M.Tech (Power System) AVANIPA SINGH 2021

Major Project Report On

"MPPT CONTROL FOR PV SYSTEM UNDER PARTIAL SHADING CONDITION WITH DIFFERENT ARRAY CONFIGURATIONS"

***Submitted* By**

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IN
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DECLARATION

I hereby declare that the work presented in this report entitled "MPPT control for PV system under partial shading conditions with different array configurations", in fulfilment of the requirement for the award of the MASTER OF TECHNOLOGY degree in Power System submitted in Electrical Engineering Department at DELHI TECHNOLOGICAL UNIVERSITY, New Delhi, is a genuine record of my own work carried out under the guidance of Prof. Rachana Garg during my degree.

The work reported in this has not been submitted by me for the award of any other degree or diploma.

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SUPERVISOR'S CERTIFICATE

This is to certify that Avanipa Singh (2K19/PSY/05) has completed the project titled "MPPT control for PV system under partial shading conditions with different array configurations" under my supervision in partial fulfilment of the MASTER OF TECHNOLOGY degree in Power System at DELHI TECHNOLOGICAL UNIVERSITY. I further certify that the publication and indexing information given by the student is correct.

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ABSTRACT

Day by day the energy demand is increasing worldwide and most of the energy demand is fulfilled by conventional energy resources. With the increasing energy demand the focus has been shifted to non-conventional energy resources like hydro, wind, solar etc. to meet the required demand as conventional energy sources are depleting fast and are causing environmental problems. Among, various available renewable energy sources, Solar PV systems due to its flexible installation, reliability, low operating cost and non-polluting operation is considered and used widely.

Solar PV cell converts solar energy into electrical energy directly. The characteristics of PV array depends upon environmental factors like solar irradiation and temperature. To obtain the maximum available power from PV array it is essential to track maximum power point under varying environmental conditions. In the present work, a 1.049 kW standalone system is designed, modelled and analysed. The system consists of PV array and a boost converter with resistive load. For maximum power point tracking under varying atmospheric condition various MPPT algorithms viz P&O, InC and fuzzy logic controller are implemented and compared. It has been observed that fuzzy logic based MPPT algorithm gives better performance for changing irradiation condition.

Along with varying environmental condition, Photovoltaic (PV) power generation faces an unescapable problem of partial shading condition (PSC). Under PSC all part of PV array doesn't receive uniform irradiation which in turn reduces the output power generated. Furthermore, in partial shading conditions (PSCs) there are multiple peaks in the Power vs Voltage (P-V) characteristics out of which one is global maximum power point (GMPP) and others are local maximum power points. Maximum power point tracking algorithm is used for tracking the GMPP. Due to the existing problem in conventional MPPT to distinguish the global maximum power point in the P-V plot and as it is only being able to find out the first local maxima. The time taking process of finding the global point by practical swarm optimization (PSO) method, modified/advanced algorithm is needed. Consequently, a PSO-P&O hybrid algorithm is proposed and implemented on PV system with PSC. The proposed algorithm is simulated in MATLAB/Simulink and it has been observed that proposed algorithm gives better performance. Along with using advanced MPPT tracker, various configurations of

PV array viz. series parallel (SP) and total cross tied (TCT) configurations. Further, fill factor, shading loss, and mismatch loss has been calculated for various PV array configurations and it has been observed that TCT gives better performance under PSC.

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LIST OF ABBREVIATION

DC	Direct current.
MPPT	Maximum power point tracking.
GMPP	Global maximum power point.
InC	Incremental conductance.
P&O	Perturb and observe.
PV	Photovoltaic.
RES	Renewable energy sources
PSO	Particle swarm optimization

CHAPTER -1

INTRODUCTION

1.1 GENERAL

Energy plays an essential role in our day-to-day activities. The most convenient form of energy for human use is electrical energy. Modern societies are highly dependent on electrical energy for its day-to-day functioning. Robust growth in prosperity and population size drives massive increases in demand of primary energy. Rapid advancement in technology and modernisation also accounts for the rise of global demand of energy at faster rate. As per international energy agency (IEA), the global energy demand is set to increase by 4.6% in 2021, more than offsetting the 4% contraction in 2020 pushing the demand above 2019 level, India's primary energy demand has increased with country GDP and population. Energy consumption has grown at 7.39% compound annual rate, and electricity demand is expected to grow to 1894.7 terawatt-hour (TWh) in 2022.

As per IEA, out of total demand in world in 2020 in Q1 ,74% of demand, and in India almost 70% of demand is met through the fuel (coal, gas, diesel, nuclear) based plant, in which fossil fuel is being brunt to bring its calorific value to generate electricity, the use of fossil fuel to produce energy has certain disadvantages as mentioned below:

Disadvantage of fossil fuel:

- Pollution is the major disadvantage of fossil fuel. This is because they give off carbon dioxide when burn thereby causing a greenhouse effect. This is also the main contributory factor to the global warming experienced by the earth today.
- While burning, coal gives off sulphur dioxide, a kind of gas which causes acid rain.
- Environmentally, the mining of coal result in to destruction of wide area of land. Mining this fossil fuel is difficult and may endanger the lives of miner.
- The fly ashes from coal-based plant causes different respiratory dieses.

Need of Renewable energy sources as a replacement of fossil fuel

Renewable energy sources are those that can be naturally replenished. Ceaselessly, the sun shines, plants grow, rivers flow, and the wind blows. These energy sources are those natural resources that can be quickly replaced and are dependable. These energy sources are not just naturally replenishable but are also have low carbon emission, plentiful, sustainable, and good for the environment.

Some of the renewable energy resources used for electrical energy generation are:

- Solar energy from the sun
- Geothermal energy (from the heat inside the earth)
- Biomass from plants
- Hydropower from flowing water
- Tidal energy.
- Wind energy

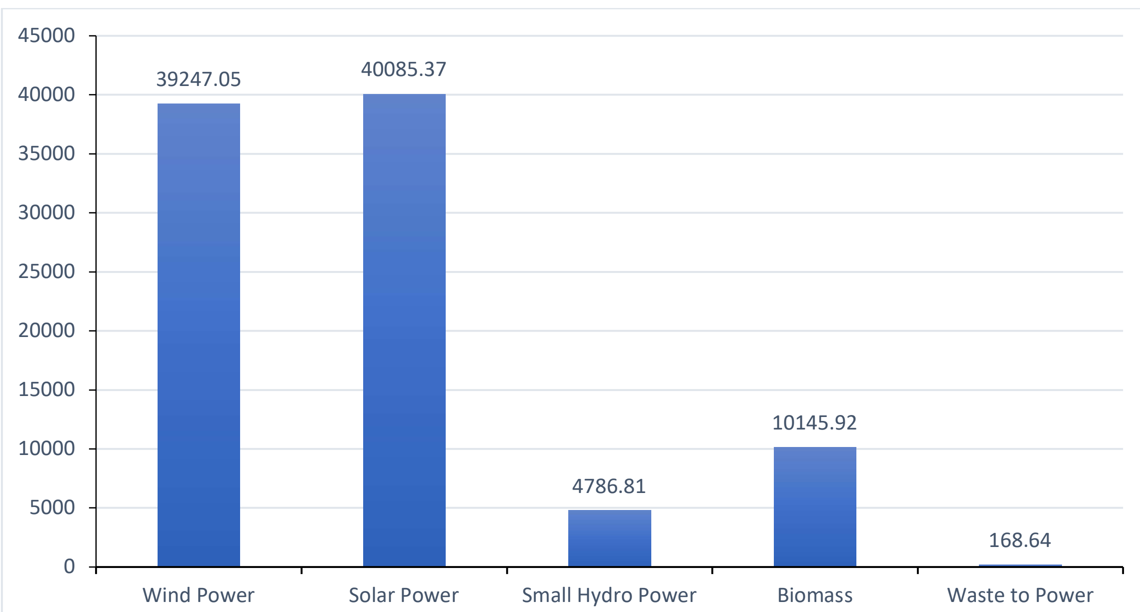

Figure1.1: Total renewable energy installed in India as of 31.03.2021

Source: MNRE website.

Figure1.1 shows the total capacity of power generation in India using renewable energy sources. Out of all the renewable energy sources mentioned above the solar based PV system are the most robust, compact, affordable, and less space requirement, even it can be mounted on the roof, zero fuel consumption, low maintenance cost etc. Due to its effectiveness and certain advantages the solar PV generation increased 22% in 2019 and represented the second-largest absolute generation growth of all renewable technology, slightly behind wind and ahead of hydro based generation,

Solar power in India is a fast-developing industry as a part of the renewable energy of India, the country's solar installed capacity was 40.09GW as on 31 march 2021. National institute of solar energy has assessed the country's solar potential of about 748 GW assuming 3% of waste land area to be covered by solar PV module. Solar energy has taken a central place in India's national action plan on climate change with national solar mission (NSM) was launched on 11^{th} January,2010.

1.2 MOTIVATION

The world is developing expeditiously and energy is nucleus to it. Through history, special attention has been given to the study of the relationship between the energy use of a country and its level of development. India has contributed almost 10% to the rise in global energy demand since the 2000s. India's share in global demand has grown from 4.4% at the beginning of the century to 6% today and is expected to rise to 11% by 2040. Nearly 80% of this demand is met through coal-based power plants. In India total power installed capacity as of 30.06.2021 is 384,116 MW. The thermal power consists of coal, lignite, gas, and diesel.

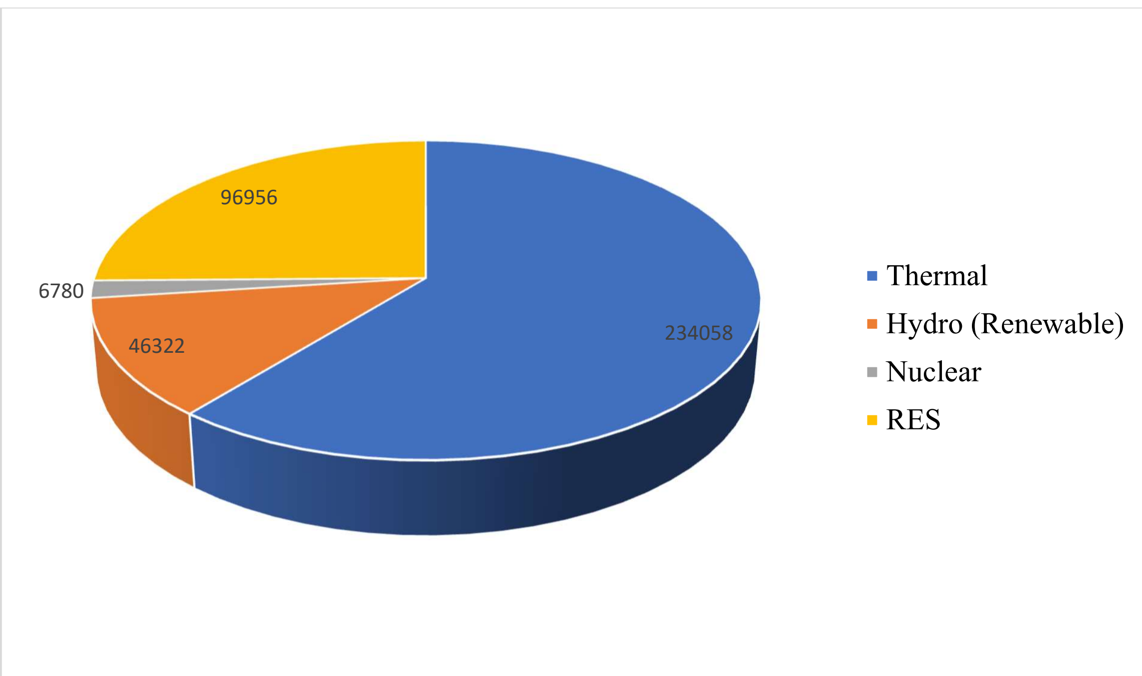

Figure1.2: Total installed capacity in India as of 30.06.2021

Source: http/powermin.gov.in

Table 1.1: Overview of India's power sector (in MW).

FUEL	Power (MW)	% OF TOTAL
Total Thermal	2,34,058	61.5%
Hydro	46,322	12.2%
Nuclear	6,780	1.8%
RES	96,956	24.5%
Total	384,116	

In India total power installed capacity as of 30.06.2021 is 384,116 MW. The thermal power consists of coal, lignite, gas, and diesel. Figure 1.2 shows the total power installed capacity in India classified according to the fuels. It is observed that the majority of electrical energy is produced by using non-renewable energy resources. Presently, around 80% of global energy consumed and 66% of electrical generation are sourced from fossil fuels, contributing roughly 60% of the greenhouse gas (GHG) discharge responsible for climate change.

The usage of conventional sources of energy for generation of electricity has numerous harmful effects on the environment either due to the way they are processed and extracted or in terms of how they are consumed and thereafter disposed of. The most infamous impact of using non-renewable energy sources is the high amount of greenhouse gas emission, in particular methane and carbon dioxide, which significantly contribute to climate change. As more and more non-renewable fuels burn, the average temperature of the planet increases.

It is not just the air that is getting polluted. Harmful pollutants that are emitted into the air can enter in the water cycle. This is the case of acid rain which forms when the atmosphere come in contact with harmful chemicals like sulphur. Chemicals suspended in air turn the rain moderately acidic. Acid rain alters the acidity of streams and lakes which can be very harmful to fish and other aquatic organisms; it also causes damage to trees thereby weakening the forest ecosystems. The use of non-renewable resources for generation of electricity can result in change of water temperature which can cause water pollution.

With the increase in environmental awareness and knowledge about the harmful effects of the use of non-renewable energy, there is a dire need to shift to more environmentally friendly alternatives- Solar Power, Bio-Power Waste to Energy, Wind Power, Small Hydro Power, and other more sustainable sources. Renewable energy has several advantages such as cost of production is low, eco-friendly, etc. Among all the renewable solar energy has an edge due to its abundant availability, low cost of maintenance, no moving part in the system, less space requirement, reliable and more lifetime.

1.3 Scope of work

India's strategic location near the equator in Torrid zone helps harness solar power to its highest capacity. Solar energy can be directly converted into electric energy by the use of photovoltaic cells.

Photovoltaic cells are connected in parallel and series to get the required amount of voltage and current respectively. Power generated by solar photovoltaic cells is DC in nature. A standalone PV system consists of a solar PV array, boost converter, and maximum power point tracking (MPPT) controller.

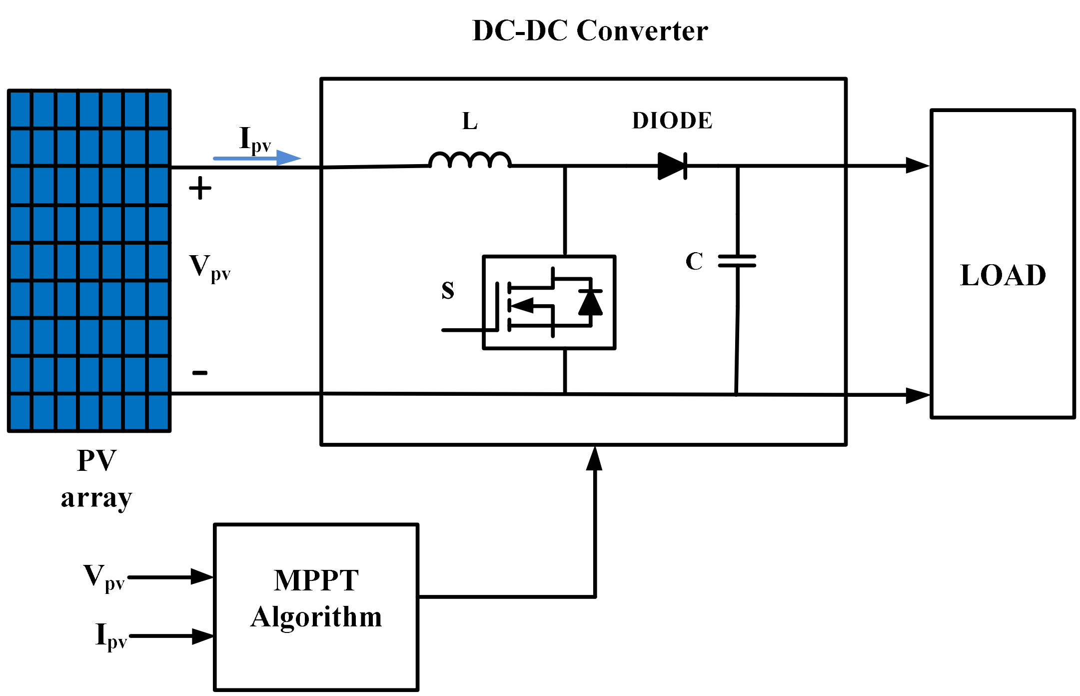

Figure1.3: Standalone PV system

The power delivered by the PV system depends upon environmental factors- irradiance and temperature that vary with time. Hence, maximum power point tracking (MPPT) algorithms are used to track maximum power points of PV modules. There are various MPPT algorithms that has been developed and implemented viz. conventional MPPT algorithms such as fractional current, Incremental Conductance (InC), Perturb and Observe (P&O), fractional voltage etc. and intelligent MPPT algorithms based on fuzzy logic, neural network (NN) and other artificial intelligence (AI) based algorithms.

Figure 1.3 shows a schematic diagram of a standalone PV system. In this work, MPPT control of the PV system is studied and developed in MATLAB/Simulink. Further for partial shading conditions, MPPT algorithms are implemented and comparisons on basis of various parameters are done.

In partial shading condition some parts of the PV array do not receive uniform irradiance due to shadow of trees, building, poles, etc. Due to partial shading the output power of PV system is reduced and multiple peaks are found in the P-V characteristics of the PV array. There are multiple local maximum power points and one global maximum power point. To track the global maximum power point MPPT algorithms are used. Along with advanced MPPT tracker, different configurations of PV array viz. series parallel (SP) and total cross tied (TCT) are used.

1.4 Organization of thesis

This thesis consists of the following chapters:

1) Chapter 1: A brief introduction about solar PV system and a review on energy scenario is discussed.
2) Chapter 2: Literature review on the work done related to the work presented in this thesis is discussed in this chapter.
3) Chapter 3: Design of the PV array and DC-DC boost converter is presented and a standalone PV system of required rating has been developed in this chapter.
4) Chapter 4: Different MPPT algorithms like P&O, InC and Fuzzy logic controller, are implemented for varying irradiation in a standalone PV system.
5) Chapter 5: The effect of partial shading on the PV system is studied. PSO, P&O and PSO-P&O hybrid MPPT algorithms are developed and implemented on the PV system

under partial shading condition. Furthermore, different configurations of PV array are used to reduce the negative effect of partial shading.

6) Chapter 6: Conclusion and future scope of work are discussed.

CHAPTER -2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is an overview of some of the works done previously on MPPT control of PV system. Following topics are covered here as mentioned below:

i. Solar PV system
ii. MPPT techniques.
iii. Partial shading condition in PV system.

2.2 LITERATURE SURVEY

2.2.1 Solar PV systems

In [1][2][3] using MATLAB/Simulink PV model is simulated and characteristics of PV cell is analysed. The current vs voltage (I-V) and power vs voltage (P-V) characteristics of PV panel is analysed for different temperature and solar irradiance. A simplified model of PV array of 125W is studied and modelled in MATLAB/Simulink[4]. The characteristics of PV array are analysed for various environmental conditions and found that proposed model results are similar to actual PV array. In [5] single stage PV system with boost converter is analysed and simulated. The detailed designing of boost converter is given and results are compared with constant dc supply fed boost converter.

The book 'Power Electronics' by Daniel W. Hart [6] helps in understanding the designing and working of boost converter.

2.2.2 MPPT algorithms for PV system

The PV system output depends on its environmental condition so PV system require MPPT controller for maximum power tracking and its efficient working under all the conditions. [7][8][9][10]gives a review on classification of MPPT algorithms like incremental and conductance (InC), hill climbing, short circuit current, perturb & observe (P&O), fuzzy logic, artificial neural network, particle swarm optimisation etc.

In [11] perturb &observe algorithm is designed and simulation is done in MATLAB/Simulink, furthermore its hardware is designed. In[12] this PV model is built and its characteristics are analysed for different temperature and irradiance using MATLAB/Simulink software. On this PV model P&O algorithm is applied and shown that it increases the efficiency of PV system under various environmental conditions.[13] in this duty cycle of boost converter is controlled by P&O algorithm for obtaining maximum power from PV system.

In [14] this incremental conductance method is implemented for a PV system with two phase interleaved boost converter. Simulation is done for various conditions and it is found that in input current and output voltage the ripple is very less.[15]gives a comparative analysis of two algorithms that are Perturb and observe (P&O) and Incremental conductance (Inc) on a standalone system with boost converter. For different irradiation values the performance of both the algorithms are observed and as a result InC is found to perform better. In [16] B. Bendib et.al presented a simulation of standalone PV system with buck converter and fuzzy logic controller for MPPT. The fuzzy logic controller is designed to track maximum power point and the components of fuzzy controller are explained i.e., fuzzification, interference rule and defuzzification in detail. The design of fuzzy logic based MPPT controller is given and the results are compared with traditional P&O algorithm in [17]. It shows that fuzzy logic gives better performance under varying environmental conditions.

2.2.3 Partial shading condition in PV systems

Due to various factors Shading on PV array can occur such as passing clouds, bird droppings, dust deposition, shade of the trees or adjacent buildings, etc. Partial shading has negative effect on PV system it redes the power output of the system and reduces its efficiency**.** Satyendra Vishwakarma presented a brief study on partial shading effect on solar PV array and bypass diode use. As a result, author found out PV characteristics of solar PV array shows more than one peak under shading condition. [18] use of bypass diodes and shading effect on PV array is studied.

In [19][20][21]a study on performance of different PV array configurations that are series-parallel, honey comb, series, total cross tied and bridge linked is presented. The analysis of configurations based on shading loss, maximum power, mismatch loss and fill factor are presented. PV array configuration for various shading conditions modelled was in MATLAB/Simulink software and the authors found out TCT gives the best performance under all shading condition and it has lowest mismatch losses. In [22] Praveen Kumar Bonthagorla et. al proposes a brief study on conventional and hybrid PV array configurations. It shows that maximum power output of array depends on nature and level of shadings, multiple peaks are present in the P-V characteristics under shading condition. Suneel Raju Pendem et. al in [23] presented the performance analysis of series-parallel, series, honey comb array configuration under various shading condition and modelled a 5×5 array using MATLAB/Simulink software. The performance of bridge linked, triple tied, honey comb and series parallel configurations is analysed for non-uniform shading conditions in [24]**.** A 7×7 array is modelled and simulated for various shading conditions such as centre, random, L-shaped etc. The authors found triple tied configuration gives better performance in most of the shading cases.

