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**FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY
AND INFORMATION AND COMMUNICATION TECHNOLOGY
(DEPARTMENT OF ELECTRICAL AND ELECTRONICS
TECHNOLOGY)**

**APPLICATION OF FUZZY LOGIC CONTROLLER FOR MAXIMUM
POWER TRACKING OF PV POWER SYSTEM UNDER PARTIAL
SHADE CONDITION**

MSc Thesis for the Partial Fulfillment of
Master of Science in Electrical Automation and Control Technology Management

By,

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Supervisor,

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**AUGUST 2022
Addis Ababa, Ethiopia**



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SHADE CONDITION**

A Thesis submitted to

**TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)
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AND INFORMATION AND COMMUNICATION TECHNOLOGY
(DEPARTMENT OF ELECTRICAL AND ELECTRONICS
TECHNOLOGY)**

In partial fulfillment for the Degree

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TECHNOLOGY MANAGEMENT**

By,

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Advisor,

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AUGUST 2022
Addis Ababa, Ethiopia

DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “**Application of fuzzy logic controller for maximum power tracking of PV power system under partial shade condition**” is the original work of my own, has not been presented for a masters thesis in this or other universities and all sources of materials used for this thesis work have been fully acknowledged.

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**TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)
FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY AND
INFORMATION AND COMMUNICATION TECHNOLOGY
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Thesis on

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APPROVED BY THESIS ADVISORY COMMITTEE

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ABSTRACT

In this thesis work, the fuzzy logic controller is used to track the maximum power of a photovoltaic system when it is partially shaded. One of the most important tasks of the MPPT algorithm is to operate the PV system at or near Maximum Power Point. Many methodologies have been put forth; however, the traditional methods of perturb and observe and incremental conductance are the most popular due to their simplicity. However, some of the disadvantages include failure to monitor the global peak in conditions of partial shadow, steady-state oscillation, and incorrect perturbation direction for rapid climatic change. In this work, the performance of the fuzzy logic control strategy is compared with the classical technique. From the simulation results, it can be concluded that the fuzzy logic controller is outperformed with reduced steady-state error, quick dynamic performance, and precise tracking of the GMPP.

Keywords: fuzzy logic controller; maximum power point tracking (MPPT); photo voltaic system, boost converter

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List of abbreviations

MPP	Maximum power point
MPPT	Maximum power point tracking
MPE	Maximum power extraction
GMPPT	Global maximum power point tracking
FLC	Fuzzy Logic Control
P&O	Perturb & observe
IC	Incremental conductance
PV	Photovoltaic
DCV	Direct Current Voltage
ACV	Alternating Current Voltage
TCT	Total cross tied
SP	Series parallel
BL	Bridge linked
LRCM	Linear reoriented coordinate method
VOL	Volume
NO	Number
IEEE	Institute of Electrical and Electronics Engineers
ICPCSI	International conference on power control and instrumentation Engineering
SSD	System signal and devices
ICCAS	International conference on control automation and systems
ICRERA	International conference on renewable energy research application
IMECS	International multi-conference of engineering and computer scientists
PSC	Partial shading Condition
VT	Voltage Time
PT	Power Time
IT	Current Time

CCM	Continues Conduct mode
PID	Proportional integral derivative
LRCM	Linear reoriented coordinate method
STC	Standard Test condition
AT	Ambient Temperature
FF	Fill factor
BC	Boost converter

CHAPTER 1

1. Introduction

1.1 Background and Motivation

The world's demand for electricity and energy is rising, yet traditional energy sources are becoming less popular. Traditional energy sources like fossil fuels emit a large quantity of pollution as a consequence. In order to satisfy its energy demands, the modern commercial and industrial world must inevitably look for alternate energy sources [1]. Renewable energy sources take on more significance in this environment. One of the most well-liked and often utilized sources is solar energy, sometimes referred to as solar photovoltaic (PV) power producing systems. Without harming the environment, solar panels are an easy method to transform solar energy into electrical energy. Without any pollution, solar panels can efficiently transform light energy into electrical energy. Solar photovoltaic cell energy production technologies are competitive and developing quickly. There are no fuel costs, no maintenance needs, plentiful solar energy availability, silent operation, no moving components, and no pollution because of the following major benefits. Therefore, we must increase the effectiveness and capacity of solar panel transportation if we want to utilize solar energy effectively. The photovoltaic voltage and current of each solar panel, however, are significantly influenced by the temperature and irradiance conditions [2]. PV array power production is influenced by a number of factors in addition to irradiation and temperature. One of the crucial components is partial shading. One of the key elements is just somewhat suspect. Partial shading is caused by the movement of clouds, structures, towers, and trees. Because a shaded module in series with other unshaded modules confines the string current, limiting the maximum power produced by the array, the electrical design of the modules in the array is mostly to blame for the losses caused by partial shading [3], [4]. The power decrease is impacted by the shade pattern and module connectivity scheme. The literature has proposed a variety of interconnection techniques, including series parallel (SP), total cross tie (TCT), and Bridge linked (BL)[3].

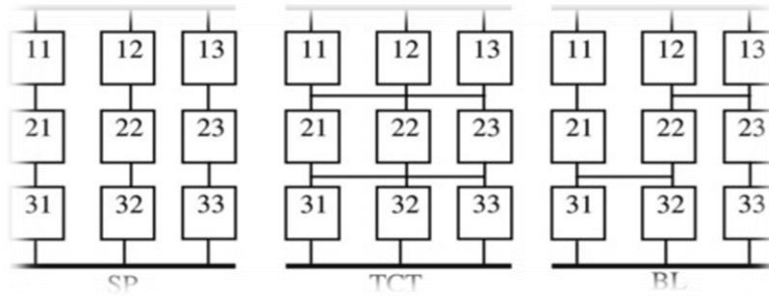


Figure 1.1: Interconnection schemes of a PV

The bulk of recent studies revealed that conventional MPPT controllers, such as the perturbation and observation (P&O) strategy and the incremental conductance (INC) method have been used in photovoltaic (PV) production. In order to overcome the drawbacks of overall efficiency, steady state oscillation, speed, and power loss, it is preferable to use intelligent tracking control systems, also known as fuzzy logic control. The majority of prior research focused on FLC, which has the capacity to support MPPT across a range of irradiation values, and PV systems under varied irradiation levels with complete shade. In order to improve performance, steady state oscillation, efficiency, and settling time, the main objective of this work is to develop an efficient MPPT algorithm for fuzzy logic controllers under partial shading situations.

1. 2. Objective of the thesis

1.2.1. General objective:

The general objectives of the thesis are to apply fuzzy logic algorithm for maximum power tracking of photovoltaic power system under partial shade condition.

1.2.2. Specific objectives:

The Specific objectives of this proposal are to achieve the following points.

- ❖ To identify forms of utilization, basic tasks and components required for efficient tracking of PV power system
- ❖ To develop fuzzy-logic based maximum power tracking algorithm that is able to respond quickly during partial shade condition
- ❖ To be able to operate the PV system at/near global maximum power point under partial shade
- ❖ To perform the Simulation and optimization of the overall PV system in MATLAB/Simulink.
- ❖ To compare the fuzzy-logic based algorithm with the classical methods.

1.3. Statement of the problem

Due to solar energy's vast supply and characteristics as a clean, quiet, and pollution-free source of energy, solar photovoltaic conversion is one of the most extensively used alternative sources of power. However, the low conversion efficiency of PV systems, their dependence on atmospheric conditions, their non-linear characteristics, and their expensive initial investment requirements make it difficult to research methods for the effective tracking and use of PV power. PV systems need methods for effective tracking and utilization of available electricity due to their low conversion efficiency and considerable climate sensitivity. The majority of related studies on maximum power point tracking (MPPT) approaches demonstrated the effectiveness and simplicity of traditional methods. However, failure to track global MPP under partial shadow conditions, steady-state oscillation, and failure to track the correct direction of perturbation are some of the issues widespread classical methods. Therefore, it is important to have a good settling time and improved steady state oscillation for successful monitoring at the global MPP as well as to reduce power loss. Due to the afore mentioned rationale, this thesis offered a comparison of traditional tracking techniques and an intelligent fuzzy logic controller.

