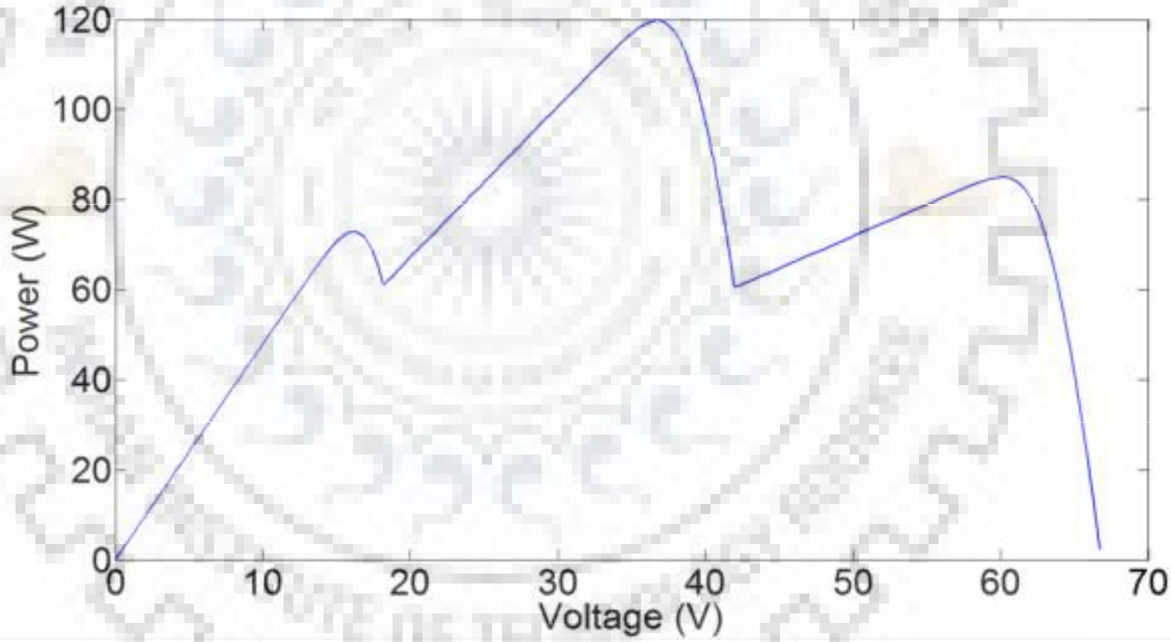


Fig. 3.2. Model of photovoltaic cell with bypass diode [4].

In the Fig 3.3 [6] shows that under the partial condition several maxima present in p-v characteristics. So by the conventional method of Perturb and Observation, & Incremental Conductance method cannot recognize the global maxima. So different technique are introduced by the researcher to find the global maxima and increase the power and efficiency of PV module. Number of maxima depends on number of partial shaded cell. Some of technique are discussed in this chapter further.



(a)



(b)

Fig 3.3 Partial Shading Characteristics, Irradiances of PV cell 1000 W/m2, 700 W/m2, 300 W/m2 respectively, temperature 25°C, (a) I-V and (b) P-V[6]

3.3 DIFFERENT MPPT METHOD UNDER PARTIAL SHADING CONDITION

3.3.1 SEPIC converter based MPPT controller for SPV module under partial shading

Partyusha,Ritesh,Nasim,Sarat Chandra [5] use SEPIC converter technology with MPPT system under partial shading to extract maximum power from the system. Under partial shading by-pass diode is used. They use 2 by-pass diode with an inductor for an ordinary PV cell module. inductor cannot allow sudden change in current so using this p-v characteristic have only one peak point . that can be easily track by conventional MPPT method

3.3.2 Use Checking Algorithm to track the maximum power under partial shading

Rozana Alik, Awang, Nur ameda [8] use the checking algorithm for track the maximum power point under partial shading. Proposed algorithm is show as flow chart:

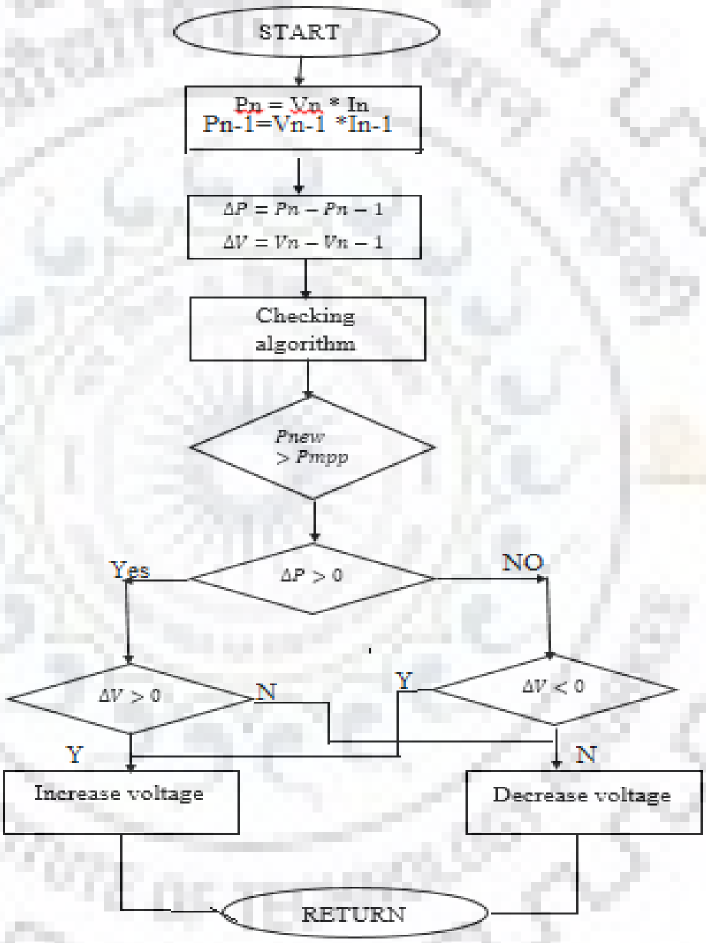


Fig 3.4 Flow chart for modified perturb and observe method [8]

The purpose of the checking algorithm is to verify whether the saved operating point reached by PO algorithm is real Maximum Power Point or only a local MPP. In order to look for the greatest Maximum Power Point, a few existing operating points are measured to compare them with the saved MPP. From now on, since noticeable mismatching effects only appear in series connection, the PV generator will be considered as a PV string.

The exploration must be realized from the minimum feasible voltage *Vmin*. Thus, the first operating point measured is the nearest to short-circuit current. Once voltage and current are measured, the power is measured and compared with the saved Maximum Power Point. If it is greater, the research has concluded and the hill-climbing algorithm recovers the control of the converter in order to match the real MPP. In the opposite case, a new operating point to be measured is calculated with the following expression:

$$V_{n+1} = \frac{P_{mpp}}{I_n}$$

where Pmpp is the power of the MPP found by PO algorithm and In is last value of saved current. The new point of voltage is measured and power of this point compare with previously saved MPP. These process are repeated successively up to finding a greater MPP or covering the whole curve. In this last case, the hill-climbing goes on tracking the same operating point already saved.

Flow chart for checking algorithm

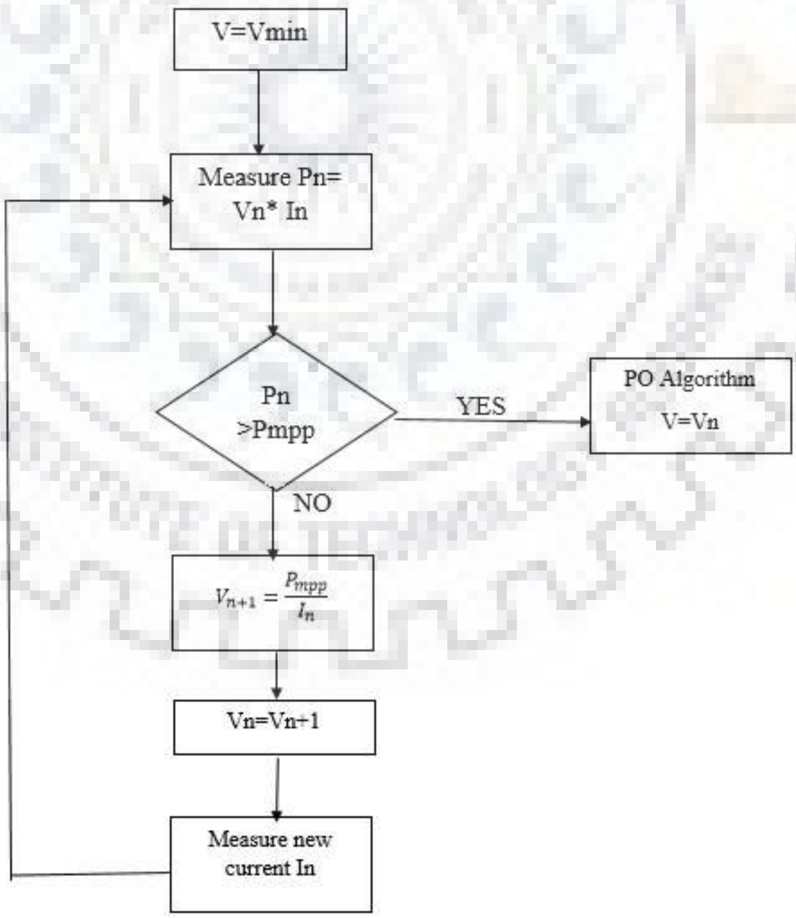


Fig 3.5 Checking algorithm [9]

So by checking algorithm method we can easily find global maximum power point under partial shading condition.

3.4 PV curve output characteristics with 2 PV module under psc:

Two PV module connected in series. Their irradiance is different. PV module 1 have greater irradiance than PV2. So short circuit current of PV1 is more than PV2. Parallel diode is connected with both PV cell.