In [25]a particle swarm optimization-based algorithm for MPPT is proposed for partial shading condition. It was found PSO based method gives better efficiency, converges to required solution and easy to implement. A novel MPPT algorithm based on improved PSO and variable step P&O is proposed in [26]for partial shading condition in PV array**.** Dileep Krishna et. al in [27]proposed a hybrid technique derived from P&O and butterfly PSO algorithms for GMPP tracking**.** In [28]Eduardo Avila et. al proposes a PSO-P&O hybrid algorithm for GMPP tracking under partial shading condition and authors found that it gives high efficiency, low integral square error and faster time of convergence than PSO algorithm. Furthermore, a Sliding Mode Control is used on a cascade scheme which results in proper steady state and dynamic response. In [29]authors presented a novel asymmetrical interval type-2 fuzzy logic control for MPPT along with this improved MPPT method two different configurations were tested under partial shading condition. It is found that TCT configuration with asymmetrical interval type-2 fuzzy logic control gives better efficiency and less losses.

2.3 CONCLUSION

This chapter contains the literature review for the work done in “Design and simulation of maximum power point tracking (MPPT) techniques for solar PV systems”. To understand about the PV system, partial shading in PV system and MPPT control literature review is carried out.

CHAPTER-3

DESIGN OF SOLAR PV SYSTEM

3.1 GENERAL

The energy harnessed by solar PV system is in form of electricity and it is used to meet the demand of load. As solar PV system require solar energy to generate electricity, the output of SPV depends largely on atmospheric conditions viz temperature and irradiance. To take into account this intermittency either battery is used as energy storage element or the SPV system is integrated with grid supply. Accordingly, there are two types of solar PV systems namely standalone PV systems and grid-connected PV systems. The fundamental elements of a solar power generation system are PV array, power conditioning elements and connected load. Solar PV array is made up of solar modules in different combinations, these modules are made up of solar cells. Power conditioning elements are power electronics devices-DC-DC converters, inverters (dc to ac) used in between the PV array and the load. This chapter contains design of solar PV system.

3.2 SOLAR PV SYSTEM

There are two basic categories of PV systems

1. **Grid-tied systems** - In grid tied system, PV system is connected to the grid.
2. **Off-grid systems** - isolated PV systems that are not connected to grid, is called off-grid or standalone PV systems. In standalone systems there can be different kinds of systems- it can be with battery, without battery or hybrid system.

In the present work standalone PV system is considered.

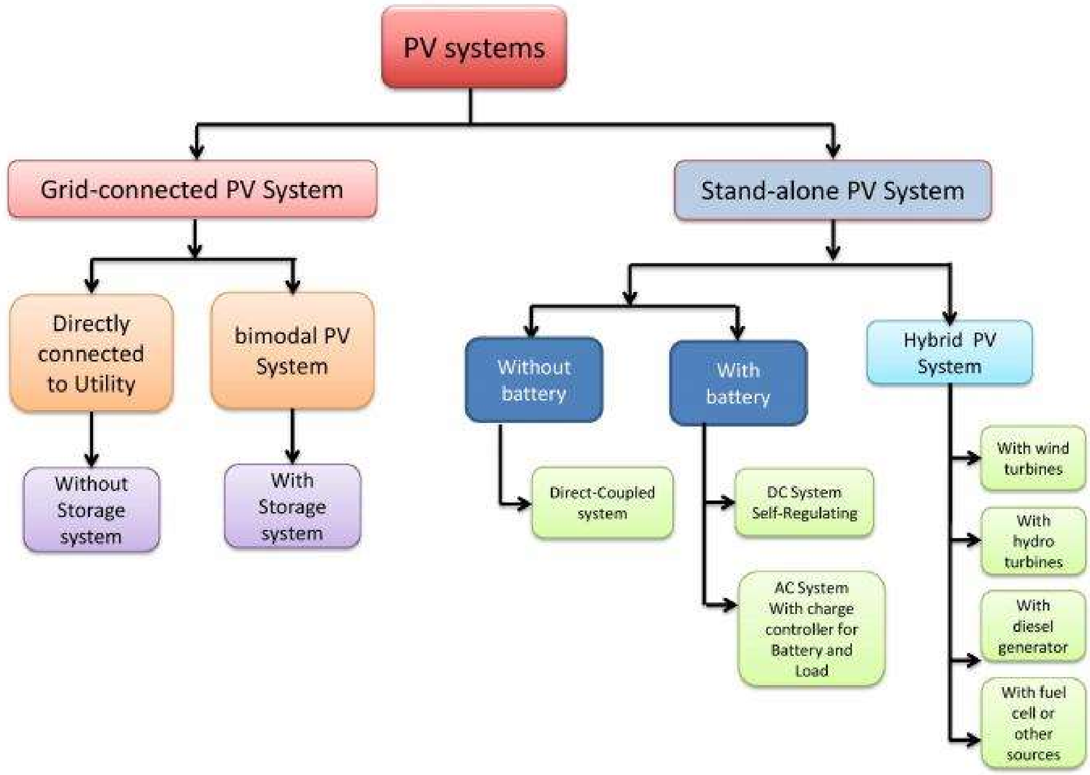

Figure 3.1: Types of PV system

Source: https://www.e-education.psu.edu/ae868/node/872

3.3 DESIGN OF STANDALONE PV SYSTEM.

The block diagram of the standalone PV system is shown in Figure 3.2. It consists of a PV panel, a dc-dc converter (boost converter is used), load and a MPPT controller. This type of system is generally used for smaller loads. For extracting the maximum power available from PV array under particular environmental conditions MPPT algorithm is used that controls the duty ratio of the boost converter.

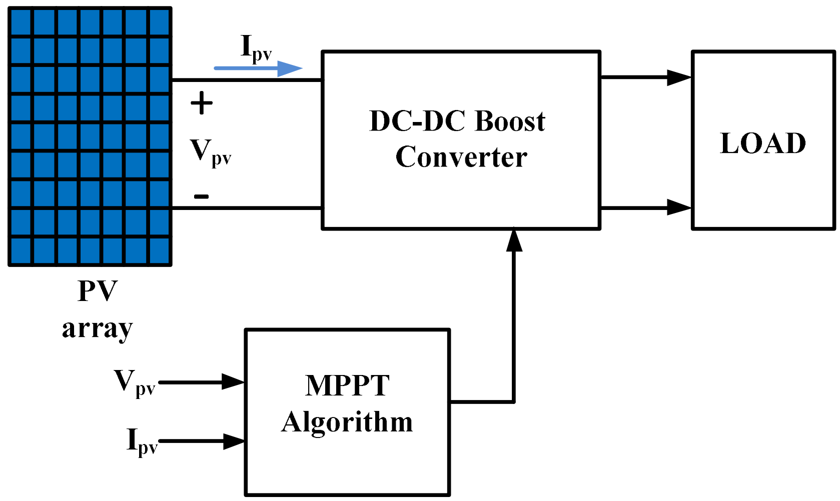

Figure3.2: Standalone PV system with DC load

3.4 SOLAR CELL

Solar cell is the basic element of the solar array used for generation of electricity. Employing solar cell, the solar energy coming from the sun can be directly converted into electricity. A p-n junction of a semiconductor diode exposed to photons is known as photovoltaic cell.

3.4.1 OPERATING PRINCIPLE

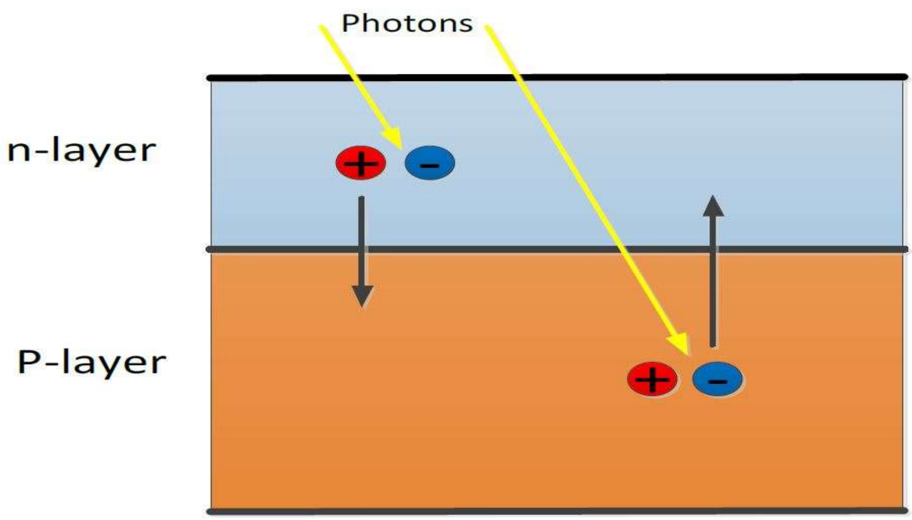

Figure 3.3 Working of a PV cell

The basic principle behind the working is photoelectric effect of the PV cell. When a certain wavelength of sunlight is absorbed by matter- non-metallic or metallic solids, liquids, or gases; as consequence electrons are ejected, this effect is called the photoelectric effect.

Solar cells are made of semiconductor materials so when their surface is exposed to sunlight some of the solar energy is absorbed by the material and if this energy is greater than the energy in its bandgap, the electron from valance band goes to the conduction band. Due to which the electron-hole pairs are formed and the electrons in conduction band can moves freely in the material. The electric field presents in the PV cells, forces the electrons to move in a specific direction and this flow of electrons constitutes the current. By connecting metal plates at the bottom and top of PV cell this current is drawn and used further.

3.4.2 EQUIVALENT CIRCUIT OF SOLAR CELL

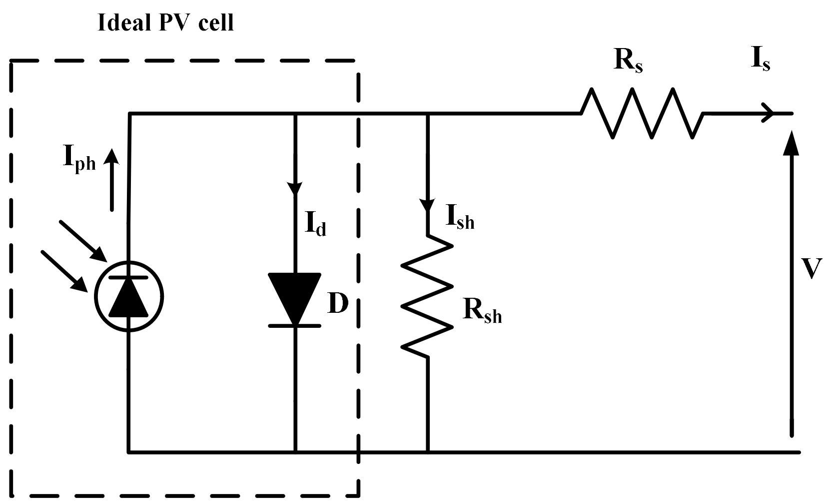

Figure 3.4: Single diode model of PV module

Sunlight can be directly converted into electricity employing PV cells. Figure2 shows circuit diagram of PV module, the equation for ideal PV cell is given by equation 3.1 which explains the I-V characteristics of the solar cell.

$$I_s = I_{ph} - I_0 \left[\exp\left(\frac{qV}{akT}\right) - 1\right] \tag{3.1}$$

Where:

I_{ph} - the current due to the photon's incident

I_0 - the Shockley diode reverse saturation current

q- the electron charge

T-the temperature in kelvin

k - Boltzmann constant

a - the ideality factor of diode.

For practical PV array the equation (3.1) does not depict the I-V characteristic. As the combination of PV cells in parallel and series is called PV array. The number of PV cells connected parallel accounts for an increase in current and in series account for increase in voltage. Equation 3.2 gives the output current equation for a PV array according to the Kirchhoff's first law of circuit as shown in figure 3.2.

$$I_s = N_p I_{ph} - N_p I_d - I_{sh} \tag{3.2}$$

$$I_{sh} = \frac{V + I_s R_s}{R_{sh}} \tag{3.3}$$

Where I_s is the output current f PV system, N_p is the number of cells in parallel, I_d is the saturation current of the diode, I_{sh} is the current flowing through shunt branch.

$$I_{ph} = \frac{G}{G_{ref}}(I_{sc} + k_i \Delta T) \tag{3.4}$$

$$\Delta T = T - T_r \tag{3.5}$$

In equation 3.4 it gives the current due to photons which depends on solar irradiance and temperature where G is the value of irradiance at the time of operation, is the reference solar irradiance, T_r is the reference temperature, T is the operating temperature. ΔT is the difference between the operating and reference temperature given by equation 3.5.

$$I_{sh} = N_p \left(\frac{\frac{V_{pv}}{N_s} + \frac{I_s R_s}{N_p}}{R_{sh}} \right) \tag{3.6}$$

I_{sh} current flowing in shunt branch of the practical PV setup where Ns is the number of cells in series, R_s is the series resistance, R_{sh} is the shunt resistance.

$$I_d = I_0 \left[\exp\left(q \frac{\frac{V_{pv}}{N_s} + \frac{I_s R_s}{N_p}}{a \times k \times T} \right) - 1 \right] \tag{3.7}$$

$$I_0 = I_{rs} \left(\frac{T}{T_r} \right)^3 \exp\left[\frac{qE_g}{a \times k} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right] \tag{3.8}$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q \times V_{oc}}{a \times k \times T_r \times N_s} \right)} \tag{3.9}$$

Where I_d is diode current, I_{rs} is nominal saturation current of the diode, E_g is energy bandgap, V_{oc} is open circuit voltage of PV array, I_{sc} is short circuit current of PV array.

$$I_s = I_{ph} - I_0 \left[\exp\left(q \frac{\frac{V}{N_s} + \frac{I_s R_s}{N_p}}{a \times k \times T} \right) - 1 \right] - \frac{V + I_s R_s}{R_{sh}} \qquad (3.10)$$

Equation 3.10 here gives mathematical equation of the circuit shown in figure 3.2 and the plot of current versus voltage of the practical solar module.

3.5 SOLAR ARRAY

A combination of solar PV modules is known as solar array. Solar module is a combination of number of solar cells in series and parallel. These modules further can be connected in series, parallel or a combination of series and parallel. To get the desired amount of voltage as output number of modules are connected in series and to get the desired current as output modules are connected in parallel. The combination of PV modules in series is known as string.

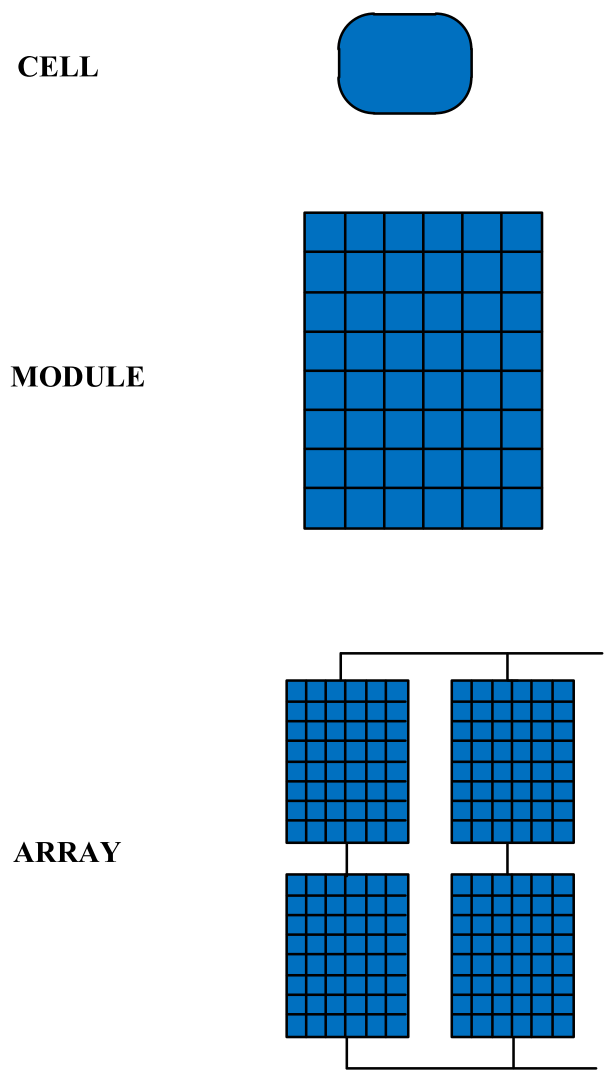

Figure 3.5: Solar setup from cell to array

A solar module is electrically connected combination of series and parallel cells mounted in a frame. The number of series and parallel cells connected depends on the amount of power required as power is product of voltage and current of the module.

Characteristics of solar PV array:

Maximum power point, short circuit current and open circuit voltage are the three important factors of a solar PV array. The value of voltage when the generated current is zero is known as the open circuit voltage (V_{OC}) given by equation (3.11). When the output voltage is zero the value of current at that point is known as short circuit current (I_{SC}) and it is the greatest value of current generated. The power generated at open circuit voltage and short circuit current is zero. The values of V_{OC} and I_{SC} can be depicted from the current vs voltage(I-V) characteristics of PV array as shown in figure3.6.

$$V_{OC} = \frac{aKT}{q} \ln \frac{I_{ph}}{I_0} \tag{3.11}$$

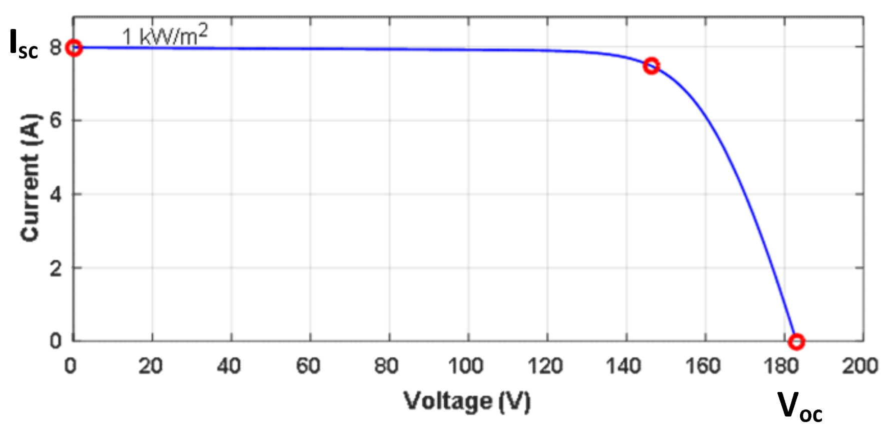

Figure 3.6: Current vs Voltage characteristics of PV array

From figure 3.7 it is observed that the power versus voltage (P-V) plot of solar PV array is not linear and it has a peak point which is known as maximum power point. It can be noticed that as the voltage increases the power also increases but after the power attains its maximum power point if voltage increases the power reduces.

$$P_{MPP} = V_{MPP} \times I_{MPP} \tag{3.12}$$

Where P_{MPP} is the maximum power, V_{MPP} is the voltage at the maximum power point, $I_{MPP}$is the current at the maximum power point.

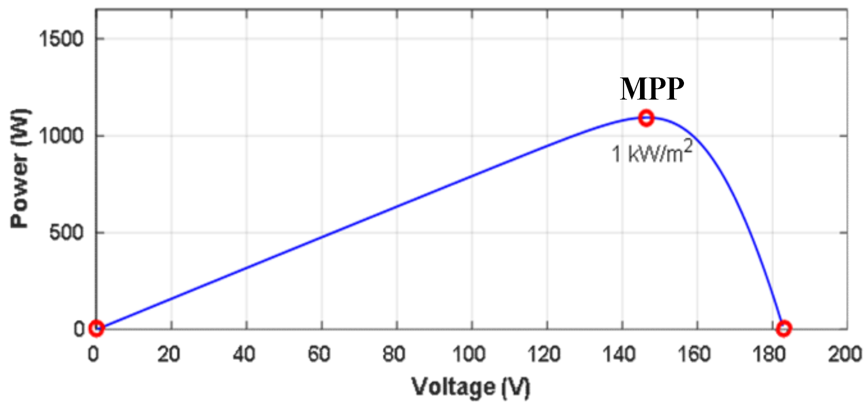

Figure 3.7: Power vs Voltage characteristics of PV array

Effect of temperature and solar irradiance on SPV array:

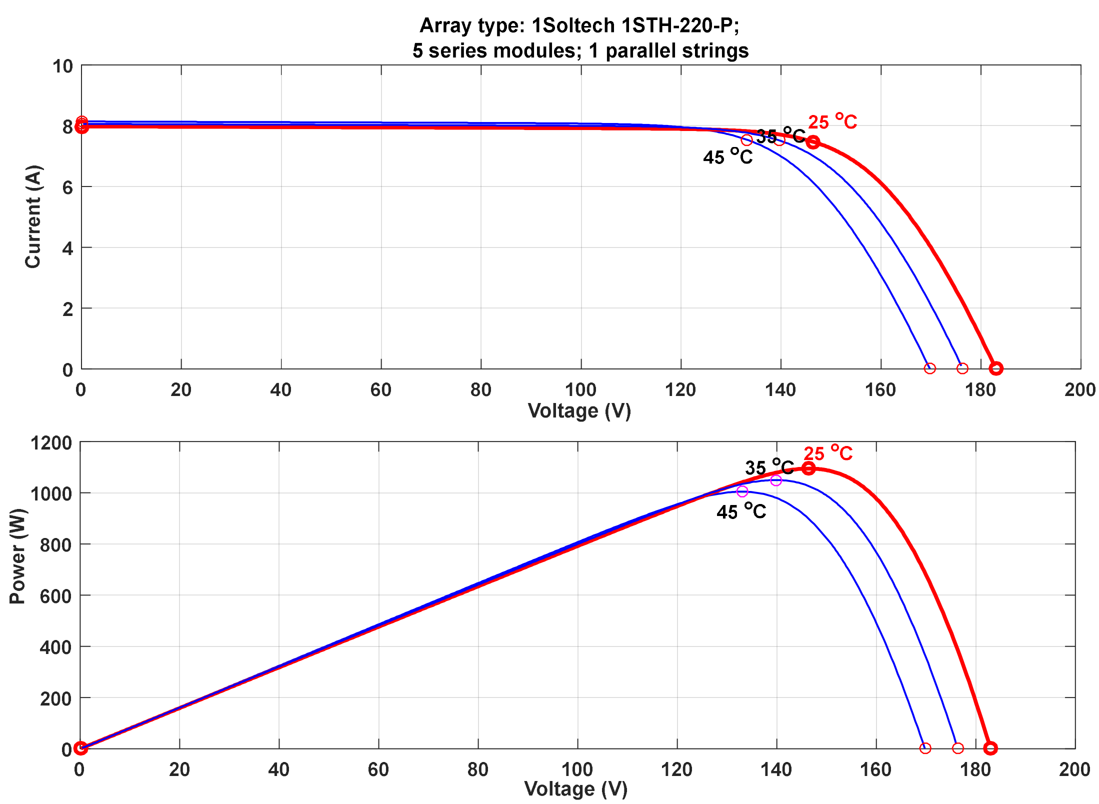

Figure 3.8: I-V and P-V plots of PV module for different temperature

The solar irradiance and temperature are two crucial factors that affect the PV array characteristics. The characteristics of PV array for different value of temperature (45^{0}C, 35^{0}C, 25^{0}C) and fixed solar irradiance(1000W/m^2) is shown in figure3.8. The characteristics of PV array for different value of solar irradiance (1000W/m^2, 500W/m^2, 300W/m^2) and fixed temperature (25^{0}C) is shown in figure3.9 respectively.