1.4. Methodology

1.4.1. Conduct literature review

By doing an up-to-date review of related publications, the status of the research in the selected themes will be clearly shown. The review conducted in Section 2 is not complete; it still needs to examine other research contributions pertinent to the problem it is meant to address and improve further the problem-solving strategy and outcome displays.

1.4.2. Modeling Photovoltaic System

Due to solar energy's vast supply and characteristics as a clean, quiet, and pollution-free source of energy, solar photovoltaic conversion is one of the most extensively used alternative sources of power. However, the low conversion efficiency of PV systems, their dependence on atmospheric conditions, their non-linear characteristics, and their expensive initial investment requirements make it difficult to research methods for the effective extraction and use of PV power. The PV system should be carefully and precisely modeled by taking into account the aforementioned circumstances

1.4.3. Develop the Algorithm

PV systems need methods for effectively extracting and utilizing the available power when there is partial shading. The majority of traditional approaches are effective for uniform irradiance conditions, according to a summary of related publications on MPP extraction. However, some of the disadvantages of widely used classical approaches include failure to track the correct direction of perturbation, steady-state oscillation, and failure to track global MPP under partial shadow condition. Specified this situation, a decent algorithm should be built using fuzzy logic that is thorough and adaptable for a wide range of weather circumstances.

1.4.4. Design of Photovoltaic System

The proposed model will be tested by contrasting the classical and fuzzy logic algorithm(s), and a better, more reliable, and high-performing solar system will be developed.

1.4.5. Optimization and Simulation

Utilizing modeling and simulation in MATLAB/Simulink, the suggested algorithm will be verified.

1.5. Significance of the study

By applying this proposed thesis on the existing maximum power tracking methods of photovoltaic power system, this thesis will provide the following significances.

- ❖ Improved solar power system utilization,
- ❖ increased electrical energy reliability and availability,
- ❖ decreased weather pollution and energy consumption,
- ❖ increased capacity to sustain MPPT under partial shadowing, and use of intelligent control system (FLC) for maximum photovoltaic power extraction Decreases maintenance cost of electrical energy
- ❖ Provide a partial response to the population's energy needs
- ❖ Environmental advantages
- ❖ Uses solar power efficiently, among other things

1.6. Scope and limitation

This thesis covers the modeling and designing of fuzzy logic control for maximum power tracking of photovoltaic power system during partial shade condition. The modeling and simulations applications of fuzzy in MPPT will be modeled in MATLAB Simulink software. The detailed analysis of their performances will be also evaluated based on the simulation results. The scope of this thesis is limited to the study of a Comparative analysis between the Classical controller and Fuzzy Logic Control before MPPT with partial shading.

1.7. Thesis Organization

There are six chapters in the thesis.

Chapter 1. provides background information and a summary of the thesis, describing the main issue and the importance of the work presented in the thesis. The study's general information is described. Under the chapter introduction to past studies on solar energy and pv cells and modules,

Chapter 2. Provides a theoretical framework of a thesis study and a summary of a review.

Chapter 3. The system block diagram and system design of the study are covered in
Along with the stated principal objectives of the study.

Chapter 4.The suggested and controller design of the system implementation methods for the thesis work are covered in depth Both the p&o algorithm INC algorithm and the fuzzy logic controller are operated under the supervision of the MPPT of a PV module

Chapter 5 includes simulation result and discussion of a proposed model performance comparison of P&O INC and fuzzy logic controller algorithm in PV MPPT under partial shade condition

Chapter 6 covers conclusion and scope for the future work

CHAPTER TWO

2. Literature review

2.1. Introduction

While traditional energy sources are becoming less popular, the world's need for electricity and energy is growing. Traditional energy sources, such as fossil fuels, result in significant pollution. Solar power will be used more efficiently since renewable energy sources are becoming more and more important. The PV cell has to be tracked efficiently in order to maximize the solar system's efficiency. In this study, fuzzy logic control for solar power systems operating in partial shadow is discussed. For a PV system to provide a consistent electrical power supply, the activities of maximum Power point tracking and system power control must both be maintained regardless of the environmental circumstances. Employing conventional methods for locating the genuine maximum power point, such as incremental conductance and perturb and observe techniques, has certain drawbacks, including the volatility around the optimum and the challenge of doing so fast. Other solutions are imprecise, while some require intricate computations. Although ID controllers are simple to build, they perform poorly in MIMO nonlinear systems. To work as needed in contexts with substantial volatility and a variety of input conditions, conventional PID controllers frequently require calibration and parameter change [8, 9]. The behavior of control systems is reflected in simulation-based research, but the performance of the system in real time and under real environmental conditions is not depicted. For the maximum power point tracking operation, a synthetically intelligent method using fuzzy logic control is designed in this study. The approach was able to push the system to run at its peak power point under all circumstances and provide an efficient reaction in the face of considerable variation. Fast responses and good voltage amplification were achieved in rapidly changing environmental circumstances. The significance of stand-alone solar system research and testing originates from the variety of uses for these systems, which include providing power to remote places, water pumping and irrigation, as well as medical and space solar vehicle systems [10]. Collaboration routes between academic institutions and business organizations are crucial for translating research into commercial products. The present knowledge transfer mechanisms and the impact of recent research on the advancement of PV systems are both examined in this article.

2.2. Review of Related Works

In 2002 Mummadi et al [6], show that, in contrast to boost converter-supplied PV systems, the IDB converter is adequate for extracting MP from the SCA in the array voltage-based peak power tracking technique.

In 2008 , Jung-Sik Choi et al [21] , with the benefit that Pmax and can be calculated using the same variable as the dynamic model without needing complicated approximations or Taylor series, have been proven MPPT utilizing the linear reoriented coordinates method (LRCM).

In 2009 Chao Zhang et al [7], suggested that the analysis and perturbation steps should change depending on the PV module's working point. Due to the symmetry of the input variable, membership function, and fuzzy rules for fuzzy control, the power pulsation can be reduced, but there is still some power oscillation at the MPP. Asymmetric fuzzy control, which features a new input variable that can precisely reflect the functioning point of a PV module, is also suggested.

In 2010 Ahamed and Ismail [12], presents the implementation of FLC to a microcontroller for MPPT of a PV module under variable temperature and isolation conditions. The FLC is easy to implement and require a small amount of inexpensive components in compact size. The designed controller is capable of rapidly locking into the MPP for a photovoltaic panel. But there is also a drawback of only looking in cost minimization but not consider the efficiency or performance of the system

In 2011 Pongsakor et al [13], presents an intelligent control strategy of MPPT for the PV system using the FLC. And FLC MPPT can track the MPP faster when compared to the conventional P&O method but in reality there may not be functional

In 2011 Bouchafaa et al [18], illustrates that fuzzy controller with greater satisfaction than that of traditional algorithms (P & O and IC) at the abrupt fluctuations in temperature and illumination and a quick response time. Nevertheless, PID or any other typical controller cannot be compared.

In 2012 Yufeng Hu et al [11], advocated the use of MPPT in photovoltaic inverter systems and advanced a fuzzy logic-based particle swarm optimization technique. Can successfully resolve the conflict between response speed and steady-state error in order to efficiently accomplish maximum power tracking change. However, research also uncovered certain flaws in the experimental procedure. It is quite challenging to create a fuzzy control table in diverse

experimental platforms since the rule set is strongly influenced by factors of strong pertinence and empirical study. As a result, further research is required.