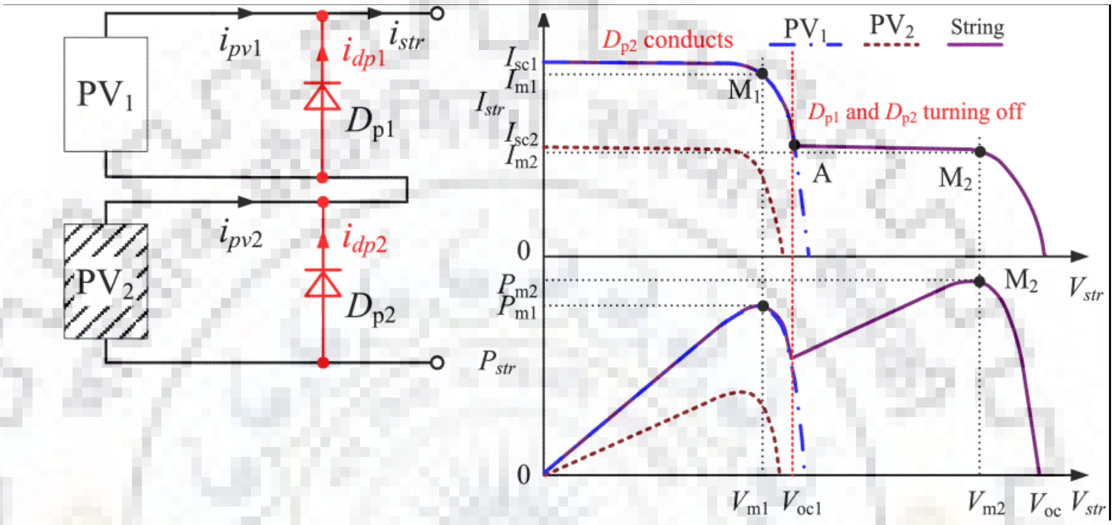


Fig 3.6 (a) PV module in series (b) output characteristics of PV module[5]

When total current is less than PV2 short circuit current than PV1 and PV2 both cell generate energy. Otherwise only PV1 generate energy and diode across PV2 forward biased and current bypassed. PV curve has two maxima. In this one is global maxima. For maximum power output global maxima should be traced.[5] When only one PV cell operated then maxima occur at some fraction of open circuit voltage of PV1 according to fraction voltage method and some fraction of short circuit current Im=0.9 Isc1. So Pm1 occur at Vm1= 0.76*Voc1. Let Voc1=Voc2 so total voltage of string is Voc/2=Voc1=Voc2[5].

Second maxima occur at Vm2 is equal to Voc1 and 0.76*Voc2 and Im=0.9*Isc2 because at this time PV short circuit current is short circuit current of PV2.[5] so for voltage and current at j^{th} no. PV cell's maxima point of j number of string connected in series is given by:

$I_{mj} = 0.9\ I_{scj}$

$V_{mj} = (j-0.24)V_{oc}/n$

n is total series connected string

3.5 Search Skip Judge (SSJ) MPPT technique

When partial shading occur multiple peaks occur at PV curve. Tracking of global maximum power point is not possible with convention MPPT method. Conventional Global MPPT method also search full range of voltage that takes time. SSJ-MPPT technique reduce the range of voltage. It will do with three process 1.search 2.skip 3.judge. Algorithm of SSJ-MPPT method given as:

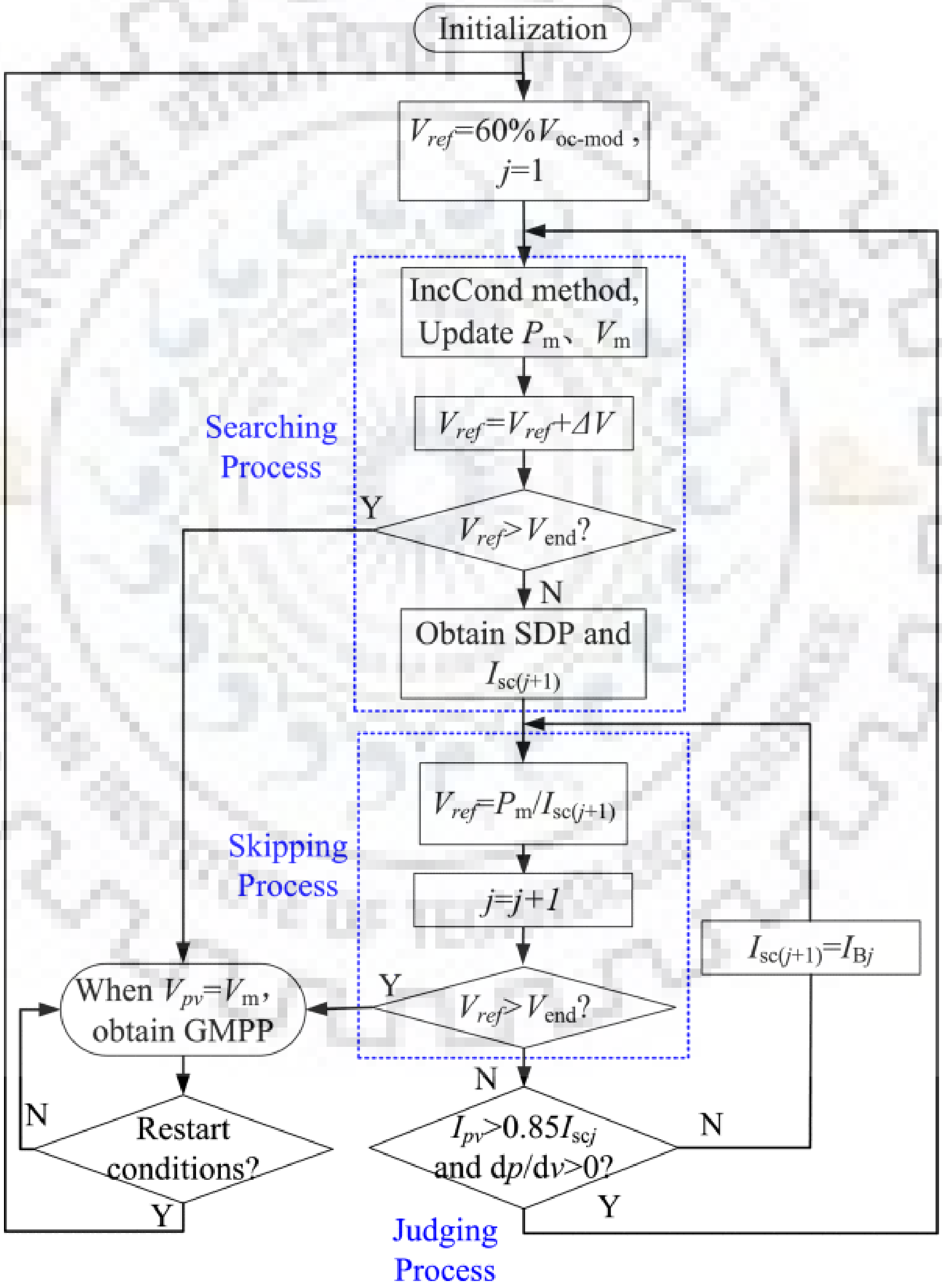


Fig 5.2 Algorithm flow chart of SSJ-MPPT technique

Fig 5.2 is complete flow chart of SSJ MPPT technique. Where Voc-mod is open circuit voltage of one PV module. j denote no. of PV cell connected in series. Pm is global maximum power tracking in process and Vm is voltage at the Pm.

Flow chart can be understand by 3 different type module as showing in fig 5.3. three PV cell is connected in each module with different irradiance showing partial shading condition. In this three MPP find name as M1, M2, M3.

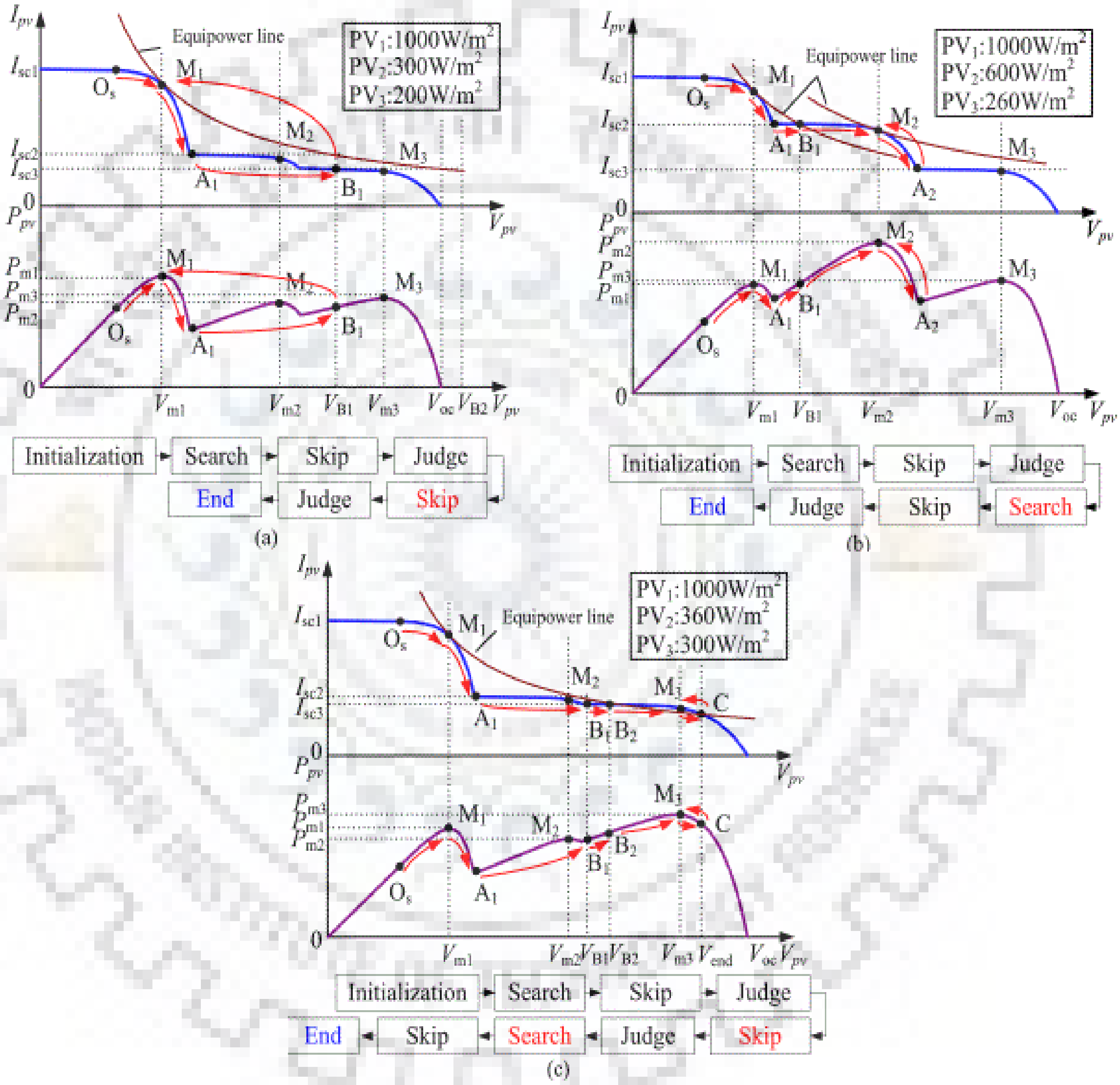


Fig 5.4 Three Pattern Of Partial Shading Showing Tracking of SSJ-MPPT[5]

First set initial voltage is 60% of Voc-mod. It gives guarantee that it track first MPP. Vend is 90% of open circuit voltage of PV string. Three process of SSJ-MPPT as follow:

(a) Searching process: Conventional incremental conductance method track the first MPP. According to this it find first MPP point. Here power and voltage is recorded as Pm and Vm respectively. Than voltage is moved in forward direction up to change in power w.r.t. voltage change sign positive to negative. At point A1 as shown in fig 5.4. Section diving point (SDP) is shown in fig 5.4 where short circuit current is shown for particular PV cell.(for Jth cell it is Iscj). SDP point is Isc2 (fig 5.4)

(b) Skipping process: According to equipower line, new operating voltage is set as $P_m = I_{sc(j+1)}$. in the skipping process from A1 to B1 is unnecessary to scan. New Pm is Vb1*Isc2. Voltage and current between A1 and B1 is smaller than voltage Vb1 and current Isc2 so power between A1 to B1 is smaller than Pm. Now do comparison for Vref and Vend. If Vref is greater than Vend than stop the process. Global maxima achived.

