A Modified Perturb and Observe Maximum Power Point Tracking Technique for Handling Partial Shading

by

Qazi Muhammad Kashif

A thesis submitted in partial fulfillment for the degree of Master of Science

in the

2019

I am dedicating this thesis to my Parents, Family, Friends and Teachers for their limitless love, care and inspiration.

CERTIFICATE OF APPROVAL

A Modified Perturb and Observe Maximum Power Point Tracking Technique for Handling Partial Shading

by

Qazi Muhammad Kashif

(MEE-161013)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Dr. Syed Ali Abbas Kazmi	NUST, Islamabad
(b)	Internal Examiner	Dr. Muhammad Ashraf	CUST, Islamabad
(c)	Supervisor	Dr. Umer Amir Khan	CUST, Islamabad

—————————————

Dr. Umer Amir Khan

Thesis Supervisor

April, 2019

——————————————————   ——————————————————

Dr. Noor Muhammad Khan   Dr. Imtiaz Ahmed Taj

Head   Dean

Dept. of Electrical Engineering   Faculty of Engineering

April, 2019   April, 2019

Author's Declaration

I, **Qazi Muhammad Kashif** hereby state that my MS thesis titled "**A Modified Perturb and Observe Maximum Power Point Tracking Technique for Handling Partial Shading**" is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.

(Qazi Muhammad Kashif)

Registration No: MEE161013

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled "**A Modified Perturb and Observe Maximum Power Point Tracking Technique for Handling Partial Shading**" is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been dully acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Capital University of Science and Technology towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.

(Qazi Muhammad Kashif)

Registration No: MEE161013

Acknowledgements

I want to thank Almighty Allah without his will, nothing can be done. I also want to thank my teachers who guided me through the crucial problems that I faced during the thesis. I thank Dr. Umer Amir Khan for assistance and his comments that greatly helped me in the thesis, who provided insight and expertise that greatly assisted the research. I would also like to show my gratitude to my several teachers for sharing their pearls of wisdom with me during the course of this thesis. Although any errors are my own and should not tarnish the reputations of these esteemed persons. My parents deserve a lot of thanks too, for, without their patience and support, this thesis would have never been complete.

(Qazi Muhammad Kashif)

Registration No: MEE161013

Abstract

Solar Energy is one of the most important renewable energy sources for generating electricity. However, its production depends immensely on the weather conditions of ambient temperature and irradiance. Therefore, there should be control techniques to manage the operation of the solar PV to have it working at the point at which it produces the maximum power. During the condition of partial shading the current-voltage and power-voltage characteristics of photovoltaic PV exhibits multiple steps and multiple peaks respectively. The peaks are local maximum power points (LMPPs) and global maximum power point (GMPP). Their are various maximum power point technique among them is Perturb and Observe. This Technique is employed commonly because of its simple implementation and cheaper in cost compared with other techniques. However this techniques has some problems during the condition of partial shading it can not differentiate between local maximum power point and global maximum power point. The proposed Modified Perturb and Observe Method will resolve the problems of conventional perturb and observe method. This new method will detect the presence of partial shading and it will show the location of GMPP and LMPP. The test bed system consists of Photovoltaic system, modified Perturb and Observe method, boost converter that is implemented in Matlab/simulink.The results have been compared with Ordinary Perturb and Observe method in order to verify the correctness of the operation of the proposed method. Results showed that, the new method successfully tracked the maximum power point at normal conditions as well as shading conditions. Not only it tracks the various conditions accurately but it also performs faster than other methods. Therefore, the new method increased the efficiency significantly and maximized the extracted energy of solar PV arrays. The proposed model is effective and workable for MPPT during partial shading and non shading.

Contents

List of Figures

List of Tables

List of Abbreviations

CdTe	Cadmium Telluride
CIGS	Copper Indium Gallium Selenide
DC	Direct Current
GMPP	Global Maximum Power Point
IGBT	Insulated-Gate Bipolar Transistor
LMPP	Local Maximum Power Point
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
PV	Photovoltaic
PSC	Partial Shading Condition
PO	Perturb and Observe

Chapter 1

Introduction

1.1 Introduction

With the growth in world's population, increase in energy demand is obvious. It is expected that world primary energy demand will increase by 60% from 2002 to 2030, globally. Figure 1.1 shows the energy mix of Pakistan, which reflects a dominant portion contributed by Hydel, Coal and Oil and less contribution of renewable energy [1]. PV is considered one of the most important resources of energy for future. By 2011, almost 30 GW of electricity had been produced by PV solar cell globally. On the other hand, climate awareness has been one of the most important factors to be concerned by all the world. Therefore, replacing the fossil fuel i.e gas and coal by the clean energy like wind, tidal, hydro, and solar energy becomes of the top interests. In addition to the clean and free pollution energy, they are a permanent source of energy [2].

Researchers have been working in improving the design and manufacturing of the components of these renewable energy in two paths. The first is the material design of the component and the second in improving and optimization of the applications of energy conversion. Researchers and engineers are working in enhancing the material of the solar cell which is the smallest unit of the solar energy. Some engineers are working on the application of energy conversion like power converters,
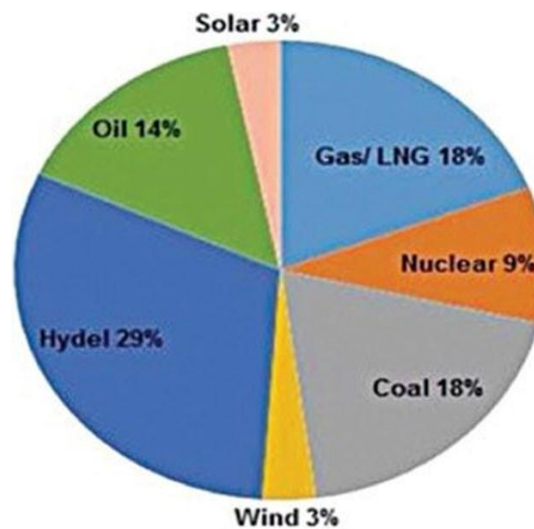
FIGURE 1.1: Energy Mix of Pakistan for Electricity production [1]

inverters, and control techniques for maximizing the extracted power of the solar panels. Solar energy can be utilized to supply standalone load without connected to the main grid which is very important for the rural areas. such areas are located far away of the transmission lines and has no mean to be fed by the utility grid. In addition, solar energy can be designed to be grid connected in order to be source to the grid. Solar energy power system has many components like solar panels, converters, inverters, battery banks and etc. The following sections introduce all of these components in details.

1.2 Background

Solar energy is one of the most common renewable energy sources. The main component of solar energy is the solar cell as shown in Figure 1.2. Solar cell is a device which converts the light energy into electrical energy. It composed of photoelectric cell which is and characterized by electrical properties of current, voltage, and resistance which can be changed by light. Its semiconductor material has been energized by being subjected to light, yielding free electrons and holes. Therefore, when it is wired with external circuit, it can produce electrical current that circulates and feed a load [3].

FIGURE 1.2: Shows Solar cell which Combine and form PV Module [2]

Solar cell material has a certain characteristic to be able to absorb the incoming sunlight. Solar cells are designed for working in the earth which work on photoelectric effects and convert light energy into electrical energy. They are manufactured either in single layer (single junction) or in multiple layers of absorbing light material (multiple junctions). At the beginning, these are made of crystalline of silicon which is called wafer-based cells either in Monocrystalline or Polycrystalline. After that, it has been made of Cadmium Telluride (CdTe), Amorphous silicon and Copper Indium Gallium Selenide (CIGS) cells which are called thin film solar cell. In addition, there are a third generation which are under research like organic based material solar cell. More details will be discussed in the later section in this chapter [4].

One solar cell can produce maximum 0.5 to 0.6 V as an open circuit voltage. Therefore, it needs to be connected in group of cells to produce much amount of voltage and current to be used in real applications. There are two topologies to connect solar cells either in series to increase the summation of output voltage or in parallel to largen the addition of current. Connecting solar cells in series and in parallel forms is so called solar module. When solar modules are connected in series and parallel, solar panels are formed. In the next sections, it will be discussed in details to show how cells, modules, and panels are connected in series

to produce a designed amount of current and voltage that is based on the load's needs [5].

The solar panels or arrays may work in one of two topologies either standalone topology in which it supplies the load directly or by using a DC to DC converter to satisfy the load requirements of current and voltage [6] [7]. It may also work in grid connected topology, in which it is connected to the utility grid via DC to AC-inverter in order to accommodate the needs of the grid of frequency and voltage characteristics [8] [9] [10].

1.3   Motivation

As it has been mentioned above, two paths have been followed by researchers to improve the performance and the efficiency of the solar energy-based systems. The first is based on enhancing the material of which the solar cell is made. The second path is the application wise by developing new topologies, control techniques and new algorithms to optimize the operation of the solar panels in order to maximize the extracted energy. In this research, the later path will be taken to present some contribution in the scope of application of energy conversion of solar energy. A complete solar energy generation system is mathematically modeled. After that, the model has been simulated by using MATLAB Simulink to search the performance parameter. The model includes a maximum power point tracking technique and validated with other works to make sure its proper functionability. In addition, different test cases have been considered including partial and fully shaded conditions.

1.4   Basics of Solar PV

Solar photovoltaic converts the sunlight into electrical current by energizing the solar cell material. In such a way, it yields holes and free electrons in the way of

semiconductor material. The solar cells would have the ability of being affected by the sunlight and its electrical characteristic of current, voltage, and resistance are changed [11].

In order to take the usage of solar cell it should be :

(i)subjected to sunlight to absorb them and then convert them to electrical energy

(ii) Connected to external circuit to circulate and produce the current

(iii) Managed the operating point to maximize the extraction of energy by using MPPTs

1.5 Components of PV Generation System

The main component in photovoltaic system is the solar PV. There are three types of PV's based on their material, and other fundamental component are :

(i) PV Module

(ii) Inverter

(iii) Batteries

(iv) Charge controller

Some of them are shown in Figure 1.3 and Figure 1.4.

1.5.1 PV Module

PV modules is an assembly of photovoltiac(PV) cells to achieve a required Current and Voltage. We can generate electricity directly from solar energy using PV modules. Photovoltaic cells convert solar energy into DC supply. It is acted through electronic process. Semiconductors are used in PV modules, which is important part of PV modules. When sunlight falls on these modules, it creates electric field across its layer and causes electricity to flow through electrical circuit.

1.5.2   Crystalline Silicon PV (c-Si)

Two types of crystalline are used to produce PV module : single crystalline also called monocrystalline silicon and multicrystalline also known as polycrystalline.

(i) Monocrystalline:

It has only single layer of light absorbing material made of silicon. Monocrystalline cells structure is made of single crystal of silicon. Life span of these cells is 25 to 30 years. It is widely used because of its high efficiency i.e 24.4%. This type of crystalline has higher efficiency than poly crystalline.

(ii) PolyCrystalline:

It has two or more layers of absorbing material made of silicon. Poly-crystalline cells structure is made of multiple smaller crystals of silicon. It is slightly less efficient then mono-crystalline cells because in polycrystalline, its crystal structure has different size of crystals, and different crystal defects occur on border which decreases the efficiency of poly-crystalline i.e 19.8%.

1.5.3   Amorphous Silicon PV (a-Si)

It is the non crystalline form of silicon and is widely used. It is popular among thin film technology, but it has low efficiecny than silicon crystalline. Its efficiecny is 13.8%. Some of the varieties of a-Si are amorphous Silicon carbide (a-SiC), amorphous Silicon germanium (a-SiGe), Microcrystalline silicon (micro-Si) and amorphous Silicon-nitride (a-SiN).

1.5.4   Inverter

An inverter refers to Power Electronic device which converts DC to AC power at required frequency and voltage output. In PV-system, we cannot integrate directly PV-system with grid without using inverter. Inverters are used because PV

modules generate output as DC supply and these are needed to convert DC into AC. An inverter can be classified by size, mode of operation and topology.

1.5.5   Batteries

Batteries convert chemical energy into electrical energy. It is the key technology which is important for PV system and also for all renewable resources. A battery Produces Direct current(DC). PV cells are totally dependent on the sun and cannot generate power at night for which we need backup supplies such as battery storage systems. Batteries may be primary or secondary. The primary batteries are thrown away when it do not produce electricity. Dry cell, Alkaline batteries etc are the examples of primary battery. Secondary battery can be recharged and reused. Lithium ion, Nickel-cadmium(Nicd)etc are the examples of secondary Batteries [13].

Mono Crystalline   **Poly Crystalline**   **Amorphous Silicon**
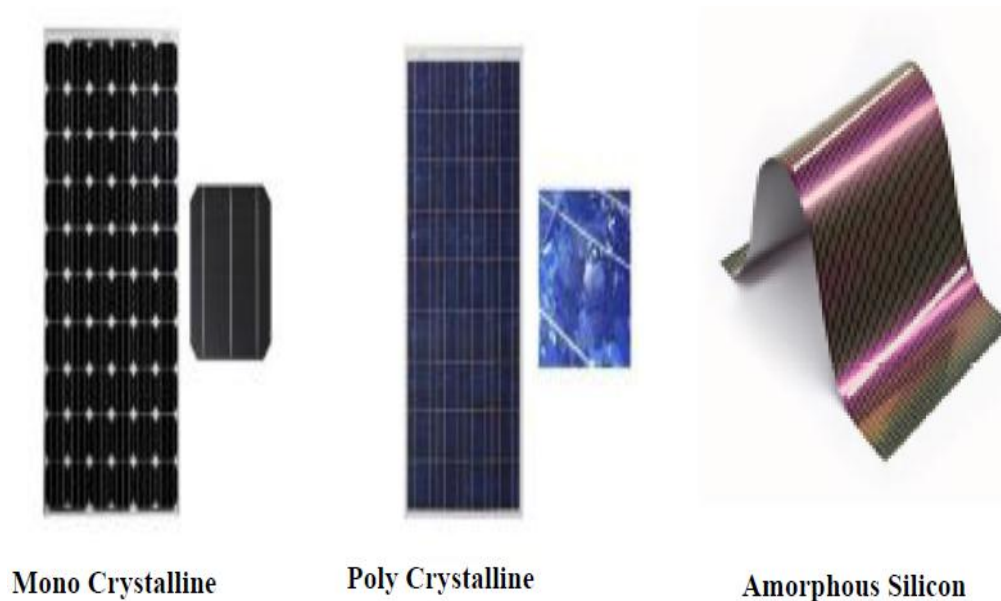
FIGURE 1.3: Shows New Technology of Solar PV Module [12]
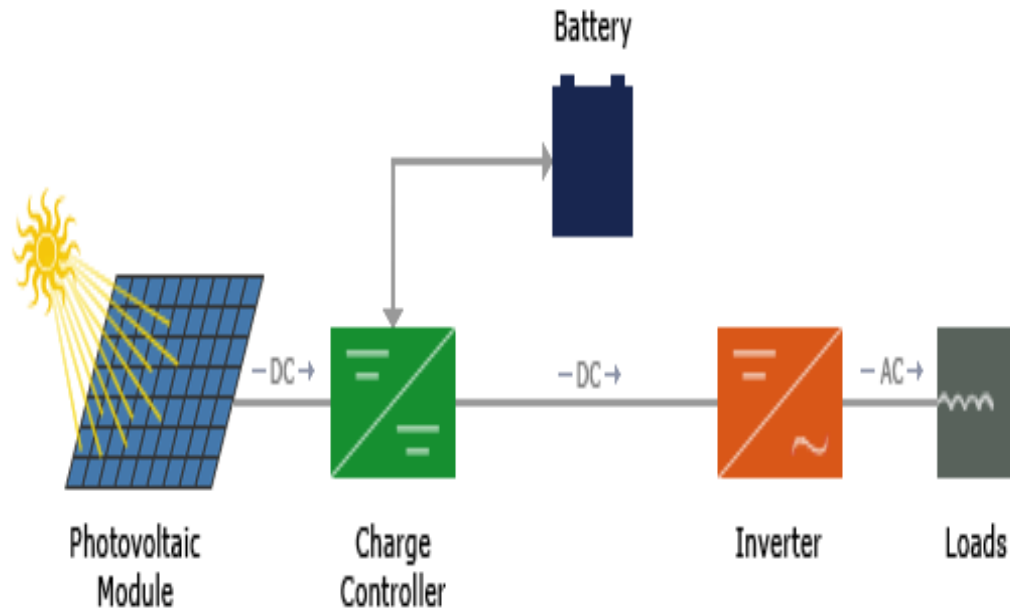
FIGURE 1.4: Shows PV and its Fundamental Components in Single line Diagram[8]

1.5.6 Charge Controller

Charge controller plays an important role in battery life. Charge controller prevents overcharging, it may protect against over voltage, that reduce battery performance or lifespan, and may pose a safety risk. Most of the charge controller have maximum power point tracking technique embedded by default.

1.6 PV Module Performance Parameter

The electrical characteristics of PV module can be seen and represented by the current, voltage and output power of the module. The PV module has been affected by the changing in temperature C and irradiance (the amount of sun per unit area of the module watt per meter square). Figure 1.5 Shows the effects of changing irradiance on the power to voltage P-V curves. It shows P-V characteristics Curves at constant temperature at 25C and at different values of irradiances

1000, 800, 600, 400, and 200 watt per meter square. When the irradiance is high, then we will get maximum power from PV and vice versa. While Figure 1.6 depicts the I-V side by side with the P-V characteristics Curves at constant irradiance at 1000 watt per meter square and different values of Temperature at 25, 50, 75, and 100C.

1.6.1 PV Module Performance in Partial Shading

Solar energy has an intermittent nature in producing electrical power due to the dependency on the weather conditions of temperature. Therefore, there are many techniques and algorithms for controlling the operation of the solar panels to optimize the extracted energy in such a away that are working at the point at which they are producing the maximum power. These methods are called Maximum
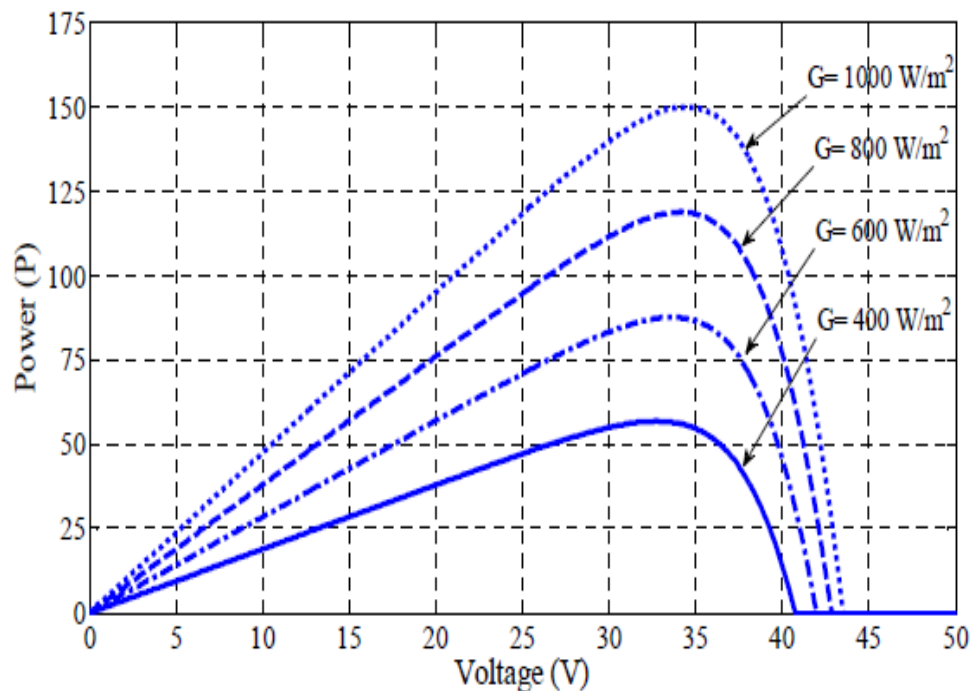
FIGURE 1.5: Shows Different Irradiance levels on P-V Curve [14]
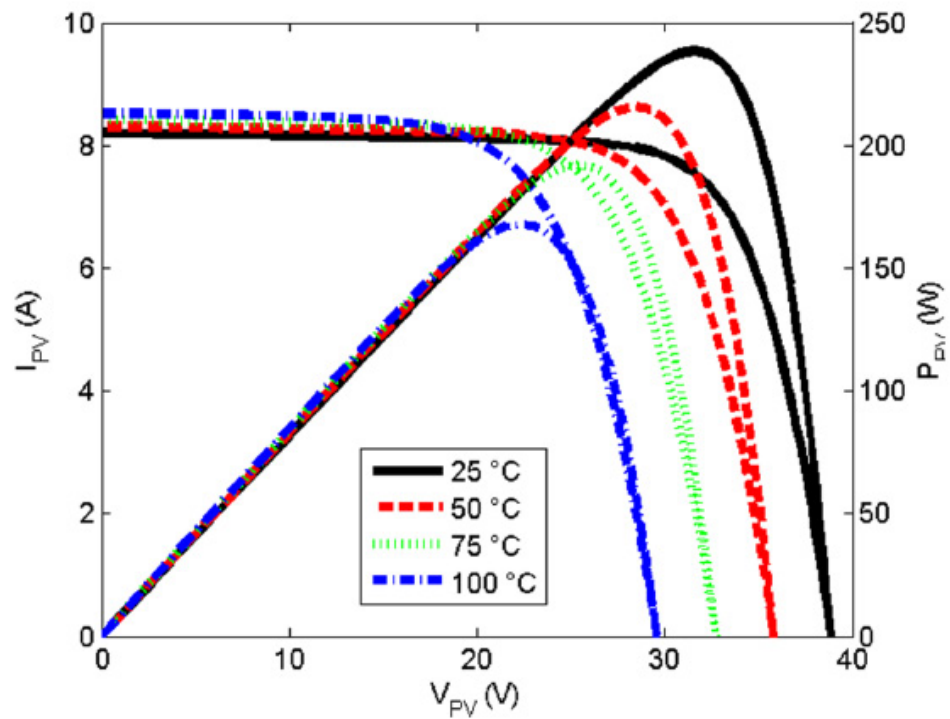
FIGURE 1.6: Shows the I-V and P-V curves at fixed Irradiance 1000 watt per meter square and Different Temperature [14]

Power Point Tracking techniques (MPPT) and they will be discussed in more detail in the incoming chapter.