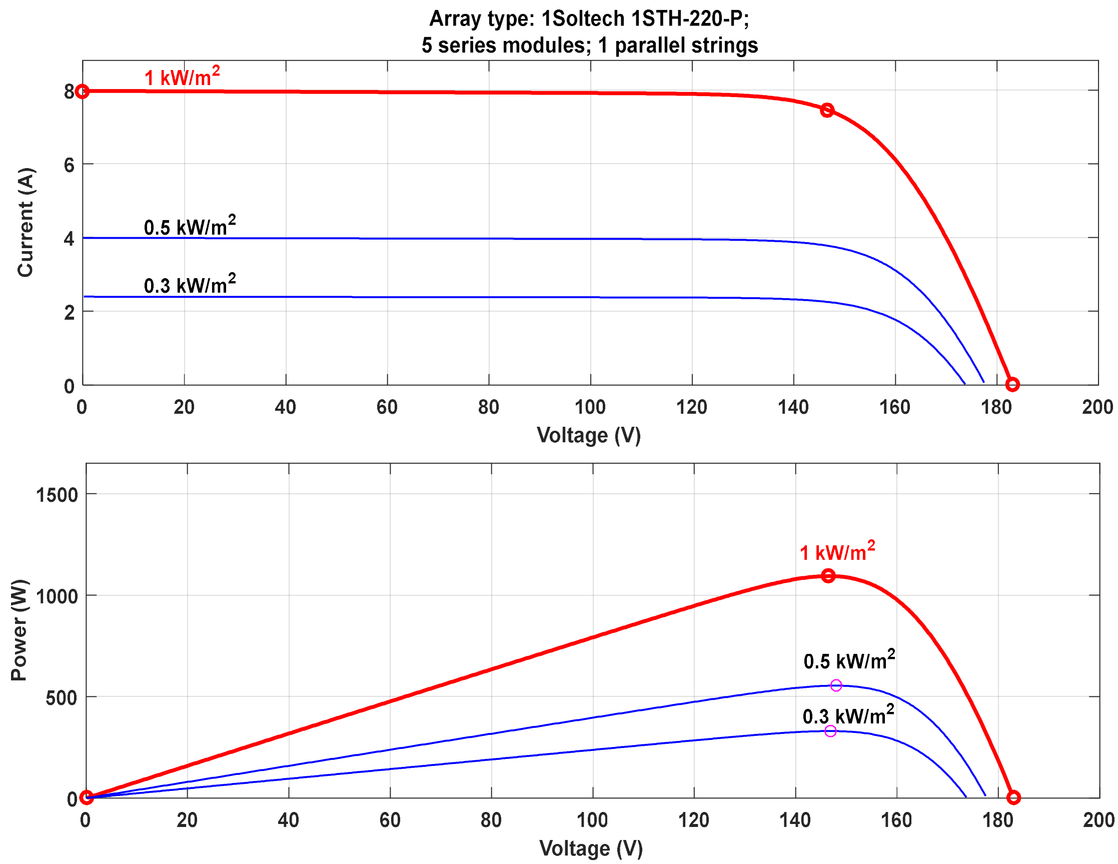

Figure 3.9: I-V and P-V plots of PV module for different values irradiance

Table 3.1 Specification of PV module.

PARAMETERS	VALUE
Maximum power of a single panel (W)	218.8
Cells per module (Ncell)	60
Open-circuit voltage, V_{oc} (V)	36.6
Voltage on maximum power point, V_{mp} (V)	29.3
Short-circuit current, I_{sc} (A)	7.97
Current on maximum power point I_{mp} (A)	7.47
Temperature coefficient of V_{oc} (% °C)	-0.35601
Number of panels in series, N_s	5

Number of panels in parallel, N_p	1
Maximum power of the P-V array (kW)	1.094

3.6 DC-DC BOOST CONVERTER

DC-DC converters are power electronic circuits used to convert a DC voltage to different DC voltage levels. The basic working of a Boost DC-DC converter is to increase the input working of a Boost DC-DC converter is to increase the input voltage applied to a higher value of voltage at the output. The figure3.8 shows the circuit diagram of boost converter having an inductor, switch, diode, capacitor and load.

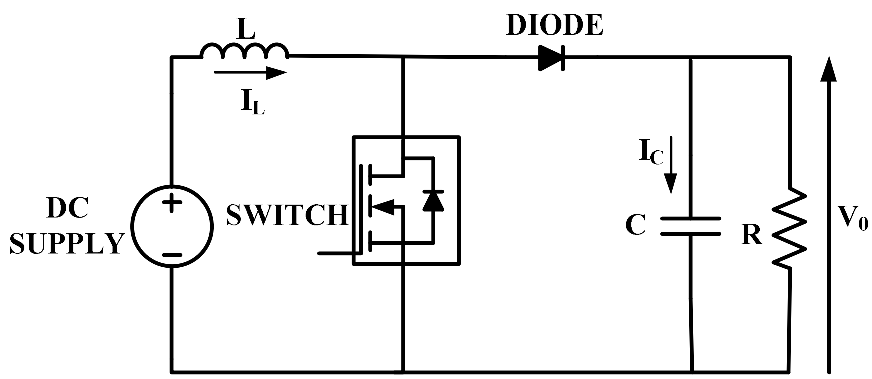

Figure 3.10: DC-DC boost converter

3.6.1 MODE OF OPERATION:

There are two modes of operation of boost converter. In one mode the switch is on or switch is in closed position and in second mode the switch is off or switch is in open position. Both the modes are explained below.

1) **CHARGING MODE:**

In charging mode, the switch is in closed position and the source current is flowing through the inductor as shown in figure 3.9. On load side the capacitor voltage is equal to the output voltage. In this mode the diode present works in reverse bias mode.

$V_S = V_L$ (3.13)

$$V_L = L\frac{di_L}{dt} \tag{3.14}$$

$$(\Delta i_L)_{closed} = \frac{V_S DT}{L} \tag{3.15}$$

Where T is the time period, D is the duty cycle, V_S is source voltage, L is inductor value and Δi_L is change in inductor current.

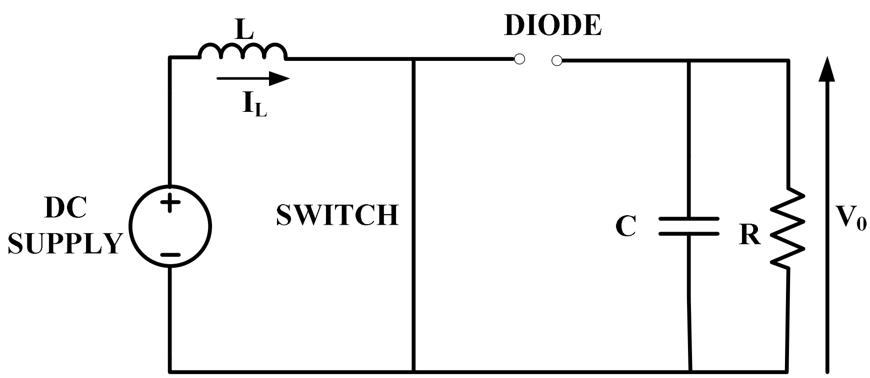

Figure 3.11: Charging DC-DC boost converter

2) DISCHARGING MODE:

In this mode the switch is in open position and as the change in inductor current can't be instantaneous the diode becomes forward bias as shown in figure 3.12.

In this mode the inductor voltage is not equal to the source voltage and is given by equation 3.16.

$$V_L = V_S - V_0 \tag{3.16}$$

$$(\Delta i_L)_{closed} = \frac{(V_S - V_0)(1-D)T}{L} \tag{3.17}$$

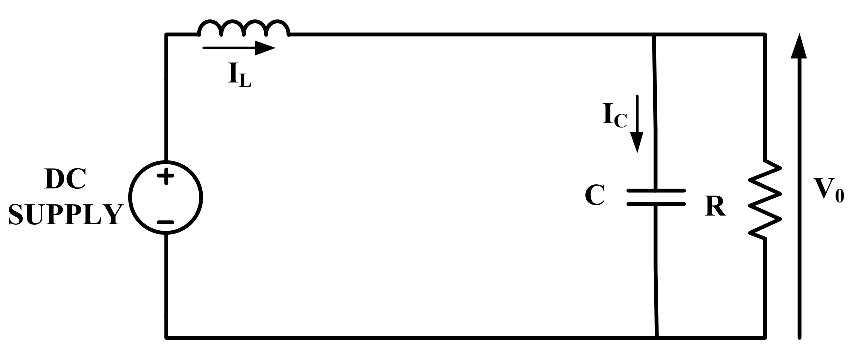

Figure 3.12: Discharging mode of DC-DC boost converter

In steady state operation,

$$V_0 = \frac{V_{in}}{(1-D)} \quad (3.18)$$

$$D = 1 - \frac{V_{in}}{V_0} \quad (3.19)$$

$$L = \frac{V_S * D}{\Delta i * f} \quad (3.20)$$

$$\frac{\Delta V_0}{V_0} = \frac{D}{R*C*f} \quad (3.21)$$

$$C = \frac{I_o D}{f \times V_0} \quad (3.22)$$

Where V_0 is output voltage of boost converter in Volt, V_{in} is the input voltage of boost converter in Volt, D is duty cycle, f is switching frequency, L is inductor, C is capacitor, R is resistance, ΔV_0 is ripple in output voltage, Δi is ripple in input current.

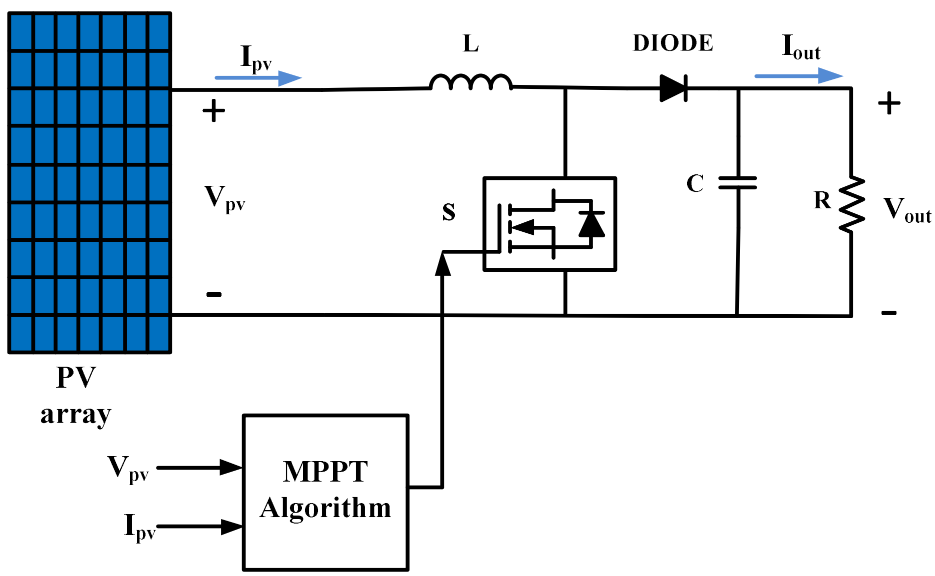

Figure 3.13: Boost converter with PV array

Using the equations (3.18-3.22) the values of components of boost converter can be calculated. Where V_{in} is equal to V_{pv}, V_{pv} is output voltage of PV, f is considered as 25kHz, Δi is considered as 5% of input current. The component values of boost converter are given in table3.2 below.

TABLE 3.2: DC-DC Converter parameters.

PARAMETERS	VALUE
Switching Frequency(f)	25kHz
Inductor(L)	5.24mH
Capacitor(C)	30.2µC
Resistor(R)	44.22Ω

3.7 CONCLUSION

In this chapter the design of 1.094kW PV system has been carried out. The output of PV system depends on the rating of the PV array and environmental factors such as temperature, solar irradiance etc. In this chapter design of standalone PV system has been explained and specifications of solar PV array and design of boost converter is discussed. The values for inductor and capacitor for the boost converter used are calculated.

CHAPTER 4

MAXIMUM POWER POINT TRACKING TECHNIQUES

4.1 GENERAL

In a solar PV system, the output power of PV cell depends on environmental conditions like temperature and solar irradiance. For different irradiance value the maximum power point is different as shown in figure 3.9, so for optimum output, tracking of maximum power point is needed. There are various maximum power point techniques that has been developed and implemented by researchers previously. In this chapter different MPPT techniques are studied and implemented in MATLAB/Simulink.

4.2 MPPT TECHNIQUES

Efficiency is one of the important factors in SPV power generation and one way to make solar PV more efficient is to track maximum power by MPPT control. There are different MPPT techniques used and a lot of work is been done in this field. Different MPPT techniques are based on different parameters like accuracy of tracking, settling time, cost and effectiveness for changing temperature and irradiance of the system.

The MPPT techniques can be classified as: conventional MPPT techniques, intelligent MPPT techniques, optimization methods of MPPT techniques and their combinations known as hybrid MPPT techniques. Figure 4.1 shows the classification of different MPPT techniques.

The conventional MPPT techniques are basically based on two aspects one is selection of the parameters and the other is direct MPPT method. In first method of selection of parameters the tracking is done based on the already defined parameters of the PV system. Constant voltage tracking, open circuit voltage tracking, short circuit current tracking, current scanning method are the different types of methods based on selection of parameters. From the I-V and P-V plot short circuit current, maximum power, open circuit voltage, current at maximum power point and voltage at maximum power point are analysed. Perturb & Observe (P&O), Incremental

Conductance (InC), are some of the MPPT techniques for direct method. In direct methods tracking is done on the base of sampled data from the PV array like its voltage, current and power. Conventional methods are simple to implement and are less complex.

Fuzzy logic, sliding mode controller and neural network are some the intelligent MPPT controllers. These methods give better performance during changing weather conditions like change in temperature and change in solar irradiance. Their tracking speed and tracking efficiencies are high.

Cuckoo search, Ant Colony Optimization, Gray wolf optimization and particle swarm optimization are some of the optimization based MPPT techniques. Even in dynamic environmental conditions these methods tend to reach the true value of MPP.

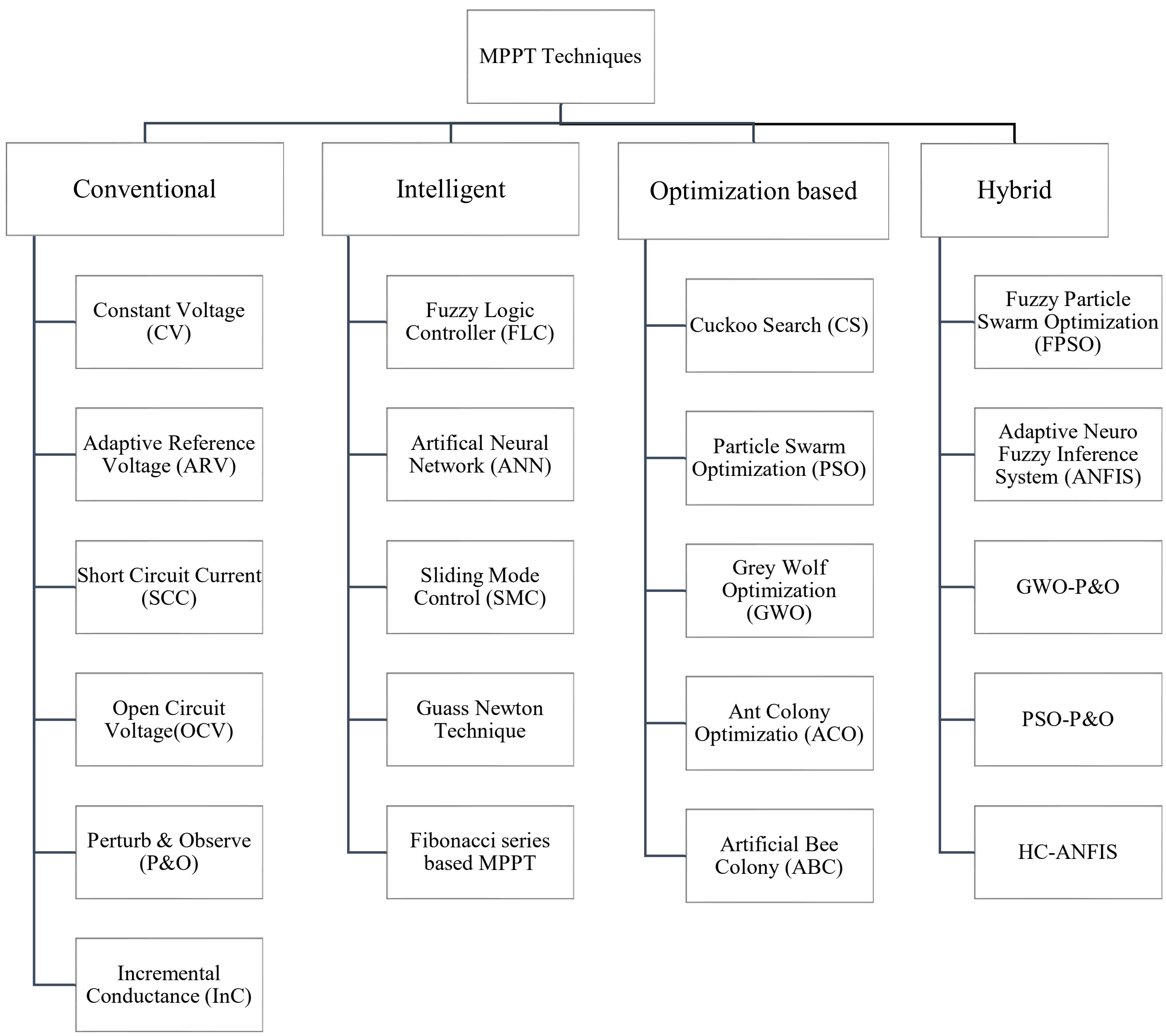

Figure 4.1: Classification of MPPT algorithm

Hybrid MPPT methods are basically combination of two different MPPT techniques like combination of conventional MPPT and intelligent or optimization based MPPT and combination of intelligent and optimization based MPPT technique. In these combined methods there are two steps: first step is the estimation of MPP and in second step by using advanced methodologies fine-tunning of MPP is done.

4.3 PERTURB AND OBSERVE MPPT TECHNIQUE

One of the traditional methods widely used is perturb and observe algorithm(P&O) due to its simplicity. Implementation of perturb and observe algorithm is easy as it does not require the information of temperature and irradiance of the system and few parameters are required for calculation of maximum power point. The P&O algorithm is used to determine the current and voltage at which the PV system gives maximum power for a particular temperature and solar irradiance.

In P&O method the sample of current and voltage are taken and power is calculated by multiplying the voltage and current. Then the present power is compared with the last power calculated. The change in power and voltage are calculated by difference in present value and past value of power and voltage. If both the change in power and voltage is either positive or negative then the value of duty cycle is reduced by a factor of dD in order to produce the successive cycle of perturbation and to move the operational point towards the maximum power point. And if the change is power and voltage are opposite to each other that, is one is negative and other is positive then the duty cycle is increased by a factor of dD for the next cycle of perturbation. Where dP is change in power and dV is change in voltage from previous to present value.

$$\frac{dP}{dV} = \begin{cases} = 0, \text{ at MPP} \\ > 0, \text{ left of MPP} \\ < 0, \text{ right of MPP} \end{cases}$$

Advantages:

1. Simple to implement and required parameters are less.
2. Cost of implementation is low.
3. Memory is not required.

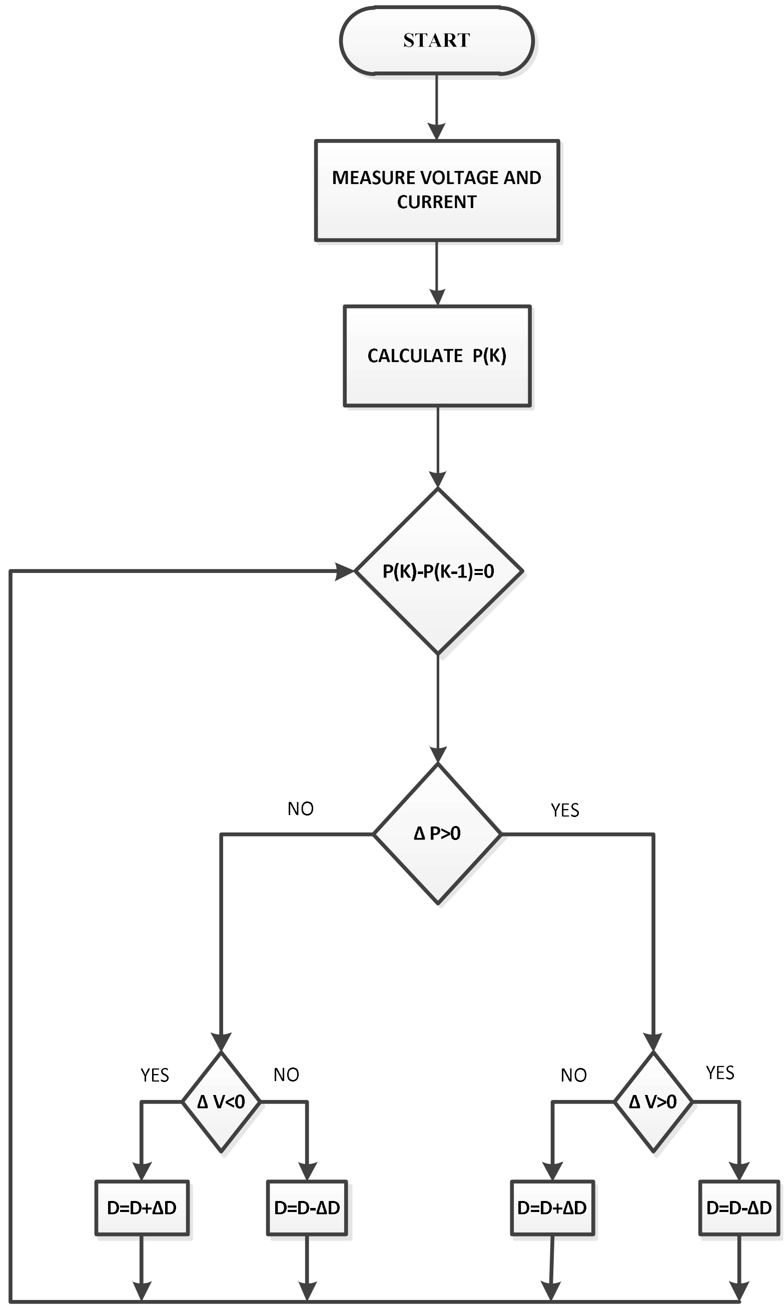

Figure 4.2: Perturb and Observe flow chart

Disadvantages:

1. The response is sluggish and fluctuations are high at the points where the parameters irradiance or temperature changes.