(c) Judging process: judging process is basically judge that global MPPT has achieved or not. We need judge to skip the process again or search the process. 0.85 of short circuit current took for ensure the tracking accuracy. Condition for judging process is $I_{B1}>0.85\ I_{sc2}$ and dP/dV > 0 as shows in fig 5.3. According to this results algorithm identifies the next process.

First condition is to know $I_{B1}>0.85\ I_{sc2}$. at maximum power point Im is nearly 0.85* Isc. If this condition is not satisfies then surely Ib2 < Im2 than algorithm should return to skipping process. If this condition not satisfied than Pm2 is larger than Pm so algorithm should go for searching process.

Second condition is to know that dP/dV > 0. When $I_{B1}<0.85\ I_{sc2}$ than no need to check this condition. Because it is confirmation of skip process. But this condition is not satisfied or $I_{B1}>0.85\ I_{sc2}$ than chacking of dP/dV > 0 is necessary. If dP/dV<0 than B1 is right side of M2 thus Pm2 < Pm. So again need to skip process. Otherwise B1 is left on M2 in this condition Pm2 > Pm so algorithm need to be searching process.[5]

CHAPTER 4: DC-DC CONVERTER FOR MPPT

4.1 INTRODUCTION

DC-DC converter used for operate a load under a specific voltage demand irrespective of input voltage variation. According to specific demand there are several types of DC-DC converter present that can regulate the output voltage according their demand. It can change unregulated voltage to regulate one with increasing and decreasing the value of DC output voltage. DC-DC converter use for draw maximum power from PV system. By varying duty cycle we can equal the load impedance with solar input impedance.

The most commonly used DC-DC converter are:

1. Buck converter
2. Boost converter
3. Buck-boost converter
4. Cuk converter
5. Flyback converter

The most commonly used and simple type of converter is boost converter. It is a power electronics device that used to step up input voltage. Here it is functionally using as a impedance matching device.

4.2 BOOST CONVERTER

Boost converter is used where requirement of voltage is more than input voltage. So boosting of voltage is done by a boost converter. Boost converter contain one switch (MOSFET or IGBT, usually MOSFET used because of suitability under high switching frequency), one inductor, one diode and one capacitor. Fig 4.1 shows the circuit diagram of boost converter.

Operation of boost converter can be shown in two mode, one when switch is on said Ton time and two when switch is off called Toff time. During the Ton time current through inductor rise shown in fig 4.3. Inductor store energy in this time. Circuit diagram under this is shown in fig 4.2

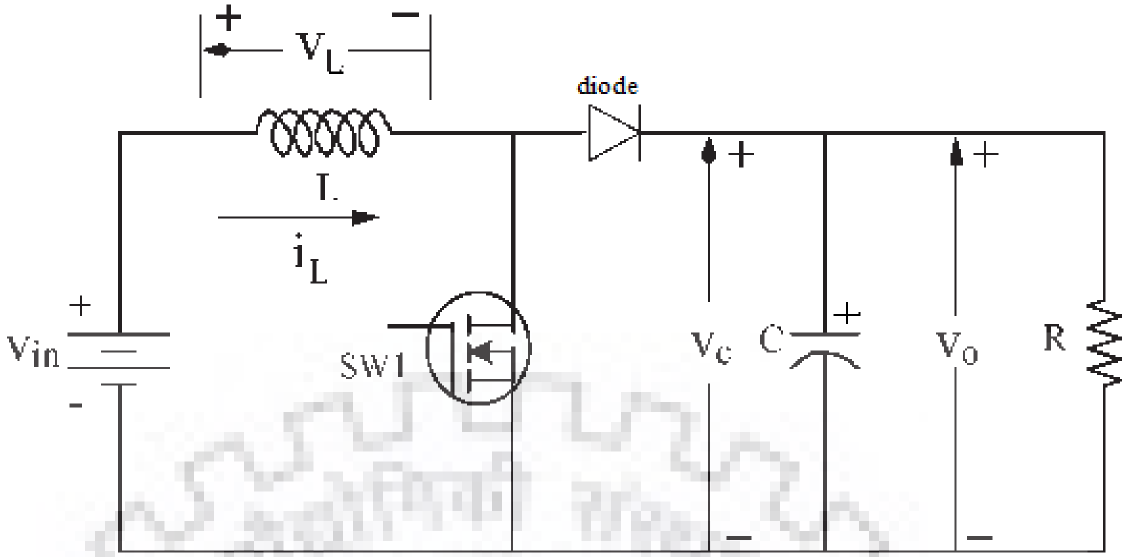


Figure 4.1: Circuit diagram of boost converter

Mode 2 is begin when switch is off. Diode is forward biased in this mode. Inductor release energy and decreases current across the inductor. It decrease until the switch is on in next cycle. This process repeated. Circuit diagram under this mode is shown in fig 4.2.

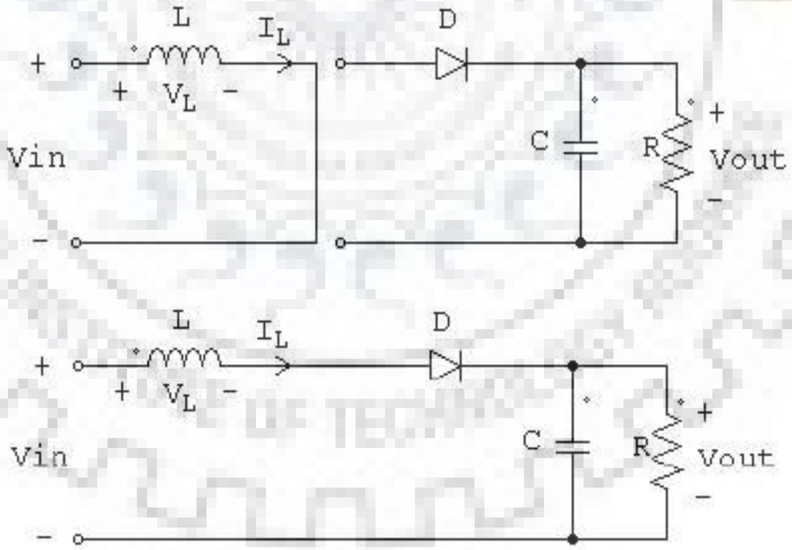


Figure 4.2: Circuit diagram of mode of operation of boost converter

Releasing energy of inductor in mode 2 permits output voltage is more than input voltage.

So equation can be written as:

$$Vout = \frac{Vin}{1 - D}$$

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

Where D is duty ratio, Vout is output voltage, Vin is input voltage(solar panel voltage), T is total time period of one cycle.

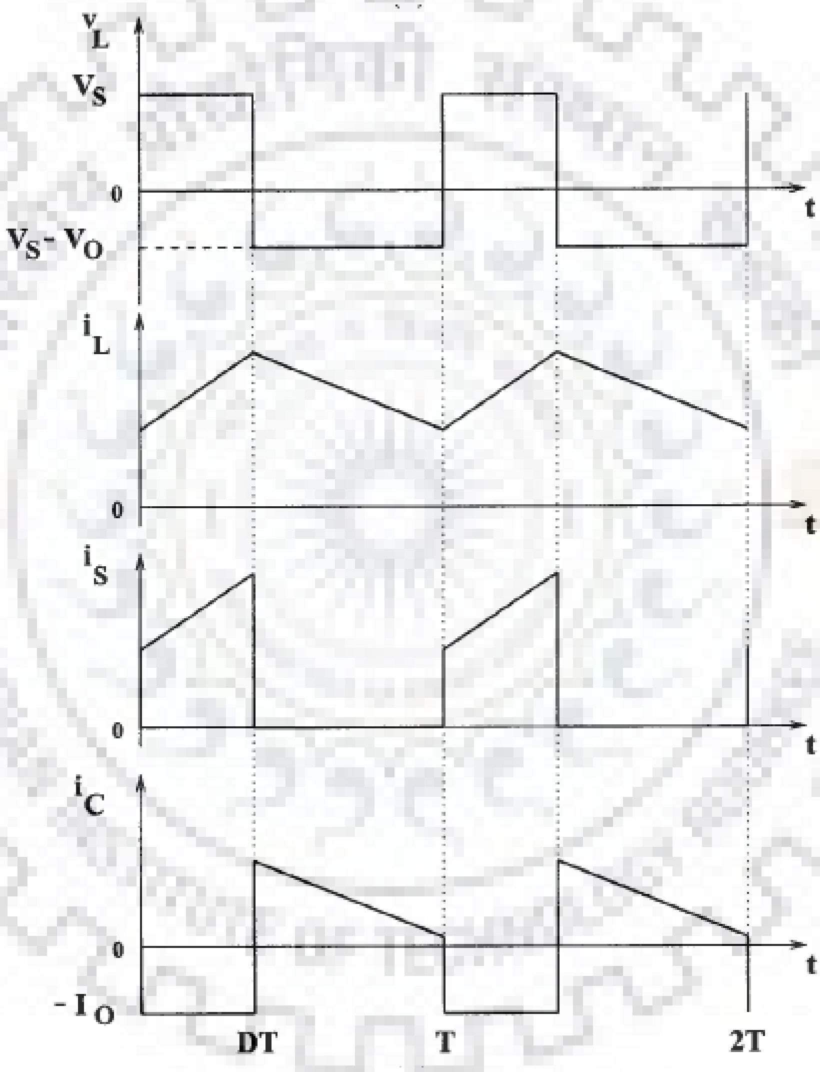


Figure 4.3: Waveforms of boost converter

This fig 4.3 shows the different waveforms of boost converters like inductor voltage, inductor current, source current, capacitor current for the two cycle of time period.

Here assuming that inductor current is continuous. DT is shows on period of switch.

Selection the parameters of boost converter

Inductor selection: inductor value should be calculated as current not to be discontinue. For continuous current mode inductor value should be:

$$L_{min} = \frac{(1-D)^2 * D * R}{2 * f_s}$$

$$L = \frac{Vin}{Fs * \Delta Il}$$

Fs switching frequency

D duty ratio

ΔIl= is input current ripple

Current ratio factor (CRF) = $\frac{\Delta Il}{Io} = 0.3$

For good estimation CRF should not be more than 30%. Current rating of inductor should always be higher than output current rating.