In 2013 Lixia Sun et al [2], suggested using fuzzy control with MPPT. The results demonstrate that the strategy delivers better outcomes in terms of speed and stability compared to the traditional P&O duty cycle. However, under situations of partial shading, the experiment is ineffective.

In 2013 IJAREEIE Rooble et al [5], identify that the input variables namely temperature, solar radiation, voltage and current obtained on solar panel and humidity condition using temperature sensor, light dependent resistor and humidity sensor respectively, for green house applications and uses a microcontroller

In 2013 GARRAOUI Radhia et al [10], provides a fuzzy logic-based algorithm for tracking the maximum power point of solar arrays. As a result, it can quickly identify a new maximum power point and has a greater power output efficiency in situations when temperature and load are rapidly changing due to illumination. So it appears to be a novel and reliable PV array solution.

In 2013 Chang-Uk Lee et al [16], advocated that PI and fuzzy controls be connected in series. The FLC-PI controller's MPPT control performance was better than that of the traditional PO and IC controllers in terms of MPPT tracking speed and steady-state error. However, it might not be ideal for light shading

In 2014 Youcef Soufi et al [17], proposed that the fuzzy can track the MPP faster when compared to the P&O. The proposed MPPT using fuzzy logic can improve the performance of the system.

In 2014, P. Srinivasa Rao [1], It has been suggested that comparing various connecting schemes based on shade levels and conditions indicates how the interconnection schemes affect the amount of PV power generated, however this has the disadvantage that the control is not precise.

In 2015 Mustafa GÖKDAĞ and Mehmet Akbaba [9], It was suggested that under partial shading conditions, convex power curves with higher peak power values may be obtained. The sub-modules in the suggested topology are organized into a string using a n/n parallel-ladder design

In 2015 A. A. Allataifeh et al [19], proposed that maximum power output of PV incorporating FLC are compared with the output of PV module when it is connected to load without MPPT

control scheme under varying irradiance levels. It is found that fuzzy logic systems are easily implemented with minimal oscillations with fast convergence around the desired MPP

In 2017 Dr. R. Sankar et al [3], introduced a new digital control strategy combining fuzzy logic and a dual-MPPT controller for a solo solar system. The FLC output is gradually updated to avoid exceeding the MPP in the opposite direction, which could cause oscillations, as well as to increase efficiency, however this thesis does not take into account the partial shade conditions of the PV of the solar system.

In 2017 Praful Raj M et al [4], have demonstrated that the comparison of Fuzzy Logic Controller with P&O and IC algorithms with respect to PV Array Dependence and also Convergence speed then the final result is FLC depends on PV array and high convergence speed respectively

.In 2017 S.Malathy and R. Ramaprabha [14], proposed that the Fibonacci based MPPT search by introducing two more search points to reliably track the GP under all irradiation conditions , the algorithm efficiently tracks the GP under varying environmental conditions. but it takes time complicated algorithms

In 2017 Mahima et al [15], presents a comparative analysis of two intelligent control techniques- Fuzzy logic based MPPT Grid Connected PV System to track the maximum power point from the PV array and is compared with Incremental Conductance algorithm based on their in dynamic behavior, transient tracking time, settling time, steady state oscillation, and efficiency since it is fast and precise in tracking MPP from PV array, and hence increasing the efficiency of the PV system but it so costly and complex

. In 2017 Taborda et al [20], The traditional solution for MPPT controllers is the perturbation and observation (P&O) algorithm, which presents oscillation problems around the operating point and fuzzy logic has excellent performance during sudden change in environments but there is not have applicable in microcontroller systems

In 2018 Hassan M. H.Farh et al [8], These findings show the superior performance of the proposed PSPV with IBC system compared to the PSPV with CBC in terms of generated power, power quality (less power losses), reliability, efficiency and flexibility.

2.3. Summary of Literature review

The major aim of this thesis was to determine the photovoltaic (PV) system's maximum power point (MPPT) in partial shade during rapid changes in the weather. The majority of research discusses how to extract the maximum power point from a PV system under full shading and full irradiation at standard conditions. However, under partial shade conditions, conventional control methods or algorithms are ineffective at obtaining the maximum power point. failure to comply Maximum power point (MPP) in terms of output power performance, steady state error reduction, and quick response dynamic transient In this case, a fuzzy logic controller is suggested as a superior intelligence control solution to traditional ones like P&O (perturb and observe). PID and INC (incremental conductance) control methods...In this thesis, I proposed the FLC method to extract GMPPT in partial shadow conditions, but there are more sophisticated intelligence controller methods that are actually more effective than the traditional ways.

CHAPTER THREE

3. MATHEMATICAL MODELING OF A SYSTEM

3.1. Photovoltaic Cell

A semiconductor-based PN junction device is the photovoltaic (PV) cell. It is frequently manufactured using doped silicon [22]. The process of converting energy in a PV cell may be divided into three parts. As a result of the solar (photon) energy being absorbed, electron-hole pairs are first created. The device then separates the electrons and holes using its architecture. At the PV cell's terminal, electrical charges are finally accumulated. Electric charge generation speed is influenced by the sun's radiation, the cell's temperature, and the type of semiconductor material used. Very little output power is produced by a single PV cell. To produce greater power levels, a PV module is made by connecting several PV cells in parallel and series [23]. Accompanying that, many modules are linked in both series and parallel to construct the PV arrays depicts in the following Diagram.

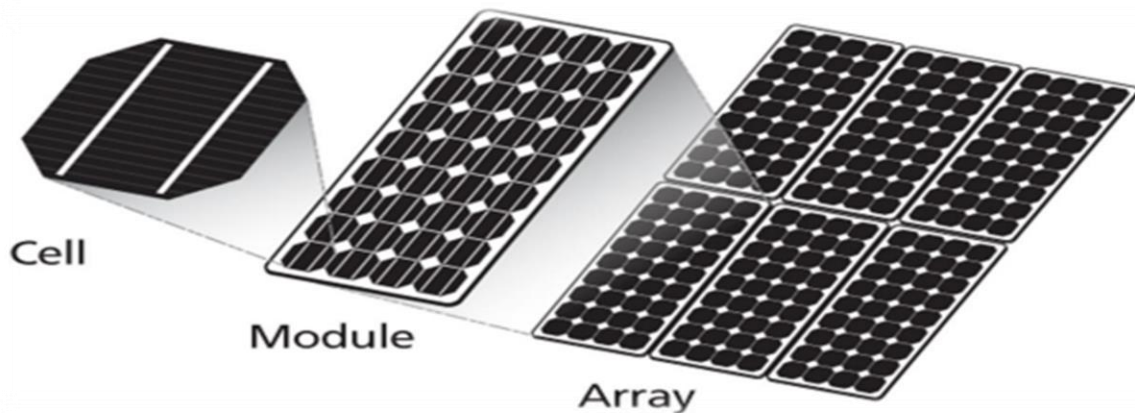


Figure 3.1 pv cell Module and array[23]

3.1.1. Modeling of PV Modules

The fundamental part of a solar cell, a p-n junction, is created using a semiconductor thin wafer. Electromagnetic radiation from solar energy may be converted into electricity immediately through the photovoltaic effect. According to the quantity of incoming radiation, photons with energies greater than the semiconductor's band-gap energy form some electron-hole pairs when exposed to sunlight [24]. The analogous circuit for the solar cell is shown. To better clarify the

characteristics of the PV cell, an analog circuit similar to the one in Figure 3.2 can be employed. The PV model consists of a current source, a diode, and a series resistance. The very low leakage resistance of the cell in a single module is indicative of the parallel resistance effect. The output of the current under constant temperature and incoming light radiation. It indicates a continuous current produced by photons.