4.4 INCREMENTAL CONDUCTANCE MPPT TECHNIQUE

The incremental conductance method is based on the slope of power curve of PV array which is zero at maximum power point (MPP), positive on left side of MPP and negative on right side of MPP. The change in PV voltage(dV) and PV current(dI) are calculated and using that change in conductance is calculated. The change in conductance is compared with the instantaneous conductance as given in below equation 4.4 and according to the operating point either on left or right side the duty cycle is adjusted.

Power of the PV system is calculated by:

$$P = V \times I \tag{4.1}$$

Differentiating equation 4.1 with respect to V, we get:

$$\frac{dP}{dV} = I + V\frac{dI}{dV} \tag{4.2}$$

$\frac{dP}{dV} = 0$ at MPP.

$\frac{dP}{dV} > 0$ on left side of MPP.

$\frac{dP}{dV} < 0$ on right side of MPP.

From above it is observed that at the maximum power point the slope of the P-V curve is zero. The slope is given by equation 4.2 so equating the above equation to zero:

$$\frac{dP}{dV} = 0 \tag{4.3}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{4.4}$$

Then according to the above explanation and equation 4.4:

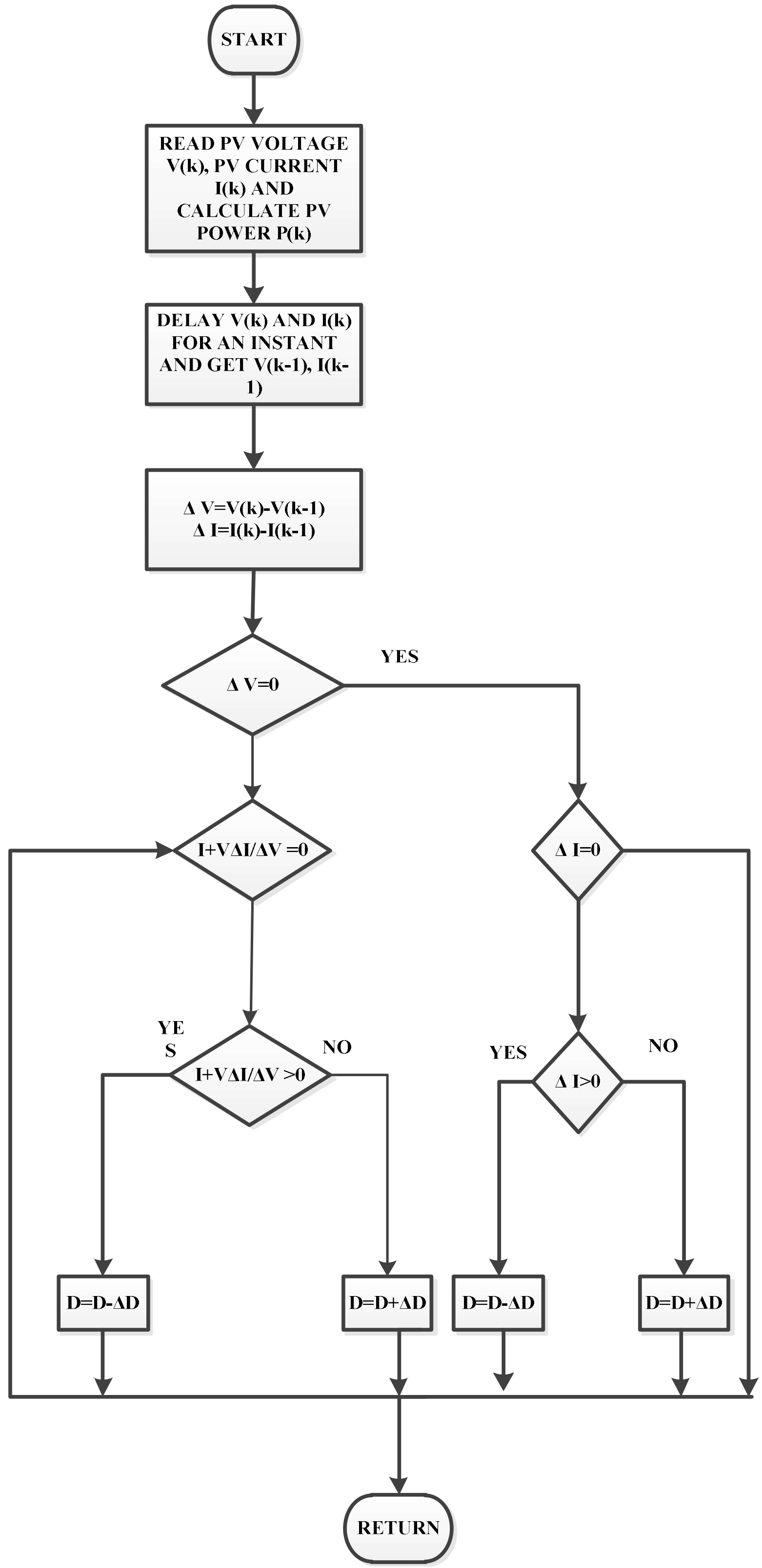

Figure 4.3: Incremental conductance flow chart

$$dI/dV = \begin{cases} = -\frac{I}{V} & \text{at MPP} \\ > -\frac{I}{V} & \text{left of MPP} \\ < -\frac{I}{V} & \text{right of MPP} \end{cases}$$

Advantages:

1) It gives accurate MPP than P&O algorithm.
2) The calculation is reduced.

Disadvantages:

1) It is more complex to implement than P&O algorithm.
2) There is oscillation when the MPP is reached.

4.5 FUZZY LOGIC BASED MPPTCONTROL

Fuzzy logic is one of the artificial intelligence technologies. For wide range of applications in renewable energy fuzzy logic is used. MPPT controller based on fuzzy logic has several advantages over P&O and InC algorithms as it improves the tracking performance of the PV system under changing temperature and changing solar irradiance.

To track the MPP of the PV system fuzzy logic controller is used. There are three stages for the tracking of maximum power point in fuzzy algorithm that are fuzzification, fuzzy rule base and defuzzification. These components of fuzzy controller are shown in figure4.4. Fuzzy logic algorithm handles the non-linearity of the PV system characteristics and reaches the maximum power point and follows the MPP with negligible oscillations.

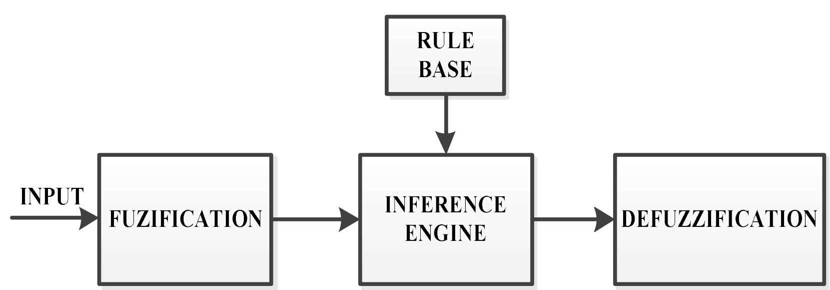

Figure 4.4: Block diagram of fuzzy controller

Fuzzifications:

This is the first step of fuzzy control where the parameters are converted into linguistic variables. Membership functions are used so as to associate values to the linguistic variables. The voltage and current are measured and power is calculated by taking their product. Two input parameters are given to the fuzzy controller one is error (E) and the other is change in error (CE). The equation and are gives the value of E and CE:

$$E(k) = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \tag{4.4}$$

$$CE(k) = E(k)-E(k-1) \tag{4.5}$$

The error here is the slope of the P-V plot of the PV array and when it is positive it means the operating point is on the left of the maximum power point and when it is negative it is on the right side of MPP. When the slope is zero that is the error here considered is zero then the operating point is on MPP.

Fuzzy rule base:

In this step the fuzzy rules written are applied to the input and then according to the rules the output is determined. The output is determined according to the two inputs. The rules are written according to the controller used to track the MPP.

Defuzzification:

In this step the output linguistic variables are converted into the actual values according to the membership function. There are different methods for defuzzification process used one is the Max Criterion Method (MCM) and Centre of Area (COA). Centre of area is most commonly used method for defuzzification.

4.7 SIMULATION AND RESULTS.

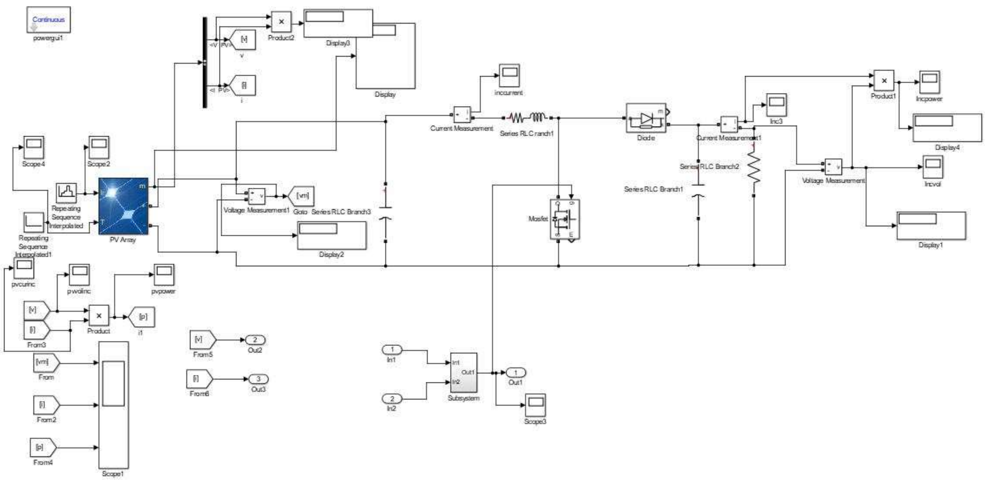

Figure 4.5: Simulink model of solar PV system used

In MATLAB/Simulink the model of single stage PV system is developed as shown in figure4.5. Results are obtained for different MPPT algorithms under varying solar irradiance and constant temperature for linear load. Waveforms of PV power (P_{pv}), PV current (I_{pv}), PV voltage (V_{pv})are plotted. Figure 4.6 and figure 4.7 shows the plot of irradiation and temperature respectively applied to the PV array for testing of MPPT algorithms.

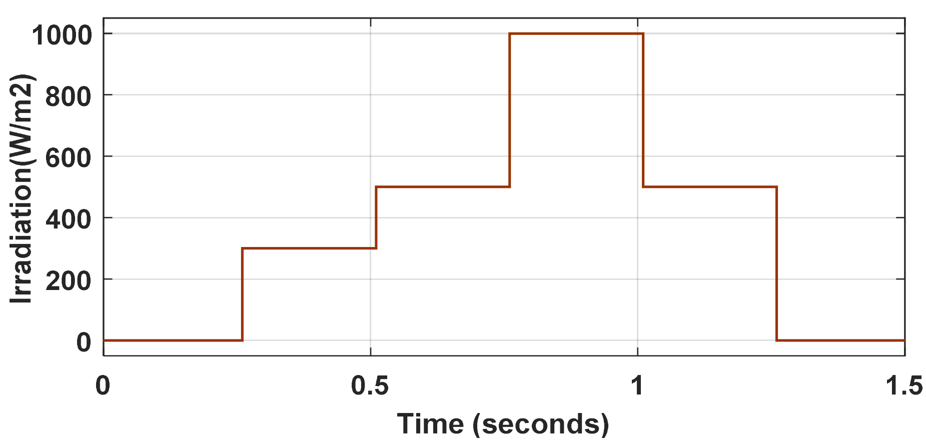

Figure 4.6: The graph of irradiation applied to the PV array

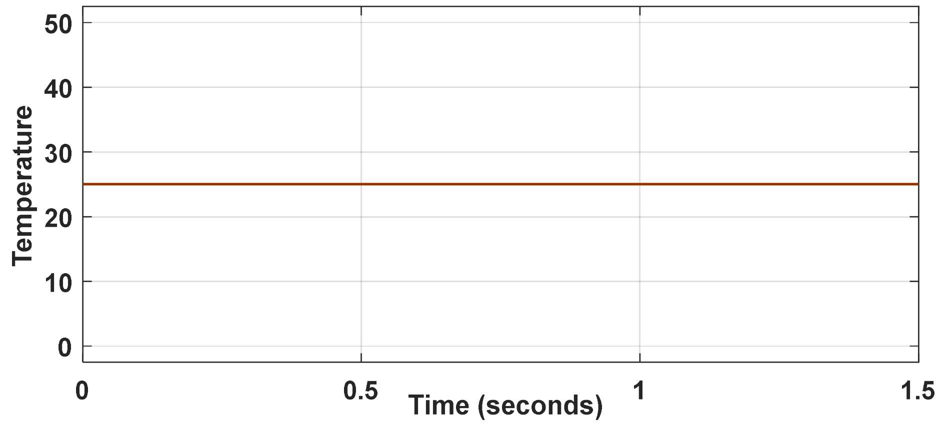

Figure 4.7: The graph of temperature applied to the PV array

1. **P&O algorithm:**

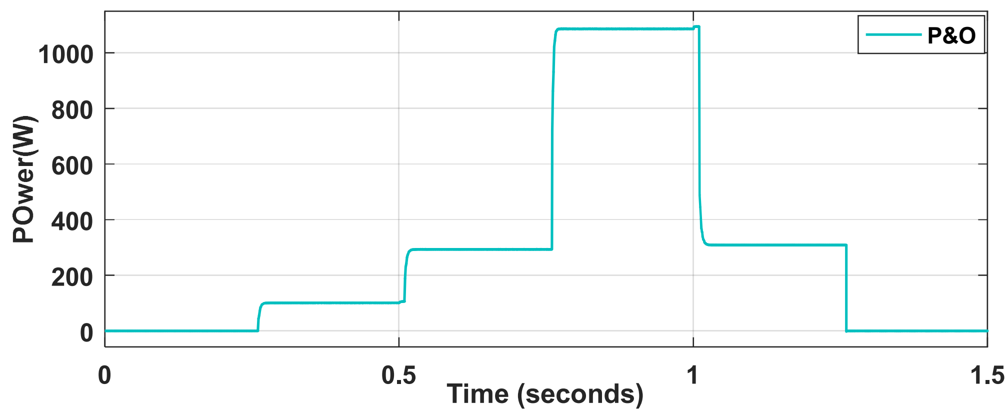

Figure 4.8: Power vs Time graph of PV array for P&O algorithm.

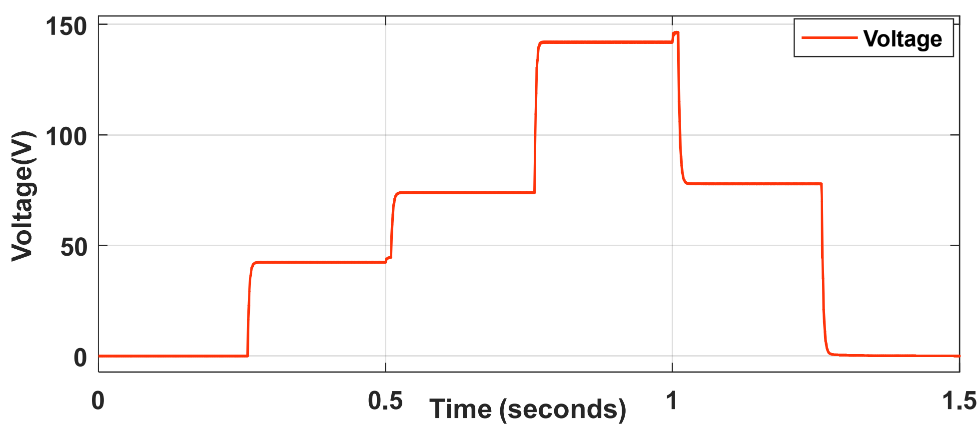

Figure 4.9: Voltage vs Time graph of PV array for P&O algorithm

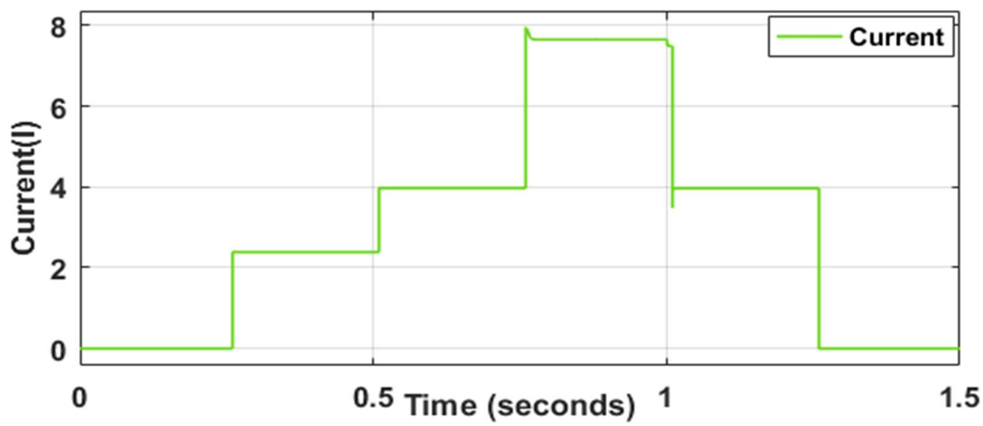

Figure 4.10: Current vs Time graph of PV array for P&O algorithm

From figure4.8 it is observed that the maximum power obtained at 300 W/m^2, 500 W/m^2 and 1000 W/m^2 irradiation are 101W, 308W and 1086W respectively when P&O algorithm is applied to the standalone PV system designed.

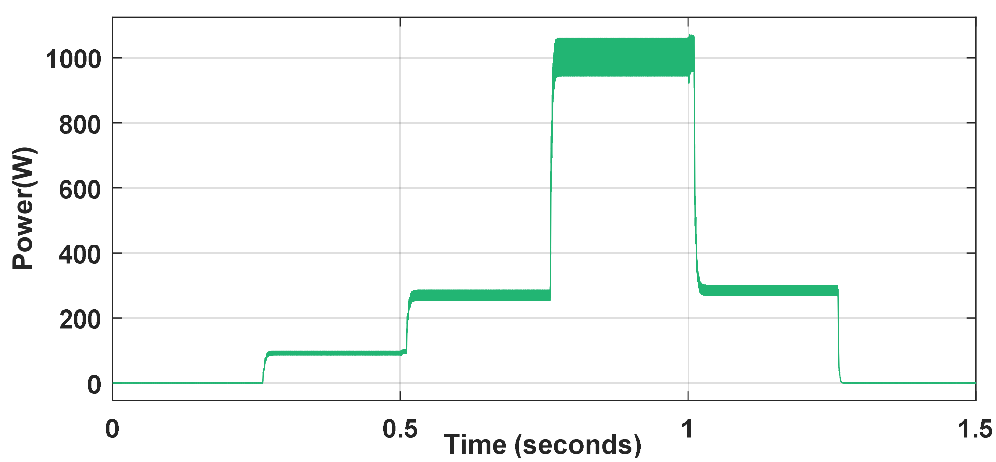

Figure 4.11: Output power of boost converter for P&O algorithm

Table 4.1: Result of P&O algorithm

Irradiation	P_{pv}(W)	P_{out} (W)	I_{pv}(A)	I_{out}(A)	V_{pv} (V)	V_{out}(V)
300W/m^2	101	96.34	2.3	1.6	42.3	58.2
500 W/m^2	308	284.3	3.96	5.42	77.8	101.3
1000 W/m^2	1086	1059	7.6	2.89	141.7	191.5

2. Incremental conductance algorithm:

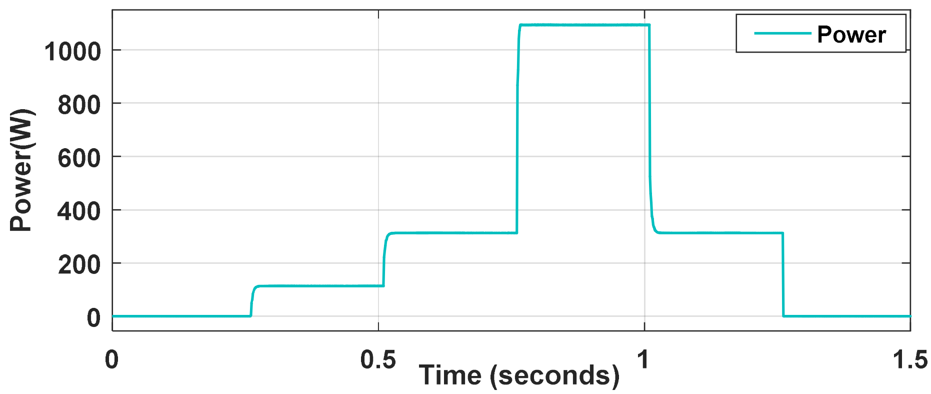

Figure 4.12: Power vs Time graph of PV array for InC algorithm

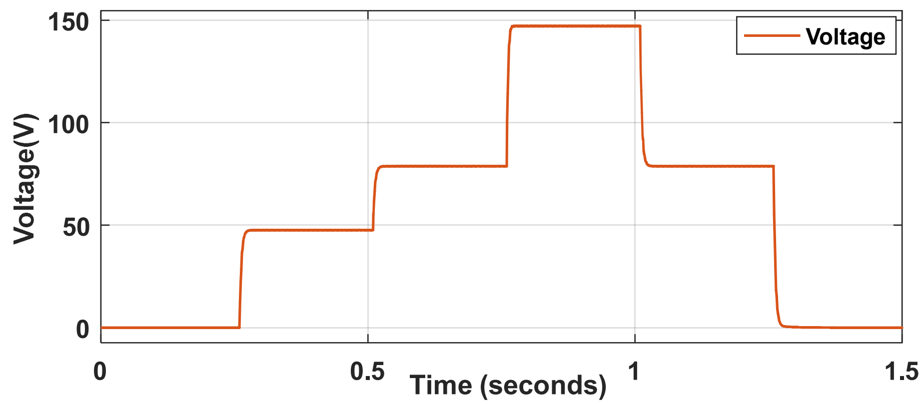

Figure 4.13: Voltage vs Time graph of PV array for InC algorithm

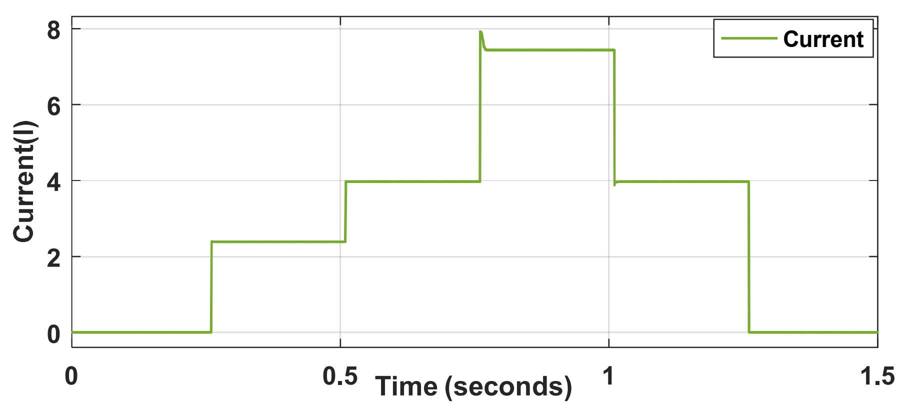

Figure 4.14: Current vs Time graph of PV array for InC algorithm

From figure 4.12 it is observed that the maximum power obtained at 300 W/m^2, 500 W/m^2 and 1000 W/m^2 irradiation are 113.5W, 312.5W and 1094W respectively when InC algorithm is applied to the standalone PV system designed.