Capacitor selection: minimum capacitor value can be given as formula

$$C_{min} = \frac{D}{R * F_s * V_r}$$

Vr is output voltage ripple

Vr should be greater than 5%

DC link capacitor selection: DC link voltage should be constant to make minimize ripple content from PV cell and also required for power balancing. Value of DC link can be calculated by this equation:

$$C_{DC-link} = \frac{2 * P_{max}}{f * V_{dc}^2 * (1-k^2)}$$

Pmax = output maximum power

Vdc= dc link voltage

K=$\frac{V_{DC-min}}{V_{DC}}$

CHAPTER 5: PROPOSED PV SYSTEM AN SIMULATION RESULTS

The proposed PV system under partial shading condition is successfully design. Under partial shading conventional MPPT unable to track maximum power point. Maximum power can be track by different method. Some of method also discuss in chapter 3. Proposed method also track maximum power point under any partial condition.

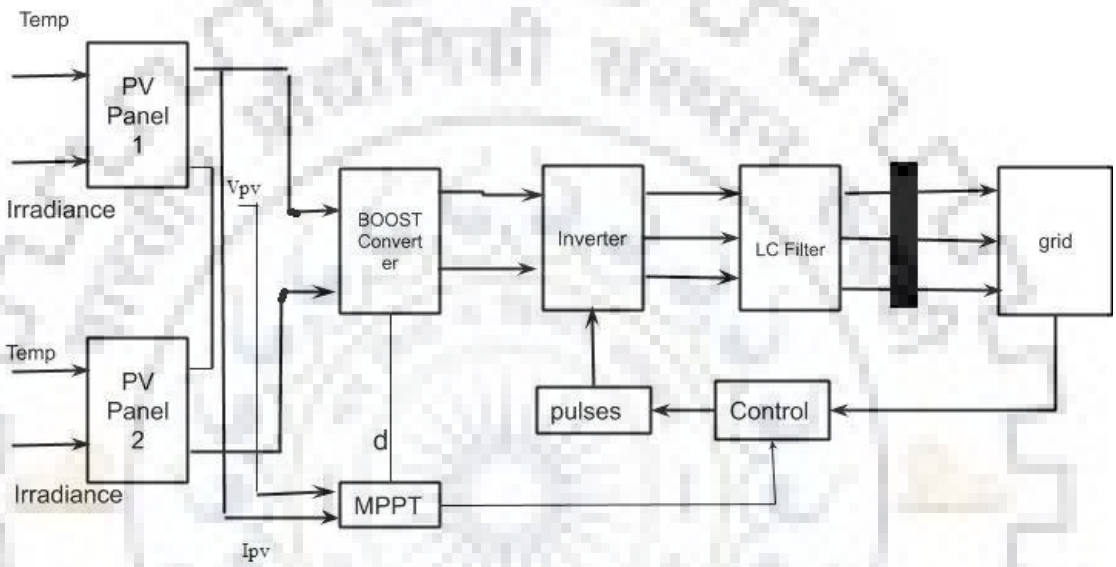


Fig 5.1 block diagram of proposed PV system under partial condition

Proposed system has been modelled and simulated on MATLAB simulation environment. Incremental conductance method has been used for track the maximum power point. For different PV cell whose irradiance is different boost converter is used separately. Thus maximum power can be track under any partial shading condition. Simulation is further connected to grid through the inverter. Synchronous reference theory used for controlling the pulses of 3 level inverter. All the parts and simulation results are as follows:

5.1 Specification of PV cell (at temp=25 ^{0}C and irradiance=1000W/m2)

open circuit voltage	23.6V
Short circuit current	7.97A
Voltage at MPP	18V
Current at MPP	7.77A
No. of parallel PV cell	1
No. of series PV cell	5
Maximum power	140*5 W

5.2 Modelling of PV cell with boost converter and incremental conductance method

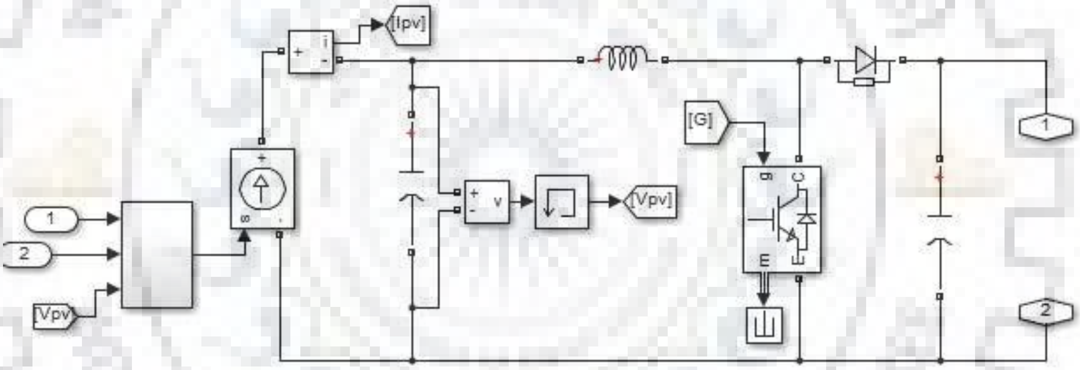


Fig 5.2 Matlab modelling of PV cell with boost converter

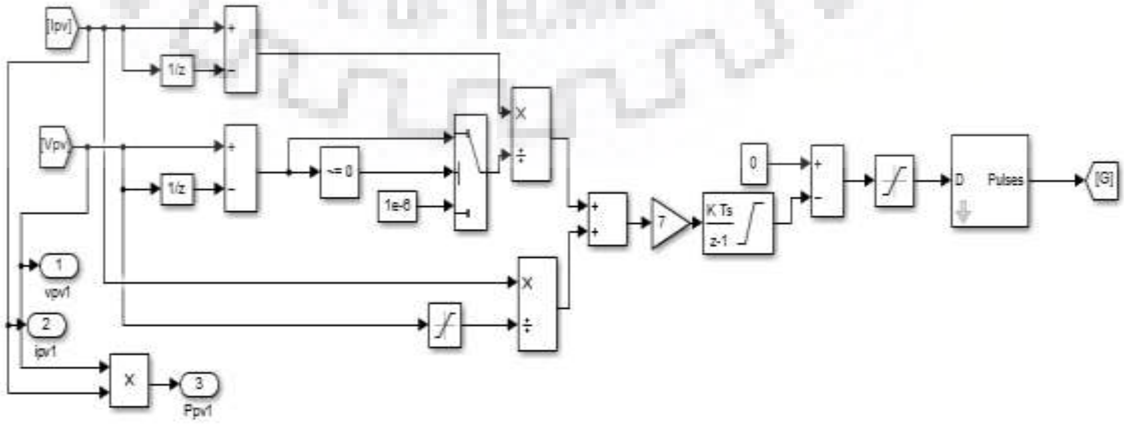


Fig 5.3 Matlab modelling of incremental conductance method

5.3 SOLAR MODULE WITH PARTIAL SHADING

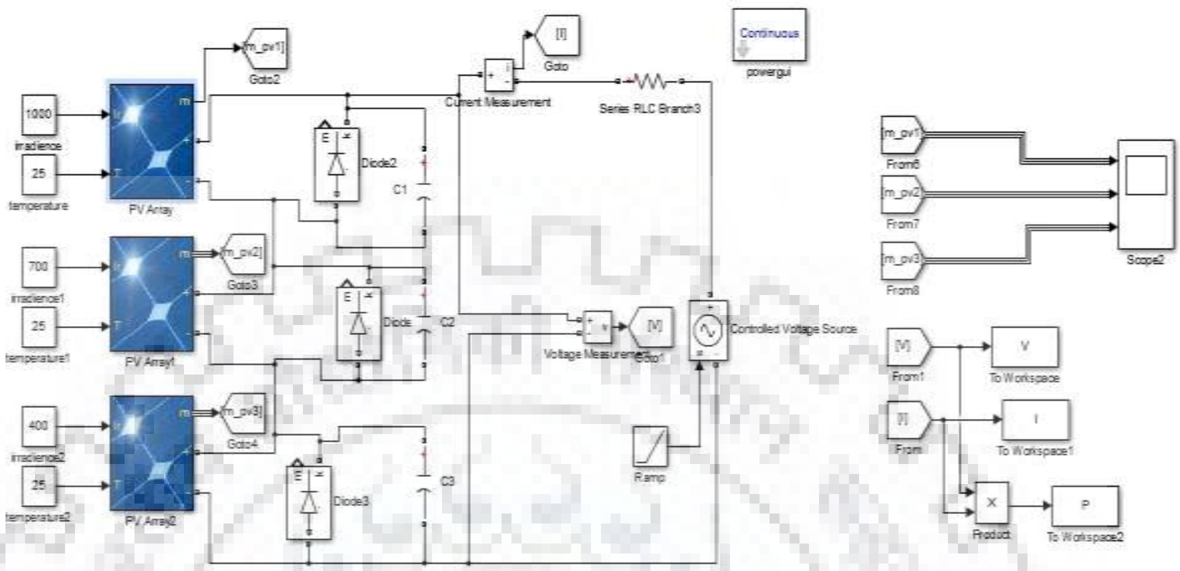


Fig 5.4 simulation model of PV system under partial shading

Here three PV cell is connected in series with different irradiance (1. 1000 w/m2 ,2.700 w/m2,3. 400w/m2)

We got several power maxima as shown in fig 5.5.