It has been mentioned in the aforementioned paragraph that the solar panels production has been affected by the weather condition. In addition, there are cases of shading which is occurred when the panel is covered partially or fully by an object like cloud or trees [15] [16]. In this case the panel output power is decayed immensely. During the condition of partial shading, the current-voltage and power-voltage characteristics of photovoltaic PV exhibits multiple steps and multiple peaks respectively. The peaks are local maximum power points (LMPPs) and global maximum power point (GMPP) is shown in above Figure.
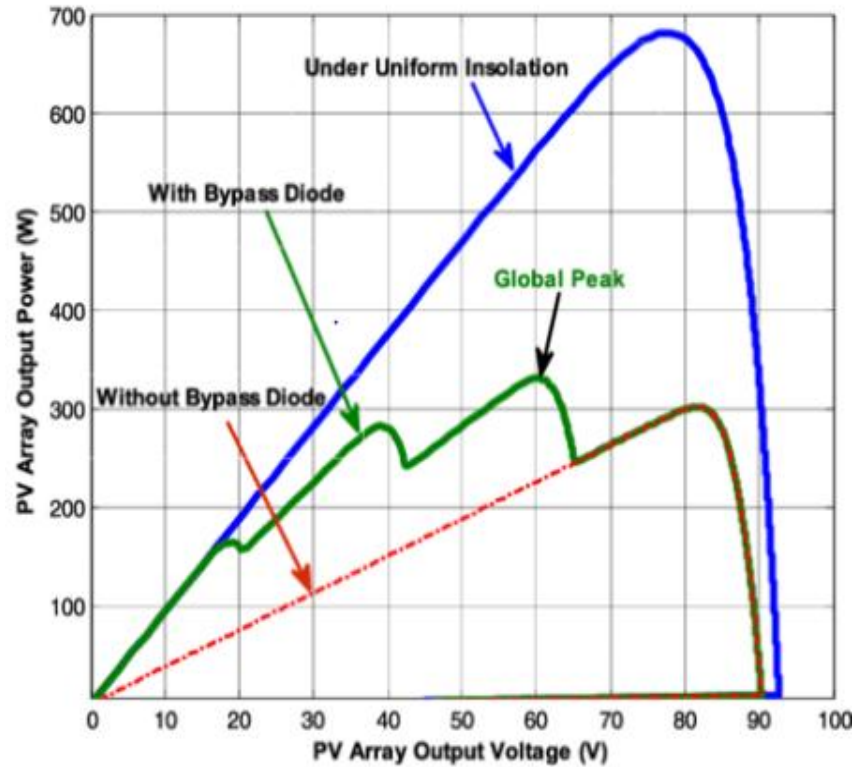
FIGURE 1.7: Shows P-V curves during Partial shading [15]

1.7 Maximum Power Point Tracking Technique

For Solar PV energy system, the MPPT techniques are aim to track the maximum power point to keep the system working at the MPP for the most of the time and hence extracting the maximum power. There are many methods to track the MPP. The most widely used techniques are:

(i)Constant Voltage (CV) (ii)Incremental Conductance (IC) (iii) Perturb and Observe (PO) (iv)Fractional open circuit voltage (v) Fuzzy Logic control (vi) Neutral Network (vii) Short circuit current
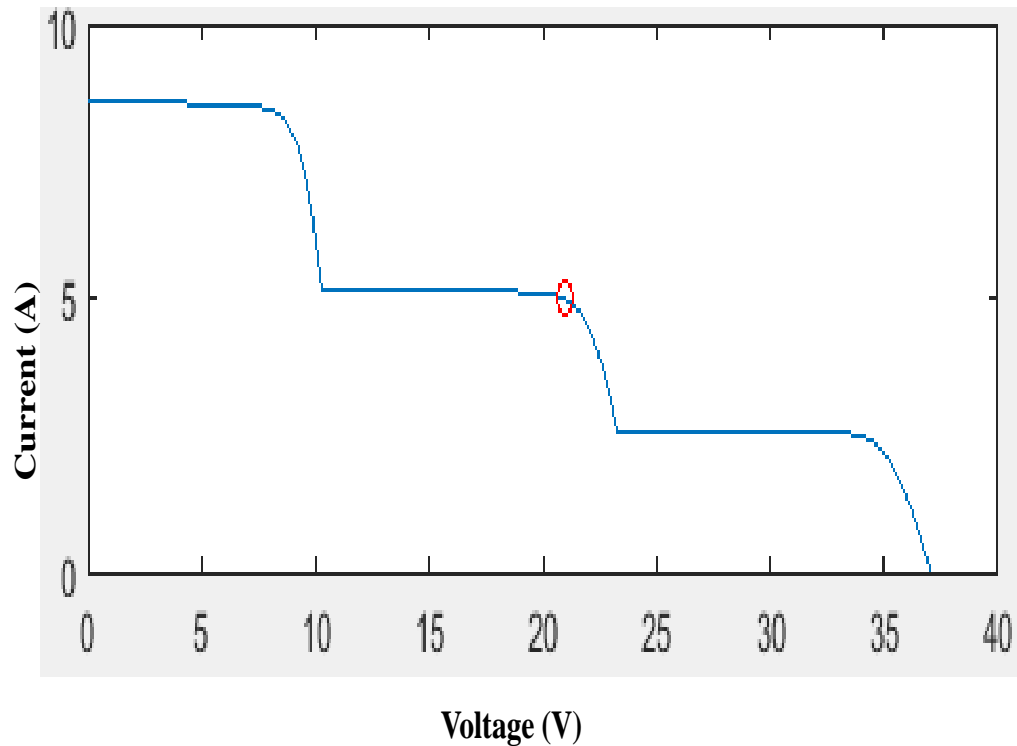
FIGURE 1.8: Shows I-V Curves During Partial Shading [15]

1.8   Objective

The objective of this study is to review the previous literature and conduct a comprehensive review on PV systems. Their are various techniques and algorithms used in tracking the maximum power point but we will focus on PO method. We will consider different conditions of operation including the non and partial shading conditions. Then, modeling a complete PV system composed of PV panels connected in series, DC-DC converter, and maximum power point tracking technique, and finally simulating the derived model by using MATLAB Simulink to determine the performance of modified PO and compare its result with ordinary

PO.

1.9 Thesis Overview

The thesis composed of five chapters as shown in Figure 1.9 including the current chapter of introduction which introduces the basic and backgrounds and the aim of the study. The second chapter presents the literature review and problem formulation, and the third chapter is System Modeling, chapter four is Result and discussion, and finally chapter five concludes the work and presents the future work.
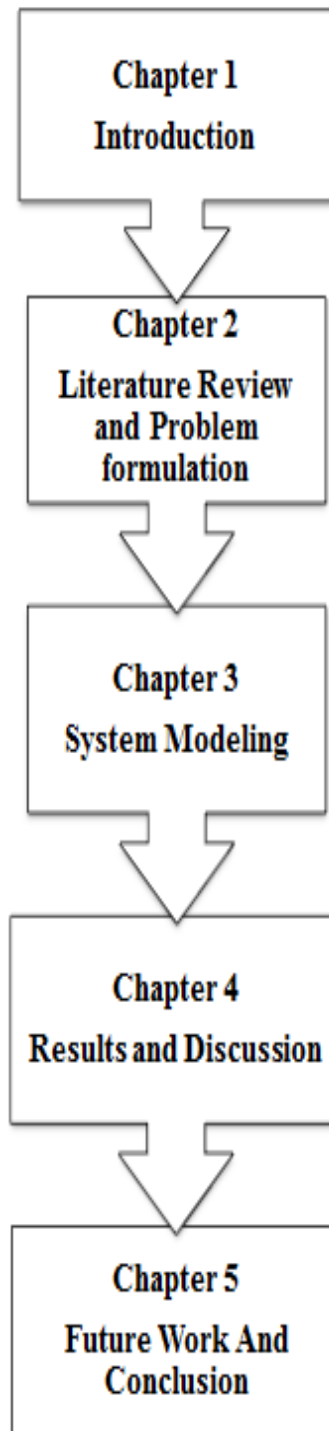
FIGURE 1.9: Shows Flow Chart of Thesis Overview

Chapter 2

Literature Review and Problem Formulation

This chapter presents detail overview of the literature. Gap Analysis, Problem statement and methodology are also discussed in this chapter.

2.1   Literature Review

The PV system is expected to reach 800 GW by the year 2030. This growth of PV system market is due to the effect that are available, plentiful, free energy source, sustainable and pollution free [17]. Although PV systems have many advantages but there are three major problems associated: (1) low efficiency that can hardly reach 20%, (2) when the weather is bad, the conversion efficiency is even poor, (3) nonlinear electrical characteristics. Normally, the efficiency of PV system mainly depends on solar irradiance level and atmospheric temperature. Therefore, PV system should be operated at maximum power point (MPP) to achieve the highest possible efficiency. A maximum power point tracking (MPPT) system is one of the important components that every PV system should include to ensure that the highest possible power is generated. It is an electronic control system, which monitors PV terminal voltage/current and achieves MPP by controlling the duty

cycle of a DC/DC converter to match output load to PV source impedance.

A Photovoltaic cell converts light energy into electricity directly. PV cells have a complex relationship among Solar irradiation, temperature, and total resistance, and exhibit a nonlinear output efficiency characteristic known as the P-V Curve. Without Using MPPT Technique the Solar PV cannot operate at Maximum power. Therefore, Maximum Power Point Tracking (MPPT) techniques should be developed in PV systems in order to maximize the output power of PV systems.

In [14] the author discussed the implementation of a maximum power point tracking algorithm for a photovoltaic system and showed that the effect of using and not using MPPT. He concluded that using MPPT technique, we get 93% efficiency and without MPPT we get 70% efficiency.

The function of MPPT is to ensure the operating voltage and current always stay at the maximum power point (MPP) on the P-V characteristic curve. To date, numerous MPPT techniques are reported in literature [18]. The most popular MPPT techniques are the perturb and observe (PO) [19] [20] [21][22] [23], and incremental conductance [24] [25] [26] [26]. These algorithms are widely used in commercial products mainly due to their simplicity and robustness. Some other MPPT techniques are Artificial Neural network [27] [28], Fuzzy logic[29] [30] [31],Particle Swarm Optimization [32] [33] [34], Fractional open circuit Voltage [35] [36], tend to be more versatile and flexible.

This matter becomes more complex when there is rapidly changing irradiance and partial shading due to Clouds, Trees, buildings etc. There will be multiple steps current-voltage(I-V) and multiple peak on Power -Voltage(P-V) curve. However when there is partial shading it cannot perform well and cannot track the GMPP. The multiple maxima occur due to bypass diode during partial shading[16]. This bypass diode prevents the PV from hot spot and allows the current to flow in accurate direction.

Some researchers suggested different techniques for tracking (GMPP) for Resolving the problems of partial shading.

In [37] they observed that there are many peaks in cases of partial shading. Their proposed method started by initialing the reference voltage to 85% of the open

circuit voltage and measured the current and voltage. It then called the traditional PO method to find out the maximum power point. They stored the current values of voltage and current as the last obtained maximum power point values Vm, Im, and Pm. It then checked the change in power to see if it significantly changed then it means partial shading has occurred. If this is the case, it is called the global maximum power point tracking procedure GP. Once the GP procedure has been done, it passes the control to the main routine and the process repeated until it reaches to the global maximum power point. They run simulation at normal condition and at different cases of partial shading conditions as well. Their results showed a successfulness in tracking the global maximum power point at different cases of partial shading conditions and also faster than the traditional methods.

In [38] they tested the most common methods of tracking like PO and Incremental conductance method. They simply tested for the local peak and store the MPP points of current, voltage, and power. Now if a significant change in power has been occurred, then they would raise a flag to make a case of Partial shading condition. At this case, they called a global maximum power point tracking separate routine in which they updated the value of current, voltage and power every time. They used MATLAB Simulink to test different conditions including partial shading conditions. Their results show that it can track Global maximum power point.

In [39] in this paper the author presents an comparative analysis of PO and incremental conductance as they are widely used in MPPT techniques. Since both technique are studied under 4 different environmental conditions i.e constant irradiance, fluctuating irradiance, rapid fluctuating irradiance. During constant irradiance the simulation is kept for 2s in which the irradiance is kept 800 watt per meter square the results shows that PO track Maximum power i.e 3043 W where as the incremental conductance track 3037 W but PO track it in 0.16 s and where as incremental conductance track it in 0.13 s. Now the second case is the fluctuating irradiance in which the irradiance is kept 800 watt per meter square, 600watt per meter square, 400 watt per meter square. During this case the PO track 3043 W, 2845 W, 2594 W where as the incremental track 3037 W, 2838 W,

2588 W but the speed accuracy of incremental was fast. During rapid fluctuating irradiance the irradiance is kept 0, 200 watt per meter square, 600 watt per meter square, 400 watt per meter square, 500 watt per meter square during this the author concluded that PO track Maximum power but speed is slow and vice versa. In [40] the authors proposed an improved MPPT technique. They initialized the reference voltage to 85% of the open circuit voltage and calculated the number of PV modules. Then they measured the modules voltage and current. After that they utilized the traditional PO method to fetch the maximum power point at which they saved the last maximum power point for current, voltage and power. They called a separate global maximum power point tracking routine when the PO reached to the MPP. They modeled their system by using MATLAB Simulink. They included 4 PV modules in one string connected in series integrated with boost converter and set each PV module different value of irradiance for testing the partial shading and non shading condition. Their simulation results showed a successfulness in tracking the global maximum power point.

In [41] their method was a modified version of the conventional PO method. They used this traditional method because of its simplicity in implementation and its lower cost and efforts as compared to other method. They targeted to fix the two main issues of the traditional method PO. One is the oscillation around the peak point and other is the problem of failure of tracking the global peak in case of partial shading conditions. When there are many peaks in the PV curve, they choose wrong local peak instead of selecting the right global peak. They resolved the first issue of oscillation by stopping the oscillation one it reached the MPPT. They fixed the other issue of which multi peaks in partial shading condition by raising flag when it detects PSC conditions and searching the P-V curve for local peak and updated the global peak. They implemented a complete system including PV array of 3 modules integrated DC-DC boost converter. They set the insolation G for the three modules to 1000, 700, and 300 watt per meter square. The results proved that their algorithm resolved the main two issues of oscillation and partial shading condition.

Every researcher proposed their own MPPT Algorithm and their target is to track

GMPP in case of partial shading. Some of them use interrupts in their coding, consequently the efficiency of this algorithm negatively affected as speed of processing is essential to detect happening of partial shading on time. Some of them do not consider rapidly changing irradiance and experimental verification, while algorithm takes long time in measuring and calculating for all local peaks to decide which is the Global peak.

2.2 Gap Anaylsis

In [37] the method is very efficient when their is no rapidly changing irradiance. However, if their is rapidly changing irradiance this method fails to track the GMPP and their is timer interrupt. Consequently, the efficiency of this algorithm negatively affected, as speed of processing is essential to detect happening of partial shading on time.

In [38] they did not mention the details of the configurations. They used and the test cases of normal and shading conditions. They did not consider the case of rapid changing irradiance and just considered non-uniform irradiance case but when there is rapid changing irradiance, there will be problem of tracking the Global maximum Power point.

In [39] their method of PO two sensors are used, complexity and implementation, need to choose either speed or accuracy as increasing speed needs increasing the step size and hence decreasing the accuracy. When increasing the accuracy, it needs using small step size, so the process will be slow down. As for the INC, they concluded some drawbacks like using two sensors for current and voltage. It is of high complexity due to the non-linearity and calculation of derivative. As overall, they did not present any originality and or novelty because they just compared two conventional methods PO and INC.

In [40] it checks the occurrence of partial shading conditions periodically using timer of presented value. Consequently, the efficiency of this algorithm negatively affected as speed of processing is essential to detect happening of partial shading on time. One of the proposed solution for this delay issue is replacing the timer

based checking event by an interrupt request which is occurred and one or more conditions are realized. For example, the conditions of partial shading may be detected by significant drop in voltage and or power. So the procedure of handling the partial shading can be called when and only this interruption has been occurred thereby, time of periodic check and test can be saved. It accelerates the processing speed and increasing the efficiency.

In [41] the drawback of this method is the algorithm takes long time in measuring and calculating all local peaks to decide the Global peak. This delay may cause the system not able to track GMPP during fast changes in weather conditions.

2.3   Problem Statement

PV arrays produce electricity based on the amount of irradiance and the temperature. Therefore, its production is intermittent and depends on the weather condition. For normal condition, when no shading effects, there is only one peak at specific temperature and irradiance, So the objective here is to track this point and to get the PV working at the maximum power point. Furthermore, there are other conditions more complicated when there are shading effects by Clouds, Trees, or any other movable objects. In these cases, there are many peaks on P-V curve and the problem here is to find the global peak and keep tracking the global maximum power point. The traditional algorithms for tracking the maximum power point fail to track the global peak and trapped at one of the local peak points. So, their is need of Modified Algorithm that will solve the Problems of partial shading. It will detect partial shading and it will extract Maximum power compare with ordinary MPPT technique as well.

2.4 Methodology

In this section of thesis, software tool, designing of model, research conclusion, future recommendations are discussed and flow diagram of methodology is shown in Figure 2.1.

2.4.1 Software Tool

A selection of software is important and software for research must have optimal structures to permit modeling of PV system. The software checked for suitability is MATLAB 2016b. In MATLAB 2016b Sim-scape Power Systems provides a large variety of examples and analysis tools for modeling and simulations for electrical power systems modeling.

2.4.2 Designing Of System

This study presents a new tracking algorithm which is able to track the maximum and global power point as well efficiently. It has been developed by modifying the PO algorithm. Therefore, fetching all parameters of performance of the new developed algorithm, a complete PV system integrated with DC/DC boost converter has been modeled in Matlab.

2.4.3 Research Conclusion

The system simulation has been run at different operational conditions. Testing included normal cases when no shading effects and also the partial shading conditions. The tests have been simulated twice. One has been run with the new algorithm and other with the traditional algorithm in order to compare their results. The results showed that the new algorithm can handle accurately all test cases including partial shading conditions. While the tradition algorithms have failed to manage the cases of shading conditions therefore, the produced energy

was maximized and also the efficiency has been increased by using modified algorithm.

2.4.4 Future Work and Recommendation

When research is completed, recommendations and future work has been recognized and labeled. Purpose of this work is to allow future studies to use these results and build upon this research.
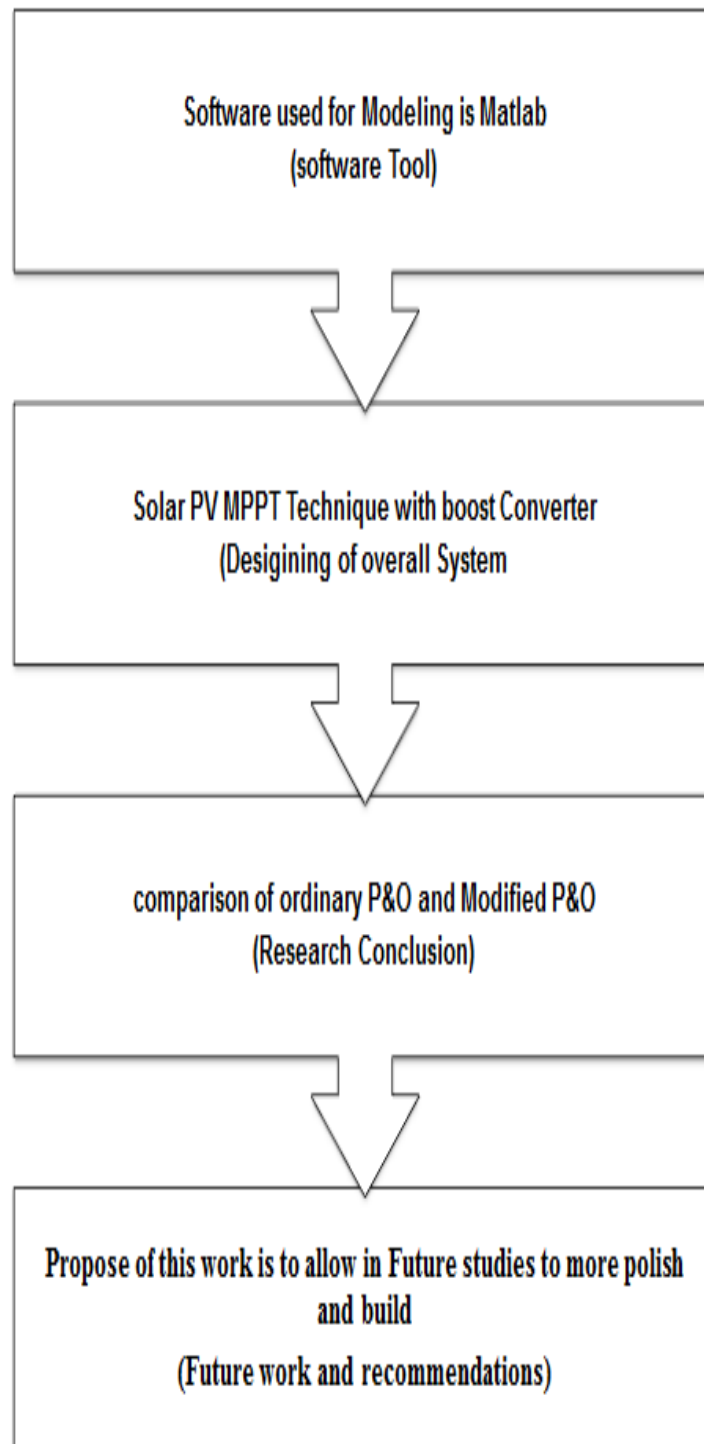
FIGURE 2.1: Flow Diagram of Methodology

Chapter 3

System Modeling

In order to simulate the system to fetch all performance parameters, this chapter presents the complete system models that is implemented in Simulink /Matlab and it would be used later in the simulation work in the next chapters.