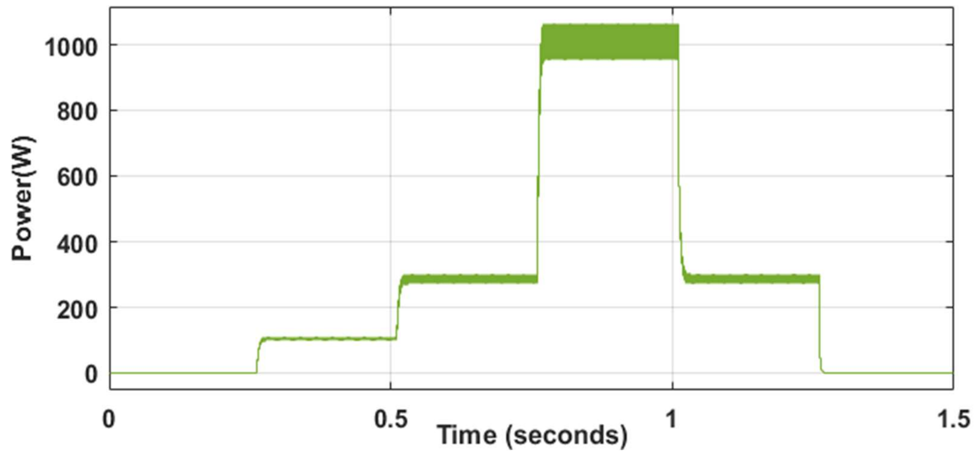

Figure 4.15: Output power of boost converter for InC algorithm

Table 4.2: Result of InC algorithm

Irradiation	P_{pv}**(W)**	P_{out}**(W)**	I_{pv}**(A)**	I_{out}**(A)**	V_{pv}**(V)**	V_{out}**(V)**
300 W/m^2	113.5	109	2.38	1.5	47.5	69.6
500 W/m^2	312.5	303	3.96	2.6	78.7	115.8
1000 W/m^2	1094	1055	7.43	4.9	147.2	216.4

3. Fuzzy Logic Controller

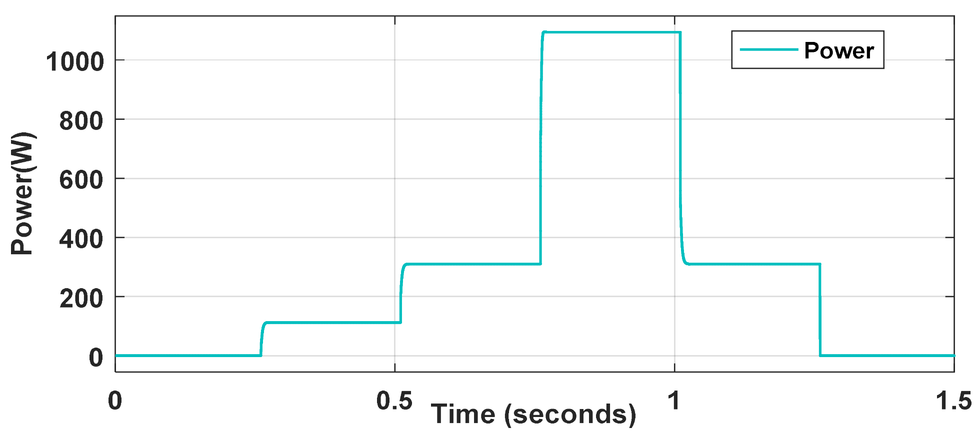

Figure 4.16: Power vs Time graph of PV array for fuzzy algorithm

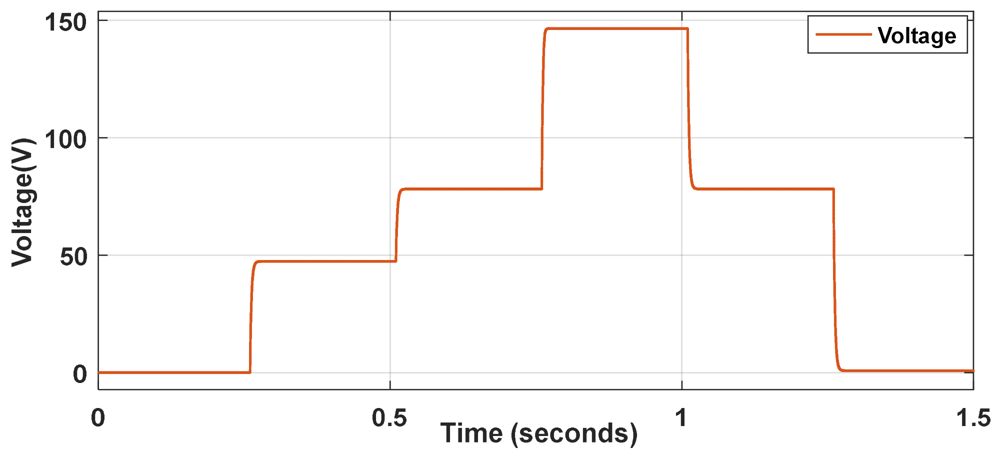

Figure 4.17: Voltage vs Time graph of PV array for fuzzy algorithm

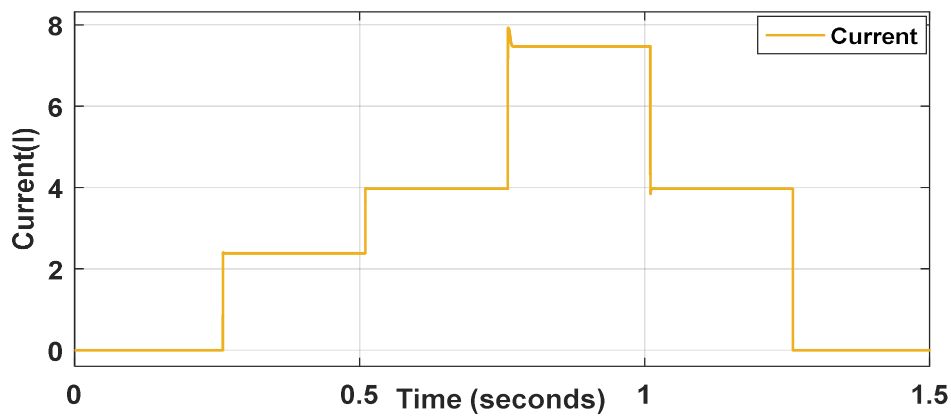

Figure 4.18: Current vs Time graph of PV array for fuzzy algorithm

From figure 4.16 it is observed that the maximum power obtained at 300 W/m^2, 500 W/m^2 and 1000 W/m^2 irradiation are 113.5W, 312.5W and 1094 W respectively when fuzzy logic controller MPPT is applied to the standalone PV system designed.

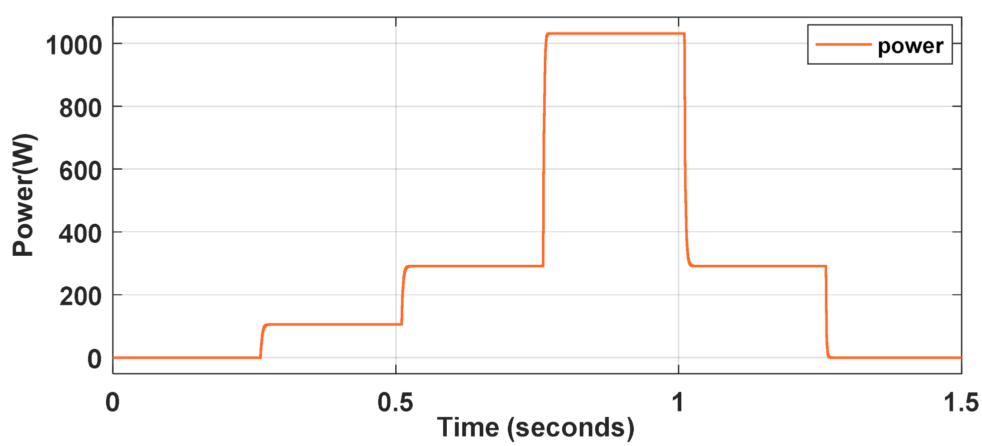

Figure 4.19: Output power of boost converter for fuzzy algorithm

4. Comparison of MPPT algorithms.
   1) InC and P&O

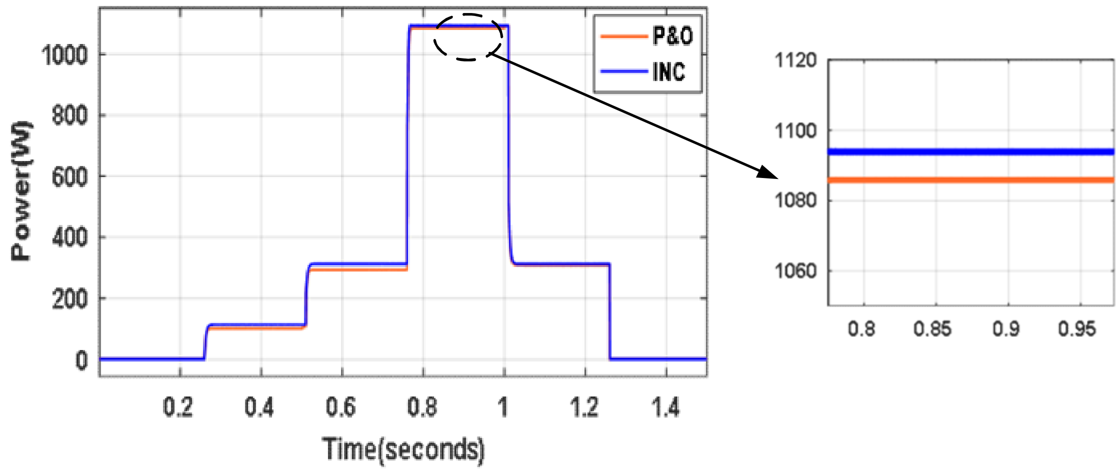

Figure 4.20: Output power vs time graph of PV array for P&O and InC methods

From figure 4.20 it is observed that InC is able to track the MPP more accurately and fluctuations around the MPP is less in InC as compared to P&O.

   2) InC and Fuzzy.

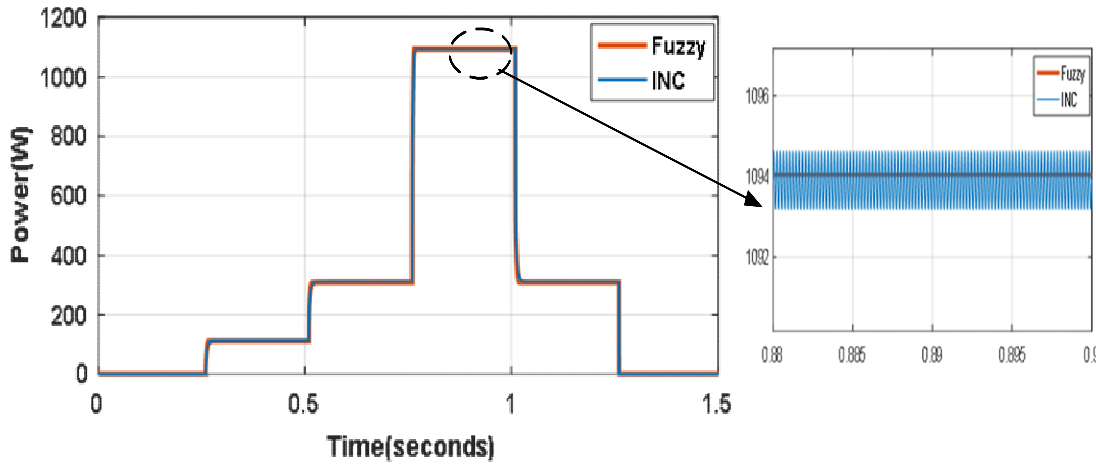

Figure 4.21: Output power vs time graph of PV array for Fuzzy and InC method

Comparative results of fuzzy controller and InC output power waveform is shown by figure 4.21. It is observed that fuzzy logic controller gives more accurate and less fluctuations as compared to InC algorithm.

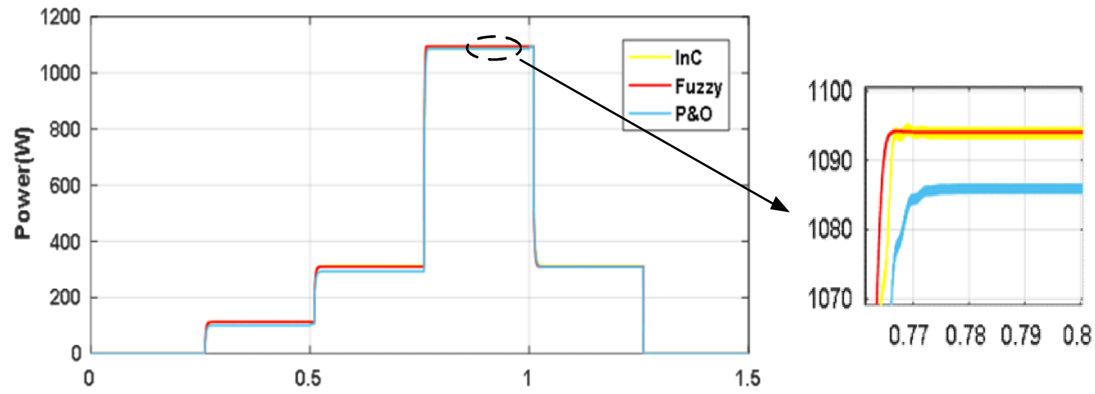

Figure 4.22: Output power vs time graph of PV array for P&O, Fuzzy and InC method

Table 4.3: Comparison of P&O, InC and fuzzy algorithm.

Irradiation value(W/m²)	**Output PV power(W) of P&O.**	**Output PV power(W) of InC.**	**Output PV power(W) of Fuzzy.**
300	101	113.5	113.5
500	308	312.5	312.5
1000	1086	1093	1094

Comparative results of output power waveform of fuzzy controller, P&O and InC is shown in figure 4.22. It is observed that fuzzy logic controller gives more accurate and less fluctuations as compared to InC and P&O algorithm.

4.8 CONCLUSION

In this chapter different MPPT techniques - both conventional and intelligent control strategy for the PV system are discussed. In conventional technique- P&O and InC and for intelligent control- fuzzy logic controller is implemented. MATLAB/Simulink software is used for simulation of maximum power point tracking techniques. The fuzzy logic-based controller can track the MPP, faster as compared to conventional InC and P&O MPPT technique. The voltage fluctuation after MPP has been reached is reduced by use of fuzzy logic controller based MPPT. The simulation results show that the output power of the fuzzy logic controller is maintaining a stable maximum power point under varying irradiation conditions.

CHAPTER-5

PARTIAL SHADING CONDITION IN PV SYSTEMS

5.1 GENERAL

A PV array consists of a number PV modules connected together for obtaining high power output. The output of the PV array depends on the environmental conditions like temperature and irradiance. There's one more problem related to PV systems that is partial shading which means some parts of the PV array do not receive uniform irradiance due to shadow of trees, building, poles, etc. To track the global maximum power point MPPT algorithms are used. Along with advanced MPPT tracker, different configurations of PV array viz. series parallel (SP) and total cross tied (TCT) are used. This chapter contains the following topics:

1) Partial shading condition.

2) Configuration of PV array.

3) MPPT algorithm for partial shading.

4) Simulation and results.

5.2 PARTIAL SHADING CONDITION

Due to various factors such as passing clouds, bird droppings, dust deposition, shade of the trees or adjacent buildings, etc shading on PV array can occur. The shading of PV arrays can be classified in two ways 1) Uniform shading and 2) non-uniform shading or partial shading. In non-uniform shading the amount of irradiation received by the modules are different. Due to partial shading the output power of PV system is reduced and multiple peaks are found in the P-V characteristics of the PV array as shown in figure5.1.

There are multiple local maximum power points and one global maximum power point. In uniform shading the PV modules receive equal amount of irradiance and there is only one global maximum power point in output P-V characteristics of PV array. Under partial shading conditions, the current is less in shaded module then the current in un-shaded module and thus the PV output current is decided by the unshaded module current and hence the power output of the array decreases.

As an outcome of partial shading of PV arrays, the current that is generated by the modules connected in series has been restricted by the shading on the PV modules. Which decreases the general power generated by PV system significantly and can also be the causes of a hotspot effect result in damaging some of PV cells as well as the malfunctioning of the solar PV system. The problem of partial shading in PV arrays the maintenance cost is increased of solar PV system, and thus the loss in power generated will make the solar power generation more expensive than it was planned originally. The voltage at the terminal of PV array which corresponds to the peak power positions of the entire PV array is one of the important data for tracking the maximum power by using the MPPT algorithm under partial shading conditions.

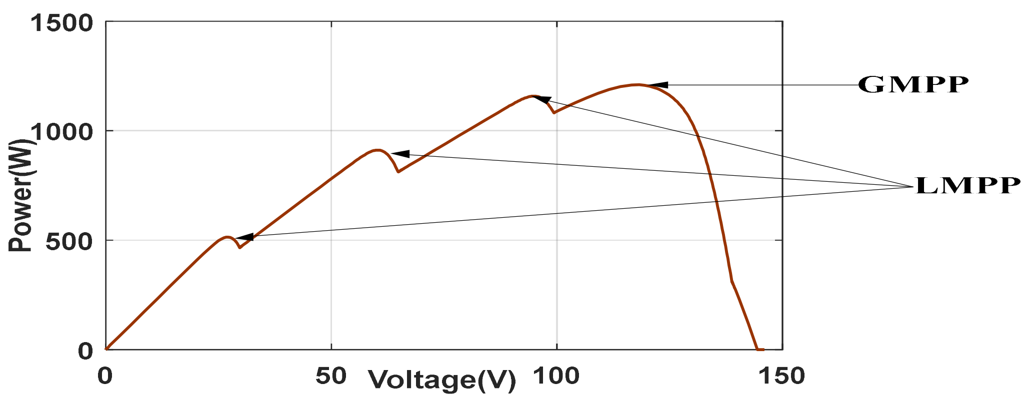

Figure 5.1: P-V characteristics of partially shaded PV array

5.3 CONFIGURATIONS OF PV ARRAY

Partial shading has a negative effect on PV system that is the power output of PV array is reduced. Reconfigurations are widely used to enhance the efficiency of the system. There are different configurations of PV arrays that are series, parallel, series-parallel, total cross tied, bridge linked and honey comb. For different shading patterns the output power is different for the different configurations.

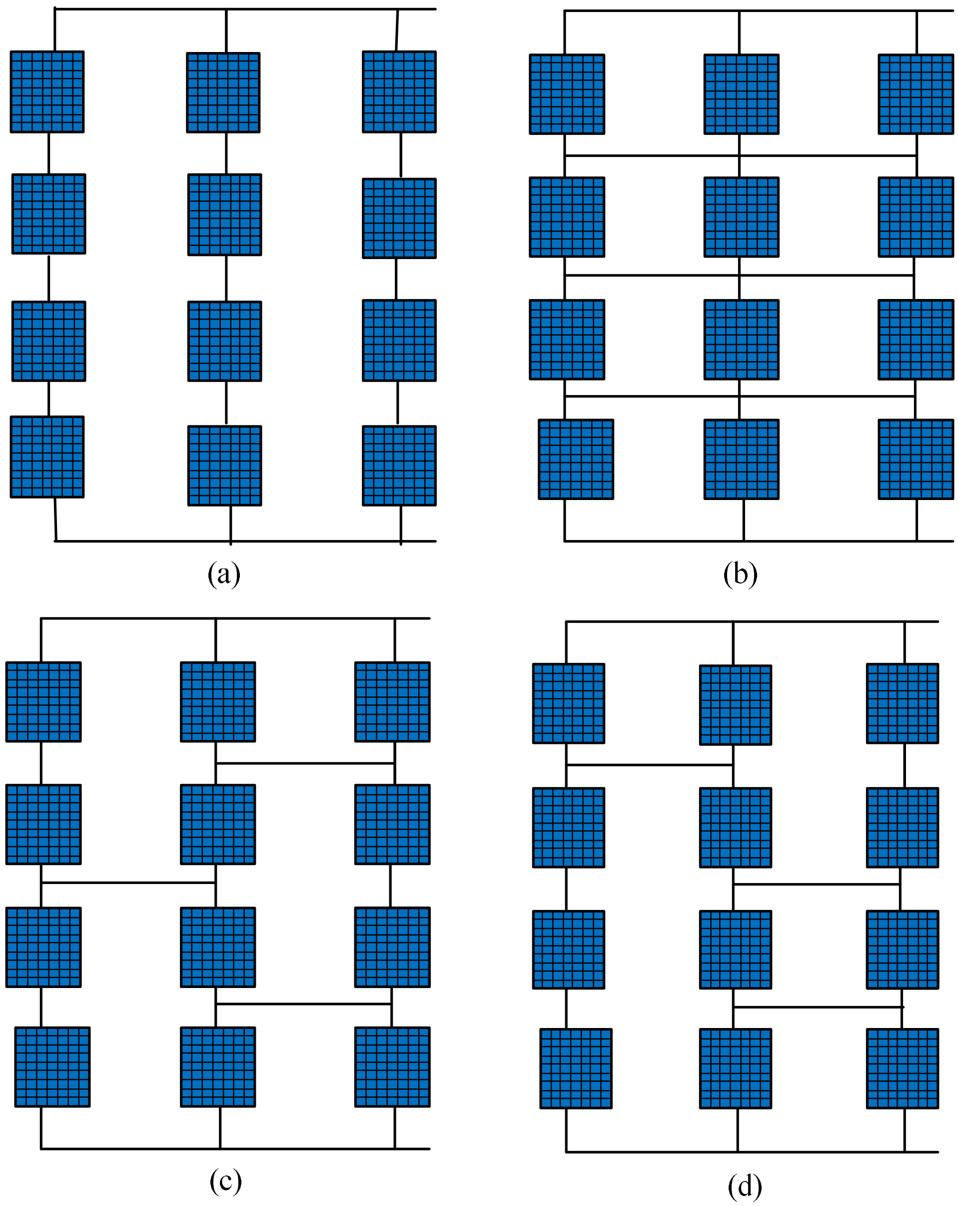

Figure 5.2: Various configurations of PV array (a)Series-parallel, (b) Total cross tied, (c)Bridge linked and (d) Honey comb

5.3.1 Different shading patterns

During partial shading conditions the output power is low and the performance of PV array is highly affected. So, to access the performance of PV array configurations, different shading conditions are applied. The shading patterns are shown in the figure 5.3.