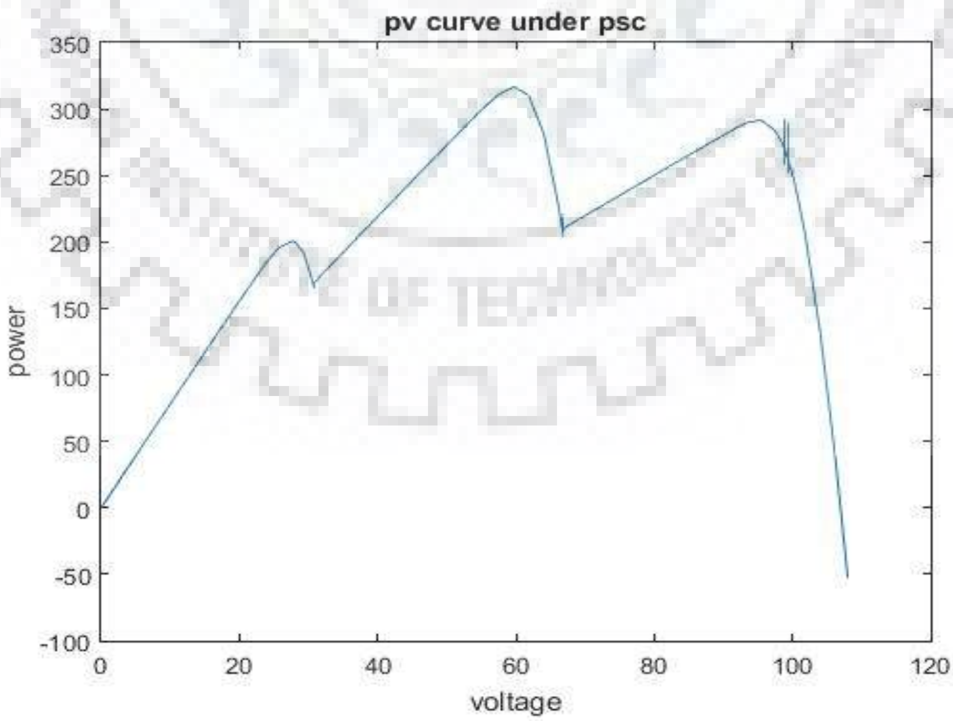


Fig 5.5 P-V characteristics under partial shading condition

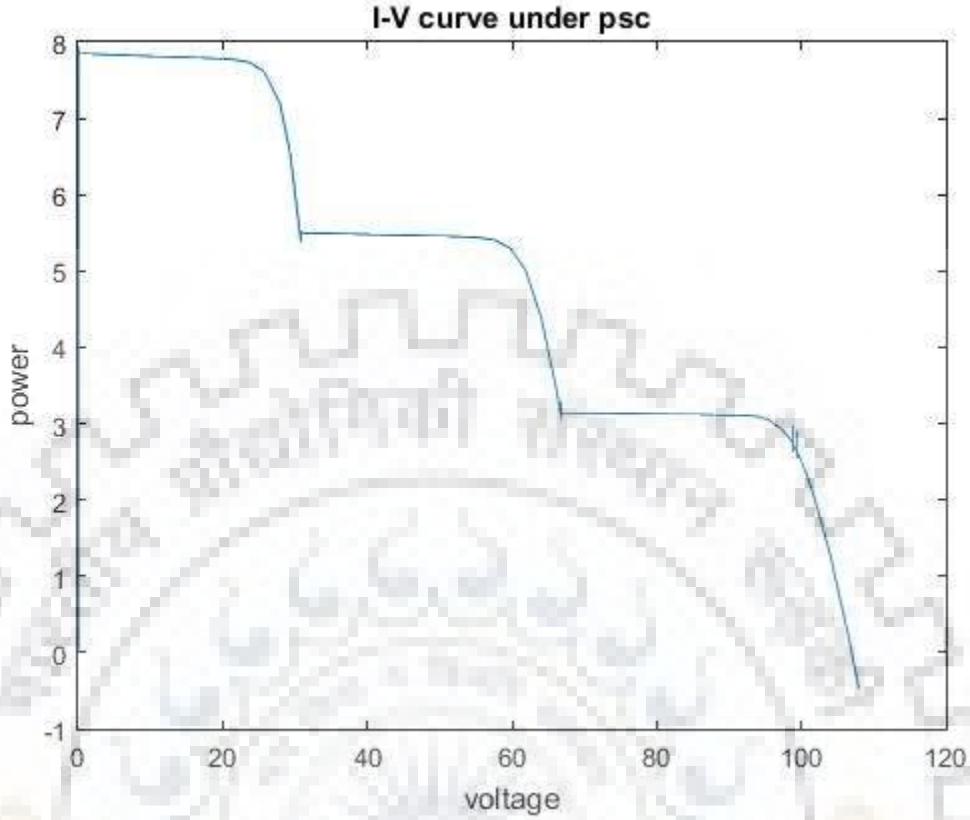


Fig 5.6 I-V characteristics under partial shading condition

5.4 INVERTER AND CONTROL

Controlling of inverter is done by using synchronous reference theory. Pulses is generated for 3 level inverter. Inverter is further connected of gird by LC filter.

5.4.1 Synchronous Reference Frame Theory

This theory is usefulness for controlling of 3 phase quantities. Synchronous reference frame theory in which a frame rotate at the speed of synchronous. Parameter of three phase (voltage and current) rotate in space with speed. This speed depends on frequency of system. For 50Hz frequency speed will be 2*pi*50 radian/second. Controlling of all three phases is costly and complicated approach. SRF theory help to minimize complication of system by changing three phase in two axis which are rotating with synchronous speed. SRF theory keeps only two controllers for all three phases. In SRF theory we consider two axis d and q. q axis lead by 90 degree from d axis. d-q is now reference frame. It is also consider that reference frame is rotating with synchronous speed. As shown in fig 5.1 phasor is rotating at speed omega. So relative speed between frame and rotating phasor is zero. Hence we observe a DC quantity and can be resolved along d and q axis. now we can deal with DC quantities. For controlling DC quantities are easily controllable without having steady state errors.

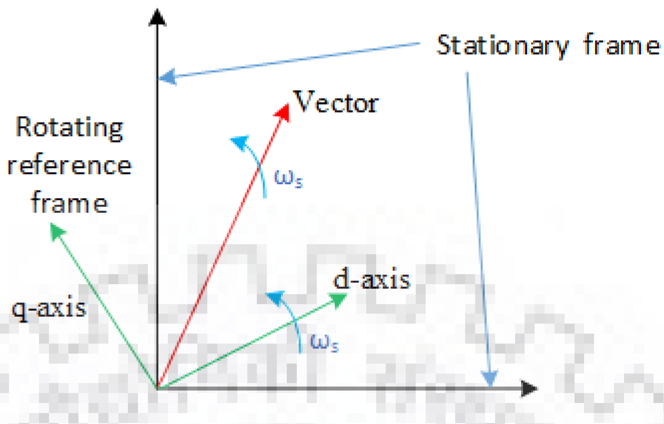


Fig 5.7 SRF rotating axis

5.4.2 Synchronous reference theory for controlling of PV grid connected inverter

If photovoltaic system connected to gird it required inverter to conversion DC to AC. Controlling on inverter is done by synchronous reference theory. Controlling pluses is generated by SRF. For maximum power tracking MPPT is required. MPPT will provide voltage and current at maximum power output. This voltage is use for generate the Id reference as shown in block diagram. According the block diagram grid current Iabc converted into the d-q axis.

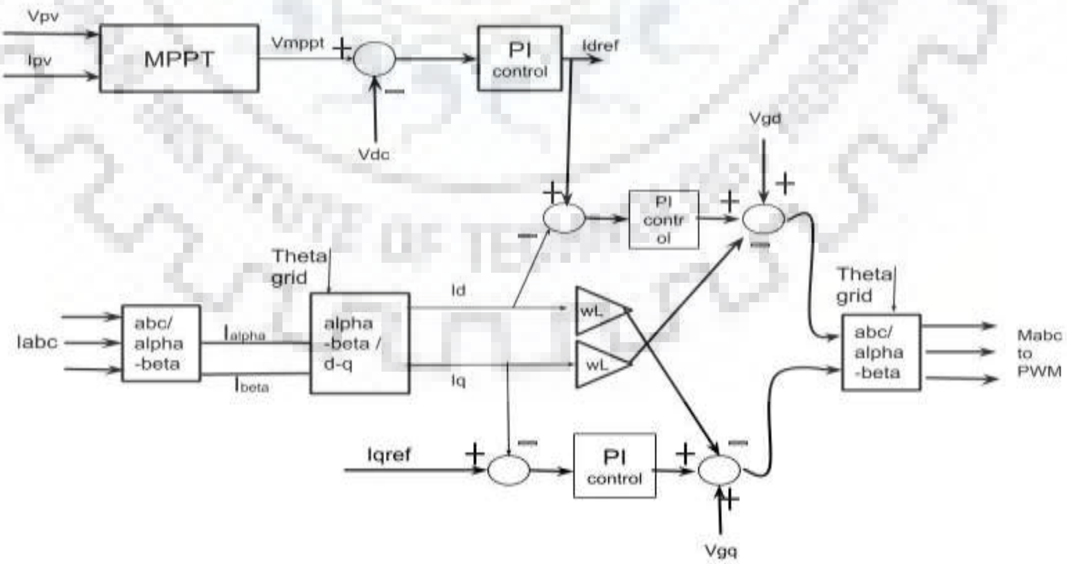


Fig 5.8 block diagram of inverter controlling

For obtaining of theta voltage signal used. Phased locked loop provide to match frequency of signal and generates theta by voltage waveforms. wL is decoupled factor. Iqref is set to be zero to do reactive power zero or unity power factor of system.

Selection of LC filter values

Output of inverter contains harmonics. For elimination of these harmonics filter is designed. LC filter is basically a low pass filter which block higher frequency contains and passed only low order frequency signal. Inductor value chosen as ripple current does not go beyond 10%. Capacitor value chosen as reactive power supply by it at 50Hz frequency. Reactive power should be 10% of the rated power.

$$Lmin = \frac{Vdc}{16 * \Delta Ilmax * fs}$$

$$Cmax = \frac{10\% * Prated}{3 * 2\pi * F * Vrated^2}$$

Vdc is DC link voltage, fs switching frequency

F is grid frequency, dIlmax is maximum permissible ripple

Vrated line to line rms voltage, Prated rated active power

For different irradiance signal builder is used. Irradiance of one cell is always 1000 W/m2 and irradiance of second PV cell is changed from 400 to 800 at time period of 0.3 sec to 0.8 sec.