3.1 PV Cell Model

The solar cell is the smallest unit of PV arrays. So, it is necessary to model the solar cell before modelling the PV model for normal and partial shading conditions. There are two models of a solar cell single and double diodes-based models. The single diode-based model is chosen for simplicity. Figure 3.1 shows the equivalent circuit of a photovoltaic array. It presents the solar cell as a current source parallel to diode and one series and one resistance in parallel and the modeling equations will be as follow. From the below equivalent circuit and using Kirchhoff's current Law, we can compute that

$$I = I_{ph} - I_o - I_{sh} \tag{3.1}$$

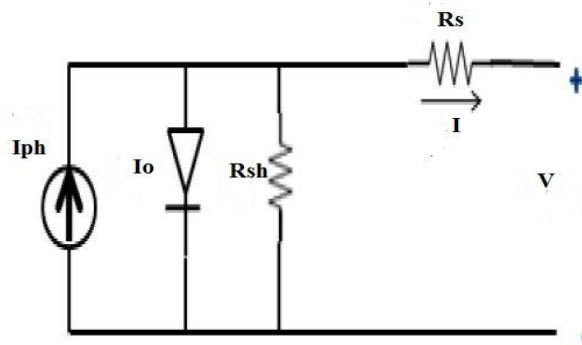where I is the total current of PV and it is equal to photo current (Iph)

Io is Diode current

FIGURE 3.1: Solar PV Model

Ish is current through shunt resistor

Now using Kirchoff's voltages law

$$V = V_d + IR_s \tag{3.2}$$

where Vd is diode voltage, V is output voltage

Rs series resistor

$$V_d = I_{sh} * R_{sh} \tag{3.3}$$

now substituting eqn (3.3) in eqn(3.2) we get

$$I_{sh} = \frac{V_d}{R_{sh}} = \frac{V + IR_s}{R_{sh}} \tag{3.4}$$

$$I_{ph}(G) = (I_sc + K_iT_{diff})\frac{G}{Gr} \tag{3.5}$$

it is clear from the above equation that it depends on irradiance G and reference Gr which is 1000 watt per meter square

Isc the short circuit current

Tdiff is the difference between temprature of operating and standard temperature

Ki is the temperature coefficient of solar cell

$$I_o = I_{o1}[exp[q\frac{V_{pv} + I_{Pv}R_s}{AK_bT_K} - 1] \tag{3.6}$$

where Io is diode current

I_{o1} is the diode saturation current

A is diode ideality factor

Tk is operating temperature(k)

q is electron charge constant

$$V_t = \frac{K_b T}{q} \tag{3.7}$$

Vt is the terminal Voltage

Kb represent Boltzman constant

T is the temprature of PV cell and

q is the magnitude of electron charge

Io is the saturation current

$$I_{o1} = Irs(\frac{Tk}{Tr})^3 exp[\frac{qEgo}{Ako}\frac{Tdiff}{TrTk}] \tag{3.8}$$

where Ego represent band gap energy for silicon and finally we get

$$Ipv = Iph - I_{o1}[exp[q\frac{V_p v + IPvR_s}{AK_b T_K} - 1]] - \frac{V_p v + IPvR_s}{R_p} \tag{3.9}$$

3.2   PV Under Normal Case

After expressing the mathematical model equations of a solar cell, now it is the turn of modeling a module composed of number of cells connected in series and parallel. When there is no shading effects and all modules has the same amount of irradiance (G) then according to equation (3.9) the PV current is presented in both sides which shows that it cannot be separately expressed as a function of the PV voltage Vpv. Therefore, it can determine the characteristic of the I-V of solar cell by solving equation below

$$F(I_{pv}, V_p v, T_k, G) = I_{ph} - I_{pv} - I_{o1}[exp[q\frac{V_{pv} + IPvR_s}{AK_b T_K} - 1]] - \frac{V_{pv} + IPvR_s}{R_p} \tag{3.10}$$
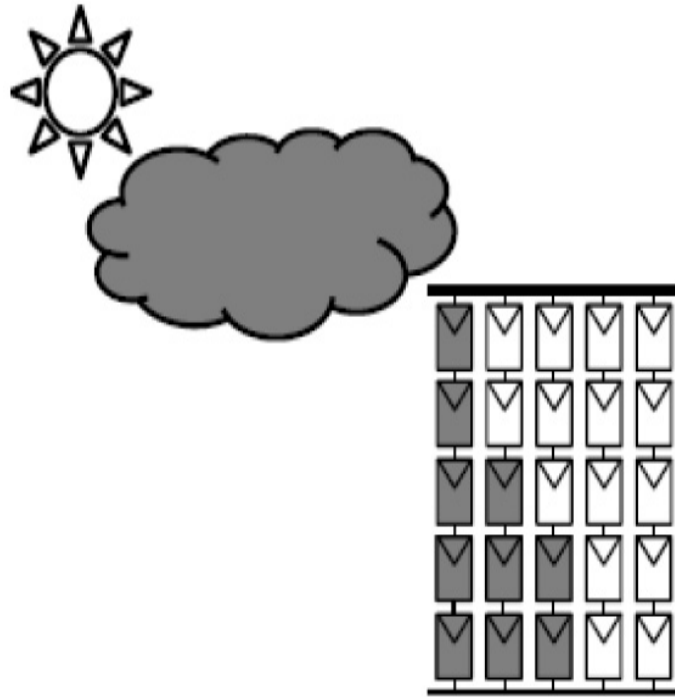
FIGURE 3.2: The Module with Partially Shaded Cells [42]

Where Rs and Ns are the number of series and parallel connected cells and branches.

3.3   PV Under Partial Shading

Figure 3.2 shows the equivalent circuit of connected cells considering the case of shading. Figure 3.3 shows the connection between cells with in module via bypass diode.

3.3.1   Causes and Consequences of Partial Shading

In the introduction section, the fact is pointed, the solar PV has a a weather dependent nature for the production of electricity. It is immensely affected by the temperature and irradiance changes. Electrical power is the product of the PV

voltage and PV current are affected negatively by increasing the temperature and by decreasing the irradiance. This condition is called shading condition. This condition has been occurred when the PV has been covered partially or fully by any static or movable object like clouds, trees, etc. Consequently, the shaded PVs produce current lower than the unshaded PVs. This difference in electrical characteristics affects the production drastically and dramatically because the shaded modules will be functioning as a load instead of its role as a source. Thereby, the total power is negatively affected and also the efficiency. In the following sections, the problem will be mathematically modeled and solutions are presented to avoid the negative effects of shading problem.

3.3.2   The Use of Bypass Diode for Partial Shading

Simply, when the cell is under shading condition, then it produce lower value of current than that of the whole cells produce. So its relevant bypass diode become forward biased. On the contrary, if it produces current more than that of the other cells it become reversed [43].

3.4   Mathematical Model of PV Module

After expressing the mathematical model equations of a solar cell, now it is the turn of modeling a module composed of number of cells connected in series and parallel. The normal case when there is no shading effects and all modules has the same amount of irradiance (G) then as it is clear in equation (3.9) the PV current is presented in both sides which means it cannot be separately expressed as a function of the PV voltage Vpv. Simply, when the cell is under shading condition then it produces lower value of current than that of the whole cells produce. So its relevant bypass diode become forward biased. On the contrary, if it produces current more than that of the other cells it become reversed. Therefore, the shaded module will be bypassed shown in Figure 3.4
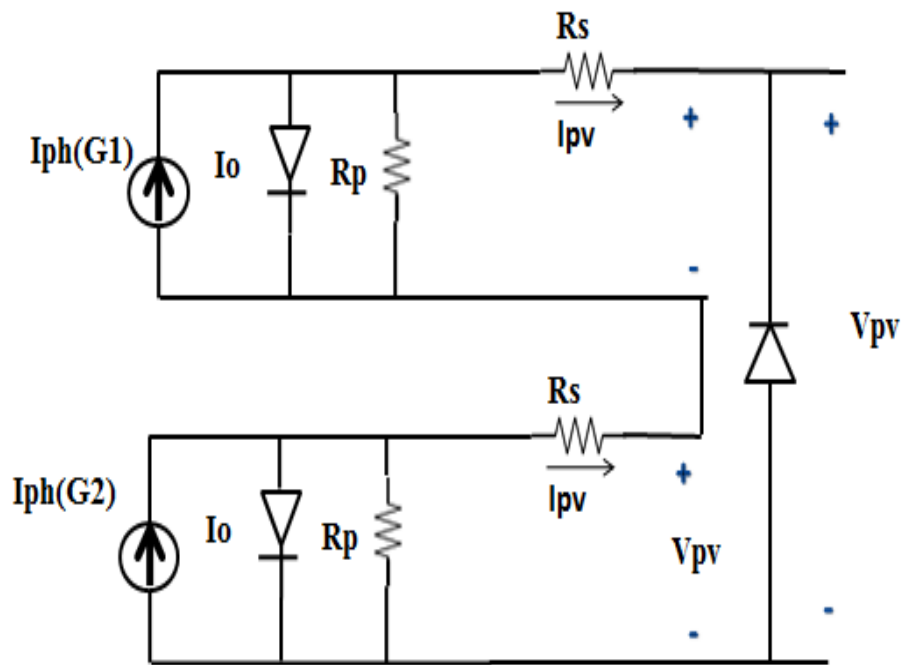
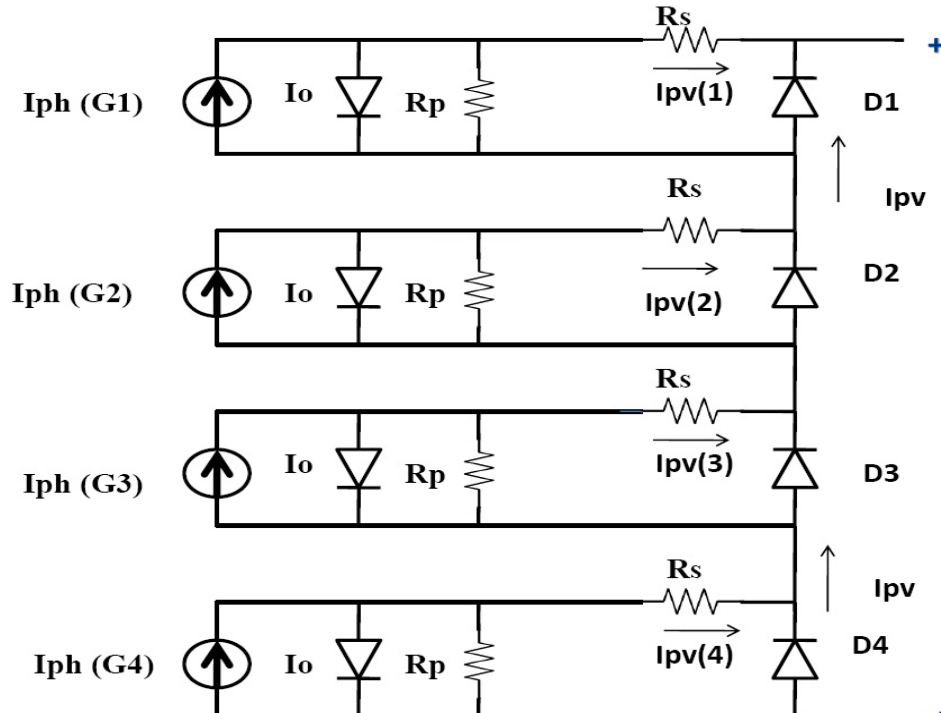FIGURE 3.3: Shows Equivalent Circuit of two Modules Connected with one bypass Diode [43]

FIGURE 3.4: Shows the Equivalent Circuit of Four PV Modules Connected with bypass Diode
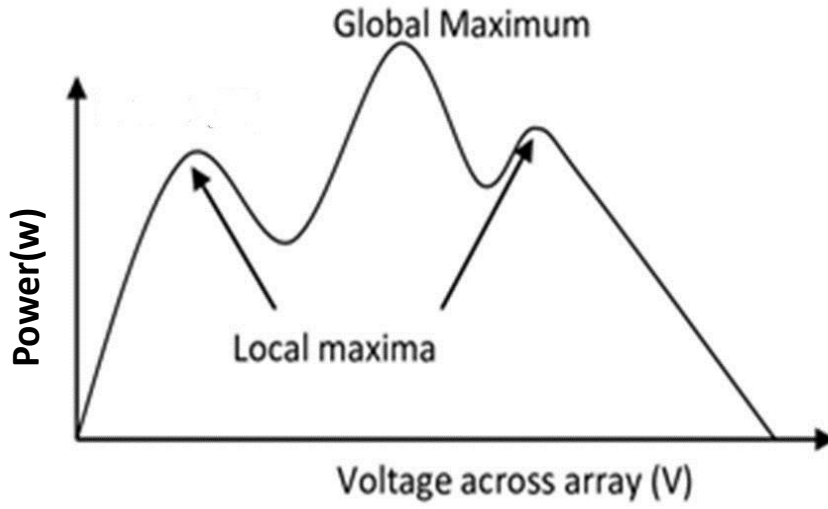
FIGURE 3.5: Shows P-V Curve During Partial Shading [16]

Now we calculate its Mathematical equation as done in single PV cell. Now the mathematical model of four PV module becomes;

$$I_{pv} = I_{ph} - I_{o1}[exp[q\frac{V_{pv1} + I_{Pv}R_s}{N_sAK_bT_K} - 1]] - \frac{V_{pv1} + I_{Pv}R_s}{N_sR_p} \tag{3.11}$$

$$I_{pv} = I_{ph} - I_{o1}[exp[q\frac{V_{pv2} + IPvR_s}{N_sAK_bT_K} - 1]] - \frac{V_{pv2} + I_{Pv}R_s}{N_sR_p} \tag{3.12}$$

$$I_{pv} = I_{ph} - I_{o1}[exp[q\frac{V_{pv3} + I_{Pv}R_s}{N_sAK_bT_K} - 1]] - \frac{V_{pv3} + I_{Pv}R_s}{NsR_p} \tag{3.13}$$

$$I_pv = I_{ph} - I_{o1}[exp[q\frac{V_{pv4} + IPvR_s}{N_sAK_bT_K} - 1]] - \frac{V_{pv4} + I_{Pv}R_s}{N_sR_p} \tag{3.14}$$

$$Vpv = Vpv1 \qquad \text{if} \quad Ipv > Iph1 \tag{3.15}$$

$$Vpv = Vpv2 + Vpv1 \qquad \text{if} \quad Ipv < Iph2 \tag{3.16}$$

$$Vpv = Vpv3 + Vpv2 + Vpv1 \qquad \text{if} \quad Ipv < Iph3 \tag{3.17}$$

$$Vpv = Vpv4 + Vpv3 + Vpv2 + Vpv1 \qquad \text{if} \quad Ipv < Iph4 \tag{3.18}$$

The equations from eqn 3.11 to 3.18 stated above govern the total voltage produced by the four PVs in case of shading as follow:

At beginning PV1 of the 1000 watt per meter square has the highest current production. So its related diode will be reversed off state and all other will be forwarded. So they are on state and the total voltage at this moment will be equal to Vpv1 until the current becomes less than that produced from PV2 which is subject to irradiance 800. In this case the voltage will be the sum of the Vpv1 + Vpv2 until the current fall down to be less than Iph3. In this case the voltage becomes equal to Vpv1+Vpv2+Vpv3 until the generated current go down to be less than the produced current from the lowest one PV4 where voltage will be the sum of the four voltages produced of the four panel and the current will be less than Iph4.

3.5   PV with MPPT and Boost Converter

Figure 3.6 shows the system block diagram including all system components of PV panels, DC-DC boost converter, MPPT controller. The proposed system has been supplied through four panels. The four panels are connected in series to produce specific value of voltage. The next main component is the Boost converter by which the voltage of the PV is boosted up to suit the required voltage of the Load. The third main component is the maximum power point tracking controller. The controller receives the temperature and irradiance of the PV and returns the optimum Duty cycle by which the system works at the maximum power point all the time.
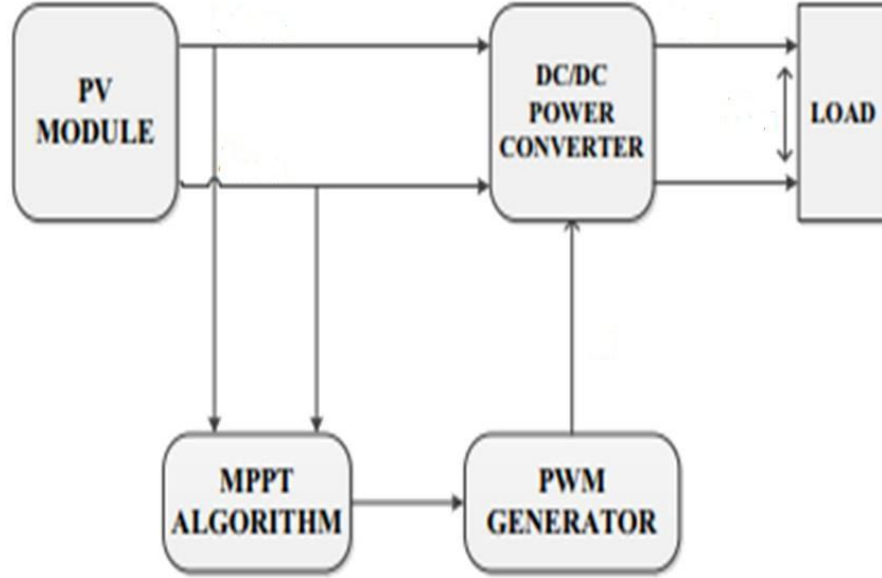
FIGURE 3.6: A General Overview of PV Module with MPPT and DC-DC Converter [44]

3.5.1 Propotional Integral Control

The PI controller is composed of proportional and integration control parts with gain Kp for the proportional and Ki for the integration control. These two combinations are adapted in order to realize two fold reducing the steady state error, reducing the rising time. The proportional effects is reducing the rising time and in turn accelerating the process of reaching the target. Adding integrator will make the output proportional to the steady state error. Consequently, it will reduce the steady state error. From the circuit of boost converter we compute the following :

$$V_{in}(s) = L\frac{dI_s}{dt} \tag{3.19}$$

$$V_{out}(s) = I_s(s)R \tag{3.20}$$

now input output relation is given as
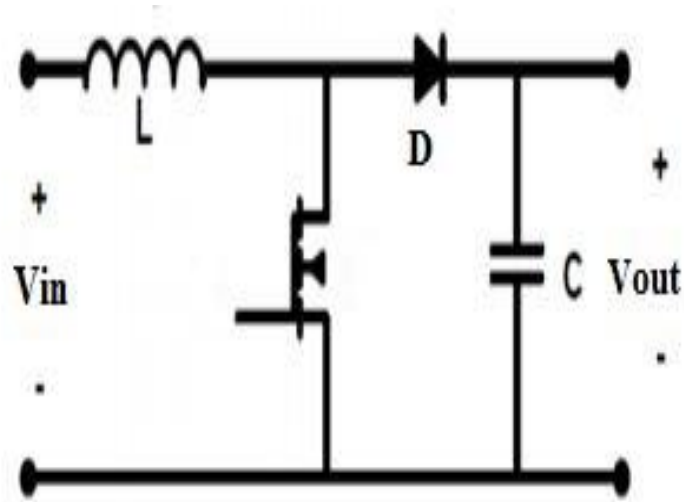
$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{R}{Ls} \tag{3.21}$$

FIGURE 3.7: Shows Circuit Diagram of Boost Converter [45]

Now considering the PI control as shown in Figure 3.8

$$V_{out} + [(\frac{R}{Ls})(k_p + \frac{k_i}{s})(\frac{1}{1-D})V_{out}] = V_{in}(\frac{R}{L \times s}) \tag{3.22}$$

and finally we get

$$\frac{V_{out}}{V_{in}} = \frac{(\frac{R}{L \times s})}{1 + [(\frac{R}{L \times s}) \times (k_p + \frac{k_i}{s}) \times (\frac{1}{1-D})]} \tag{3.23}$$

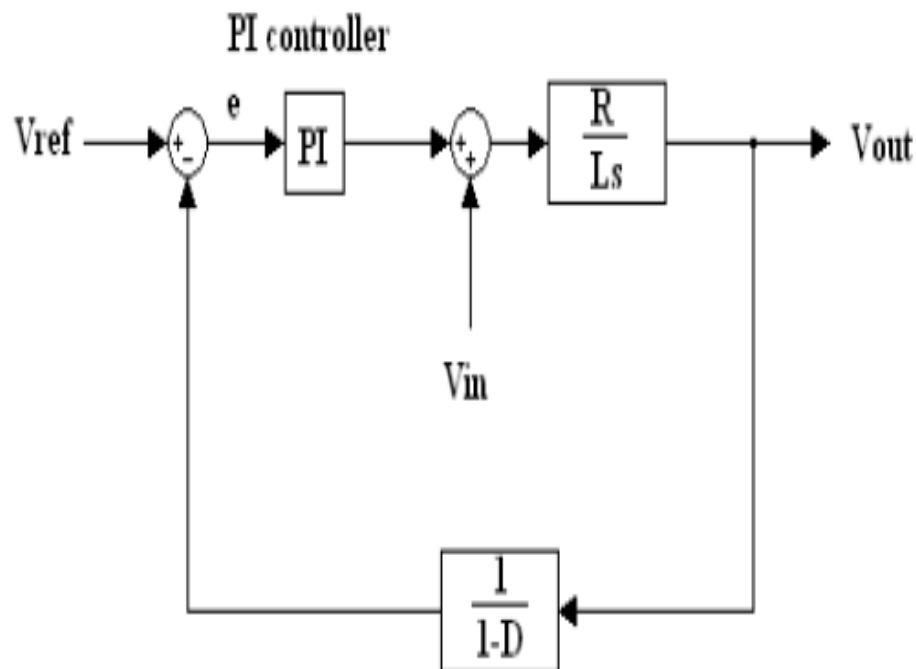Equation 3.23 shows the transfer function of closed loop system

FIGURE 3.8: Shows Circuit Diagram of PI Controller [45]

3.6 PV with Ordinary MPPT

Their are alot of MPPT technique for PV and they are proposed by many researchers and that have a common goal to extract maximum power from PV and operate the PV at its maximum power point (Pmax).