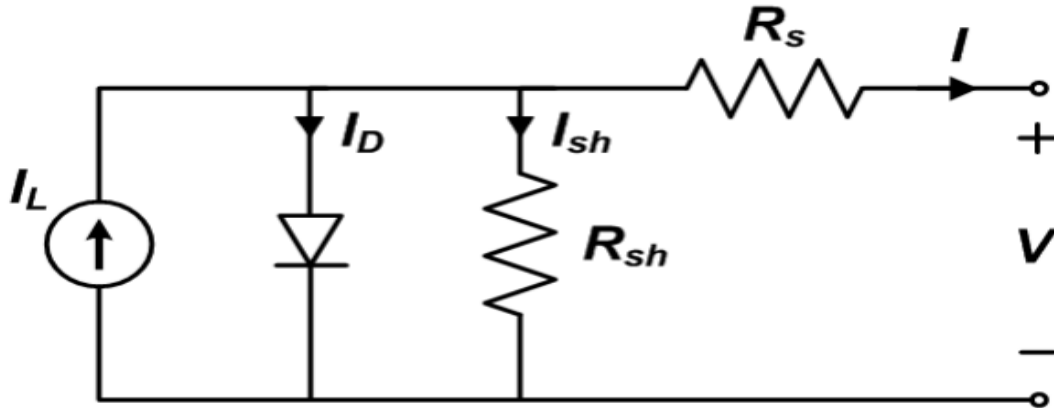


Figure 3.2 : Equivalent Circuit of Solar PV Cell [25].

The relationship between current and voltage in a PV cell is seen below: The current source (I_{ph}) in the circuit schematic above stands in for the cell photo current. The letters R_{sh} and R_s , respectively, stand for the cell's series and shunt resistances. The series resistance is typically exceedingly low while the shunt resistance is rather substantial. As a result, they might be ignored while doing analysis PV arrays are constructed by joining together PV modules, which are composed of a number of smaller components called PV cells [25]. The photo current, which is influenced by the level of solar radiation and the ambient temperature, is calculated using the formula below.

$$I_{ph} = \frac{G}{1000} [I_{sc} + K_i(T - T_{ref})] \quad (3.1)$$

Where G is solar radiation, I_{sc} is the PV cell's short circuit current, T_{ref} is the nominal temperature, and K_i is the cell's temperature-dependent short circuit current at 25 degrees Celsius and 1000 watts per square meter The cell's diode current from equivalent-circuit can be written as:

$$I_D = I_o \left[\frac{V + IR}{e^{V/T} - 1} \right] \quad (3.2)$$

The thermal voltage is given by:

$$V_T = \left[\frac{KT}{q} \right] \quad (3.3)$$

where I is the solar cell's external current and V is the external voltage.

Thermal voltage is denoted by V_T , and the diode's dark saturation current is denoted by I_0 .

The mathematical formula for the diode's dark saturation current is:

$$I_0 = I_{rs} \left(\frac{T}{T_{ref}} \right) \left[e(qEg_0 \left(\frac{1}{T_{ref}} - \frac{1}{T} \right)) \right] \quad (3.4)$$

where A is the diode's ideality factor.

The Boltzmann constant is K.

The electron charge is q.

The band-gap energy of the semiconductor is called E_g .

The solar cell's reverse saturation current is calculated as,

$$I_{rs} = \frac{I_{sc}}{\left[e \left(\frac{qV_{oc}}{A_n S K T} \right) - 1 \right]} \quad (3.5)$$

V_{oc} stands for open-circuit voltage.

N_s represents the quantity of PV modules wired in series.

The solar PV module's response to temperature is denoted by T.

The current via shunt resistance is equal to: according to Ohm's law

$$I_{sh} = \frac{V + I_{rs}}{R_{sh}} \quad (3.6)$$

By applying all the above equations, the external current can be found

$$I_{PV} = I_{ph} - I_0 \left[e \left(\frac{qV_{pv}}{N_s A K T} \right) - 1 \right] - I_{sh} \quad (3.7)$$

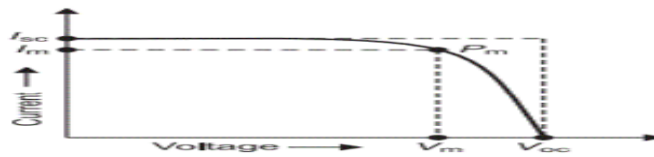


Figure 3.3: I-V and P-V graphs showing the characteristic of a solar cell [26]

The current-voltage (I-V) characteristics of a typical silicon photovoltaic cell are shown in Figure 3.3. The power output of a solar cell is the product of its current and voltage (I-V). When the multiplication is done point by point for all voltages, from short-circuit to open circuit conditions, the power curve above is generated for a certain radiation intensity. When the solar cell is open-circuited, or V_{oc} , the voltage around it is at its highest, and when it is not connected to any loads, the current is at its lowest (zero). The voltage around a solar cell is at its lowest point (zero) when a short circuit occurs, which means that the positive and negative leads are linked. However, the short circuit current, or ISC, is discharging more fluid than the cell can hold. The I-V characteristics of the solar cell then span from zero output volts for short circuit current (ISC) to zero output volts for maximum open circuit voltage (VOC). In other words, a cell's maximum voltage in an open circuit is equivalent to its maximum current in a closed circuit. There must be a point between the maximum power the solar cell can produce and that point because, obviously, neither of these two scenarios generate any electricity. The power, however, achieves its peak value at a certain combination of current and voltage at I_{mp} and V_{MP} .

3.2 .Block diagram and system design of the study

3.2.1 Simulink model of Solar Module

The parameters considered for modeling of PV Panel on Simulink are as follows-

Table 3.1:. Electrical parameter of PV Module Data [27]

parameter	value
Peak Power P_{max} (Wp)	250W
Maximum Voltage V_{mpp} (V)	30.6V
Maximum Current I_{mpp} (A)	8.17A
Open Circuit Voltage V_{oc} (V)	37.5V
Short Circuit Current I_{sc} (A)	8.7A

All data refers to STC (1000 W/m^2 , 25 degrees Celsius).

Table 3.2.: Parameter of Solar Cell Constant [27]

parameter	Value
Q	$1.6 \cdot 10^{19} \text{c}$
K	$1.38 \cdot 10^{-23} \text{J/K}$
Ki	0.002
A	1.6
Ego	1.1eV

- Where
- Q is charge of electron
 - K is Boltzmann's Constant
 - Ki is temperature coefficient
 - A is Ideal factor of a Diode
 - Ego is band gap energy of semi conductor

The conversion of temperature from degree Celsius to kelvin is shown in figure 3.4

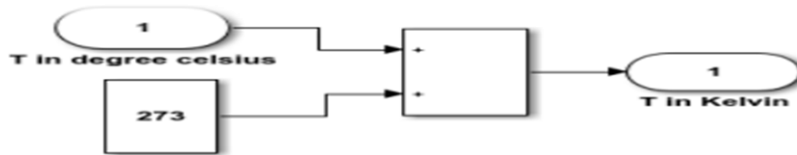


Figure 3.4: Block Diagram of Temperature Conversion

Figure 3.5 demonstrates the block diagram for Simulink that is used to determine the photo current (I_{ph}). The photo current (I_{ph}) is calculated using eq (3.1). Employing the converted values of temperature and irradiance level as well as the value of current. Temperature coefficient from the PV module data sheet

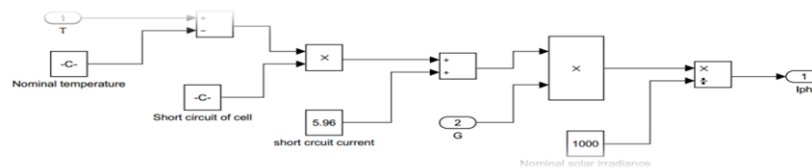


Figure 3.5; Block Diagram of Photo Current

The Simulink block diagram displays the diode saturation current (I_0), which was computed using eq. (3.4). shown in figure 3.6