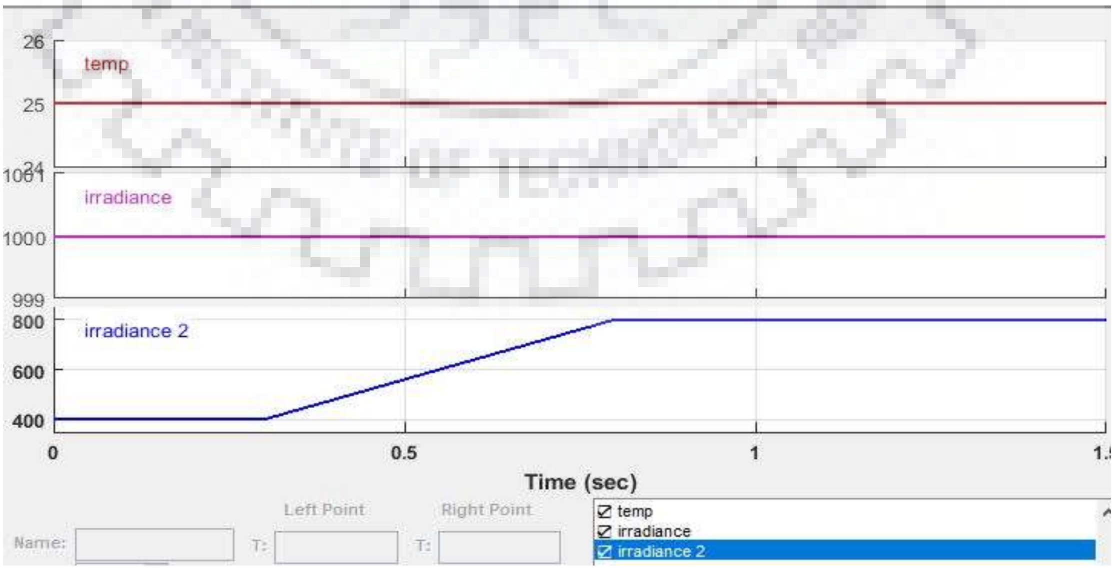


Fig 5.9 Signal builder

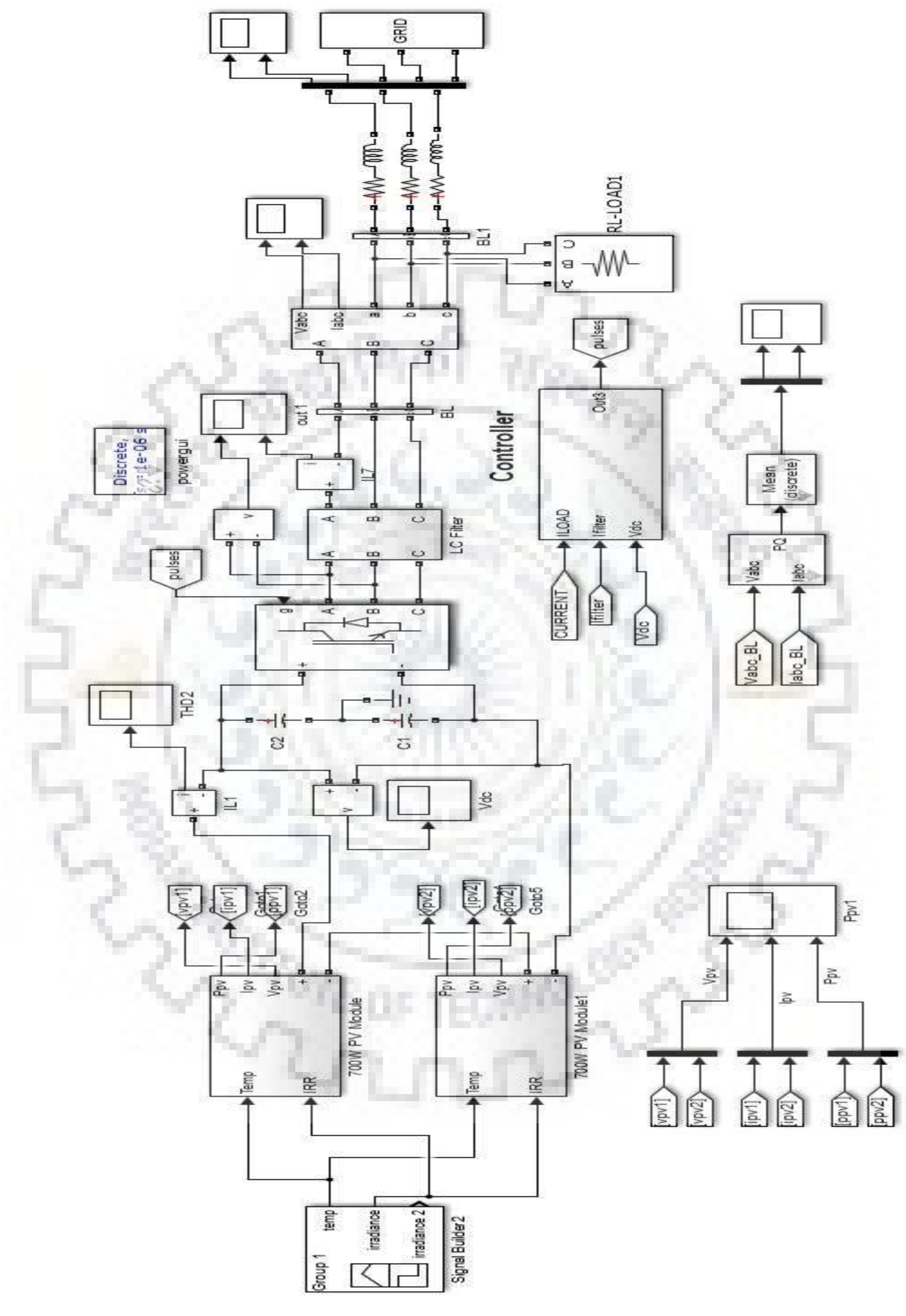


Fig 5.10 Complete PV MATLAB simulation

5.5 RESULTS

Two PV module is connected in series. Maximum power of one module is 700W. total power under without partial shading is 1400W.

PV power, voltage, current without partial shading condition

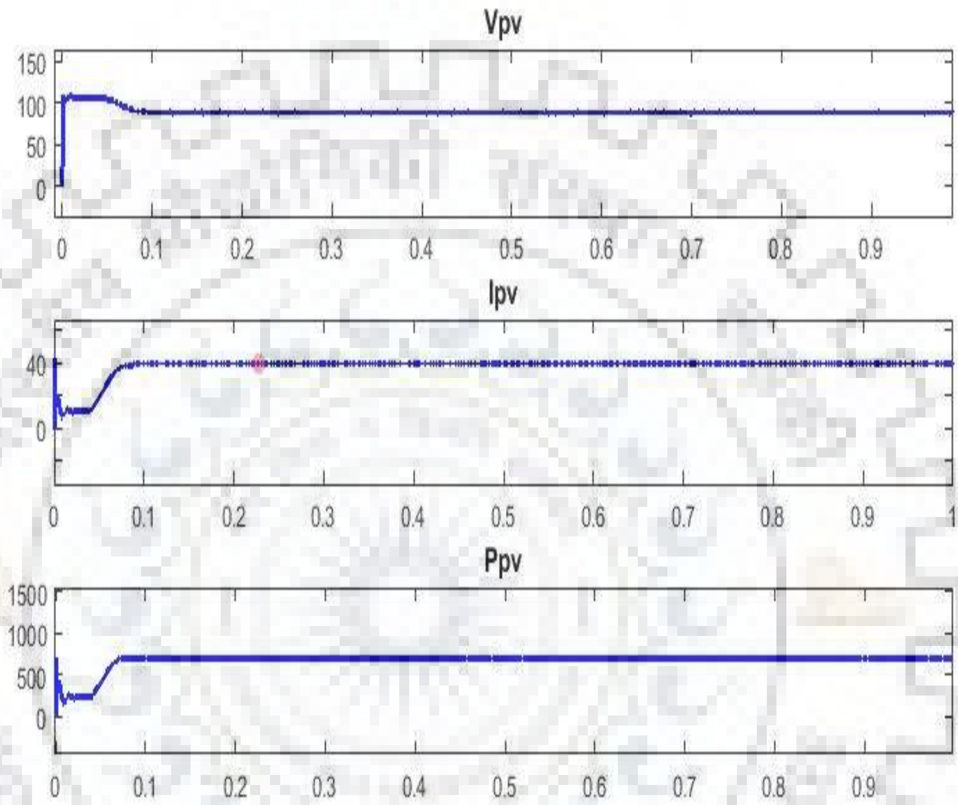
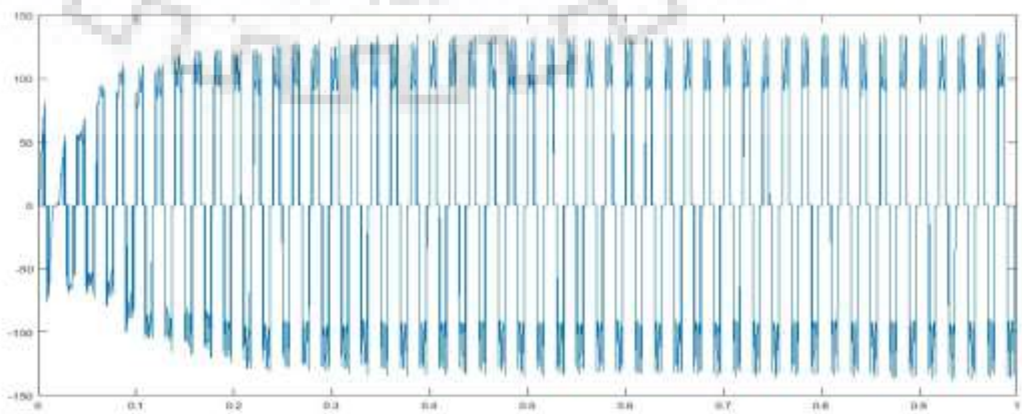