Perturb and Observe is very common Technique which is used for extracting maximum power from solar PV because it is very simple in implementation and very cheap compared to other MPPT Technique. This method senses the current and voltage of PV array and then compare power with respect to voltage as shown in Figure 3.9 and its Block diagram is shown in Figure 3.10. There are three conditions of checking power with respect to voltage if $\frac{dp}{dv} > 0$ it means that we are at the left side of power -voltage (P-V) curve. if $\frac{dp}{dv} < 0$ then we are at the right side of curve and if $\frac{dp}{dv} = 0$ then we are at maximum power point. In literature, it is shown that the method has efficiency of 90-93%. However, when there is condition of partial shading its efficiency declines. In figure 3.10 the reference of Voltage and Current is varied to set the MPP. After setting that the operating point of
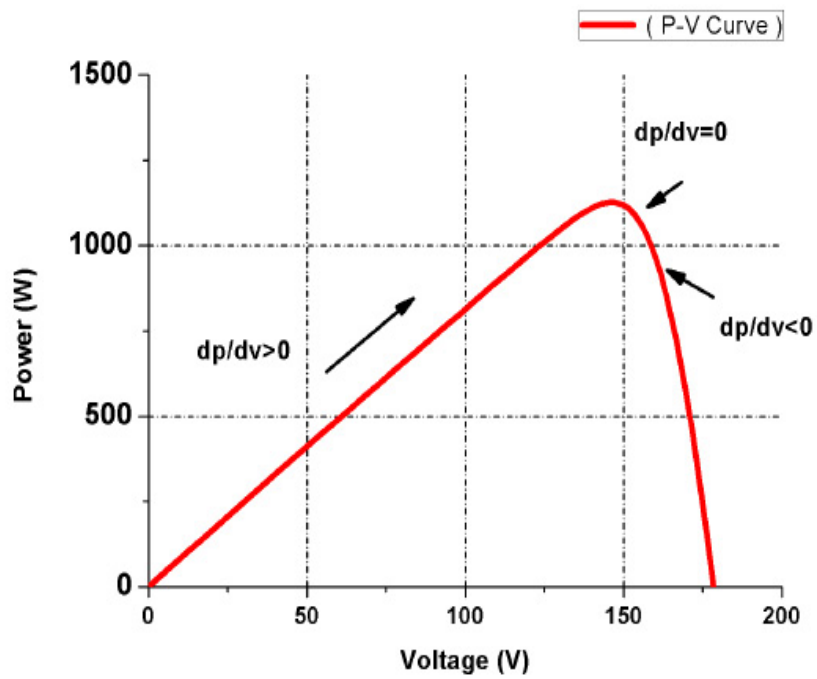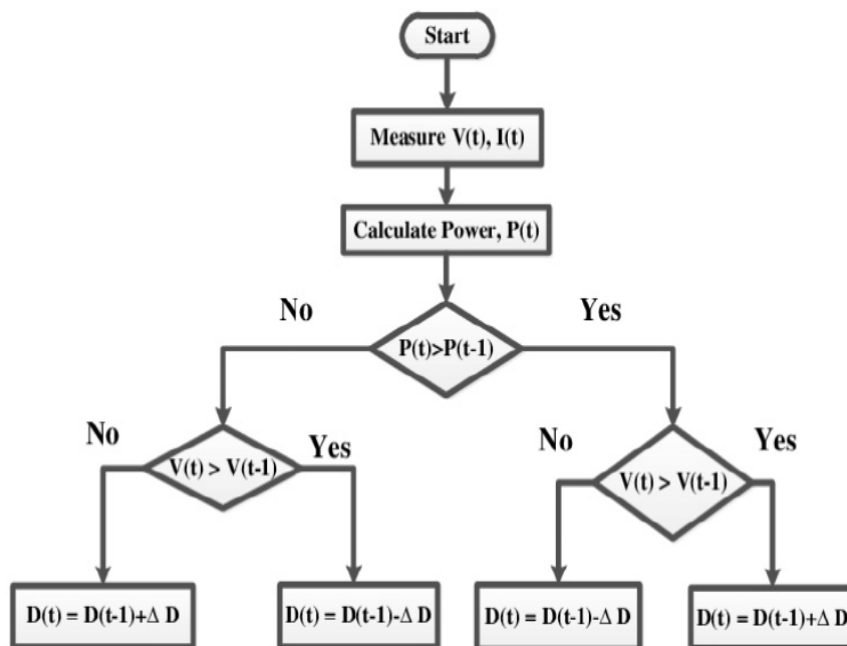
FIGURE 3.9: P-V Characteristic Curve of PV

FIGURE 3.10: Shows Flow Chart of Conventional Perturb and Observe Algorithm [46]

system is moved periodically by incrementing or decrementing the PV array Voltage or Current, if the operating voltage of PV is perturbed by small increment and the resulting change in power is positive, then we are in the direction of MPP and we keep on perturbing in the same direction to reach maximum power point and vice versa.

3.6.1   Matlab Model Of Ordinary PO

This section deals with system modeling and results. Matlab was chosen for testing the model and algorithm. The test bed system consists of Photovoltaic system, Ordinary perturb and observe method, boost converter that is implemented in Matlab/Simulink shown in Figure 3.11. The system simulation results, with both ordinary PO and Modified PO MPPT algorithms, are presented and discussed in next chapter.

This ordinary P0 system has been supplied through four panels. The four panels are connected in series to produce specific value of voltage and current. The next main component is the Boost converter by which the voltage of the PV is boosted up to suit the requirement voltage of the Load. The third main component is the maximum power point tracking controller. The controller receives the temperature and irradiance of the PV and returns the optimum duty cycle by which the system works at the maximum power point all the time.

when we click on Figure 3.11 in Solar PV Array Block we can adjust its parameter and it is given in Figure 3.13.
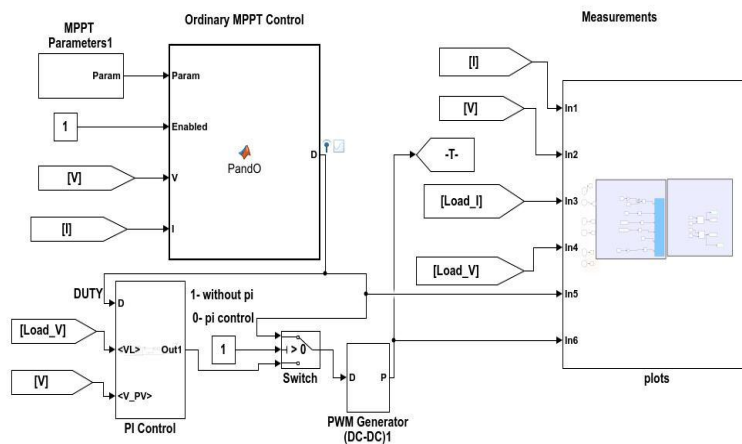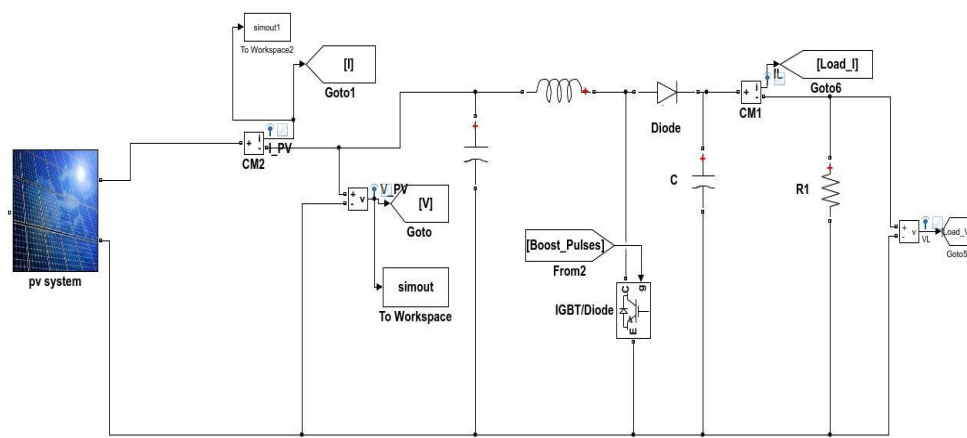
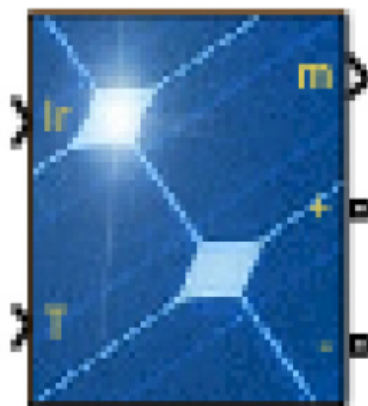FIGURE 3.11: Shows Overall Simulink Model with Ordinary Algorithm

FIGURE 3.12: Shows Matlab Model of Solar PV

FIGURE 3.13: Shows Parameter of Solar PV in Matlab

If we click on the block of PO in Figure 3.14 then its Coding is done in m file and it work on flow chart of Figure 3.10 its coding is given in appendix. The next feature is PI control and it is given in Figure 3.15 when we click PI control Block we get its block diagram that is implemented in matlab. The gains of Pi control are Kp, Ki and are set 1.3, 8.3 respectively.
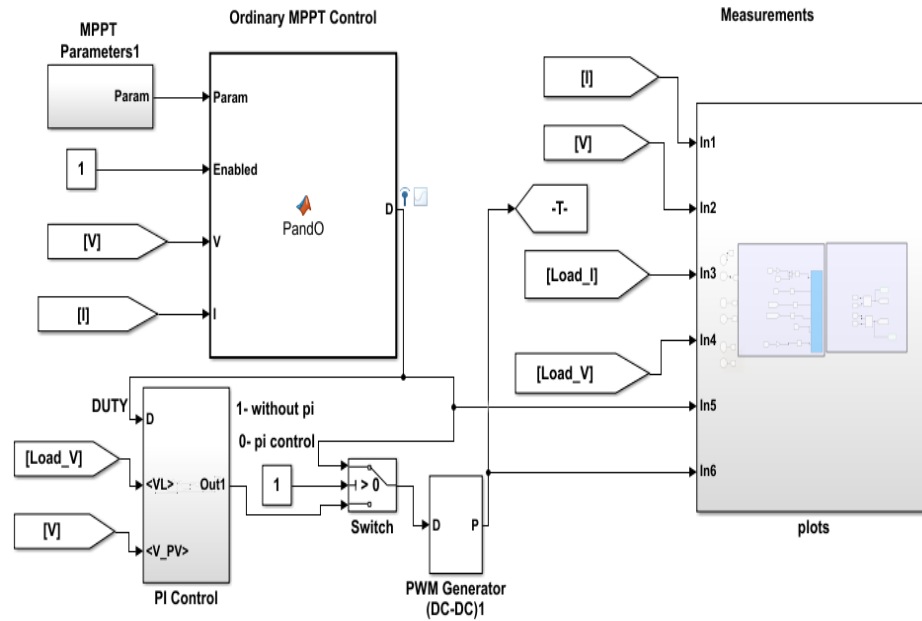
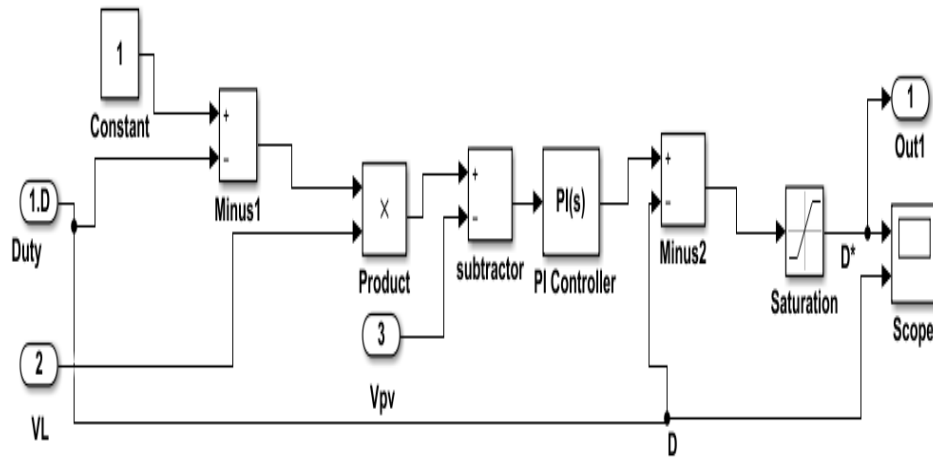FIGURE 3.14: Shows MPPT Control and PI Control and its Plots

FIGURE 3.15: Show PI Control Model in Matlab

TABLE 3.1: The Parameter of Boost Converter

Parameter	Value
Boost Converter inductor	L=5mH
Boost Converter Capacitor	C=1000microF
PV side Capacitor	C=2.5mF
Switching Frequency	7.5KHz

3.7 Matlab Model with Proposed Algorithm

This section deals with system modeling. Matlab was chosen for testing the model and algorithm. The test bed system consists of Photovoltaic system, Modified perturb and observe method, boost converter that is implemented in Matlab/simulink Figure 3.15. All the parameters are Kept same i.e PV Array, Boost converter Parameter, PI Control as done in case of Ordinary PO but the M File coding is changed because we propose a modified PO.

Figure 3.16 shows the flow chart of proposed algorithm The program always start with setting reference Voltage set to 80% of Voc. When their is no shading then ordinary MPPT will track the maximum power point and it will be in GMPP because it has one peak. So it measures the current and voltage and then calculate the power. It notices the change in voltage and the changes in power. It then determines the direction of movements in form of steps change in duty cycle. The reference of Voltage and Current is varied to set the MPP. After setting that Operating point of system is moved periodically by incrementing or decrementing the PV array Voltage or Current. The reference of Voltage and Current is varied to set the MPP, if the operating voltage of PV is perturbed by small increment and the resulting change in power is positive, then we are in the direction of MPP and we keep on perturbing in the same direction to reach maximum power point and vice versa. When we are at the MPP, it will store the Vmax and Pmax. Now

if the module Voltage is greater then a predetermined constant, it means that partial shading has occured and it will be called the GMPP Tracking.

GMPP Tracking is used for tracking the maximum power point. If any array has voltage less then zero, it means that the peak is on left side curve. So it will update
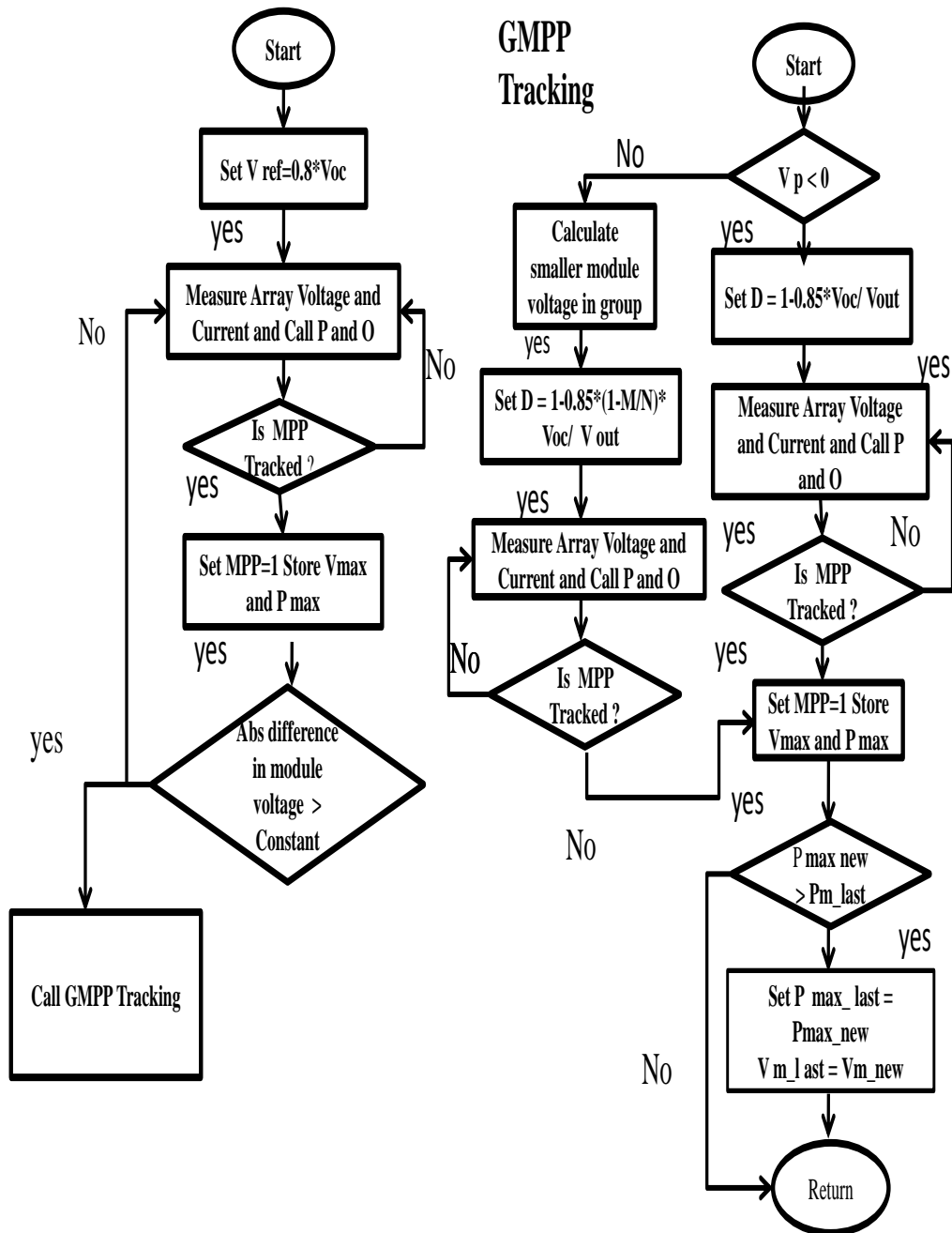
FIGURE 3.16: Shows Flow Chart of Proposed Algorithm

the Vref indirectly by setting the duty cycle and it will call the ordinary perturb and observe method. If the array voltage is greater then zero it will calculate the smaller voltage of array and calculate M, then it will set the Vref indirectly by setting the duty cycle and it will call the perturb and observe method and then it will store Vmax and Pmax. It will check power and compare it with last one and update it.
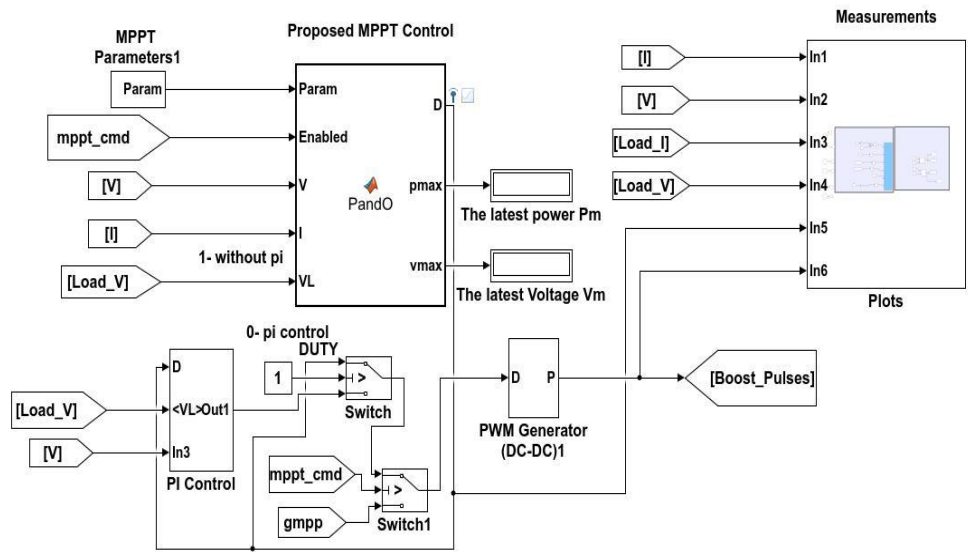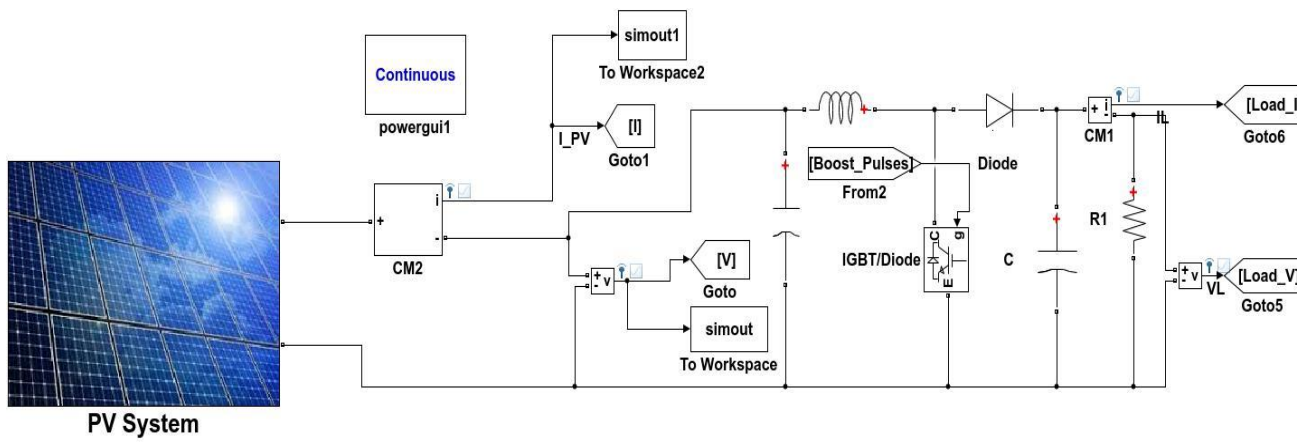
FIGURE 3.17: Shows Simulink Model With Proposed Algorithm

Chapter 4

Results and Simulations

This chapter presents the obtained results of the proposed model and also shows the results of the conventional model of PO. Two algorithms have been implemented in this regard. One for the conventional PO method and the other is the proposed technique for tracking the Global Maximum Power point. This chapter introduces the test cases that cover all conditions of operation including normal cases and shading cases. Furthermore, a complete comparison analysis of old and the proposed techniques is presented in this chapter.