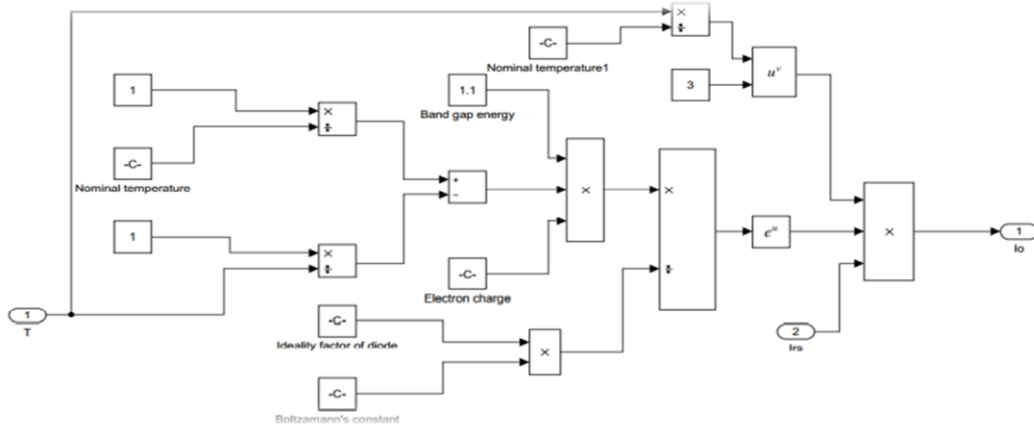


Figure 3.6 Block diagram of diode saturation current

in order to calculate the reverse saturation current (I_{rs}) at STC using equation (3.5), the following block diagram is used: shown in figure 3.7

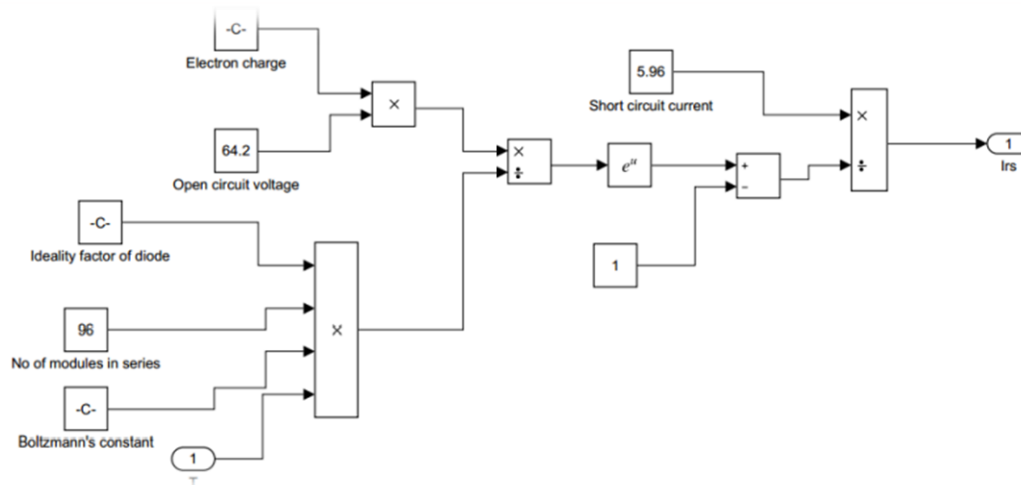


Figure 3.7 block Diagram of reverse saturation current

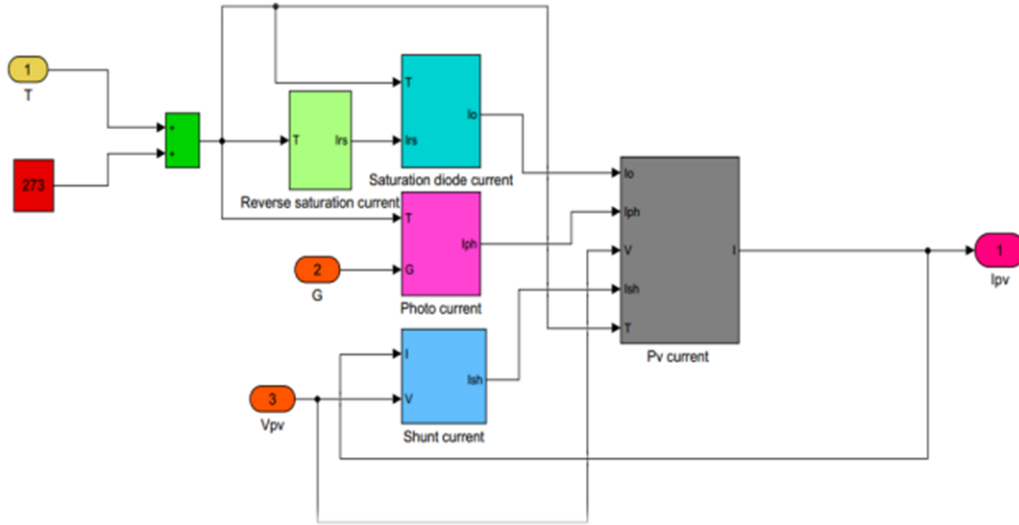


Figure 3.10. Block diagram of solar PV system for single PV module

The following PV array model is formed by integrating of Nine a single PV module which is connected in different interconnection schemes such that series parallel(SP),bridge linked(BL),and Total cross tide(TCT) to generate a power about 2.2 kw At STC(standard test condition). A single PV module produces only a power of 250W.

3.3. Modeling of Boost converter

DC/DC power converters are used in PV systems to change the output voltage. A DC/DC converter is frequently connected in series between the load and the PV panel in order to draw electricity from the solar panel. It is beneficial for a PV system with erratic and variable production. If the PV system has both AC and DC converters, a DC-link capacitor can enhance the DC output voltage stability and minimize the effect of fluctuation on the AC output [27]. DC converters can be either boost converters (step-up), buck converters (step-down), or a mix of the two as CUK converters and buck-boost converters. The converter type may be selected depending on the desired size or capacity of the output voltage [27] to provide the proper input voltage for the inverter with the ability to stabilize and control dc voltage. For independent, grid-connected, and hybrid energy systems, this is crucial. To boost the PV system's output in these systems, the DC/DC converter runs using a maximum power operating algorithm..

The basic boost converter circuit schematic used in this work is shown in Figure 3.11.

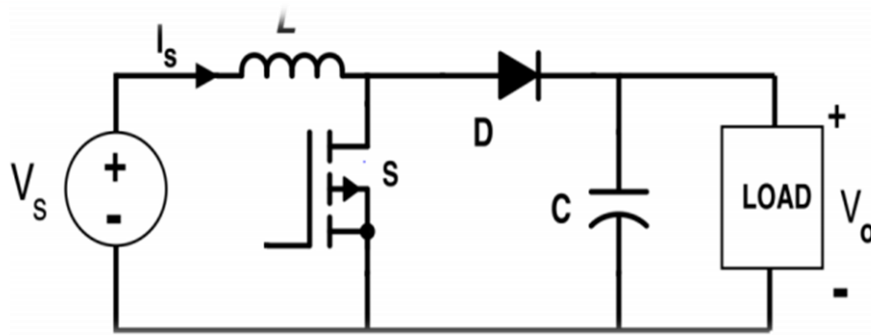


Figure 3.11. Circuit Diagram of Boost Converter [28]

3.3.1. Design of DC-DC converter

The maximum power point tracking essentially involves a load matching problem. To match the load resistance, the input resistance of the panel must be changed using a DC to DC converter (by altering the duty cycle). In principle, it converts DC voltage levels, or going from one DC voltage level to another DC voltage level. The DC-DC boost converter used in this model outputs DC voltage that has been increased (an output voltage greater than its input voltage). Typically, filters made of capacitors are added to the converter's output to lessen voltage ripple. This output voltage is delivered to a load or battery. The DC/DC conversion process depends on the switching component. The switching device is choosing based on the specific design of the system, such as switching speed and power capacity. When compared to MOSFET, which is often used for lower power capacities and rapid switching rates, IGBT is typically used for bigger power capacities with medium switching speeds [33]. The boost converter receives a 91.8 volt input from the PV array and a 200 volt target output voltage. The switching MOSFET's switching frequency has been set at 3 kHz. using the formula, the boost converter's duty cycle is determined.

$$D = 1 - \frac{V_{PV}}{V_{DC}} \quad (3.8)$$

The boost converter's minimum inductance will be:

$$L = \frac{DxV_{pv}}{fx\Delta I_L} \quad (3.9)$$

$I_L=30\% \times I_{in}$ is the formula used to determine the inductor ripple current, which is often selected to be 30- 40% of the maximum input current.