Fig 5.11 PV power, voltage, current without partial shading condition

Output of inverter without partial condition



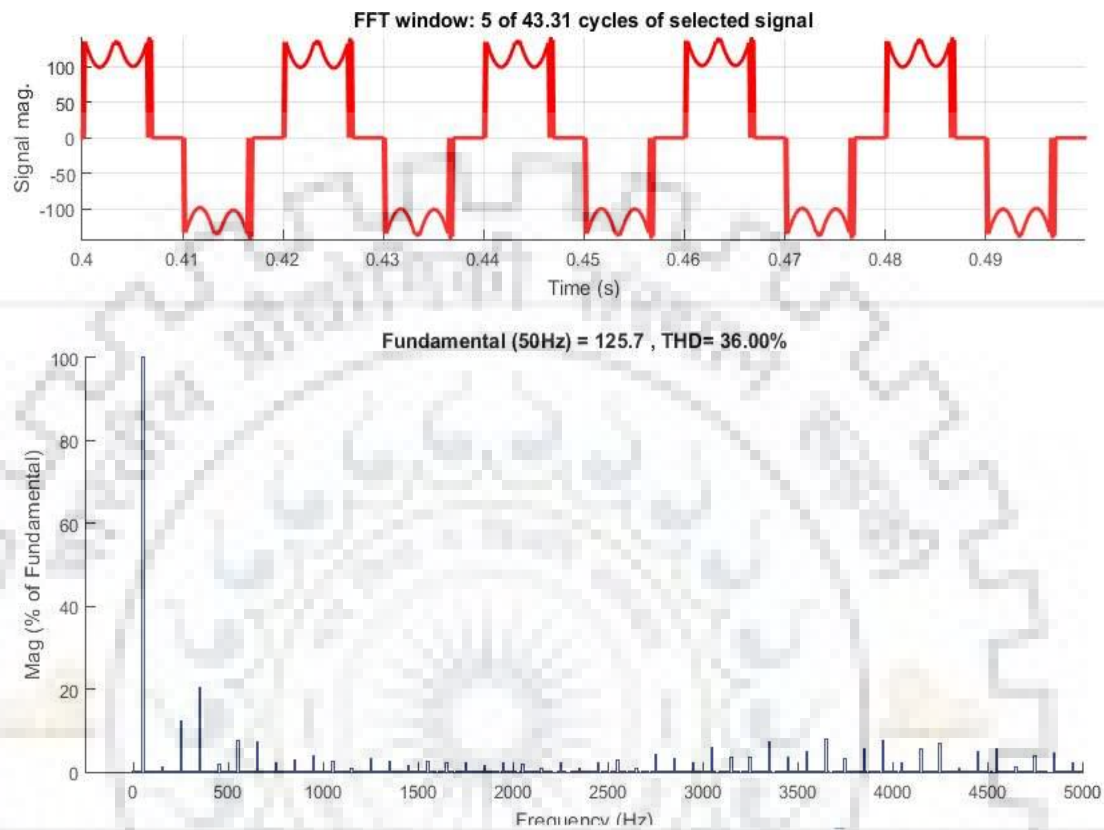


Fig 5.12 Output of inverter without partial condition

Total THD at output of inverter is 36.00%

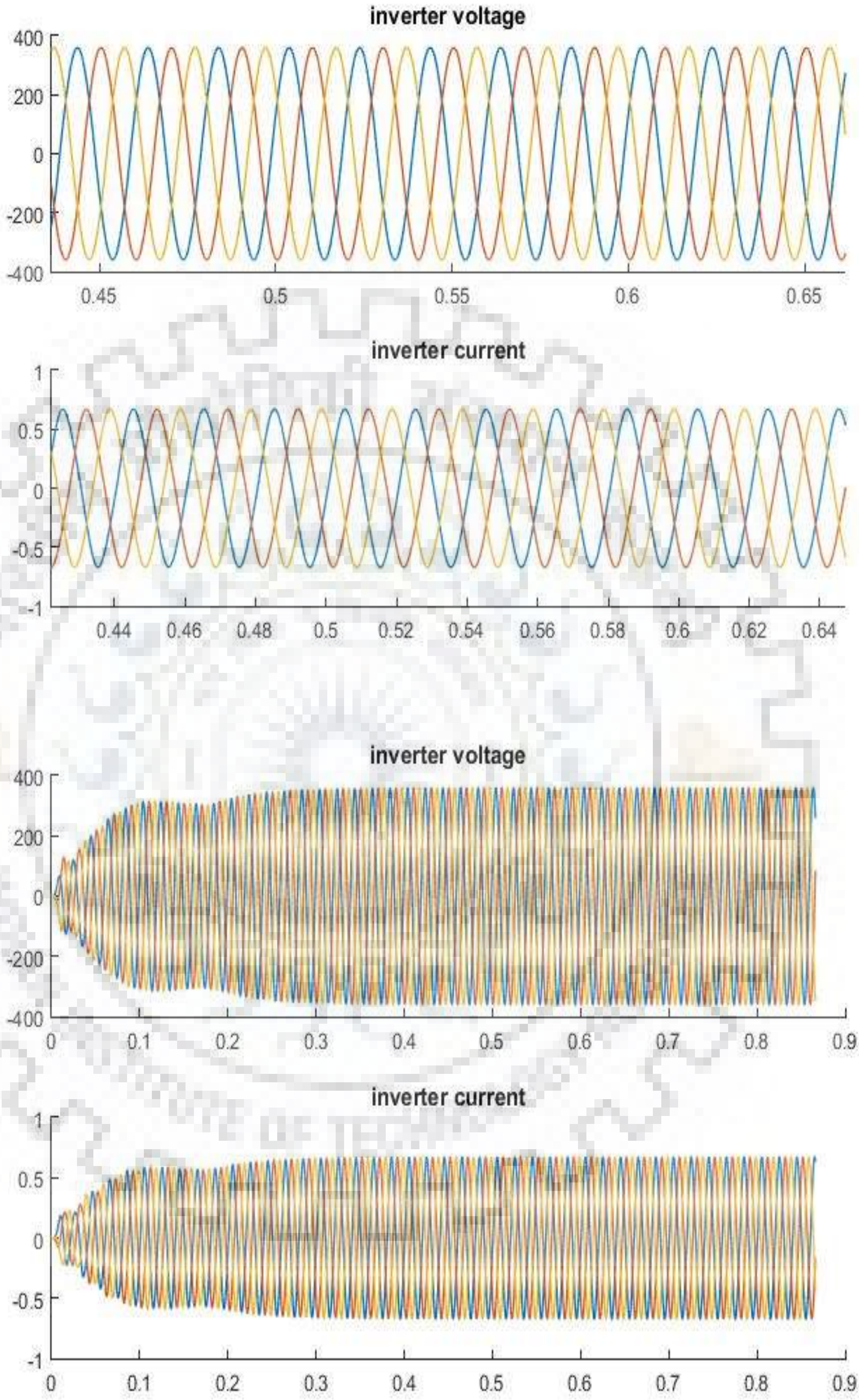


Fig 5.13 grid voltage and current

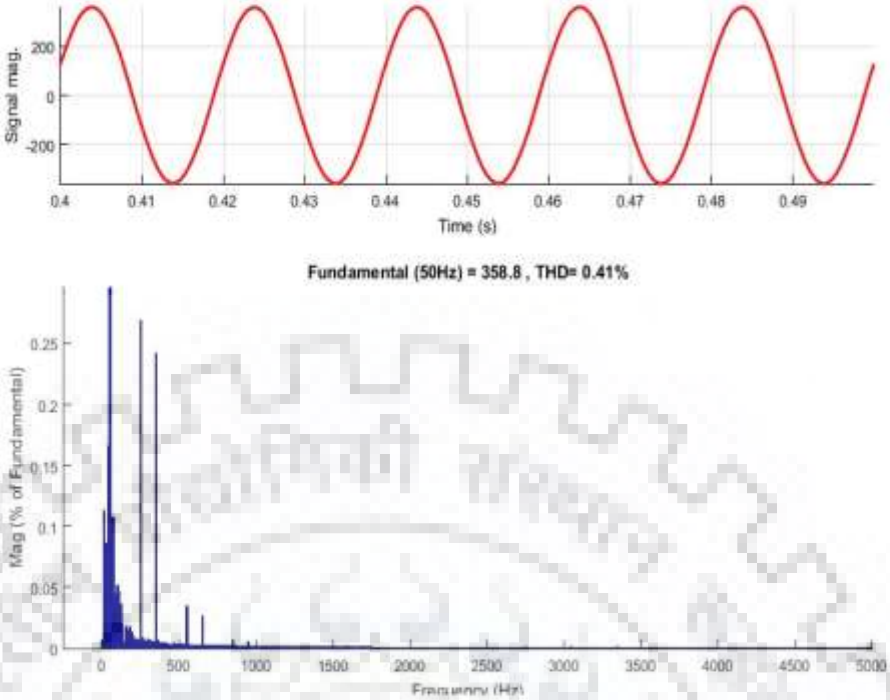


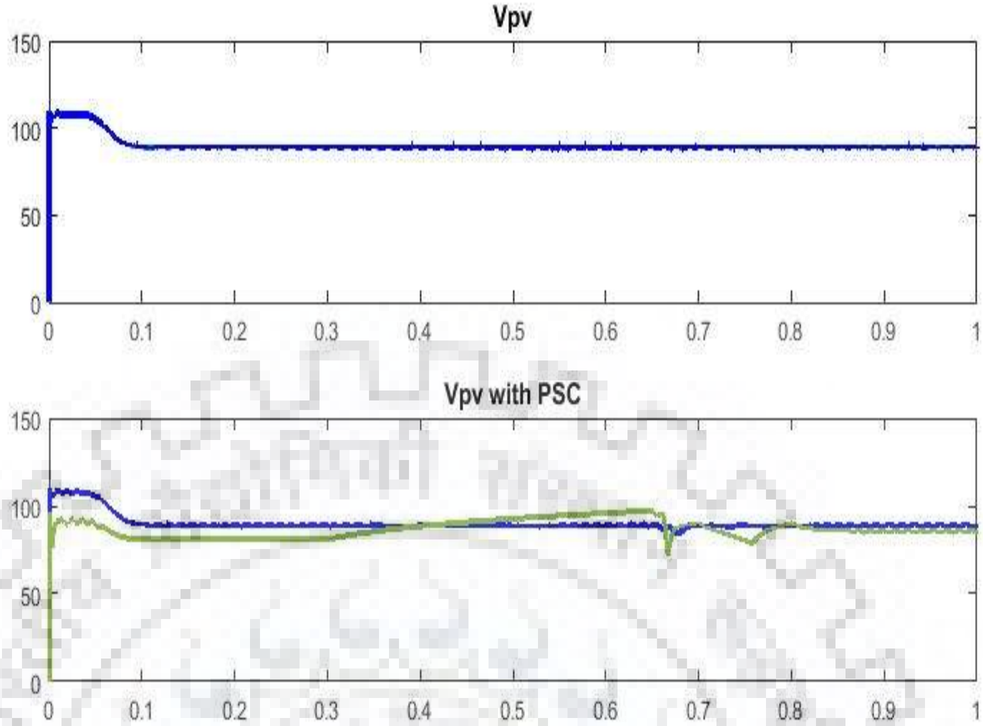
Fig 5.14 THD of output voltage

Total harmonic distortion is 0.41%. THD should be less than 5%.

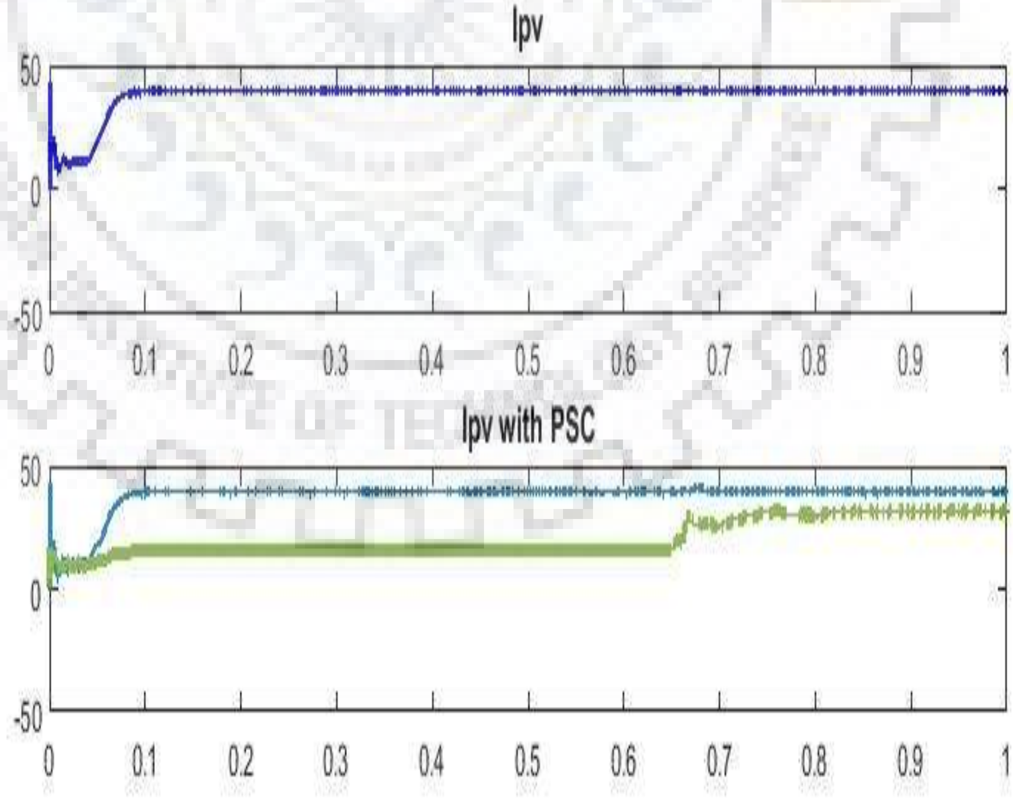
Under partial shading condition:

When one of cell partial shaded then output power decrease. Multiple peaks at PV curve occur. Conventional method cannot track this point. For tracking of this point is done by modified conventional method as discuss in previous chapter.