In this work a PV array configuration of 4×3 array with seven different shading conditions is modelled. 1000W/m^2, 800W/m^2, 600W/m^2, 500W/m^2, 300W/m^2 and 200W/m^2 are the values of irradiation used for testing. The shading cases are described below.

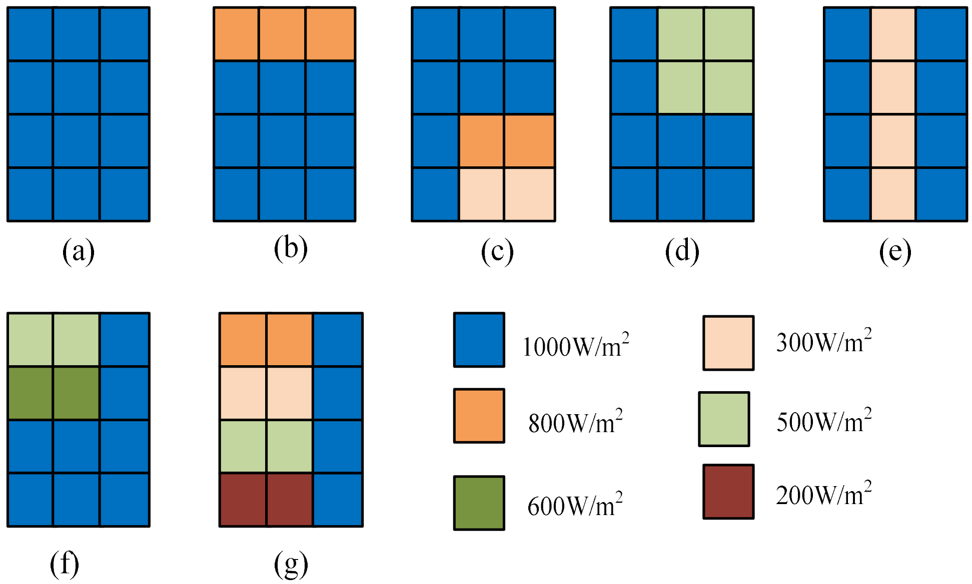

Figure 5.3: Different shading conditions of PV array system (a) Unshaded, (b) case1, (c) case2, (d)case3 (e)case4, (f)case5 and (g)case6

Unshaded: Unshaded case is basically the uniform radiation case. In this case all the PV modules in the PV array receive equal irradiation, here its 1000W/m^2 as shown in figure5.3(a).

Case1: In this case one row of the PV array is shaded and the three PV modules in that row receives an irradiation of 800W/m^2 and other two rows receive irradiation of 1000W/m^2 as shown in figure5.3(b).

Case2: In this case lower corner of the PV array is shaded, four modules at the corner are shaded two of them receive 300 W/m^2 and other two receive 800 W/m^2 amount of irradiation as shown in figure5.3(c).

Case3: In this case upper corner of the PV array is shaded and the four modules are receiving an irradiation of 500 W/m^2 as shown in the figure5.3(d).

Case4: In this case one column of the PV array is shaded, here middle column receives an irradiation of 300 W/m^2 as shown in figure5.3(e).

Case5: In case 5 left upper side corner of the PV array is shaded, four arrays are shaded in which two receive 500 W/m^2 and other two 600W/m^2 as shown in the figure5.3(f).

Case6: In this case out of three, two columns are shaded. The PV modules in these two columns each row receives 200W/m^2, 500W/m^2, 300W/m^2 and 800W/m^2 respectively as shown in figure5.3(g).

Series-parallel configurations:

In series -parallel (SP) configuration firstly the PV modules are connected in series to form a string to get desired output voltage and then these strings are connected in parallel to get desired output current. Due to its simple connection and economical operation SP configurations are widely used.

The figure5.2(a) shows 4×3 SP array configuration in which 4 modules are connected in series and then three such strings are connected in parallel. For all the PSCs cases the output performance characteristics of the series parallel configuration are presented in figure5.4 and figure5.5. The mismatch loss is high in SP configuration due to more series connection in the string.

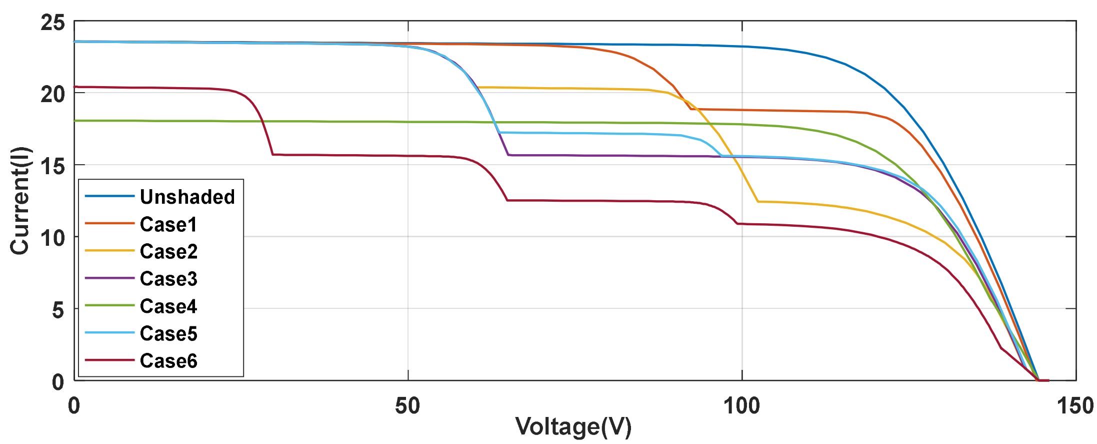

Figure 5.4: Current-voltage characteristics of series parallel configuration in different shading condition

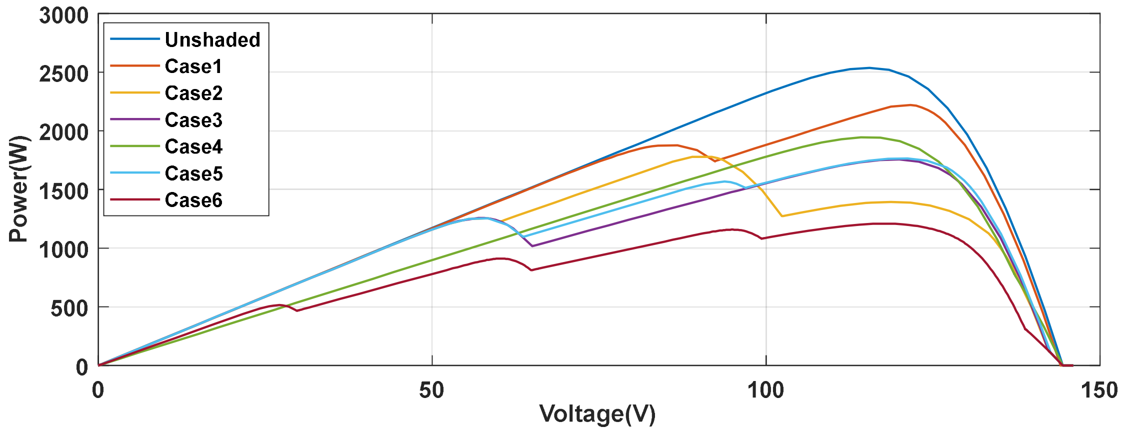

Figure 5.5: Power-voltage characteristics of series parallel configuration during different shading conditions

Total cross tied configuration:

The drawbacks of SP configuration can be overcome by TCT configuration. In total cross tied configuration cross ties are connected across each row of the junctions. All modules in a column are connected in series and each module in a row has modules connected in parallel. The number of electrical connections is more in TCT configuration hence more wiring cost and complex operation.

Figure5.2(b) shows the model of TCT configuration for a 4×3 PV array. For all the PSCs cases the output performance characteristics of the total cross tied configuration are presented in figure5.6 and figure5.7.

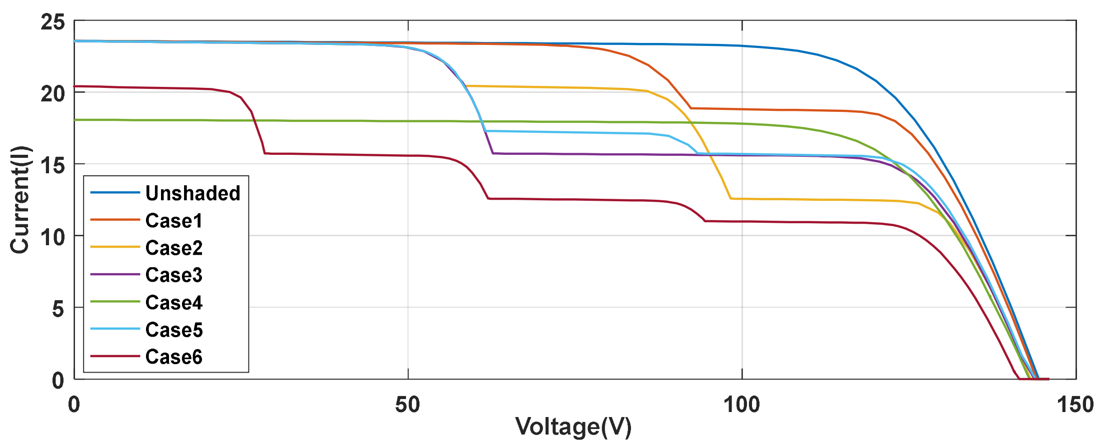

Figure 5.6: Current-voltage graph of TCT configuration in different shading

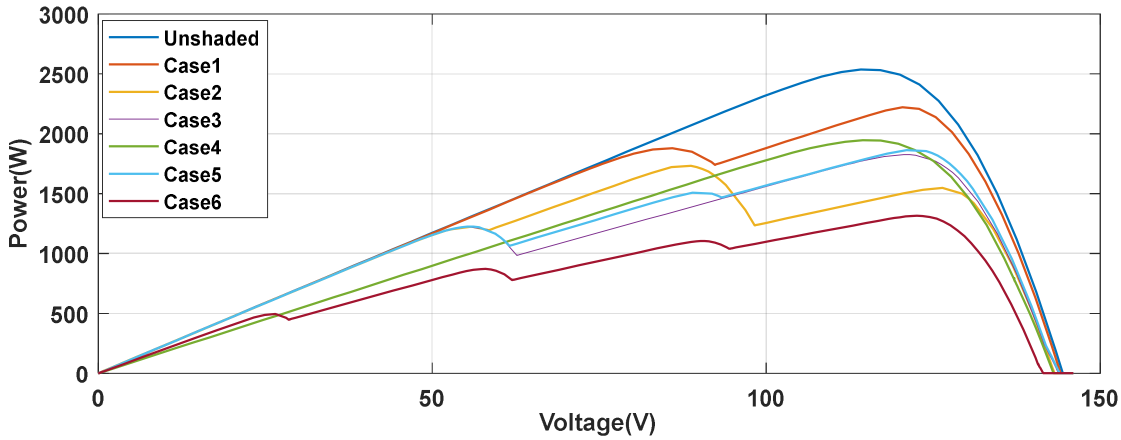

Figure 5.7: Power-voltage graph of TCT configuration in different shading

Bridge linked configuration:

In bridge linked configuration the modules are connected in bridge rectifier structure. In this configuration four modules are connected as a bridge rectifier structure that consists of a parallel combination of two modules connected in series. The number of electrical connections is more than series parallel and less than the TCT connection.

The figure5.2(c) shows the model of BL configuration for 4×3 PV array. For all the PSCs cases the output performance characteristics of the bridge linked configuration are presented in figure5.8 and figure5.9.

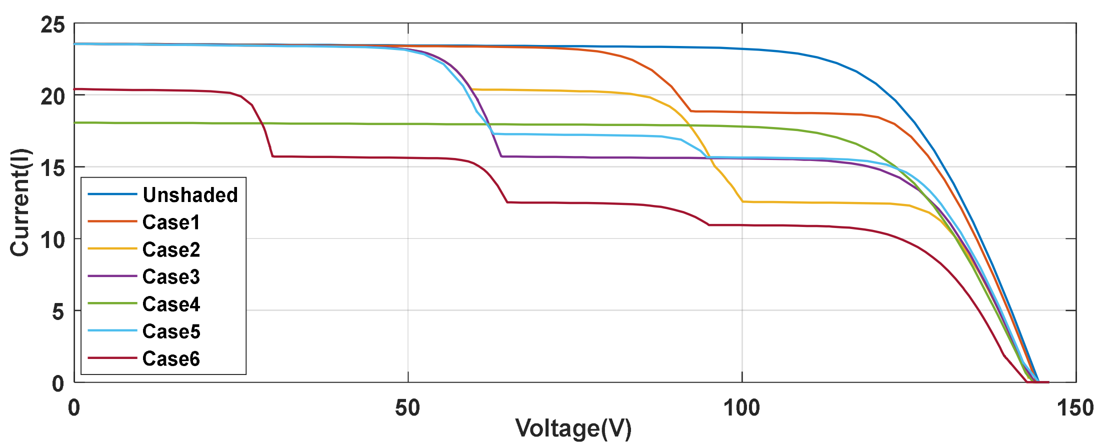

Figure 5.8: Current-voltage graph of bridge-linked configuration in different shading

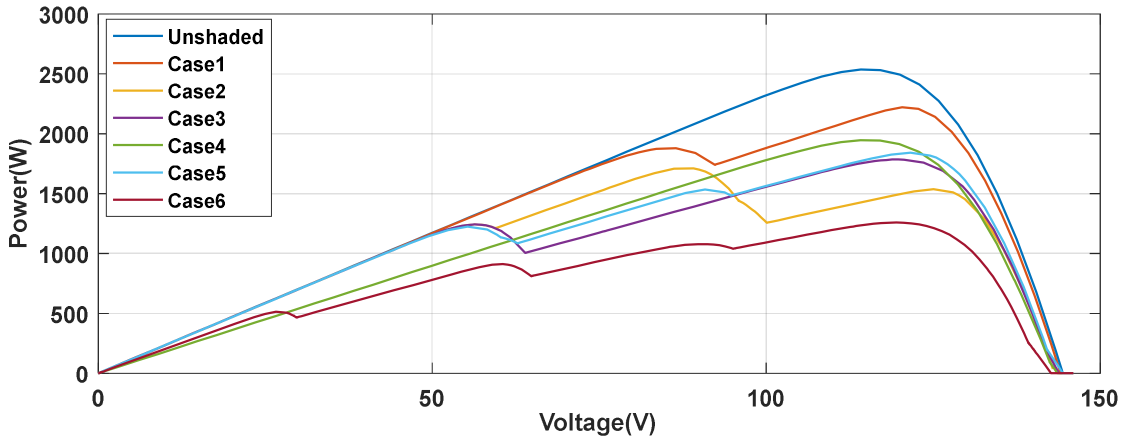

Figure 5.9: Power-voltage graph of Bridge linked configuration in different shading

Honey comb configuration:

In honey comb (HC) the connection is made in such way that it gives a hexagonal shape. The number of series connected modules in honey comb configuration are more than bridge linked and less than series in parallel configuration.

The figure5.2(d) shows the model of honey comb configuration for 4×3 PV array. For all the PSCs cases the output performance characteristics of the bridge linked configuration are presented in figure5.10 and figure5.11.

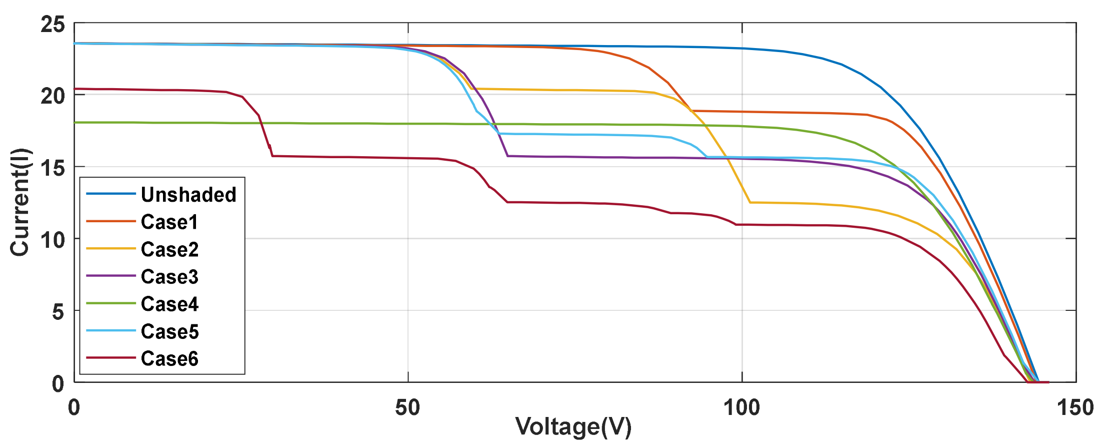

Figure 5.10: Current-voltage characteristics of Honey comb configuration in different shading conditions

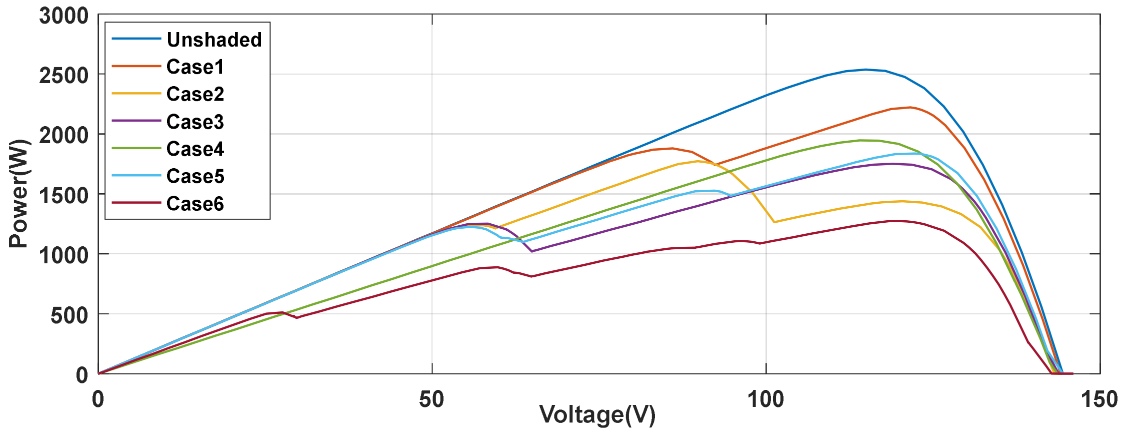

Figure 5.11: Power-voltage characteristics of Honey comb configuration in different shading conditions

The global maximum power, voltage and current at maximum power are tabulated in table5.1 for all the configurations discussed above with different shading cases

TABLE 5.1. Global maximum power, voltage and current at maximum power for all the shading cases of different configurations.

Shading cases	**configuration**	**P_{mpp}(W)**	**V_{mpp}(V)**	**I_{mpp}(A)**
Case1	SP	2221	120.3	18.51
	TCT	2229	120.5	18.5
	HC	2227	122.4	18.19
	BL	2221	121.9	18.3
Case2	SP	1779	90.52	19.72
	TCT	1734	87.6	19.79
	HC	1771	89.74	19.71
	BL	1718	86.89	19.77
Case3	SP	1758	118.7	14.81
	TCT	1828	122.3	14.94

	HC	1751	120	14.5
	BL	1788	120.6	14.83
Case4	SP	1946	115.9	16.83
	TCT	1945	113.9	17.8
	HC	1945	114	17.06
	BL	1946	114.1	17.05
Case5	SP	1767	121.1	14.6
	TCT	1866	122.6	15.22
	HC	1838	122.2	15.04
	BL	1842	121.6	15.148
Case6	SP	1209	116.4	10.38
	TCT	1315	122.6	10.725
	HC	1274	119.3	10.678
	BL	1259	119.5	10.535

5.4 MPPT ALGORIYHM FOR PARTIAL SHADING

During partial shading global and local MPPT's are present so to track the maximum power point that is the global MPPT different algorithms were implemented.

5.4.1 PERTURB AND OBSERVE ALGORITHM

Perturb and observe algorithm is one of the conventional algorithms implemented here for system under partial shading with some improvement. P&O technique has been used for tracking the MPP with the regulation of the duty cycle or the output voltage. P&O technique is most frequently used technique due to its simplicity and ease of implementation it does not require any previous information about the PV system, the inputs to this technique is the output voltage and current of PV array.

The original P&O control procedure approves a general fixed step, also, in case the step is extensive, it can result in oscillation around MPPT [15]; otherwise, a small step can cause slow tracking speed of the MPPT control. For solving the flaw between the speed of tracking of the P&O method and accuracy of tracking of stable state, the following work gives P&O algorithm with an adaptive variable step. Regulation of the MPPT cycle is every time done by the duty cycle, so the disturbance constant selected is duty cycle for this algorithm.

The perturbation expression for change in duty cycle can be given by equation (5.1) as

$$\Delta D = \alpha \frac{P - P_{Old}}{D - D_{Old}} \tag{1.1}$$

where α is an empirical value, called the adaptive factor, and the value of parameter α can be calculated by the equation given below:

$$\alpha \approx \frac{D_{STEP}}{\left|\frac{dP}{dD}\right|_{Max}} \tag{5.2}$$

where $\left|\frac{dP}{dD}\right|_{Max}$ gives the maximum value in the dP/dD-D curve, and D_{STEP} is an initial step length. Actually, equation (5.2) is used to only calculated the estimate value of the parameter α, as well as the adjustments of the final value needs is done by experiments.

5.4.2 PSO ALGORITHM

In 1995, Eberhart and Kennedy developed an algorithm named particle swarm optimisation which is based on social behaviour of social behaviour of bird flocking and fish schooling. It is a global optimization technique which deals with the problem on which a point in an n-dimensional space represents a best solution. Several cooperative agents are used in this algorithm and information is exchanged between each agent that was obtained in their respective search process. In this algorithm each agent is referred to as particle has to follow two rules that are to move towards the best conditions found by the agent itself and to follow the best performing particle. By following these rules, the particle finally evolves to an value close to optimal position.