ΔI_L is the ripple current of the inductor

Where, V_{pv} is the input voltage to the converter, $V_{pv}=91.8V$

f_s is the switching frequency in the boost converter which is chosen to be 3KHz

The formula can be used to determine the photovoltaic capacitor[28].

$$C_{PV} = \frac{V_{PV.D}}{4\Delta V_{PV}(f_s)^2.L} \quad (3.10)$$

The following formula can be used to calculate the DC-link capacitor [31].

$$C_{DC} = \frac{P_{PV}}{4\pi f_s.V_{O}\Delta V_o} \quad (3.11)$$

Where, P_{PV} the nominal power of PV module

f_s the switching frequency, the voltage across the capacitor

ΔV_o the amplitude of the ripple voltage which is chosen to be 3%

Table 3.3: Boost Converter calculated parameter [28]

parameter	value
Duty cycle (D)	54.1%
PV Capacitor (C_{PV})	222.2 μ F
Inductance(L)	2.25mH
DC Link Capacitor ($C_{DC Link}$)	49.7 μ F
Resistance (R)	100 Ω

3.4. Operation and Working principle of Solar PV Maximum Power point trucking system

3.4.1. Maximum power point tracking

Highest Power Point A solar system's maximum power that is available under any atmospheric condition is tracked using tracking techniques. A crucial aspect of this method is tracking the voltage at which maximum power occurs. Maximum Power Point Tracking (MPPT) is a technique employed by controllers to draw the most amount of power from PV modules under particular conditions. A PV module's Maximum power Point, or VMP, is the voltage at which it can produce the most power. Depending on solar radiation (sunlight and clouds), the atmospheres, and cell temperature, the maximum power varies. It is feasible to utilize MPPT to automatically estimate the voltage (VMPP) or current (IMPP) at which a PV array should operate in order to produce the most power (PMPP) at a certain temperature and irradiance.

3.4.2. Working Principle of MPPT

The fundamental element of Maximum Power Point Tracking is electronic tracking (MPPT).to get the most out of a PV panel, a controller should be able to choose the optimal current voltage point on the current-voltage curve, or the Maximum Power Point. An MPPT controller does that. The more advanced MPPT controller will adjust its input voltage to maximize the amount of energy that can be obtained from the PV array before converting that energy to meet the varied voltage requirements of the battery and load. To achieve high output power, it essentially isolates the battery and array voltages.

A DC to DC voltage converter that effectively converts the array's voltage to the batteries' required voltage is included in an MPPT controller in addition to its fundamental controller functions. The following criteria indicate that maximum Power Point will occur: Voltage, current, irradiance, using observable data, and mathematical expressions of approximate numerical computations are only a few examples. A specific PV generator that is already integrated into the system is used in the estimation. The MPPT controller is a DC to DC transformer that can change power from a higher voltage to power at a lower voltage. Power generation is constant (except for a small loss in the transformation process).The equation $P=V \times I$ remains constant because if the output voltage is lower than the input voltage, the output current will be larger than the input current.

3.4.3. MPPT controller

The MPPT controller receives inputs from the PV voltage and current and then applies the MPPT algorithm to generate the required pulse for the DC-DC converter. Any control circuit type may be employed. It makes the most of the available power by applying the MPPT algorithm to increase PV system operation efficiency. As a result, a PV system uses a controller with an MPPT implementation to change the duty cycle of the converter in response to shifting atmospheric conditions.

3.5. Partial Shading Condition (PSC) of PV MPPT

Partial shading just covers a piece of the PV panel's surface. Partial shading can happen when some panels in a panel string are shaded while the others are completely hit. Partial shading is the darkening of a portion of the PV array's surface due to core or other shading. Core shade and partial shade have an impact on how much shadow there is on the panels (not the surface). The core shadow will strike the panel if the shadow-casting item is placed close to the array, reducing incidence energy by around 60–80%. Partial shade, which is brighter than core shadow, is produced when there are greater distances between the shadow-casting item and the panel. On the PV panel, around 30 to 40 percent less energy is incident.

3.5.1 Causes of power loss

The solar panel's cells are connected to one another in series. Cell groups, which are clusters of cells linked in anti-parallel to a single diode, develop as a result of bypass diodes. Bypass diodes are used to offer a different channel for the current of the lit cells when group cells are unable to provide the same current (for example, when shaded). As a consequence, if a cell group is shaded and the ignited cells generate 5A, the solar panel will as well. However, because to the short circuit on the collection of shaded cells and the lower voltage at the Maximum Power Point, power output will drop. Solar strings are made of series-connected PV panels. The amount of current produced by all PV panels when they are linked in series is referred to as the string current. But, for the panels to generate the same current, they must be exposed to the same amount of irradiance.

3.6. Operation of Boost Converter

- When switch S is closed- Current flows through Inductor L and switch S and back to the source. The polarity of L is +ve on left side and -ve on the right side. It stores energy in the form of magnetic field.
- When switch S is open- There is reversal of polarity across the Inductor. Thus right side becomes +ve and left becomes -ve. Current, now flows through L, diode and the capacitor. Capacitor sees two sources, the first source and L in series, hence perceives voltage greater than input voltage. Hence, it gets charged to a stepped up voltage. Thus, energy stored in the L is transferred to Capacitor C.
- During the period when switch S is closed, capacitor discharges through the load because right side of the circuit is shorted out. Hence, energy is transferred to the load. Diode prevents the capacitor from discharging through the switch.

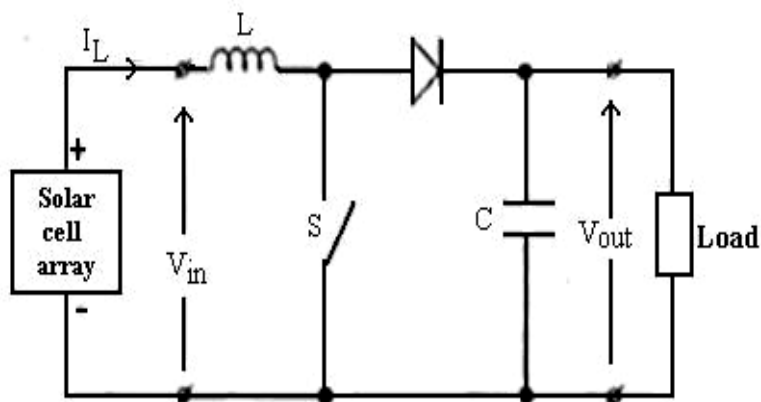


Figure 3.12. DC- DC Boost Converter [29]

CHAPTER FOUR

4. Control Design

4.1. Design of MPP controller for PV system partial shade condition

4.1.1. Photo voltaic (PV) system design

From the parameters that are estimated and illustrated in chapter three, a 250Watt PV module will be create Poly-crystalline framed photovoltaic solar modules with a rated output of 250 Watts under Standard Test Conditions (STC) will be chosen since they degrade power more slowly. The suggested model created a single 3×3=9 PV moduels.To produce the most power under partial shading, solar modules are interconnected using different connecting schemes