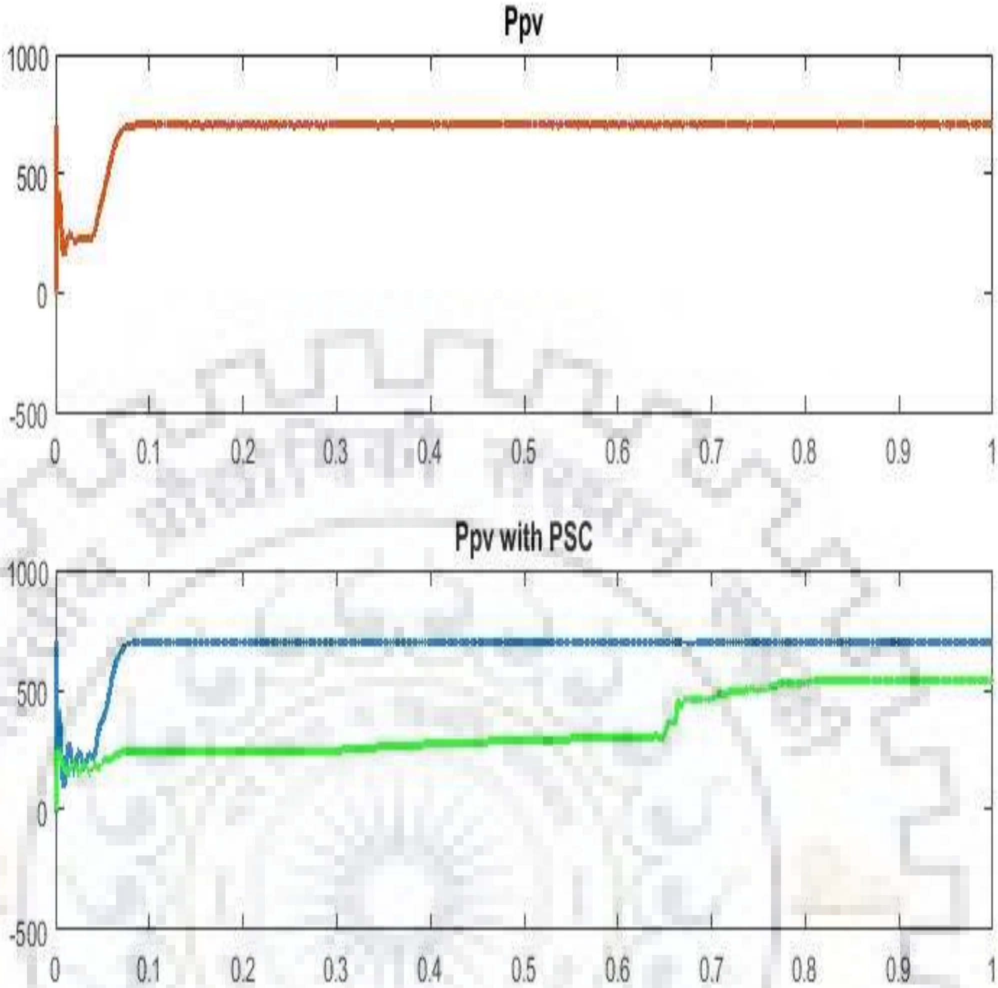
Here comparison of output PV power, current, and voltage will be shown in below figures. Irradiance of PV module 2 is changed at 0.3 sec. up to 0.3 sec irradiance is 400W/m2 after that it changes 400 to 800 W/m2 up to 0.8 sec by using signal builder. As shown if fig 5.9.


Vpv
150
100
50
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Vpv with PSC
150
100
50
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

(a)


Ipv
50
0
-50
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Ipv with PSC
50
0
-50
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

(b)



(c)

Fig 5.15 comparison of (a) voltage (b) current (c) power, under without partial and partial

As shown in above fig output power is changed from 0.3 sec to 0.8 sec of one PV module. For other PV module it is constant at maximum output,700W. Output voltage is same for both PV module. That shows voltage doesn't much change in case of irradiance change. Current is change simultaneously change in irradiance. Output voltage total harmonics under partial shading condition is about 3.62% as shown in fig 5.17.

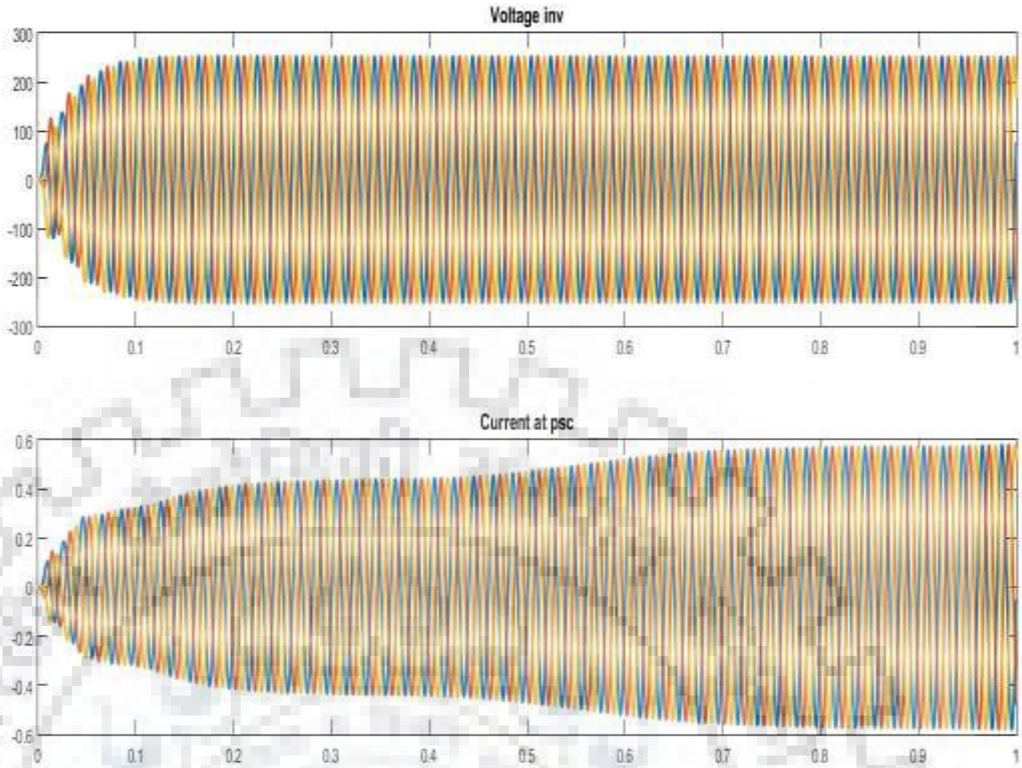


Fig 5.16 output voltage and current under partial shading condition

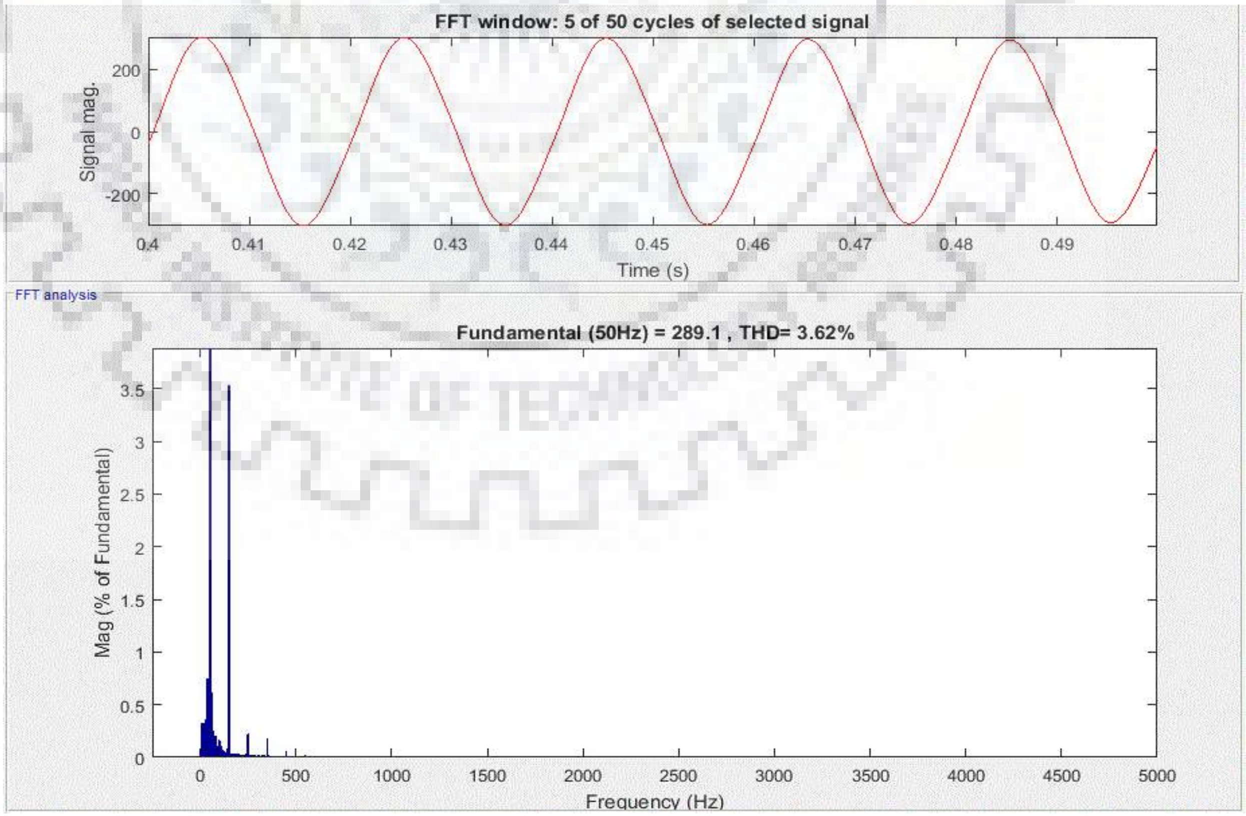


Fig 5.17 THD of output voltage under partial shading condition

CONCLUSION

The design of a control system for three phase grid connected photovoltaic array was detailed in dissertation. It discussed technique which can track global maximum power point. One method used to track global maxima which one is simple to implement. Incremental conductance technique used which change duty cycle of boost converter to achieved maximum power output at partial shading also. For different PV module whose irradiance is different connected to different DC-DC converter. Which helps to track maximum power point. Further system is connected to three level three phase inverter. Filtered output of inverter is feeding power to three phase grid.

Synchronous reference theory is used for controlling the inverter output. Modulation index is changed according to input, to achieved desired output. SPWM is used for give pulses to inverter driver circuit. Detail explanation of the control strategy is presented. PV sources justifies with operation near maximum power point in simulation and experimental results. In addition a detail controlling of inverter is simulated and got desired output. To conclude, the proposed system is effectively achieving global maximum power point as well as grid connected inverter is also working properly as shown in results.

FUTURE SCOPE

Future work can be carried on to expand the scope of this work. Different types of modified MPPT algorithm which can track global maxima point under partial shading with one BOOST converter. Which reduces cost of whole system. Improvements of system efficiency with different types of motor load and industries load.

Further system can be done in single stage boosting and inverting instead of two stage first boosting and then inversion.

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