The equation for standard PSO algorithm is given below:

$v_i^{k+1} = wv_i^k + c_i r_i(p_i^k - x_i^k) + c_2 r_2(p_g^k - x_i^k)$
(5.3)

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{5.4}$$

Where, p_i is to store the best particle position, p_g is to store the global best value, r_1, r_2 are random variables within [0,1] and c_1, c_2 are cognitive and social coefficient and x_i is position of particle.

The flow chart of the PSO algorithm is shown in figure5.12. For realising the MPPT of solar PV system in partial shading condition the above mentioned PSO algorithm is used. In partial shading condition the P-V plot of the system will have more than one peak point and among these points one is GMPP and to track that PSO algorithm is used. The following steps are involved in the calculation as in flow chart given in figure5.12.

Step 1: (Particle selection) In this step some particles are initialized in the search space randomly. Here the duty cycle is defined as the particle position and generated power is chosen as the function for fitness value evaluation. For more accurate results the number of particles should be more for tracking accurately the MPP even for the partial shading conditions. Due to a greater number of particles, it takes longer time for computation. The balance between the speed and accuracy should be maintained. So, the number of particles is chosen as the number of the cells connected in series.

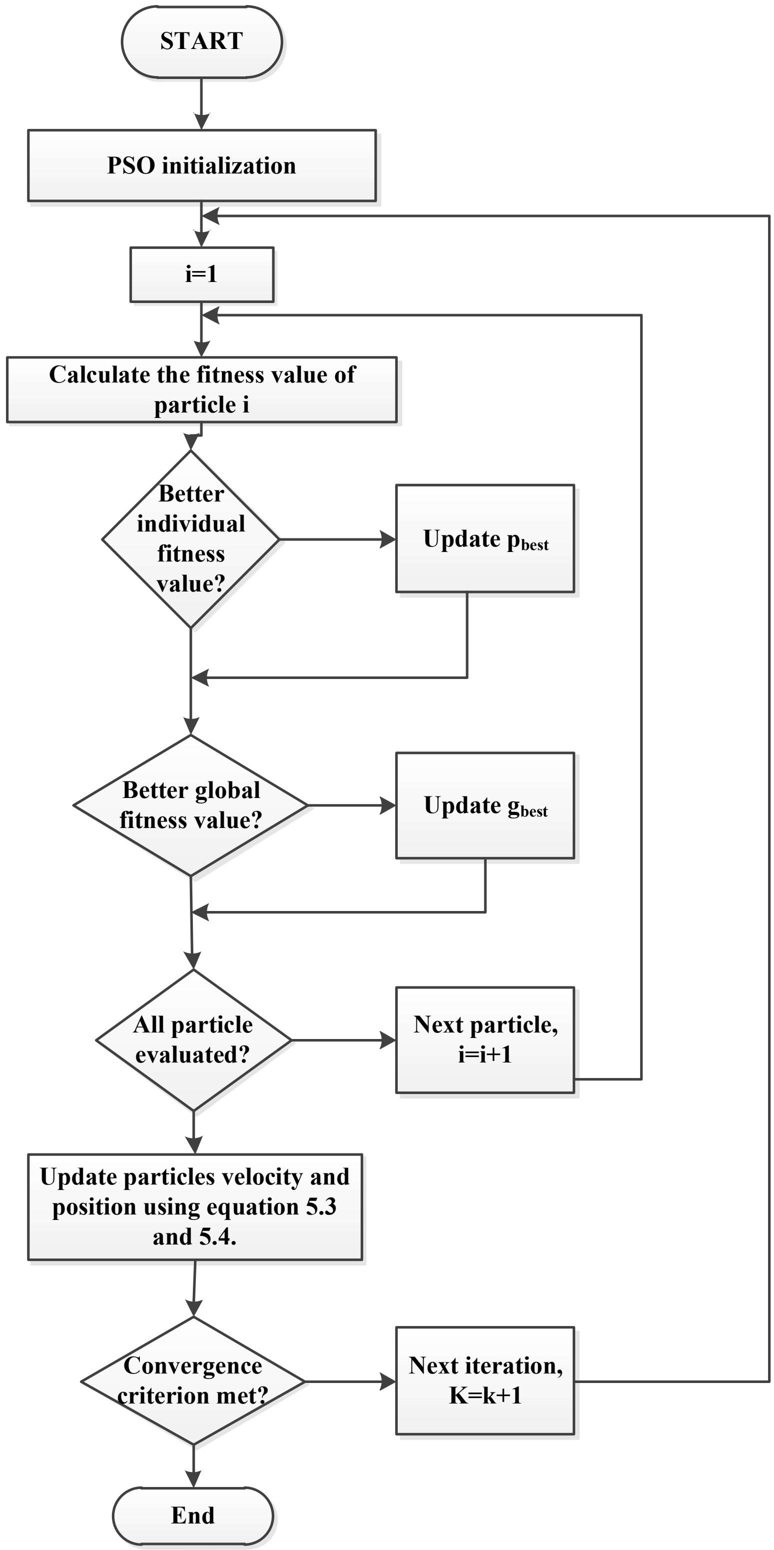

Figure 5.12: Flow chart of PSO algorithm

Step 2: (PSO initialization) In this phase the particles are placed in their position or placed randomly in space. If the information about the location of GMPP is known than the particle can be initialize around it.

Step 3: (Fitness evaluation) The main aim of the PSO based MPPT algorithm is to obtain the maximum power generated. PV current and voltage are measured to compute PV output power as the fitness value for evaluation.

Step 4: (Update individual and global best data) By comparing the new and previous fitness values the position and the global and individual fitness values are updated.

Step 5: (Update velocity and position of each particle) After evaluation of all the particles the velocity and position are updated using equation5.3 and equation5.4 respectively.

Step 6: (Convergence determination) Two criteria for convergence are used in this step. If the maximum number of iterations is reached or the velocity of particle becomes lower than the set value, then computation will be stopped in proposed algorithm and GMPP is obtained.

Step 7: (Re-initialization) In this the fitness value that is GMPP changes with environmental conditions. So, for this particle are reinitialized and search new GMPP. To detect the environmental conditions and reinitialization of particle in PSO algorithm equation5.5 is used.

$$\frac{|P_{PV,new}-P_{PV,last}|}{P_{PV,last}} \geq \Delta P \tag{5.5}$$

5.4.3 HYBRID ALGORITHM

P&O MPPT based system is possibly achieving only the first local maxima, however it is unable to find the global maximum power point. So, it was the issue with P&O MPPT algorithm-based system. But the issue we found with PSO-MPPT based system is the PSO algorithm is based on random population to get the global solution, if the no. of population is very high then the process of finding the global point is taking much more time or vice-versa. So, in order to overcome all these problems, we simulated the combination of the PO-PSO algorithm-based hybrid MPPT technique. Hence, the system and find the global maximum point quickly. In this the particle with best performance is considered and others are not used which means now the whole swarm is reduced to a single particle.

Here the acceleration coefficient c_1 in equation5.3 is taken zero and to reach the GMPP the equation5.6 is applied.

$$v_i^{k+1} = v_i^k + c_2 r_2 \left(G_{best} - x_i^k \right) + v_{P\&O} \tag{5.6}$$

Where G_{best} is the global best value stored, v_i^k and v_i^{k+1} are the particle velocity for instant and next instant respectively, $v_{P\&O}$ is the voltage provided by P&O algorithm and position of particle is given by x_i^k.

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{5.7}$$

Equation5.8 is the condition to be fulfilled for algorithm to reset and to detect the change in partial shading condition.

$$\frac{\left| P_i^k - P_i^{k-1} \right|}{P_i^{k-1}} > \Delta P \tag{5.8}$$

Where P_i^k is the actual value of output power of PV system, P_i^{k-1} is the previous value of output power of PV system and ΔP is the maximum variation allowed in power output.

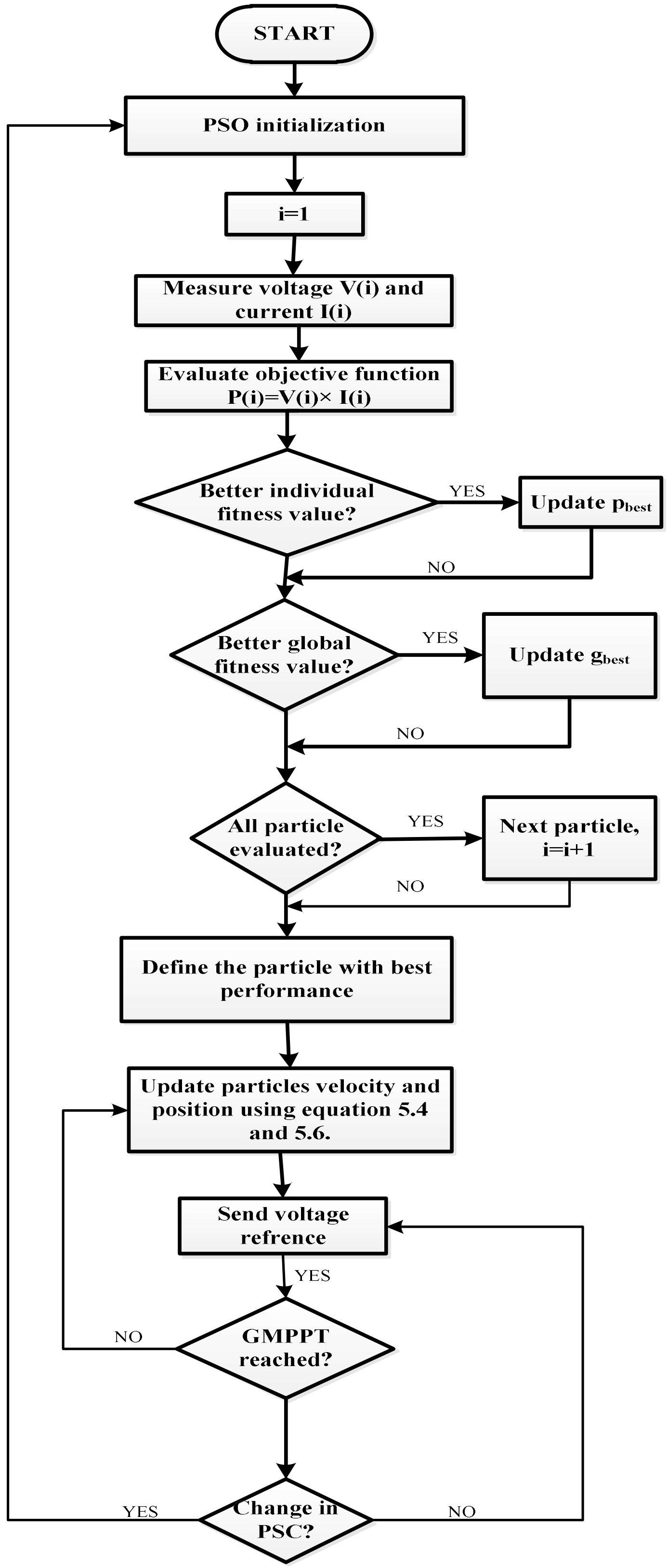

Figure5.13: Flow chart of PSO-P&O hybrid algorithm

5.5 SIMULATION AND RESULT OF P&O, PSO AND HYBRID ALGORITHM.

Figure5.14 shows the system designed in MATLAB/Simulink comprising of PV array, boost converter with resistive load. The switching of boost converter is done by MPPT algorithm.

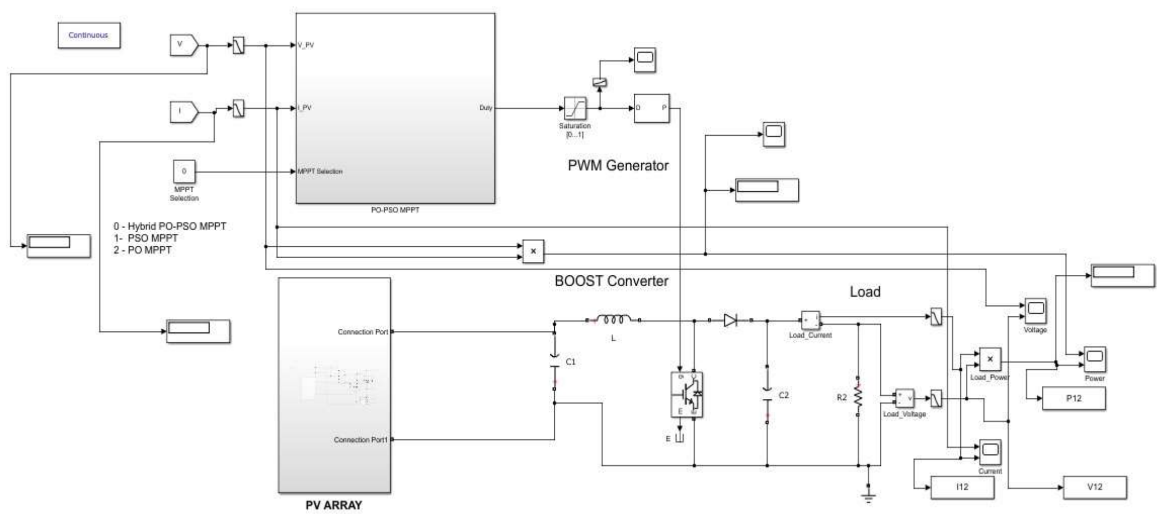

Figure 5.14: System in MATLAB/Simulink used

Unshaded:

Unshaded case is basically the uniform radiation case. In this case all the PV modules in the PV array receive equal irradiation, here its $1000W/m^2$ as shown in figure5.3(a). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

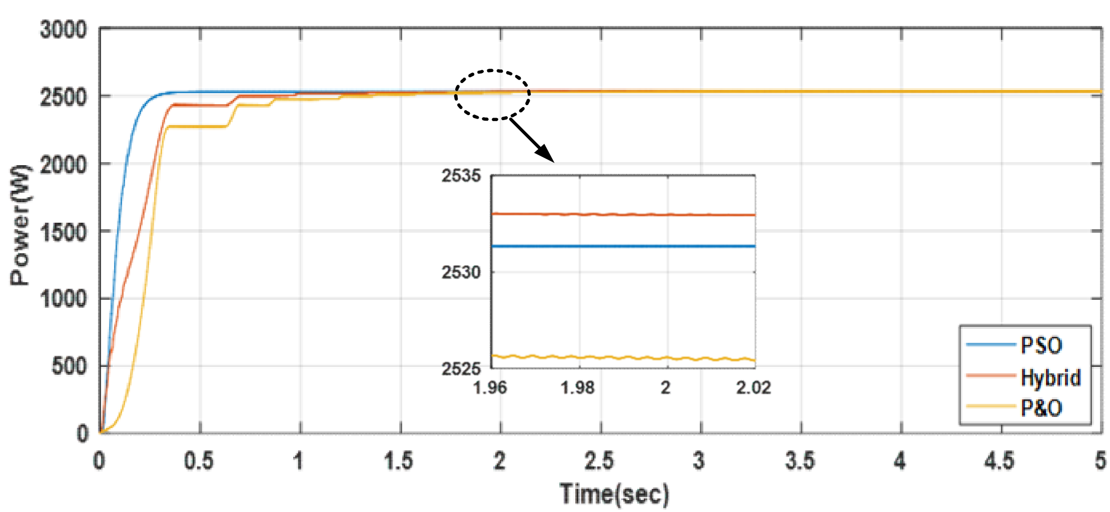

Figure 5.15: P&O, PSO and PSO-P&O hybrid algorithm for uniform shading for series-parallel configuration

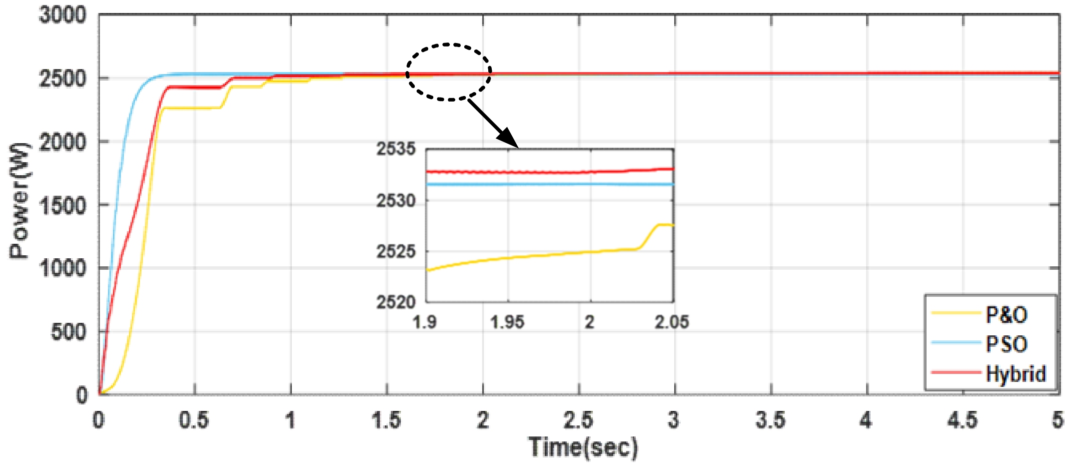

Figure 5.16: P&O, PSO and PSO-P&O hybrid algorithm for uniform shading for TCT configuration

Figure5.15 and figure5.16 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case1:

In this case one row of the PV array is shaded and the three PV modules in that row receives an irradiation of 800W/m^2 and other two rows receive irradiation of 1000W/m^2 as shown in figure5.3(b). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

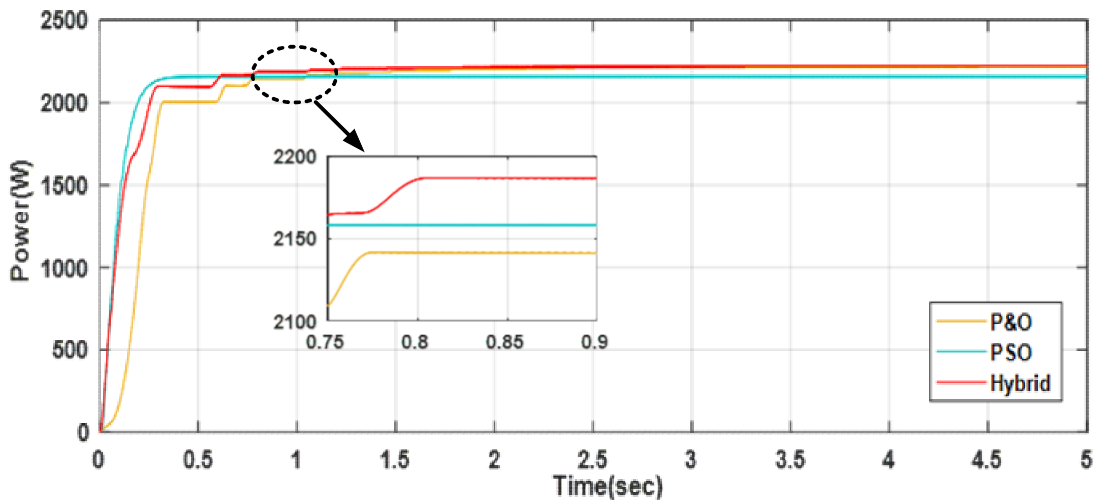

Figure 5.17: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case1 for series-parallel configuration

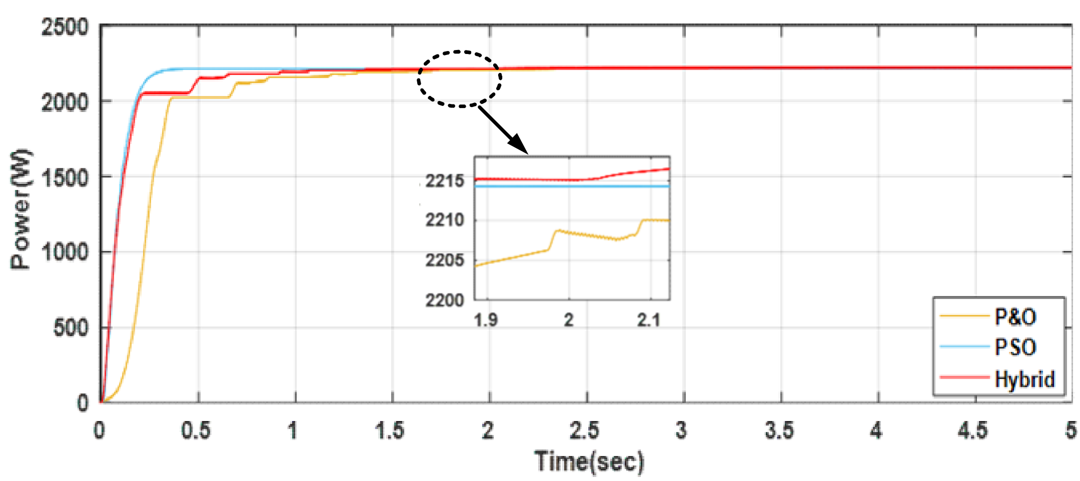

Figure5.18: Comparative analysis of P&O, PSO and hybrid algorithm for case1 in TCT configuration

Figure5.17 and figure5.18 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case2:

In this case lower corner of the PV array is shaded, four modules at the corner are shaded two of them receive 300 W/m^2 and other two receive 800 W/m^2 amount of irradiation as shown in figure5.3(c). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

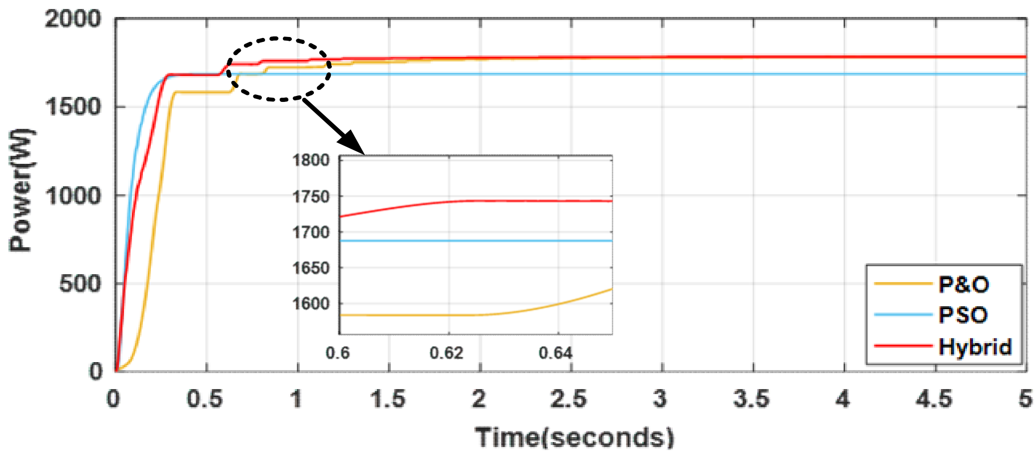

Figure5.19 P&O, PSO and PSO-P&O hybrid algorithm for partial shading case2 for series-parallel configuration