4.1   The Conventional Method of PO

The traditional P0 method has been described logically in Figure 4.1. It shows the flow chart of the PO method. It measures the current and voltage and then calculate the power. It notices the change in voltage and the changes in power and then determines the direction of movements in form of step change in duty cycle as follow.
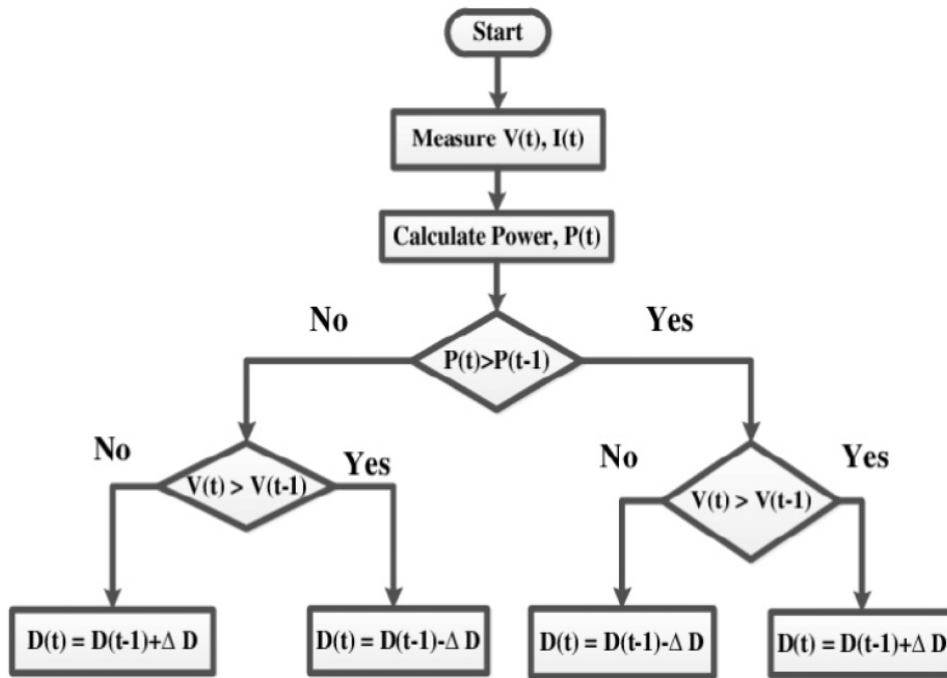
FIGURE 4.1: Shows Flow Chart of Conventional Perturb and Observe Algorithm[46]

4.2 The Proposed PO Working Principle

As it is fully described in the design and modeling chapter, the proposed method utilizes the MPPT PO with some modifications to bypass the shaded modules and remove its negative effects on the net power. It is simply searching the MPP and then checks the occurrence condition of a partial shading at which it triggers a global maximum power point GMPP. The GMPP logic is described in details in the design and modeling chapter. The advantage of this method appears obviously at when partial shading condition has been occurred. It can manage such condition efficiently. In the next section, the test cases, test results and discussion are presented in details.

According to the system, description that has been presented in the design and modeling chapter, the system composed of PV array of 4 modules, DC-DC converter, and the mppt controller. There are two algorithms to be tested with. The conventional PO MPPT algorithm and the proposed technique. The same configuration and system components will be utilized in every test. For testing

different operating condition, it should be gathering all cases of operation and run the system twice. One with the traditional PO and other time with the proposed techniques.

4.3 Normal Condition

In this condition, all modules receive the full sun irradiation as there is no shading. All modules are subject to 1000 Watt per meter square of irradiance.

4.3.1 Shading Condition with non Equal Distribution of Irradiance

In this case, there is a differences in the amount of sun to which they are subjected. In simulation two test pattern are considered. For pattern one Shown in Figure 4.3 each solar pannel are subjected to 1000, 800, 600, and 400 Watt per meter square respectively. For pattern two they are subjected to extreme rapid fluctuating irradiance.

The system will be run twice, one for the conventional technique and other run for the proposed method. The results are commented and discussed in details and separately to show the differences between the proposed method and the traditional one for every test cases.

4.4 Simulation with Ordinary P0 for Shading Pattern One

This ordinary P0 system has been supplied by four panels. The four panels are connected in series to produce specific value of voltage and current. The next main component is the Boost converter by which the voltage of the PV is boosted up to suit the requirement voltage of the load. And the third main component is the
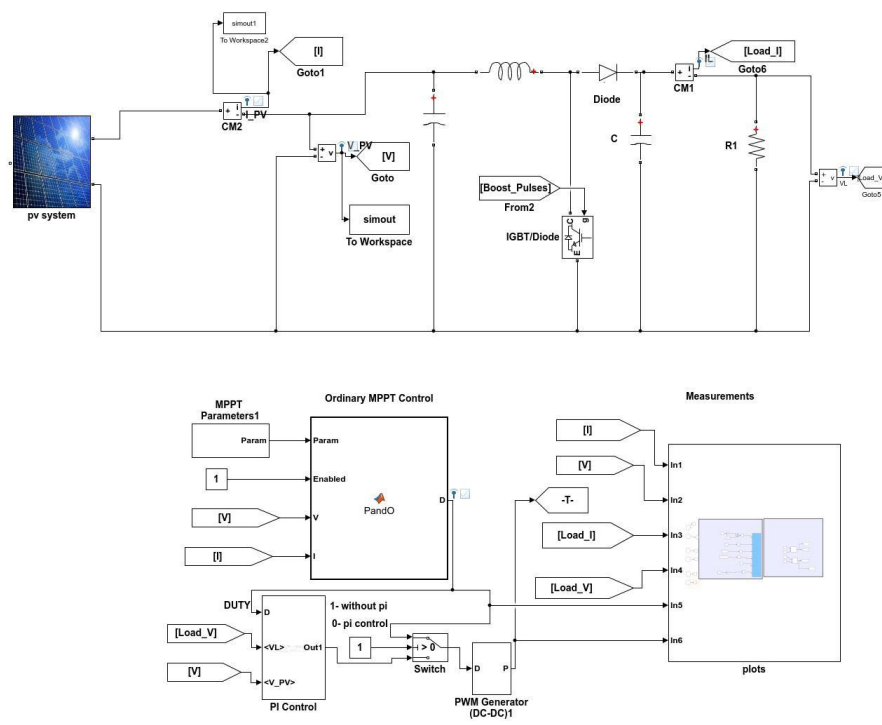
FIGURE 4.2: Shows Simulink Model with Ordinary P0

maximum power point tracking controller. The controller receives the temperature and irradiance of the PV and returns the optimum Duty cycle by which the system works at the maximum power point all the time.

The system simulation results, with ordinary P0 are presented and discussed in this section in Figure 4.2.

The non-shading period is from 0 to 0.3 s, so from the figure 4.4, it is clear that during non shading condition Vpv is increasing and it finally touch around 146V and which is constant. The shading period is from 0.33 to 0.7 s. During partial shading condition that starts from 0.33 s the Voltage of Vpv starts decreasing as shading may occur due to multiple reasons (Clouds, Trees, buildings etc) and it is almost constant at approximately at 103 V with oscillation. The same scenario is for output voltage of Boost converter during non-shading it reaches 179 V and during shading it touches 121 V.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.5 it is clear that during non shading condition Array current is almost at 8.3 A, and it is constant at 7.4 A and their is oscillation also. The shading period is from 0.33 to 0.7 s.
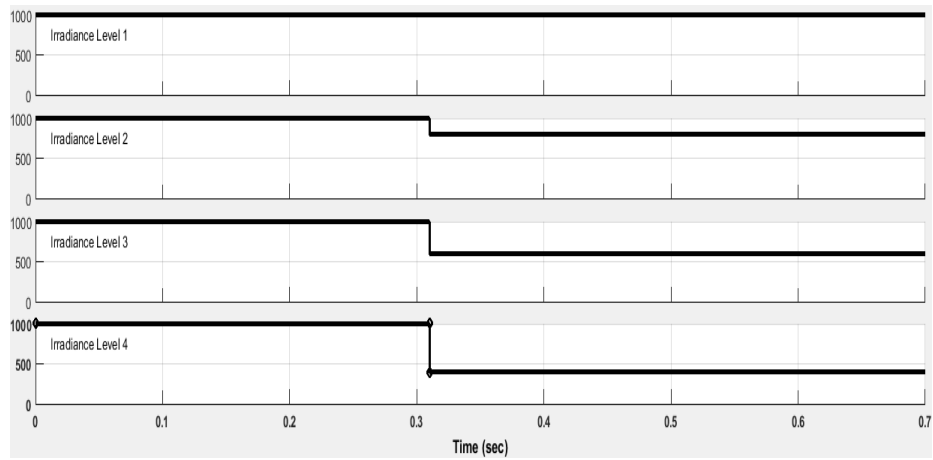
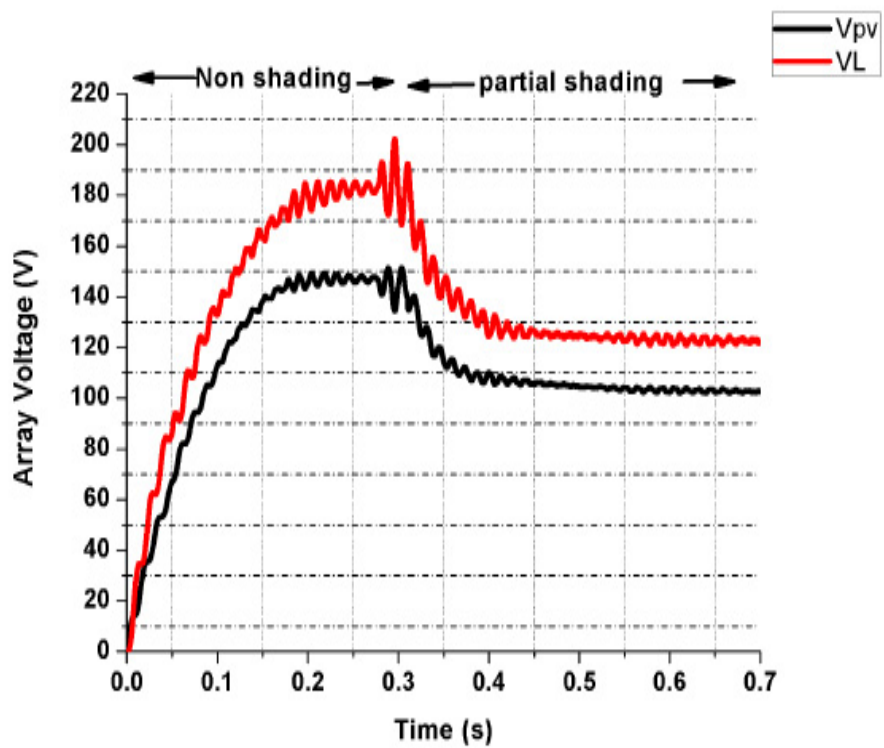FIGURE 4.3: Shows Different Irradiance levels on Solar Pannels

FIGURE 4.4: Shows PV Array Voltage and Output Voltage Of Boost Converter for Case Of Ordinary PO
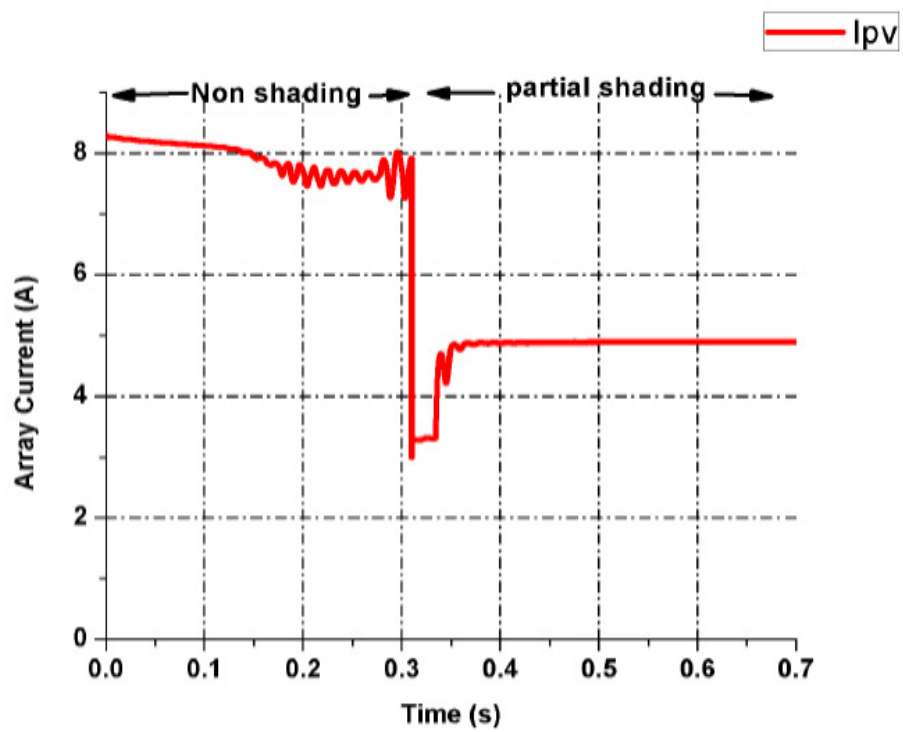
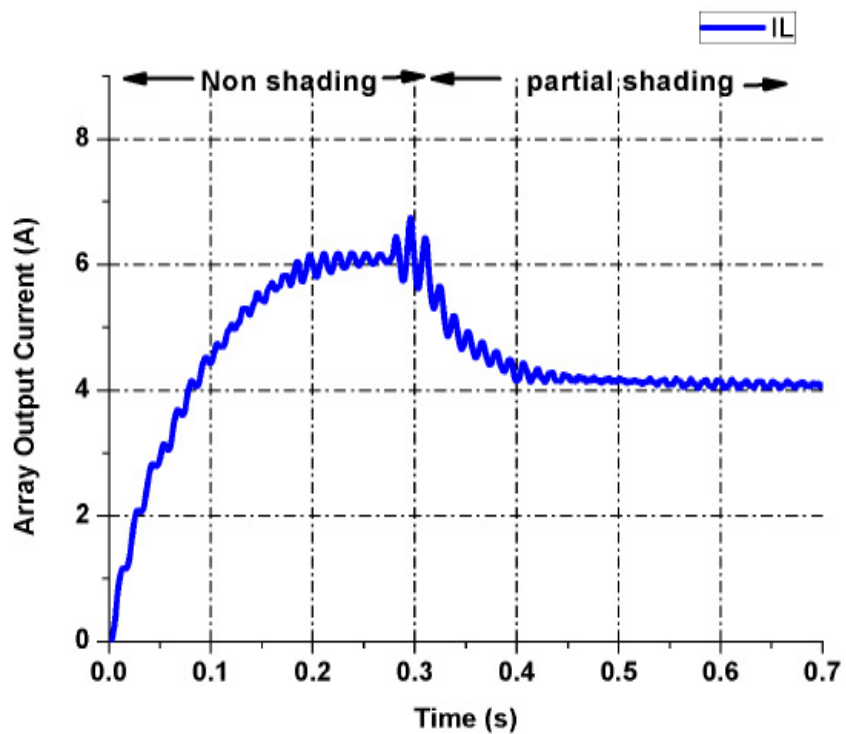FIGURE 4.5: Shows PV Array Current in case Ordinary PO

FIGURE 4.6: Shows Output Current in case of Ordinary PO
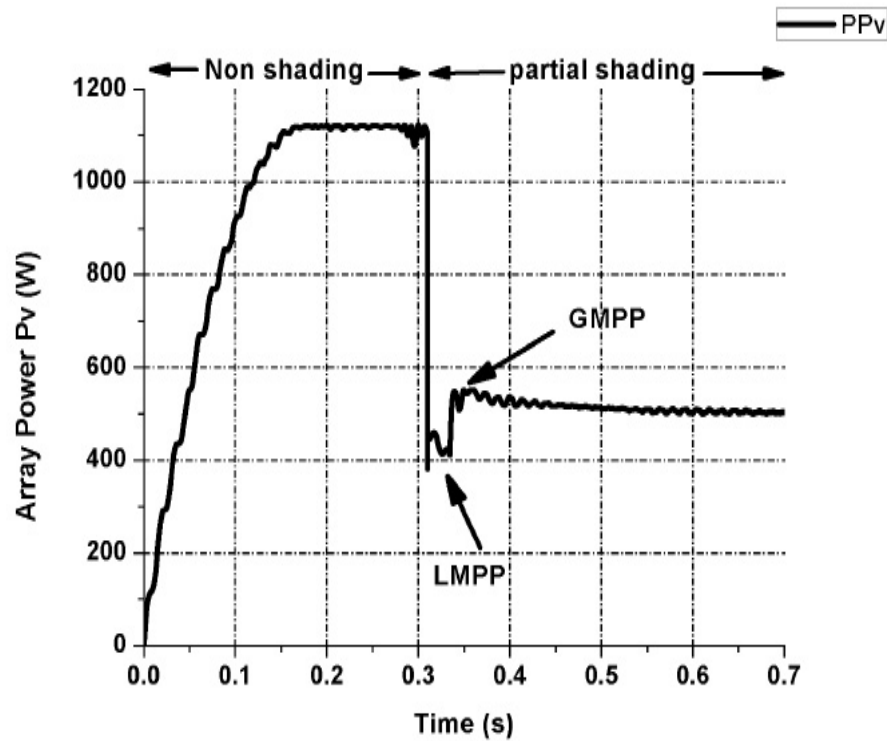
FIGURE 4.7: Shows PV Array Power in case of Ordinary PO

During this period Array current PV (Ipv) abruptly reach to 2.5 A as shading may occur due to multiple reasons and it is almost constant at approximately at 4.85 A.

The same scenario is for output current shown in figure 4.5. During non-shading case, the current is increasing gradually and then it is constant approximately at 6 A with oscillation also. But when it reaches 0.33 s the current decreases which is the disadvantage of partial shading but remains constant at 4.08 A.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.7. It is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant. During partial shading condition as it starts from 0.3 s during this period power is abruptly reaches to 400 W and it is almost constant at approximately at 499 W. The same scenario is for output power. During non-shading case the power increases gradually and then it becomes constant approximately 1080 W with oscillation. But when it reaches 0.3 s the partial shading occur and the power decreases which is the disadvantage of partial shading but remain constants at 494 W. This is given in figure 4.8.
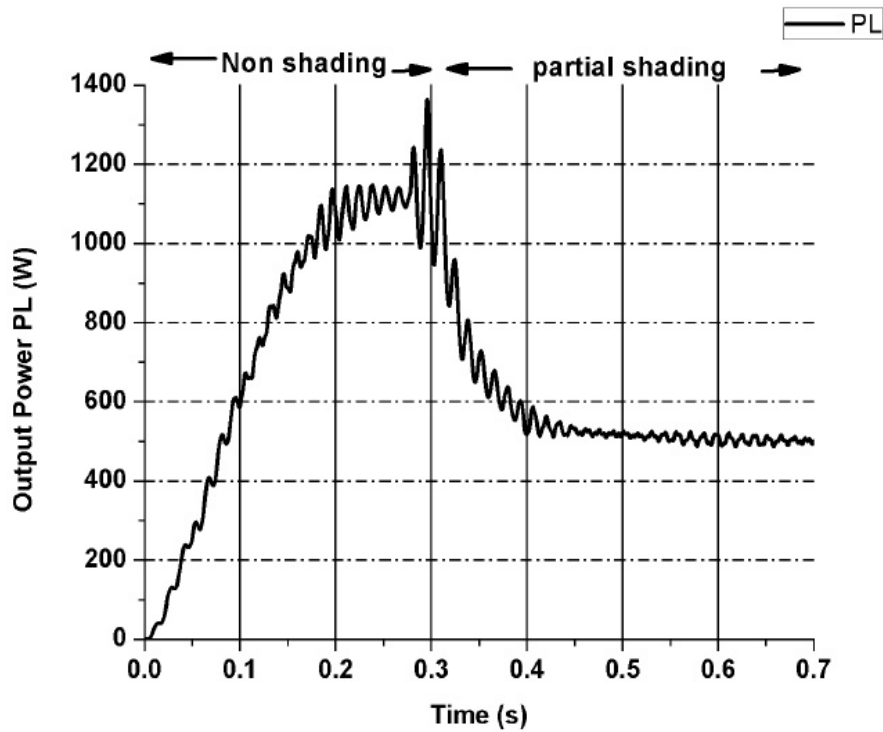
FIGURE 4.8: Shows Output Power in case of Ordinary PO

4.5 Simulation with Proposed P0 for Shading Pattern One

This proposed PO system has been supplied by four panels. The same parameter was chosen for proposed PO. The four panels are connected in series to produce specific value of voltage and curren. The next main components is the Boost converter by which the voltage of the PV is boosted up to suit the required voltage of the load. And the third main components is the maximum power point tracking controller. The controller receives the temperature and irradiance of the PV and returns the optimum Duty cycle by which the system works at the maximum power point all the time.