4.1.2. DC Operating Point Analysis of PV System

A DC working point examination is required to decide the input and output characteristics of the boost converter whereas the PV framework is working consistently. The PV cluster is expected to be working at its MPP under steady-state circumstances for the purpose of the DC think about. The ostensible and most extreme input necessities for the boost converter for the sun oriented cluster were decided utilizing the PV Module and the Converter parameters Points of interest. The DC input control is decided by increasing the string number, the number of PV modules within the string, and the panel's appraised yield control.

$$P_{array} = 250wxn \times xm = 250wx3 \times 3 = 2250watt \quad (4.1)$$

$$V_{in} = V_{mp,module} \times 3 \text{ modules} \quad (4.2)$$

$$V_{in} = 30.6V \times 3 = 91.8V$$

$$I_{in} = I_{mp,module} \times 3 \quad (4.3)$$

$$I_{in} = 8.17A \times 3 = 24.51A$$

$$P_{in} = P_{array} = V_{in} \times I_{in} \quad (4.4)$$

$$P_{in} = 91.8 \times 24.51 = 2250Watt$$

The two-piece direct development of figure 3.2 is utilized for the solar panel. Agreeing to the PV module's determinations, the input voltage, current, and control of the boost converter can be calculated as takes after:.

$$R_s = \frac{V_{oc} - V_{mp}}{I_{mp}} \quad (4.5)$$

$$R_s = \frac{37.05 - 30.06}{8.17} = 0.855\Omega$$

$$R_{sh} = \frac{V_{mp}}{I_{sc} - I_{mp}} - R_s \quad (4.6)$$

$$R_{sh} = \frac{30.06V}{8.7A - 8.17A} - 0.855\Omega = 56.717\Omega$$

$$I_L = I_{sc} \times \frac{R_s + R_{sh}}{R_{sh}} \quad (4.7)$$

$$I_L = 8.7A \times \frac{0.855\Omega + 56.717\Omega}{56.717\Omega} = 8.83A$$

The equivalent of Thévenin's PV array resistance is calculated as follows:

$$R_{eq} = (R_{sh} + R_s) \times \frac{N_{ser}}{N_{par}} \quad (4.8)$$

$$R_{eq} = (56.717\Omega + 0.855\Omega) \times \frac{3}{3} = 57.572\Omega$$

Since the DC connection's voltage is regulated to 1000V, the current of the DC link may be calculated using:

$$I_{dc} = \frac{P_{mp}}{v_{dc}} \quad (4.9)$$

$$I_{dc} = \frac{2250W}{200V} = 11.25A$$

The boost converter's relationship between input and output voltages can be used to calculate the steady-state duty cycle value

$$D = 1 - \frac{V_{in}}{V_{dc}} \quad (4.10)$$

$$D = 1 - \frac{91.8V}{200V} = 0.541$$

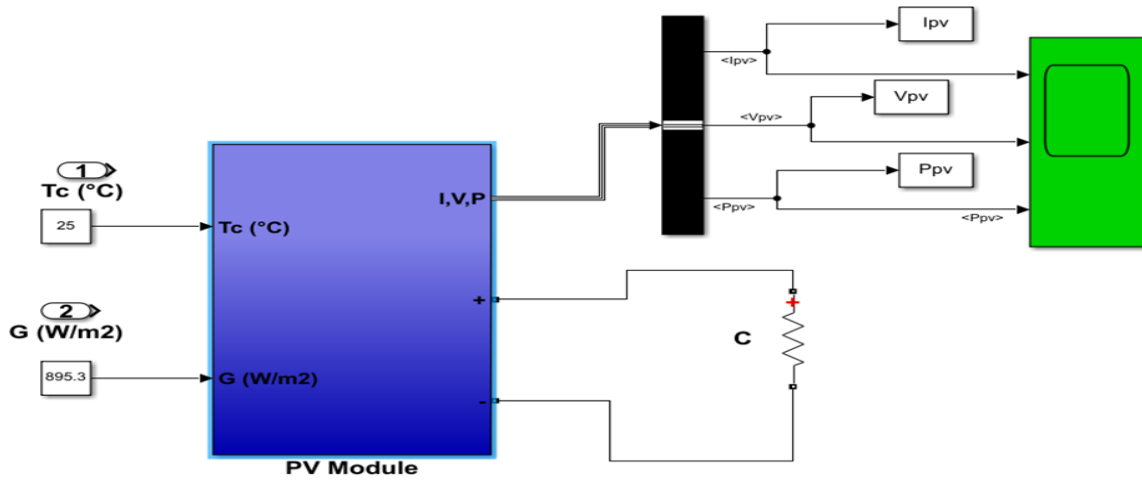


Figure 4.1: Simulink Model of Single PV Module

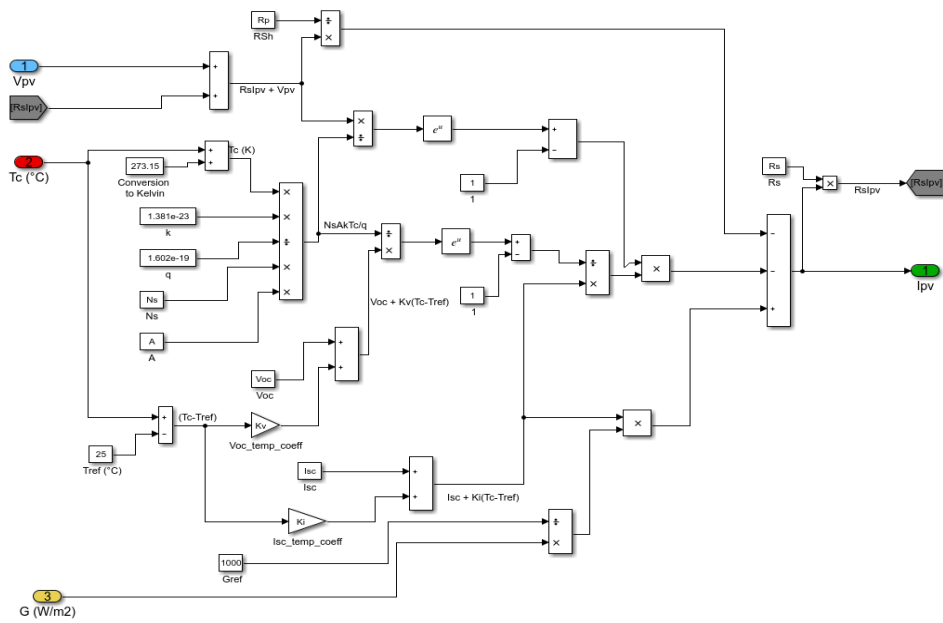


Figure 4.2: Sub-Simulink Model of PV Module

4.2. Design of Boost Converter

It is apparent that the boost converter in this arrangement regularly works in continuous conduction mode (CCM). It is profitable to have a DC-DC converter with a high switching frequency since it permits for the lessening of the measure of both inductors and capacitors. A high switching frequency can be utilized to diminish the effect of PV array voltage ripples. High switching frequencies disable converter proficiency generally and can require an enormous warm sink in arrange to scatter the extra warm produced by the switches since they cause more control misfortune within the switches. It is additionally easier to choose an exchanging recurrence that compromises the yield of the converter and the estimate of the component. The exchanging recurrence in this setup is set to 3 kHz, and the boost converter is gathered to continuously work within the CCM.