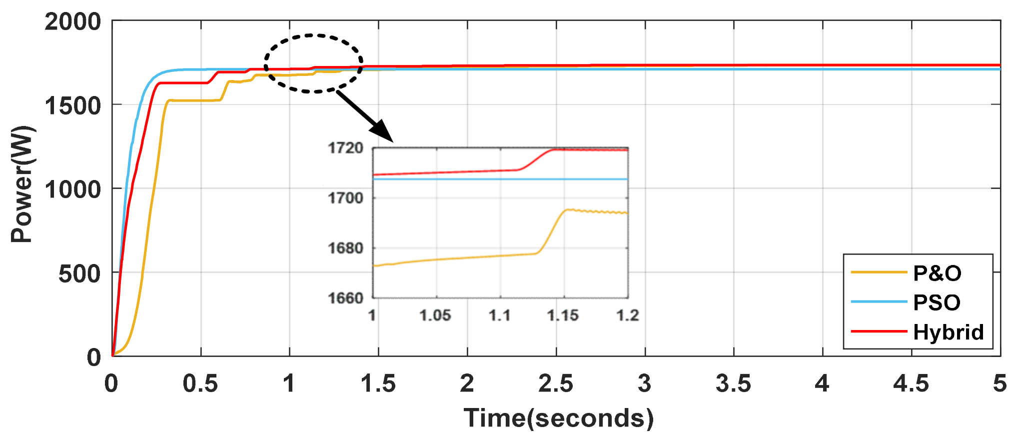

Figure 5.20: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case2 for TCT configuration

Figure5.19 and figure5.20 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case3:

In this case upper corner of the PV array is shaded and the four modules are receiving an irradiation of 500 W/m^2 as shown in the figure5.3(d). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

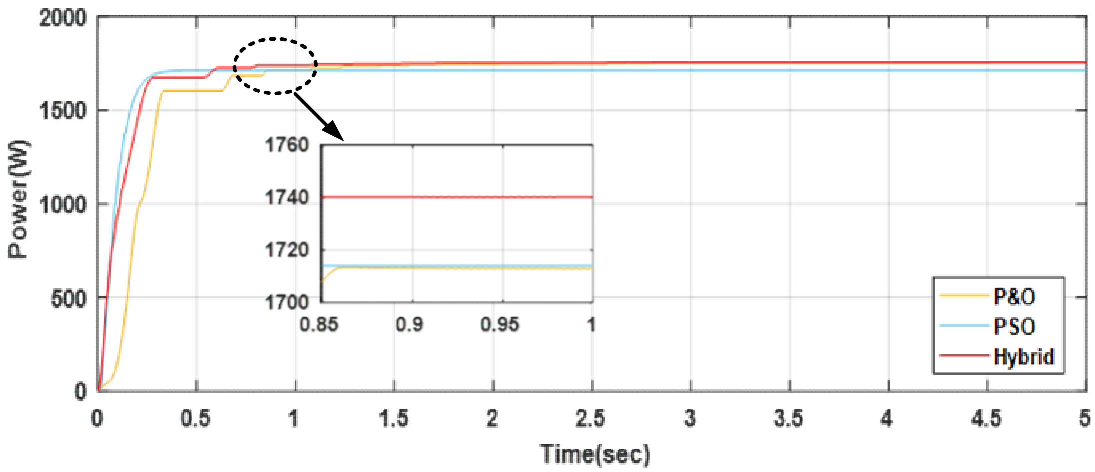

Figure5.21: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case3 for series-parallel configuration

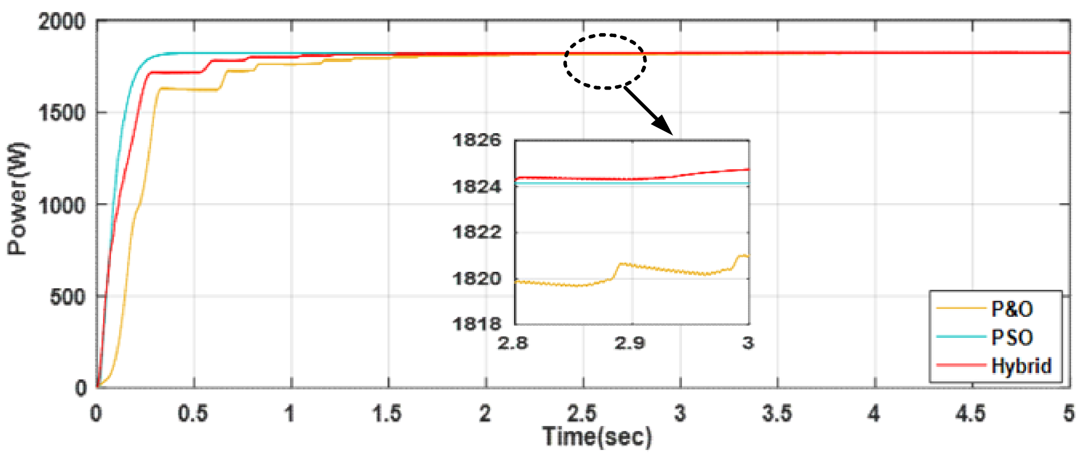

Figure5.22: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case3 for TCT configuration

Figure5.21 and figure5.22 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case4:

In this case one column of the PV array is shaded, here middle column receives an irradiation of 300 W/m^2 as shown in figure5.3(e). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

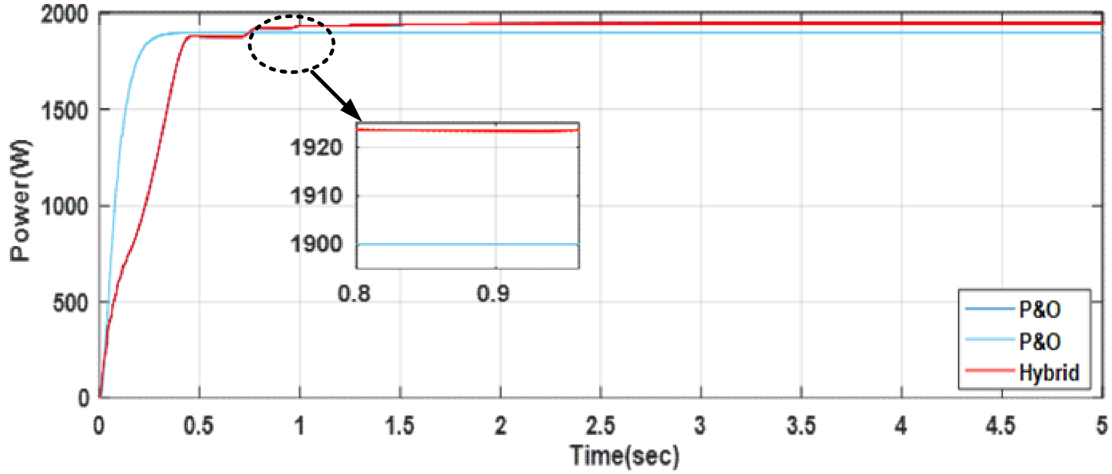

Figure5.23: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case4 for series-parallel configuration

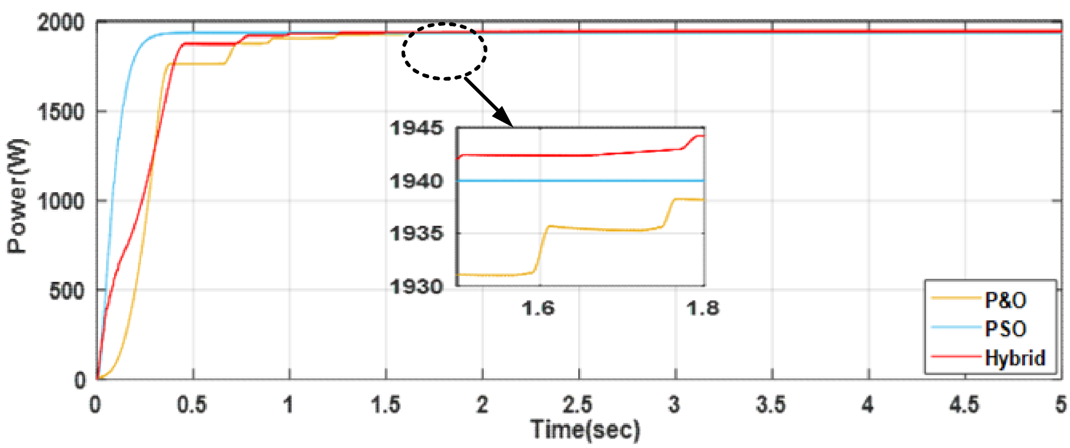

Figure5.24: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case4 for TCT configuration

Figure5.23 and figure5.24 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case5:

In case 5 left upper side corner of the PV array is shaded, four arrays are shaded in which two receive 500 W/m^2 and other two 600W/m^2 as shown in the figure5.3(f). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

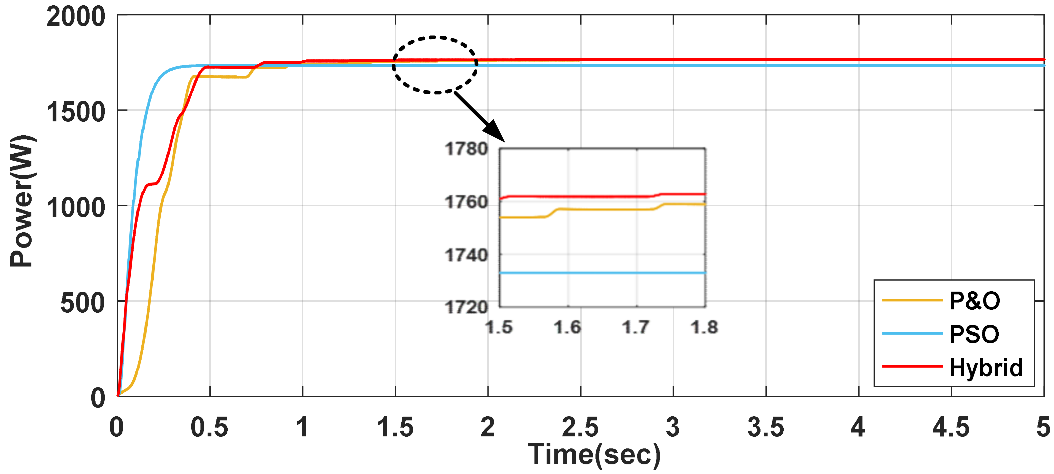

Figure5.25: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case5 for series-parallel configuration

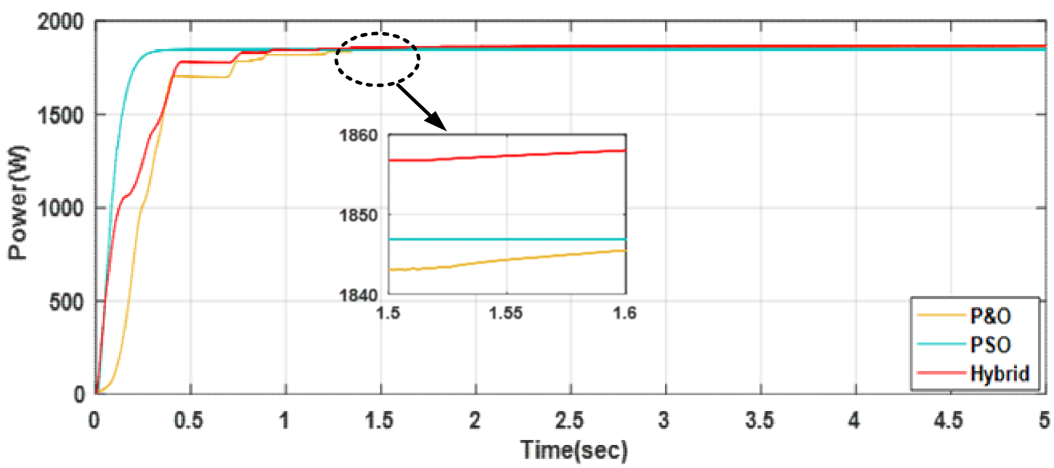

Figure 5.26: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case5 for TCT configuration

Figure5.25 and figure5.26 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm

PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

Case6:

In this case out of three, two columns are shaded. The PV modules in these two columns each row receives 200W/m^2, 500W/m^2, 300W/m^2 and 800W/m^2 respectively as shown in figure5.3(g). For TCT and series-parallel configuration all the three algorithms are applied and results are obtained.

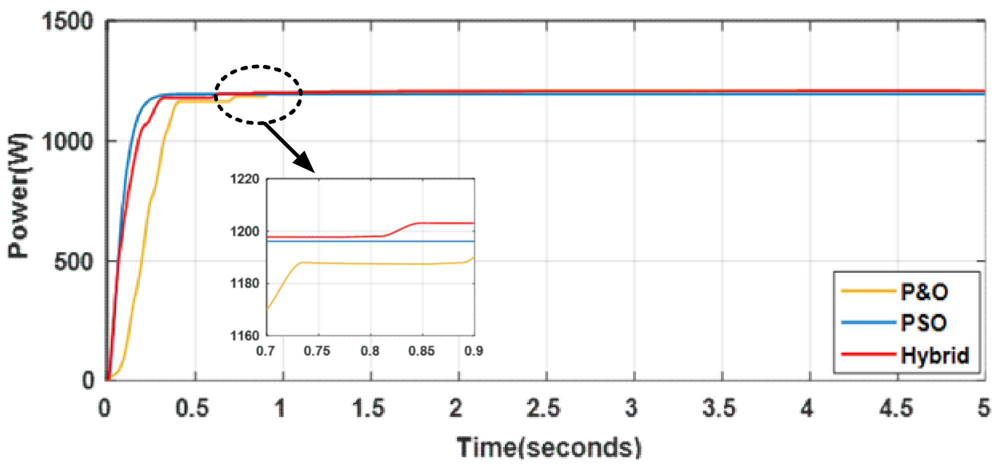

Figure 5.27: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case6 for series-parallel configuration

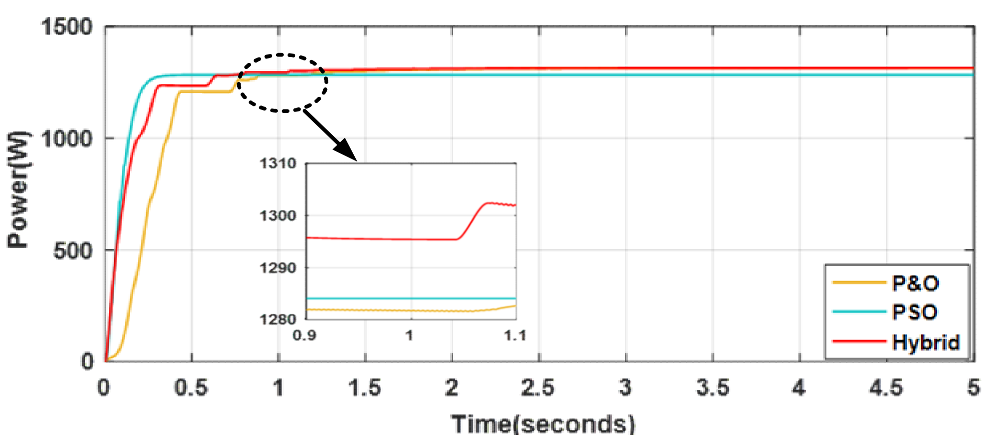

Figure 5.28: P&O, PSO and PSO-P&O hybrid algorithm for partial shading case6 for TCT configuration

Figure5.27 and figure5.28 shows the comparison of PSO-P&O hybrid algorithm with P&O and PSO methods for series-parallel and TCT configuration respectively for case3. Although PSO settles fast but PSO-P&O hybrid gives higher power output. But as compared to P&O algorithm PSO-P&O hybrid is settling much fast. The hybrid algorithm registered the global maximum power of 1947W under TCT configuration.

5.7.1 GLOBAL MAXIMUM POWER POINT

Global maximum power point is the value of generated when the voltage and current of the system is maximum. The value of GMPP is given by equation (5.) as given below:

$$P_{mpp} = V_{mpp} * I_{mpp} \tag{5.9}$$

The results for maximum power are tabulated in table5.2 and from the table it can be observed that PSO-P&O hybrid is giving better results for TCT configuration.

TABLE 5.2. Global maximum power for all the shading cases of different configurations.

Shading cases	**MPPT Algorithms**	**Series-parallel**	**TCT**
Unshaded	P&O	2535	2530
	PSO	2531	2532
	HYBRID	2537	2537
Case1	P&O	2206	2159
	PSO	2158	2214
	HYBRID	2222	2222
Case2	P&O	1780	1730
	PSO	1688	1708
	HYBRID	1785	1734
Case3	P&O	1713	1826
	PSO	1715	1824
	HYBRID	1727	1762
Case4	P&O	1862	1908

	PSO	1900	1940
	HYBRID	1947	1947
Case5	P&O	1760	1818
	PSO	1733	1847
	HYBRID	1765	1867
Case6	P&O	1200	1300
	PSO	1196	1284
	HYBRID	1210	1315

5.7.1 MISMATCH LOSSES

Mismatch losses are the difference in the individual maximum power (P_{ind}) and the maximum power during shading (P_{ind}).

$P_m = P_{ind} - P_{ind}$ (5.10)

TABLE5.3 Individual maximum power (in W) for all the shading cases.

Unshaded	Case1	Case2	Case3	Case4	Case5	Case6
2557.4	2433.3	2177.8	2136.8	1962.36	2179.8	1619.84

TABLE 5.4. Mismatch losses for all the shading cases of different configurations.

Shading cases	**MPPT Algorithms**	**Series-parallel**	**TCT**
Unshaded	P&O	22	82
	PSO	26	25
	HYBRID	20	20
Case1	P&O	227.3	274.3
	PSO	275.3	219.3

	HYBRID	213.3	211.3
Case2	P&O	397.8	477.8
	PSO	489.8	469.8
	HYBRID	392.8	443.8
Case3	P&O	423.8	374.8
	PSO	421.8	312.8
	HYBRID	409.8	310.8
Case4	P&O	100.36	54.36
	PSO	237.36	22.36
	HYBRID	15.36	15.36
Case5	P&O	419.8	361.8
	PSO	4468	332.8
	HYBRID	414.8	312.8
Case6	P&O	419.84	319.84
	PSO	423.84	335.84
	HYBRID	409.84	304.84

The mismatch losses are calculated and tabulated in table5.4 and from the table it can be observed that PSO-P&O hybrid is giving better results for TCT configuration.

5.7.1 SHADING LOSSES

The loss of power under shading condition is the shading losses. It is the difference of maximum power at standard condition (P_{std}) and maximum power obtained during shading (P_{mpp}).

$$P_{sh} = P_{std} - P_{mpp} \quad (5.11)$$

TABLE 5.5. Shading losses for all the shading cases of different configurations.

Shading cases	MPPT Algorithms	Series-parallel	TCT
Unshaded	P&O	22	82
	PSO	26	25
	HYBRID	20	20
Case1	P&O	351	398
	PSO	399	343
	HYBRID	335	335
Case2	P&O	777	827
	PSO	869	849
	HYBRID	772	823
Case3	P&O	844	795
	PSO	842	733
	HYBRID	830	731
Case4	P&O	695	649
	PSO	832	617
	HYBRID	610	610
Case5	P&O	792	739
	PSO	824	710
	HYBRID	787	690
Case6	P&O	1359	1265
	PSO	1363	1275
	HYBRID	1349	1244

The shading losses for different shading cases are calculated and tabulated in table5.5 and from the table it can be observed that PSO-P&O hybrid is giving better results for TCT configuration.

5.7.1 FILL FACTOR

The ratio of the maximum power and the multiplication of short circuit current (I_{sc}) and open circuit voltage (V_{oc}) during partial shading is known as fill factor. Where V_{max} is maximum voltage at GMPP and I_{max} is the maximum current at GMPP.

$$\text{Fill Factor (FF)} = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \tag{5.12}$$

TABLE 5.6. Fill factor for all the shading cases of different configurations.

Shading cases	MPPT Algorithms	Series-parallel	TCT
Unshaded	P&O	0.744	0.726
	PSO	0.744	0.743
	HYBRID	0.744	0.744
Case1	P&O	0.648	0.636
	PSO	0.634	0.652
	HYBRID	0.653	0.654
Case2	P&O	0.525	0.501
	PSO	0.498	0.504
	HYBRID	0.526	0.511
Case3	P&O	0.507	0.520
	PSO	0.508	0.539
	HYBRID	0.511	0.539
Case4	P&O	0.719	0.737
	PSO	0.666	0.749
	HYBRID	0.752	0.752
Case5	P&O	0.519	0.549
	PSO	0.512	0.544

	HYBRID	0.521	0.547
Case6	P&O	0.406	0.440
	PSO	0.4054	0.4352
	HYBRID	0.4101	0.445

The fill factor for different shading cases is calculated and tabulated in table 5.6 and from the table it can be observed that PSO-P&O hybrid is giving better results for TCT configuration.

5.6 CONCLUSION

In this chapter the effects of partial shading on solar PV system are discussed. For obtaining the global maximum power point different MPPT techniques are designed for a 2.55kW PV system. Furthermore, different PV array configuration are studied. In this chapter PSO-P&O hybrid algorithm is developed and found that PSO-P&O hybrid algorithm with TCT configuration gives better performance.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE OF THE WORK

6.1 CONCLUSIONS

In this work the main aim was to analyse the working PV system and MPPT control. The characteristics of PV array are acquired by electrical equivalent version of PV cell. For implementation of MPPT a boost is designed. A stand-alone PV system with boost converter is designed and simulated using MATLAB/Simulink software. Various MPPT algorithm for traditional and non-conventional are studied and applied on the system designed.

For varying solar irradiation various MPPT algorithms are studied:

- P&O
- InC
- Fuzzy logic controller

These algorithms are implemented and comparison of conventional and intelligent algorithm is done. It is found out that for time-varying irradiation although the conventional algorithm reaches MPPT but intelligent algorithm gives better results in terms of power tracked, overshoots and undershoots.

For partial shading condition following MPPT algorithms are studied:

- P&O
- PSO
- PSO-P&O hybrid.

For partial shading conditions PV array configurations are studied and PV array characteristics for different cases of shading is obtained. It is observed that during partial shading there is power loss in the system and multiple peaks are found in PV array characteristics. Along with MPPT algorithms used to track global maximum power point, PV array configurations are used and is found that PSO-P&O hybrid algorithm with TCT configuration gives better results in terms of fill factor, shading losses, mismatch losses and GMPP.

6.2 FUTURE SCOPE OF THE WORK

In future the work presented in thesis can be extended to:

- For the proposed system hardware implementation can be done.
- Other intelligent and adaptive control algorithms for MPPT for PV system under partial shading can be developed and implemented.
- The settling time of the proposed system can be improved.
- Implementation of the proposed MPPT algorithm for grid connected system.

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