The system simulation results, with proposed PO are presented and discussed in this section. Figure 4.9 shows Simulink model with proposed algorithm.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.10 it is clear that during non-shading condition Vpv is increasing and it finally touches around 146 V and then it is constant. If we compare to ordinary PO oscillation is less.

The shading period is from 0.33 to 0.7 s. During partial shading condition as it starts from 0.3 s the Voltage of Vpv starts decreasing and it is almost constant at approximately at 103 V. The same scenario is for output voltage of boost converter shown in figure 4.9. It reaches to 204 V during non shading and 144 V during shading.

 The non-shading period is from 0.33 to 0.7 s so, from the figure 4.11 it is clear that during non-shading condition Array current is almost at 8.3 A. It is constant at 7.4 A. The shading period is from 0.3 to 0.7 s. During partial shading condition as it starts from 0.33 s the PV Array current PV (Ipv) abruptly reaches to 2.5 A as shading may occur due to multiple reasons and it is almost constant at approximately at 5.2 A.

The same scenario is for output current. During non-shading case the current is increasing gradually and then becomes constant approximately at 5.2 A with less oscillation as compare with ordinary PO. But when it reaches 0.33 s the partial shading occurs and the current decreases which is the disadvantage of partial shading but it is remains constant at 3.7 A. This is given in figure 4.12.
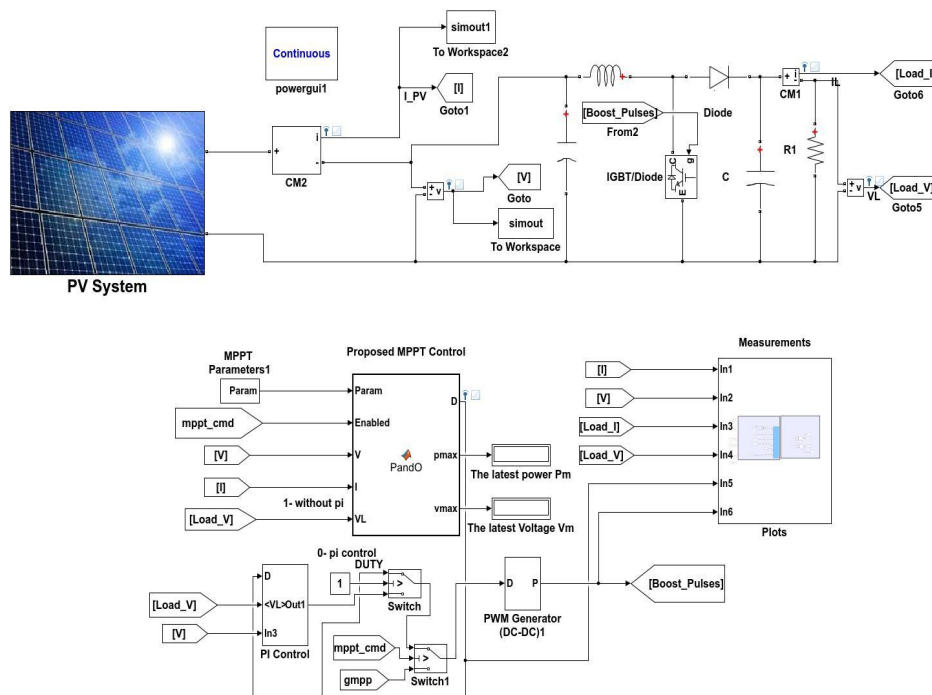

FIGURE 4.9: Shows Simulink Model with Proposed P0
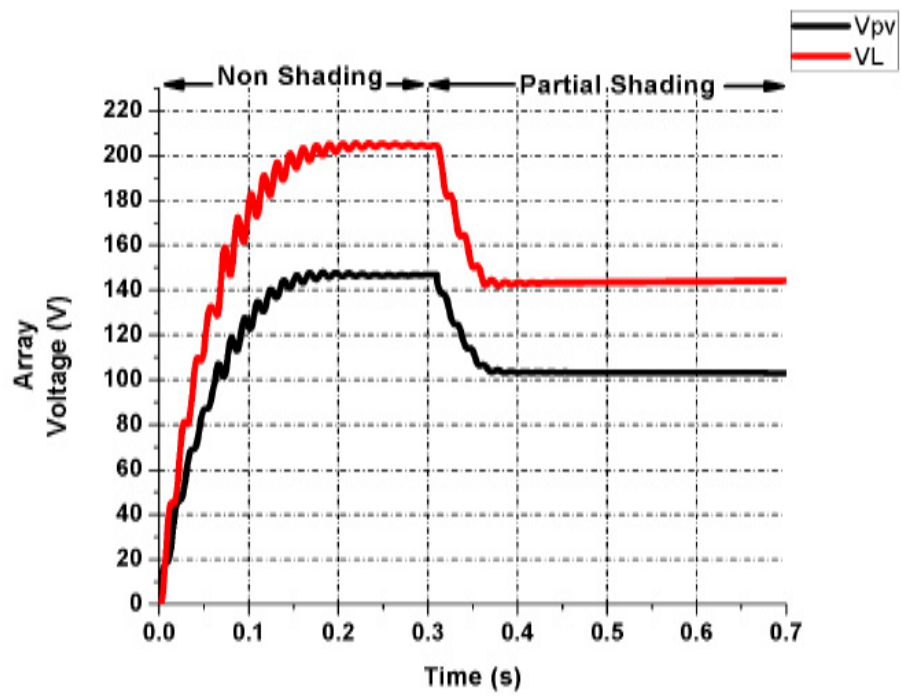
FIGURE 4.10: Shows PV Array voltage and Output Voltage Of Boost Converter for Case Of Proposed P0
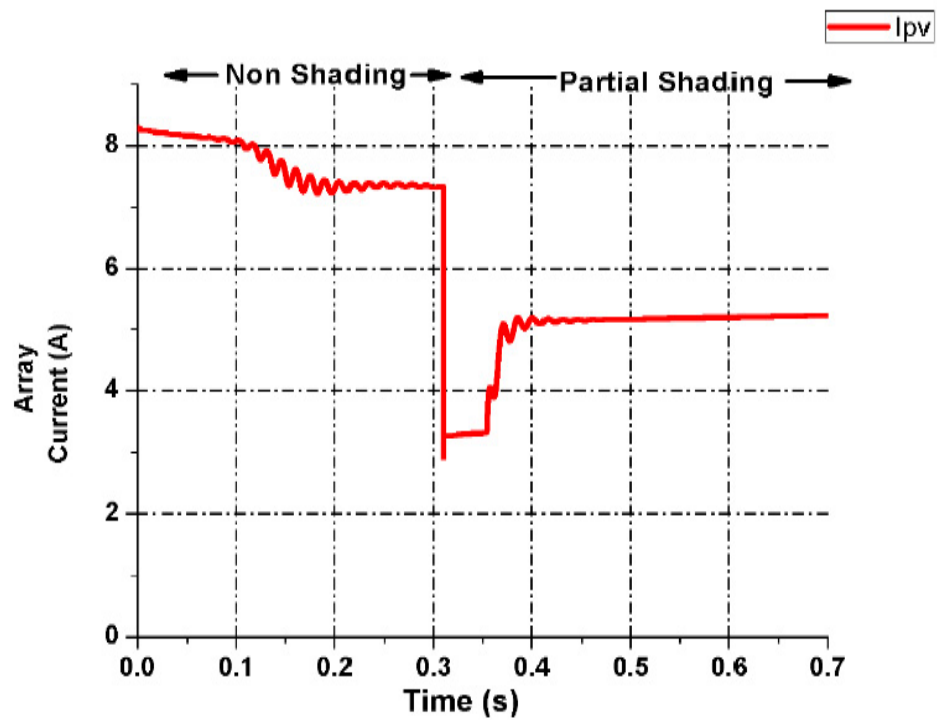
FIGURE 4.11: Shows PV Array Current in case of Proposed PO
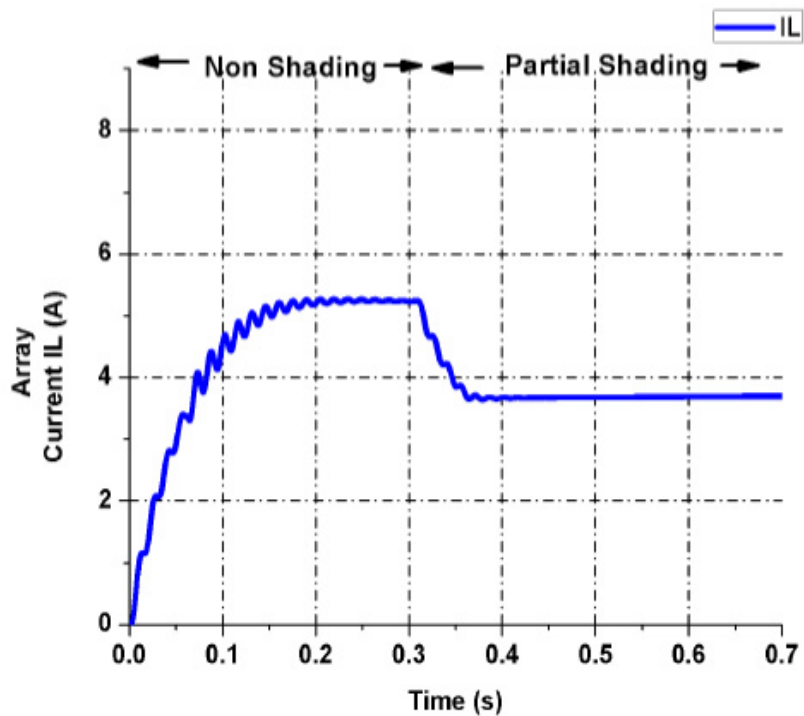
FIGURE 4.12: Shows Output Current in case of Proposed P0

The non-shading period is from 0 to 0.3 s, so from the figure 4.13 it is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant with little oscillation as compared to ordinary PO. The shading period is from 0.33 to 0.7 s. During partial shading condition that starts from 0.33 s the power is abruptly reaches to 400 W and it is almost constant at approximately at 537 W. It has less oscillation compare with PO method.

The same scenario is for output power. During non-shading case the power is increasing gradually and then it is constant approximately 1080 W with oscillation. But when it reaches 0.3 s the partial shading occurs and the current decreases but is remains constant at 531 W. This is given in figure 4.14.
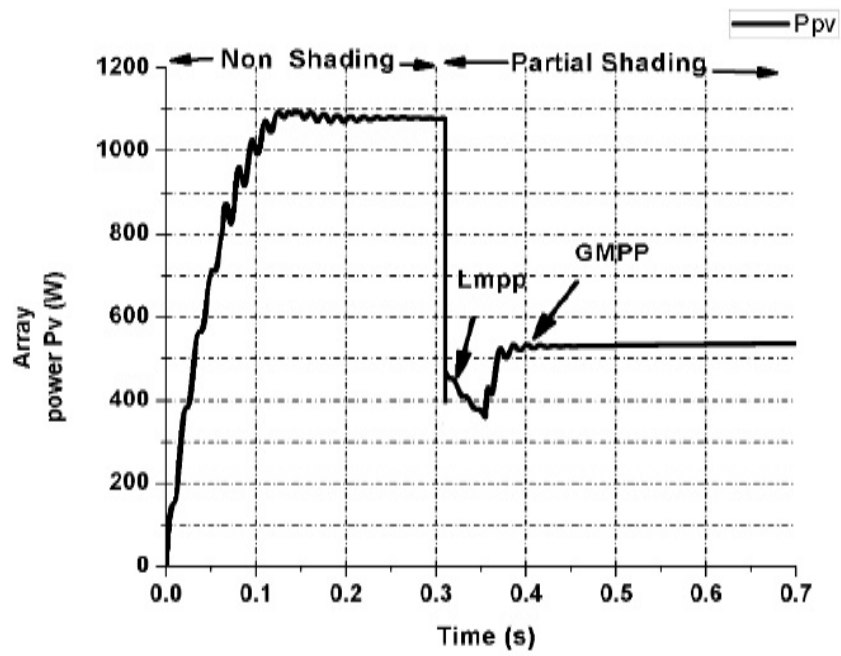
FIGURE 4.13: Shows PV Array Power in Case of Proposed P0
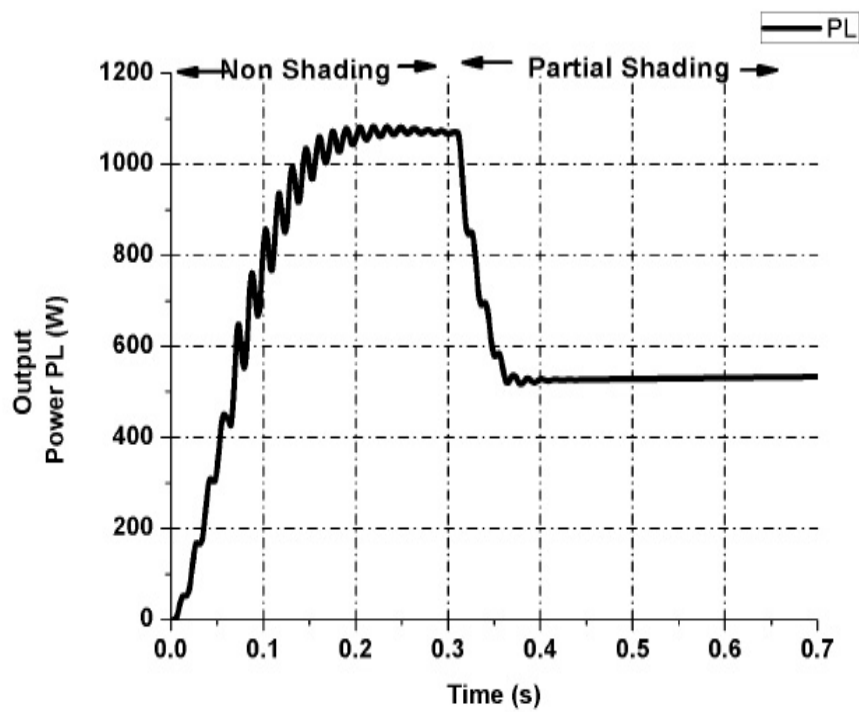
FIGURE 4.14: Shows Output Power in case of Proposed P0

TABLE 4.1: Comparison of Proposed and Ordinary Algorithm for Pattern One

Tracking Method	During Non shading	During Shading
Ordinary PO Method	1080W	499W
Proposed PO Method	1080W	537W
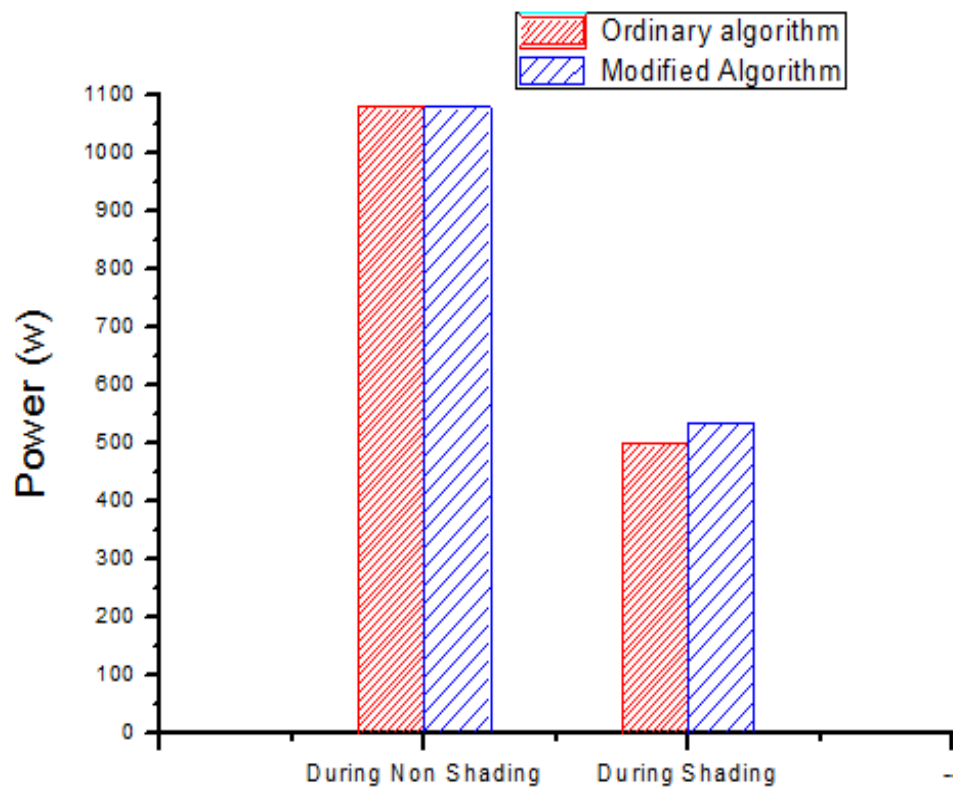
FIGURE 4.15: Shows Bar Graph of Comparison Proposed and Ordinary Algorithm for Pattern one
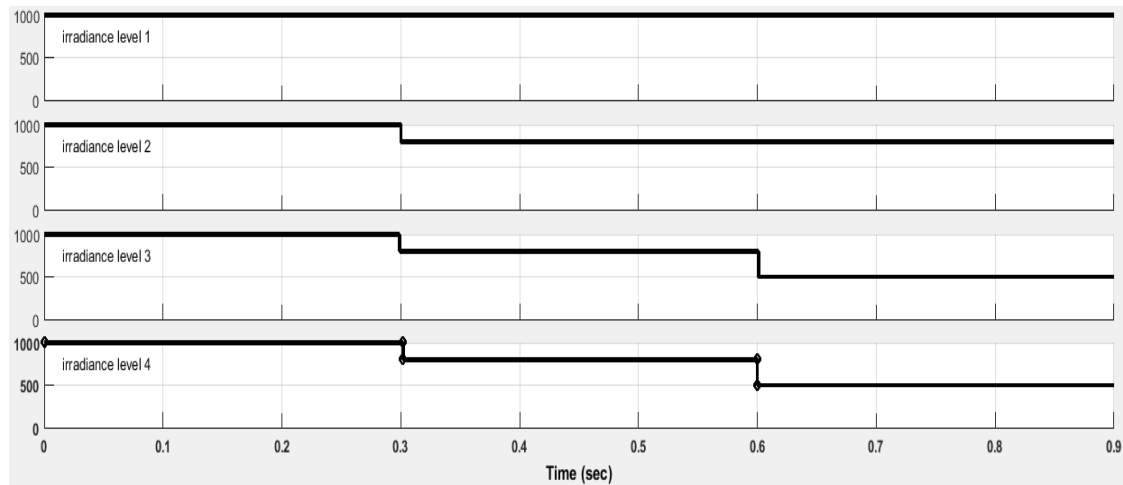
FIGURE 4.16: Shows different Irradiance levels on Solar Pannels

4.6 Simulation with Ordinary P0 for Pattern Two

For pattern two all Solar Panels are subjected to extreme rapid fluctuating irradiance. There are four different irradiance levels as shown in figure 4.16.

The non-shading period is from 0 to 0.3 s, so from the figure 4.17, it is clear that during non shading condition Vpv is increasing and it finally touch around 146V and which is constant. The shading period is from 0.3 to 0.9 s. During partial shading condition that starts from 0.3 s to 0.6 s the Voltage of Vpv starts decreasing. During this period it is 137 V and from 0.6 s to 0.9 s it is almost constant approximately at 89 V with oscillation. The same scenario is for output voltage of Boost converter during non-shading it reaches 179 V and during shading it touches 105 V.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.18 it is clear that during non shading condition Array current is almost at 8.3 A, and it is constant at 7.4 A and their is oscillation also. The shading period is from 0.3 to 0.9 s. During 0.3 s to 0.6 s the current is 6.4 A. During 0.6 s to 0.9 s it is almost constant

FIGURE 4.17: Shows PV Array voltage and Output Voltage Of Boost Converter for Case Of ordinary PO

approximately at 4.13 A.

The same scenario is for output current shown in Figure 4.19. During non-shading case, the current is increasing gradually and then it is constant approximately at 7.4 A with oscillation also. From 0.3 s to 0.6 s the current decreases and it reaches to 5.4 A and then from 0.6 s to 0.9 s remains constant at 3.44 A.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.20. It is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant. The partial shading condition as it starts from 0.3 s to 0.9 s. During 0.3 to 0.6 s the power is 876 W and from 0.6 s to 0.9 s it is constant approximately at 367W.

The same scenario is for output power. The non-shading period is from 0 to 0.3 s so, from the Figure 4.21. It is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant. The partial shading condition as it starts from 0.3 s to 0.9 s. During 0.3 to 0.6 s the
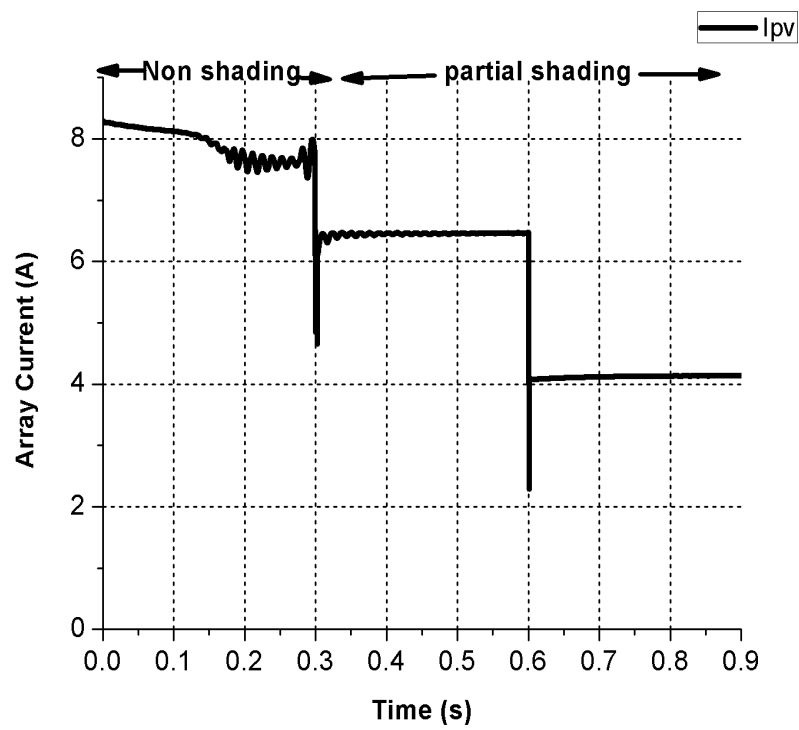
FIGURE 4.18: Shows PV Array Current in case Ordinary PO
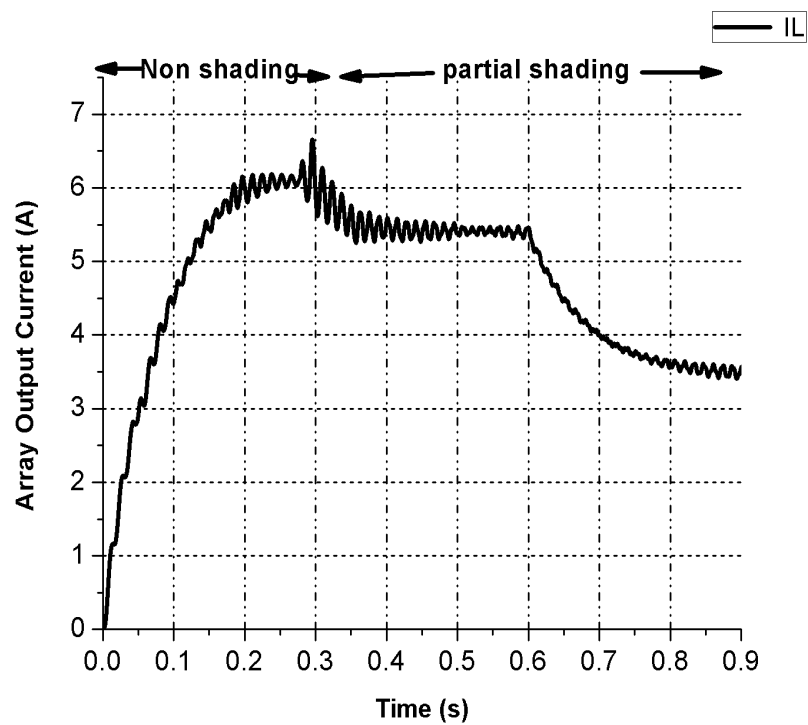
FIGURE 4.19: Shows PV Array Output Current in case Ordinary PO
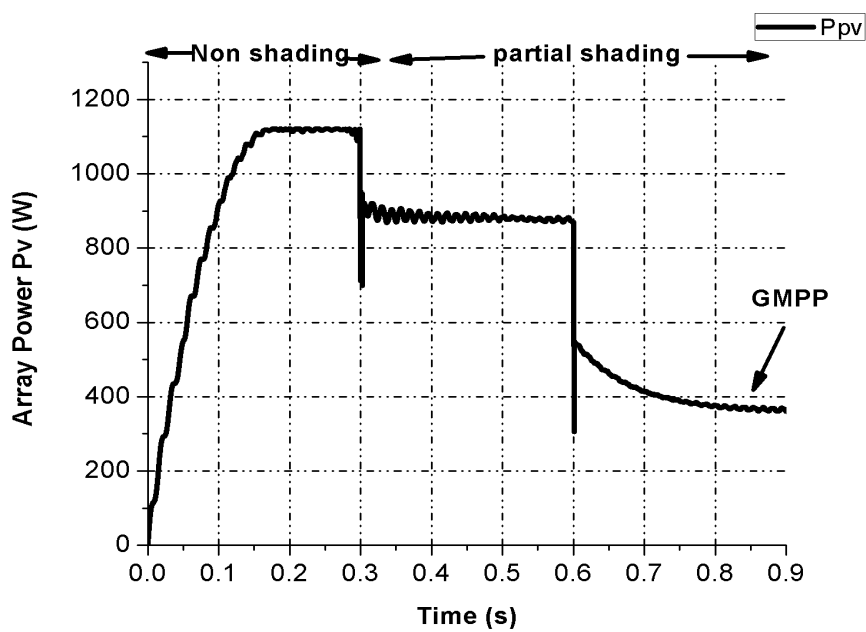
FIGURE 4.20: Shows PV Array Power in case of Ordinary PO

output power is 873 W and from 0.6 s to 0.9 s it is constant approximately at 367W.
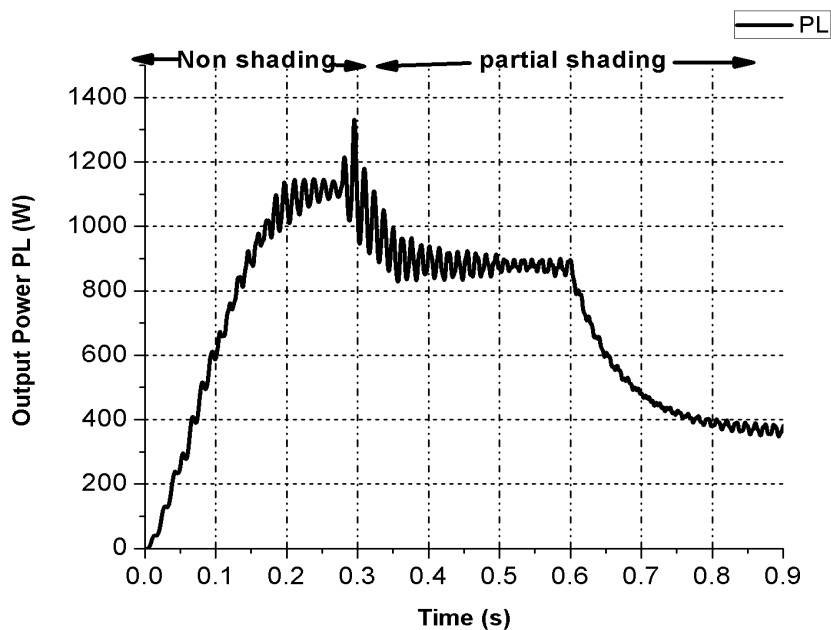
FIGURE 4.21: Shows Output Power in case of Ordinary PO
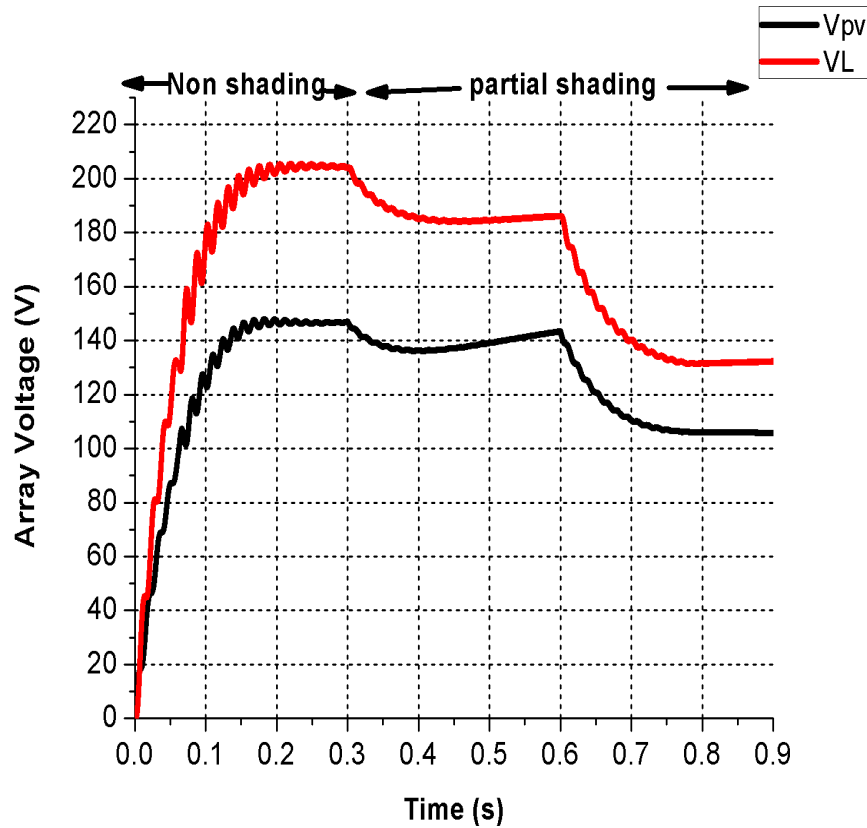
FIGURE 4.22: Shows PV Array voltage and Output Voltage Of Boost Converter for Case of Proposed PO

4.7 Simulation with Proposed P0 for Pattern Two

For pattern two all Solar Panels are subjected to extreme rapid fluctuating irradiance. There are four different irradiance levels shown in Figure 4.16.

The non-shading period is from 0 to 0.3 s, so from the figure 4.22, it is clear that during non shading condition Vpv is increasing and it finally touch around 146V and which is constant. The shading period is from 0.3 to 0.9 s. During partial shading condition that starts from 0.3 s to 0.6 s the Voltage of Vpv starts decreasing. During this period it is 138 V and from 0.6 s to 0.9 s it is almost constant approximately at 106 V with oscillation. The same scenario is for output voltage of Boost converter during non-shading it reaches 179 V and during shading it touches 131 V.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.23 it is clear that during non shading condition Array current is almost at 8.3 A, and it is constant
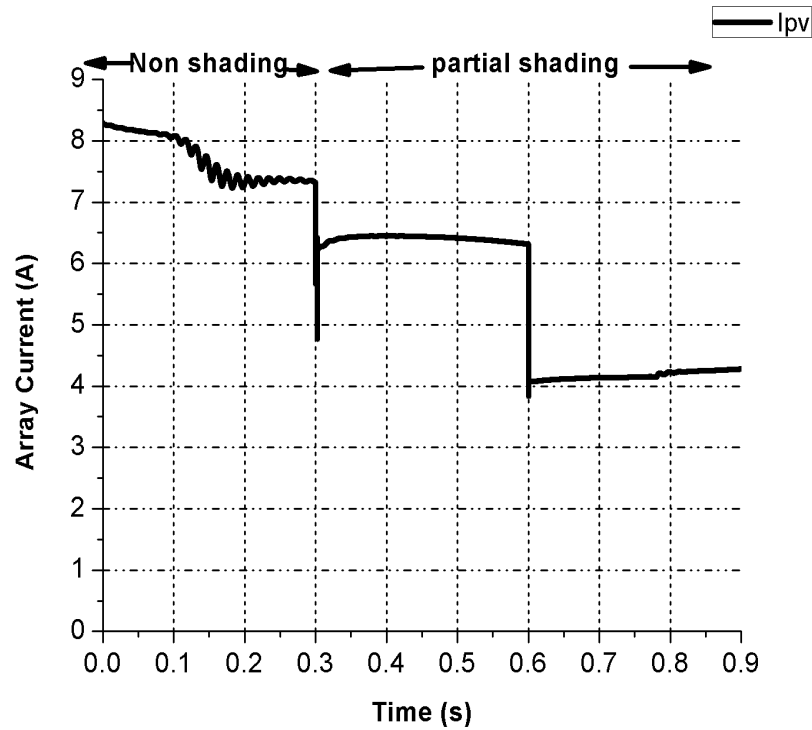
FIGURE 4.23: Shows PV Array Current in case Proposed PO

at 7.4 A and their is oscillation also. The shading period is from 0.3 to 0.9 s. During 0.3 s to 0.6 s the current is 6.4 A. During 0.6 s to 0.9 s it is almost constant approximately at 4.23 A.
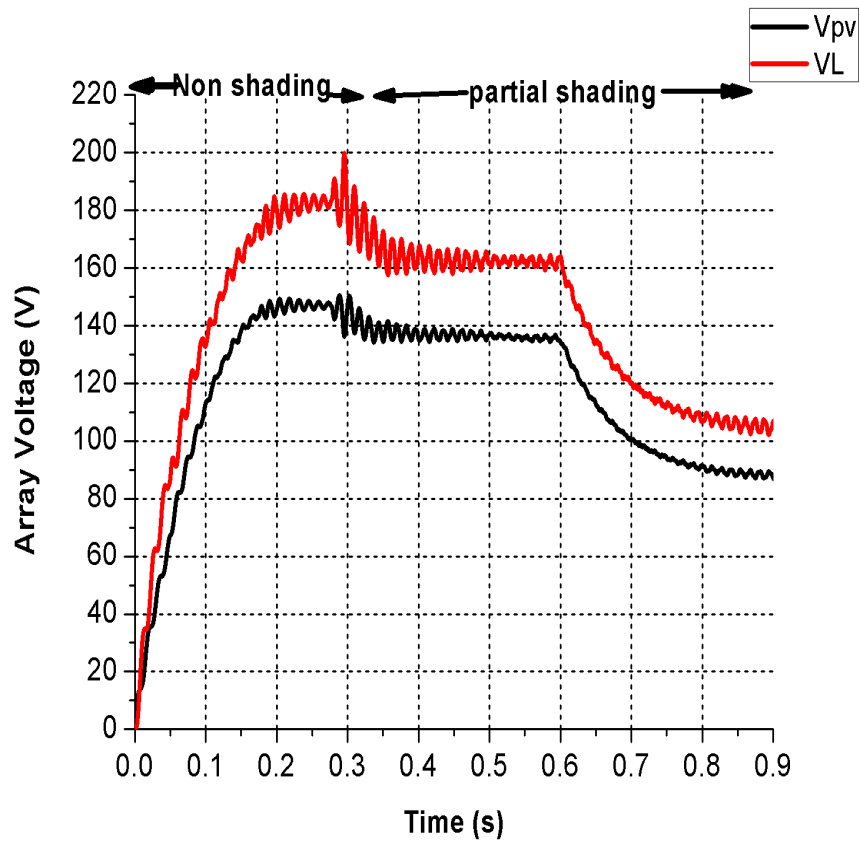
The same scenario is for output current shown in Figure 4.24. During non-shading case, the current is increasing gradually and then it is constant approximately at 7.4 A with oscillation also. From 0.3 s to 0.6 s the current decreases and it reaches to 6.4 A and then from 0.6 s to 0.9 s remains constant at 4.23 A.

The non-shading period is from 0 to 0.3 s so, from the Figure 4.25. It is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant. The partial shading condition as it starts from 0.3 s to 0.9 s. During 0.3 to 0.6 s the Array power Ppv is 884 W and from 0.6 s to 0.9 s it is constant approximately at 448 W. The same scenario is for output power. The non-shading period is from 0 to 0.3 s so, from the Figure 4.26. It is clear that during non shading condition Array Power Ppv is increasing and it finally touches around 1080W and then it is constant. The partial shading condition as it starts from 0.3 s to 0.9 s. During 0.3 to 0.6 s the output power is 878 W
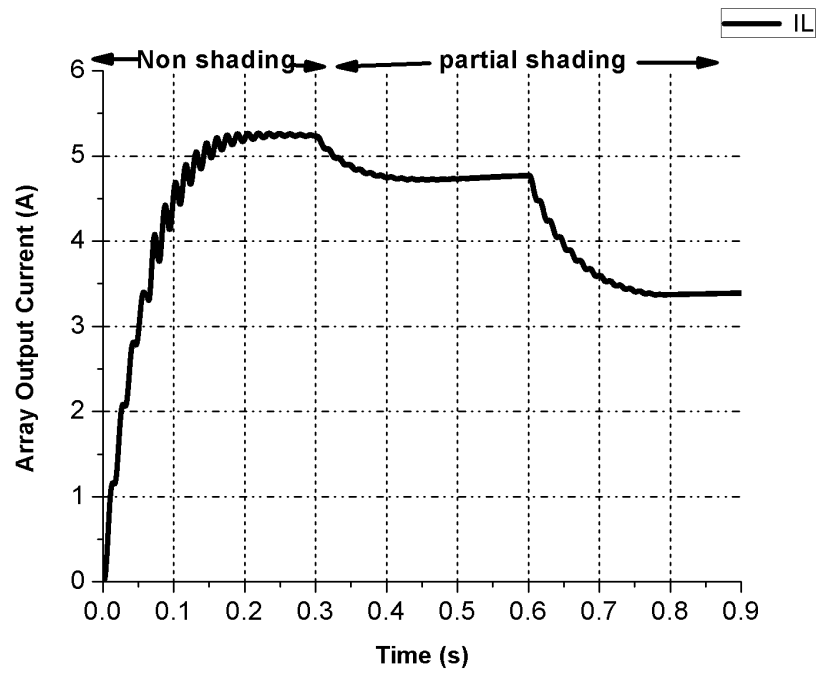
FIGURE 4.24: Shows PV Array Output Current in case Proposed PO

and from 0.6 s to 0.9 s it is constant approximately at 441 W.
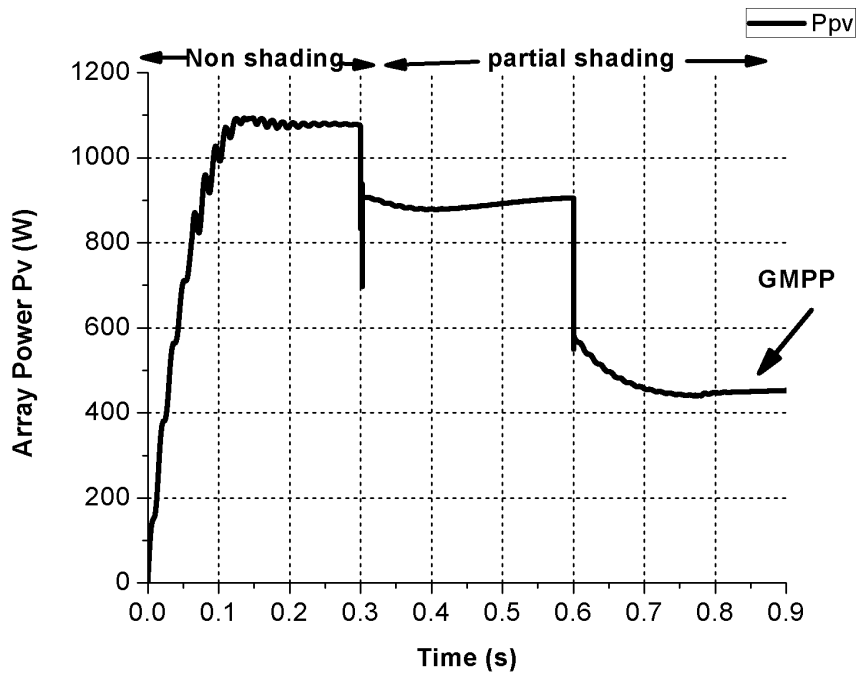
FIGURE 4.25: Shows PV Array Power in case of Proposed PO
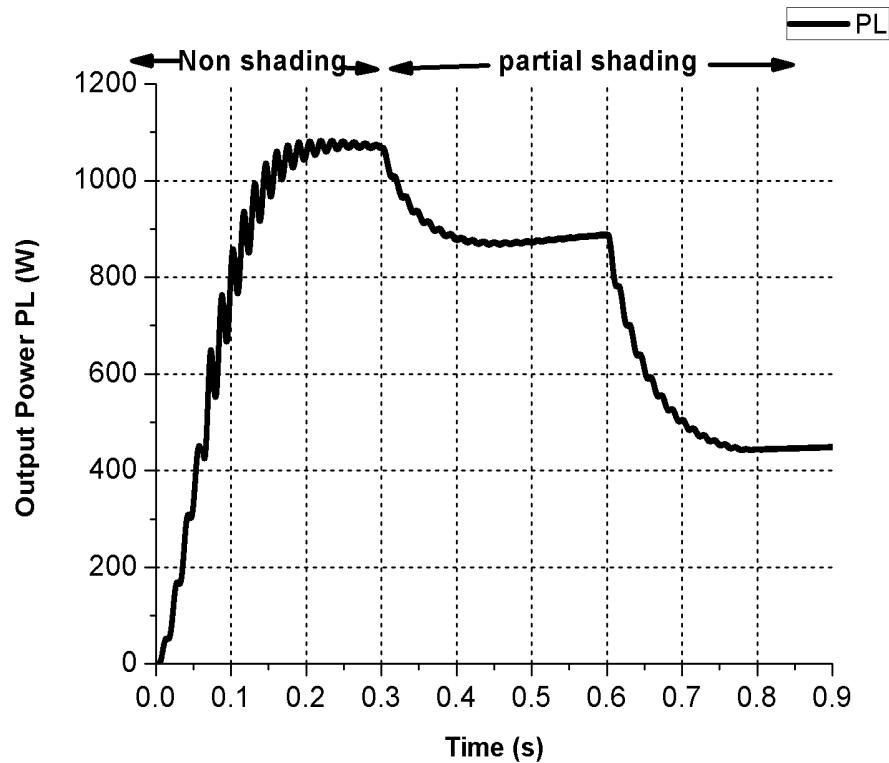
FIGURE 4.26: Shows Output Power in case of Proposed PO

4.8 Discussion

Solar Energy is one of the most important renewable energy sources for generating electricity. However, its production depends immensely on the weather conditions of ambient temperature and irradiance. Therefore, there should be a control techniques to manage the operation of the solar PV to have it working at the point at which it produces the maximum power.

The aim of this algorithm is to detect partial shading, and indicate the direction of LMPP and GMPP. Testing included normal cases when there is no shading effects and also the partial shading conditions. The tests have been simulated twice. One has been run with the new algorithm and other with the traditional algorithm in order to compare their results. The results showed that the new algorithm can handle accurately all test cases including partial shading conditions. While, the traditional algorithm have failed to manage the case of shading conditions. Thereby, the produced energy was maximized and also the efficiency increased by using modified algorithm.

By comparing the tradition and the proposed method, we conclude that, they behave identically because in case of no shading the proposed method just uses the PO as traditional method. However, there is a big difference in performance in case of shading, the proposed method has been settled at 537 W while the traditional method only produces 499 W for Pattern one. For Pattern two Proposed and traditional method settled 448 W, 367 W respectively.

TABLE 4.2: Comparison Of Proposed and Ordinary Algorithm for Pattern Two

Tracking Method	During Non shading	During Shading
Ordinary PO Method	1080W	367W
Proposed PO Method	1080W	448W
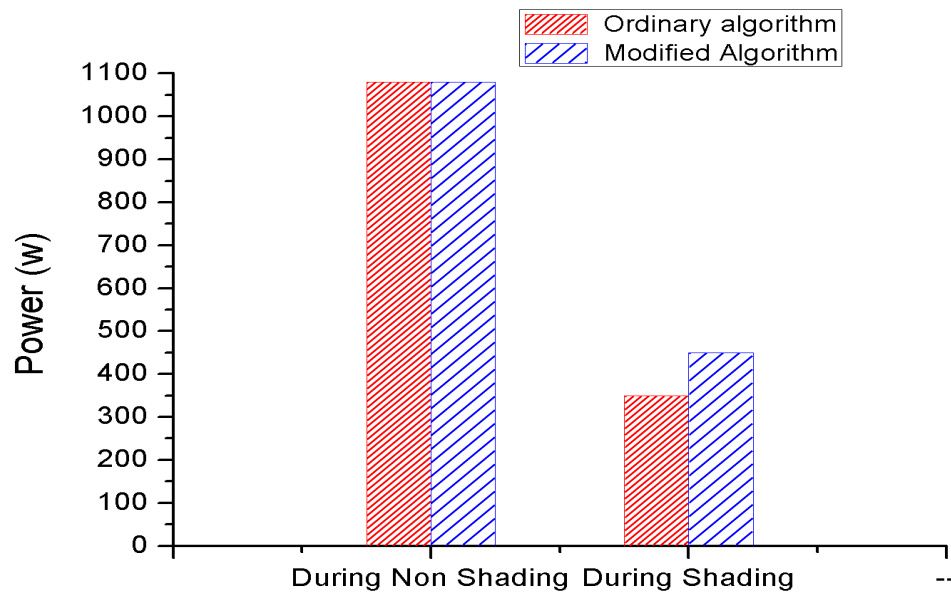
FIGURE 4.27: Shows Bar Graph of Comparison Proposed and Ordinary Algorithm for Pattern two
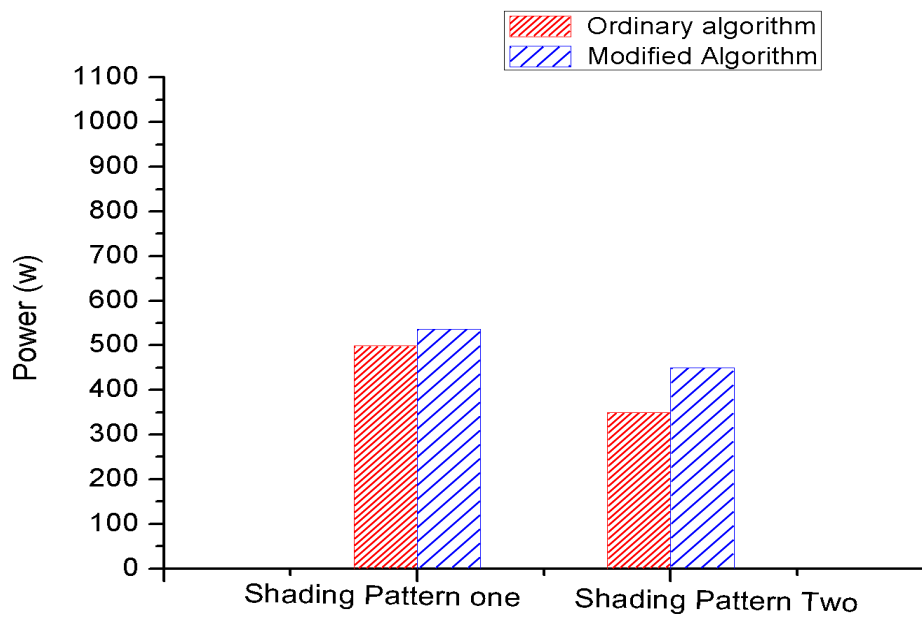
FIGURE 4.28: Shows Bar Graph of Comparison Shading Pattern One and Two

TABLE 4.3: Comparison Of Proposed and Ordinary Algorithm for Shading Patterns

Feature	Ordinary PO Method	Proposed PO Method
Oscillation	It has high oscillations	It has less oscillations
Partial Shading	It cannot handle Partial Shading	It handle Partial Shading as well as non-shading
Tracking Speed	It has low Speed of Tracking the Maximum Power Point	It has high Speed of Tracking the Maximum Power Point
Efficiency	It has low Efficiency in terms of Power etc	It has high Efficiency in terms of Power etc

Chapter 5

Conclusion and Future Work

In this chapter conclusions and future work is discussed, as area of this research is so vast and there are many opportunities for new research in this area future recommendations are discussed also.

5.1   Conclusion

Renewable energy sources compete the natural gas in the second position after coal as a source of electricity thanks to Solar PV and Wind. However, the most of renewable energy sources have intermittent nature in their production due to dependency on weather conditions. For example, solar PV depends on temperature and solar irradiance. Therefore, tracking algorithms are very essential to follow the operating point at which solar PV arrays produces the maximum energy and working at maximum power tracking conditions.

There are many algorithms that track the MPP. The most common algorithms are perturb and observe. The survey shows that the Ordinary PO methods are able to track the maximum power point at normal conditions when there is no shading effects. However, this method fail to track GMPP during partial shading.

The proposed method utilized the PO to search the local peak and then it called a separate routine for handling the search process for the global peak based. The

condition of partial shading may be detected by a significant drop in voltage and or power. So, the procedure of handling the partial shading can be called when and only when this interrupt has been occurred instead of periodically check and test which cause delay and failure to follow the rapid weather changes. Consequently, the developed algorithm accelerates the processing speed and increasing the net efficiency.

Different scenarios have been tested like normal conditions of operation and partial shading conditions have been tested. The results have been validated with that of the other model in order to verify the correctness of the operation of the proposed method. Results showed that the new method successfully tracked the maximum power point at normal conditions as well as shading conditions. Thereby, the new method increases the efficiency significantly and maximized the extracted energy of solar PV arrays.

5.2 Future Work

The MPPT techniques including artificial intelligence based techniques play vital role in advancing the optimization and global searching problem. Therefore, one of the suggested approach is replacing the PO traditional technique with one of that methods like Genetic algorithm, Particle swarm optimazition, Fuzzy logic, Artificial neural network ANN or using two of them in hybrid topology to searching for the global peak. For example, the shading condition specifications and parameters like temperature, and irradiance of each module are input parameters which are given to Genetic algorithm, Particle swarm optimazition etc in order to result the global peak.

In future, centralized PV farms will be integrated with conventional grid. It is important to analyze the impact of centralized generation on the conventional grid. For the protection of grid, grid-tied inverters should be operational and intelligent.

Bibliography

[1] M. H. Uddin, M. A. Baig, and M. Ali, "Comparision of perturb & observeand incremental conductance, maximum power point tracking algorithms on real environmental conditions," in *2016 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube)*, pp. 313–317, IEEE, 2016.

[2] K. Harijan, M. A. Uqaili, and U. K. Mirza, "Assessment of solar pv power generation potential in pakistan," *Journal of Clean Energy Technologies*, vol. 3, no. 1, pp. 54–56, 2015.

[3] N. H. Selman and J. R. Mahmood, "Comparison between perturb & observe, incremental conductance and fuzzy logicmppt techniques at different weather conditions," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 5, no. 7, 2016.

[4] M. Gul, Y. Kotak, and T. Muneer, "Review on recent trend of solar photovoltaic technology," *Energy Exploration & Exploitation*, vol. 34, no. 4, pp. 485–526, 2016.

[5] T. Shimizu, M. Hirakata, T. Kamezawa, and H. Watanabe, "Generation control circuit for photovoltaic modules," *IEEE Transactions on Power Electronics*, vol. 16, no. 3, pp. 293–300, 2001.

[6] F. Paz and M. Ordonez, "Zero oscillation and irradiance slope tracking for photovoltaic mppt.," *IEEE Trans on Industrial Electronics*, vol. 61, no. 11, pp. 6138–6147, 2014.

[7] K. S. Tey and S. Mekhilef, "Modified incremental conductance algorithm for photovoltaic system under partial shading conditions and load variation,"

IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5384–5392, 2014.

[8] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," *IEEE transactions on industry applications*, vol. 41, no. 5, pp. 1292–1306, 2005.

[9] A. Sangwongwanich, Y. Yang, and F. Blaabjerg, "High-performance constant power generation in grid-connected pv systems," *IEEE transactions on Power Electronics*, vol. 31, no. 3, pp. 1822–1825, 2016.

[10] K. Kim, H. Cha, and H.-G. Kim, "A new single-phase switched-coupled-inductor dc–ac inverter for photovoltaic systems," *IEEE Transactions on Power Electronics*, vol. 32, no. 7, pp. 5016–5022, 2017.

[11] P. Gevorkian, *Sustainable energy systems engineering: the complete green building design resource*. McGraw-Hill New York, 2007.

[12] A. H. Eldin, M. Refaey, and A. Farghly, "A review on photovoltaic solar energy technology and its efficiency,"

[13] S. Y. Mousazadeh, M. Savaghebi, A. Beirami, A. Jalilian, J. M. Guerrero, and C. Li, "Control of a multi-functional inverter for grid integration of pv and battery energy storage system," in *2015 IEEE 10th International Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives (SDEMPED)*, pp. 474–480, IEEE, 2015.

[14] I. V. Banu and M. Istrate, "Modeling of maximum power point tracking algorithm for photovoltaic systems," in *2012 International Conference and Exposition on Electrical and Power Engineering (EPE)*, pp. 953–957, IEEE, 2012.

[15] I. R. Balasubramanian, S. I. Ganesan, and N. Chilakapati, "Impact of partial shading on the output power of pv systems under partial shading conditions," *IET Power Electronics*, vol. 7, no. 3, pp. 657–666, 2014.

[16] A. Bidram, A. Davoudi, and R. S. Balog, "Control and circuit techniques to mitigate partial shading effects in photovoltaic arrays," *IEEE Journal of Photovoltaics*, vol. 2, no. 4, pp. 532–546, 2012.

[17] C.-C. Hua and Y.-m. Chen, "Modified perturb and observe mppt with zero oscillation in steady-state for pv systems under partial shaded conditions," in *2017 IEEE Conference on Energy Conversion (CENCON)*, pp. 5–9, IEEE, 2017.

[18] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Transactions on energy conversion*, vol. 22, no. 2, pp. 439–449, 2007.

[19] A. Nigam and A. K. Gupta, "Performance and simulation between conventional and improved perturb & observe mppt algorithm for solar pvcell using matlab/simulink," in *Control, Computing, Communication and Materials (ICCCCM), 2016 International Conference on*, pp. 1–4, IEEE, 2016.

[20] O. Ibrahim, N. Z. Yahaya, N. Saad, and M. W. Umar, "Matlab/simulink model of solar pv array with perturb and observe mppt for maximising pv array efficiency," in *Energy Conversion (CENCON), 2015 IEEE Conference on*, pp. 254–258, IEEE, 2015.

[21] L. Piegari and R. Rizzo, "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking," *IET Renewable Power Generation*, vol. 4, no. 4, pp. 317–328, 2010.

[22] J. Ahmed and Z. Salam, "An enhanced adaptive p&o mppt for fast and efficient tracking under varying environmental conditions," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 3, pp. 1487–1496, 2018.

[23] A. Sellami, K. Kandoussi, R. El Otmani, M. Eljouad, A. Hajjaji, and F. Lakrami, "Improvement of perturb and observe method for pv array under partial shading conditions," in *2016 International Renewable and Sustainable Energy Conference (IRSEC)*, pp. 75–79, IEEE, 2016.

[24] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, "Development of a microcontroller-based, photovoltaic maximum power point tracking control system," *IEEE Transactions on power electronics*, vol. 16, no. 1, pp. 46–54, 2001.

[25] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru, and R. Teodorescu, "On the perturb-and-observe and incremental conductance mppt methods for pv systems," *IEEE journal of photovoltaics*, vol. 3, no. 3, pp. 1070–1078, 2013.

[26] K. Lian and V. Andrean, "A new mppt method for partially shaded pv system by combining modified inc and simulated annealing algorithm," in *2017 International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, pp. 388–393, IEEE, 2017.

[27] E. Karatepe, T. Hiyama, *et al.*, "Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions," *IET Renewable Power Generation*, vol. 3, no. 2, pp. 239–253, 2009.

[28] R. M. Essefi, M. Souissi, and H. H. Abdallah, "Maximum power point tracking control using neural networks for stand-alone photovoltaic systems," *International Journal of Modern Nonlinear Theory and Application*, vol. 3, no. 03, p. 53, 2014.

[29] B. N. Alajmi, K. H. Ahmed, S. J. Finney, and B. W. Williams, "A maximum power point tracking technique for partially shaded photovoltaic systems in microgrids," *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1596–1606, 2013.

[30] N. Shah and C. Rajagopalan, "Experimental evaluation of a partially shaded photovoltaic system with a fuzzy logic-based peak power tracking control strategy," *IET Renewable Power Generation*, vol. 10, no. 1, pp. 98–107, 2016.

[31] D. K. Mandall, S. Chowdhuril, S. Saha, B. Majumdar, D. Maity, and S. K. Biswas, "Efficient power extraction from spv system in partially shaded condition: A comparative study between classical and fuzzy logic control," in

2018 Fifth International Conference on Emerging Applications of Information Technology (EAIT), pp. 1–4, IEEE, 2018.

[32] R. B. Koad, A. F. Zobaa, and A. El-Shahat, "A novel mppt algorithm based on particle swarm optimization for photovoltaic systems," *IEEE Transactions on Sustainable Energy*, vol. 8, no. 2, pp. 468–476, 2017.

[33] M. Abdulkadir and A. H. M. Yatim, "Hybrid maximum power point tracking technique based on pso and incremental conductance," in *2014 IEEE Conference on Energy Conversion (CENCON)*, pp. 271–276, IEEE, 2014.

[34] F. M. Oliveira, S. A. da Silva, F. R. Durand, and L. P. Sampaio, "Application of pso method for maximum power point extraction in photovoltaic systems under partial shading conditions," in *2015 IEEE 13th Brazilian Power Electronics Conference and 1st Southern Power Electronics Conference (COBEP/SPEC)*, pp. 1–6, IEEE, 2015.

[35] J. Ahmad, "A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays," in *Software Technology and Engineering (ICSTE), 2010 2nd International Conference on*, vol. 1, pp. V1–247, IEEE, 2010.

[36] A. F. Murtaza, H. A. Sher, M. Chiaberge, D. Boero, M. De Giuseppe, and K. E. Addoweesh, "A novel hybrid mppt technique for solar pv applications using perturb & observe and fractional open circuit voltage techniques," in *Proceedings of 15th International Conference MECHATRONIKA*, pp. 1–8, IEEE, 2012.

[37] H. Patel and V. Agarwal, "Maximum power point tracking scheme for pv systems operating under partially shaded conditions," *IEEE transactions on industrial electronics*, vol. 55, no. 4, pp. 1689–1698, 2008.

[38] S. Pachpande and P. Zope, "Studying the effect of shading on solar panel using matlab," *International Journal of Science and Applied Information Technology*, vol. 1, no. 2, pp. 2278–3083, 2012.

[39] P. R. s. R. S. sobhit panda, Sheetal singh, "Tracking comparison of p and o and inc under varying weather condition," *2nd International Conference on Data Science and Business Analytics*, no. 6, pp. 198–203, 2018 organizationIEEE.

[40] K. Chen, S. Tian, Y. Cheng, and L. Bai, "An improved mppt controller for photovoltaic system under partial shading condition," *IEEE transactions on sustainable energy*, vol. 5, no. 3, pp. 978–985, 2014.

[41] C.-C. Hua and W.-Y. Kuo, "Modified perturb and observe mppt with zero oscillation in steady-state for pv systems under partial shaded conditions," in *Energy Conversion (CENCON), 2017 IEEE Conference on*, pp. 5–9, IEEE, 2017.

[42] J. S. Kumari and C. S. Babu, "Mathematical modeling and simulation of photovoltaic cell using matlab-simulink environment," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 2, no. 1, pp. 26–34, 2011.

[43] M. Seyedmahmoudian, S. Mekhilef, R. Rahmani, R. Yusof, and E. T. Renani, "Analytical modeling of partially shaded photovoltaic systems," *Energies*, vol. 6, no. 1, pp. 128–144, 2013.

[44] M. Jazayeri, S. Uysal, and K. Jazayeri, "Evaluation of maximum power point tracking techniques in pv systems using matlab/simulink," in *Green Technologies Conference (GreenTech), 2014 Sixth Annual IEEE*, pp. 54–60, IEEE, 2014.

[45] M. R. Dave and K. Dave, "Analysis of boost converter using pi control algorithms," *International Journal of Engineering Trends and Technology*, vol. 3, no. 2, pp. 71–73, 2012.

[46] R. Alik, A. Jusoh, and N. A. Shukri, "An improved perturb and observe checking algorithm mppt for photovoltaic system under partial shading condition," in *2015 IEEE Conference on Energy Conversion (CENCON)*, pp. 398–402, IEEE, 2015.

Appendix-I

The pseudo coding of ordinary PO is given as

The initialisation is given as function D = P and O(Param, Enabled, V, I)

Dinit = Param(1); %Initial value for Vdc_ref

Dmax = Param(2); %Maximum value for Vdc_ref

Dmin = Param(3); %Minimum value for Vdc_ref

deltaD = Param(4); %Increment value used to increase/decrease Vdc_ref

persistent Vold Pold Dold;

dataType = 'double';

if isempty(Vold) Vold=0;

Pold=0;

Dold=Dinit;

% V=0.85*44.9;

P= V*I;

dV= V - Vold;

dP= P - Pold;

if dP not equalto 0 && Enabled not equal to 0

if dP < 0

if dV < 0 D = Dold - deltaD;

else

D = Dold + deltaD;

else

if dV < 0

D = Dold + deltaD;

else D = Dold - deltaD;

D=Dold;

if D > Dmax

D=Dmax;

if D < Dmin

D=Dmin;

Dold=D;

Vold=V;

Pold=P;

The Modified coding

function [D,pmax,vmax] = PandO(Param, Enabled, V, I,VL)

Dinit = Param(1); %Initial value for Vdc_ref

Dmax = Param(2); %Maximum value for Vdc_ref

Dmin = Param(3); %Minimum value for Vdc_ref

dpvo=Param(5); % store the previous slope to fetch the time at which mppt has been done

deltaD = Param(4); %Increment value used to increase/decrease Vdc_ref

mpp_done=0; % flag indicates the reach to the mpp

dp_crit=4*280*.05; % initial value of the critical disturbance 4-5% of the module capacity

% data stoarage for persisted values throughlong the code and program persistent

Vold Pold Dold dpv_old repeat Vm_last Pm_last; dataType = 'double';

%if isempty(Vold) Vm_last=0;

Pm_last=0;

repeat =0;

Vold=0;

Pold=0;

Dold=Dinit;

dpv_old=dpv_o;

% regular mppt based on PO

P= V*I;

dV= V - Vold;

dP= P - Pold;

if dP not equal to 0 && Enabled not equal to 0

if dP < 0

if dV< 0

GMPP

const=25;

% the critical voltage disturbances 0.3-.4 of the Voc

if (abs(u(1)-u(2))>=const

abs(u(1)-u(3))>=const

abs(u(1)-u(4))>=const

abs(u(2)-u(3))>=const

abs(u(2)-u(4))>=const

abs(u(3)-u(4))>=const

if (u) <=0

%any of the module voltages <0

D=1-0.85*Voc*4/VL;

repeat=0;

%loop for mpp mpp_done=0;

call P and O

else

cat1=sum(u<=Voc/4);

cat2=sum(u>Voc/4 and u<=Voc/2);

cat3=sum(u>Voc/2 and u<=Voc/3);

cat4=sum(u>Voc/3);

if cat1>0 M=cat1;

elseif cat2>0

M=cat2;

elseif cat3>0

```
M=cat3;
else
M=cat4;
end
n=4;
D=1-0.85*(1-M/n)*Voc*4/VL;
repeat=0;
else if if P>Pm_last || (abs(P-Pm_last)>=dp_crit) % only saving and uopading the
last Vm and Pm in case it is greater value as regard to the power
Vm_last=V;
Pm_last=P;
if abs(P-Pm_last)>=dp_crit
D=1-V/VL;
% updating the Vref indirectly via the setting the duty D
end
repeat=1;
% and reset the counters
end % display the recent Pm_last and Vm_last
pmax=Pm_last;
vmax=Vm_last;
end
% set limiter to the duty as design restriction
if y<0.1;
y=0.1;
end
if y>0.9
y=0.9;
end
%stop mpp and calculation for the GMPP
y_done=0;
else
```

% calculation is done and call back the MPP to get the last Pm , Vm

y=0;

y_done=1;