4.2.1. The Minimum Inductance

The duty cycle value and the most extreme allowed ripple current are the two criteria utilized to select the inductance for a boost converter. When the allowable ripple current is as well low. Unsteady PWM action can happen, though electromagnetic impedances (EMI) is significant when the reasonable swell current is as well tall. The boost converter yield current is at first calculated utilizing:

$$I_o = \frac{P_{array}}{V_{dc}} \quad (4.11)$$

$$I_o = \frac{2250W}{200V} = 11.25A$$

As a general rule, the inductor ripple I_L current is chosen to be 30% of the maximum input current and is calculated as follows:

$$\Delta I_L = 30\% \times I_{in} = 24.51 \times 30\% = 7.35A \quad (4.12)$$

The boost converter's minimum inductance will be:

f_s is the switching frequency in the boost converter which is chosen to be 3KHz

$$L = \frac{D \times V_{in}}{f_s \times \Delta I_L} = \frac{0.54 \times 91.8}{3000 \text{ hz} \times 7.35A} = 2.25mH \quad (4.13)$$

4.2.2. Determination DC Link Capacitance

The least capacity of the DC connection capacitor is decided by the most extreme input control step required and the allowed voltage variety restrains details. A common limitation could be a ten percent flight from the DC connection voltage at each step-on and step-off stack reaction. The anticipated most extreme input control organize is in distinguishable to the greatest control

point of the sun based board control (MPP). Hence The DC-link capacitor can be gotten Using the taking after equation [30],

$$C_{DC} = \frac{P_{PV}}{4\pi f_s V_O \Delta V_O} \quad (4.14)$$

$$C_{DC} = \frac{2250}{4\pi \times 3000 \times 200 \times 6} = 49.7 \mu F$$

Where P_{pv} is the maximum Power of the PV array

ΔV_O is the amplitude of the ripple voltage which is chosen to be 3%

$$3\% \times 200 = 6$$

4.2.3. Determination of the Input Filter Capacitance

The input filter capacitor is utilized beneath commonplace working conditions to decrease the voltage ripple within the PV cluster. The boost converter can too maintain a strategic distance from a few hurt due to the intermittent nature of sun based vitality within the PV array voltage changes. A significant voltage rippel within the PV cluster will develop from the inductor's current swell, which can be reduced with a DC input channel capacitor. Accepting that the nonlinearity of the PV array's yield characteristics is neglected which the boost converter is still working in persistent.

$$\Delta V_{in} = \frac{DT^2 P_{array}}{4C_{pv} L} = \frac{DV_{array}}{4C_{pv} L f^2} \quad (4.15)$$

The PV array voltage ripple is selected as 3% of the V_{pv} voltage, which is 2.75V.

Now

$$C_{pv} = \frac{DV_{pv}}{4\Delta V_{in} f^2 L} \quad (4.16)$$

$$C_{pv} = \frac{0.54 \times 91.8V}{4 \times 2.75 \times 3000^2 \times 0.00225} = 222.2 \mu F$$

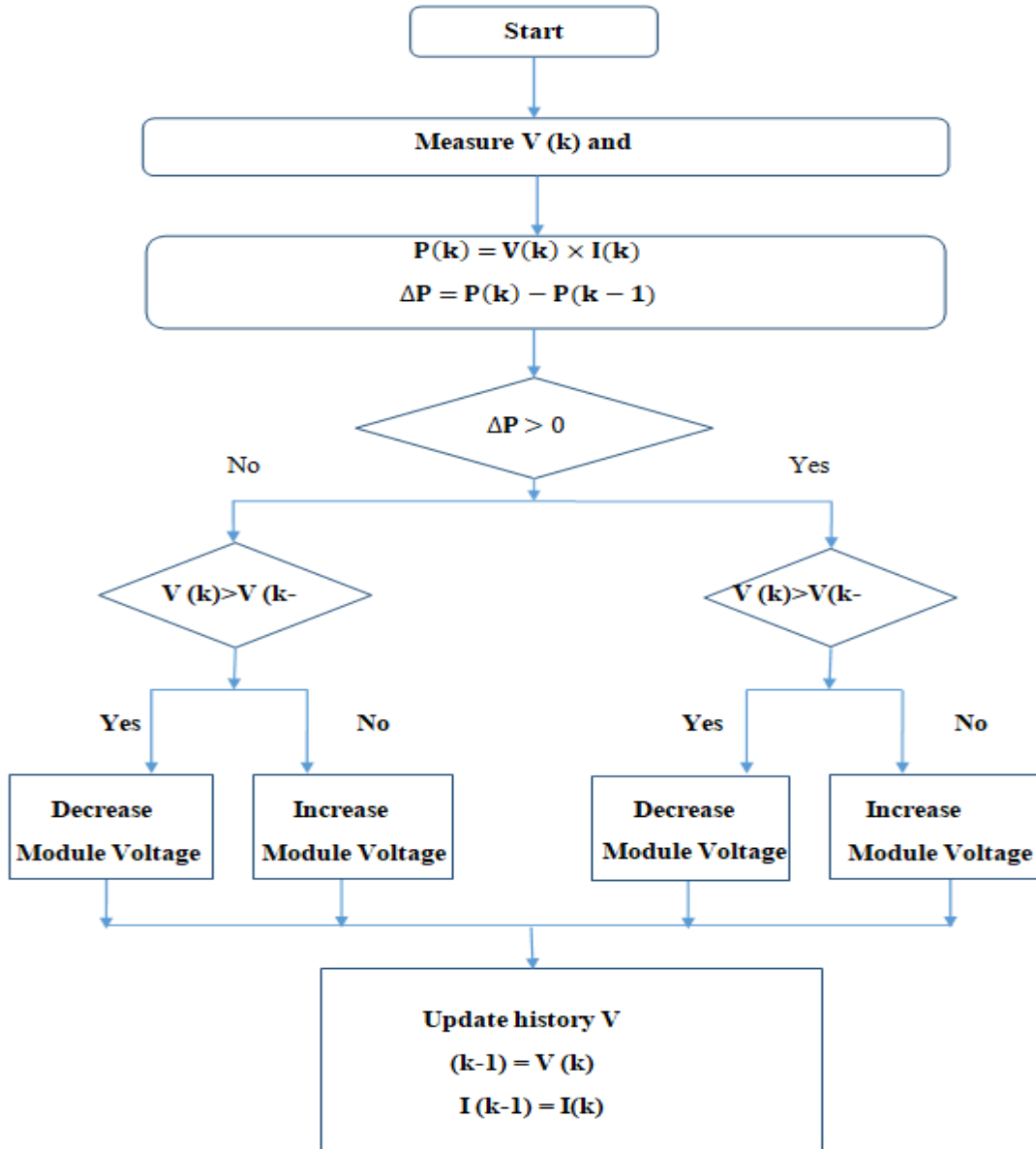


Figure 4.4: Flowchart of Perturb and Observe algorithm

4.3.2. Incremental Conductance Method

The Incremental Conductance Approach was created to follow a P-V characteristic curve-based observation. This algorithm was created in 1993 with the intention of addressing some P&O algorithm shortcomings. The MPP can be calculated using the relationship between dI/dV and I/V . Based on the fact that the slope of the PV array on the power curve is zero at the MPP, positive to the left of the MPP, and negative to the right of the MPP, the incremental conductance method is used. This is accessible through,

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV} = I + V \frac{dI}{dV} \quad (4.17)$$

MPP is reached when $\frac{dP}{dV} = 0$ and

$$\frac{dI}{dV} = -\frac{I}{V} \quad (4.18)$$

$$\frac{dP}{dV} > 0 \text{ Then } V_p < V_{mpp} \quad (4.19)$$

$$\frac{dP}{dV} = 0 \text{ Then } V_p = V_{mpp} \quad (4.20)$$

$$\frac{dP}{dV} < 0 \text{ Then } V_p > V_{mpp} \quad (4.21)$$

So if the MPP is on the right side, $< -I / V$ and then to enter the MPP, the Photo Voltaic voltage must be decreased. It has been known to increase the PV performance, decrease power loss and also the device cost in order to find the MPP IC technique that can be used. It is shown to produce a much more reliable performance compared to the P&O method when the IC method is implemented in a microcontroller. The procedure begins by calculating the present values of the voltage and current of the PV module. Then the gradual shifts, dI (change in current) and dV (change in voltage) are calculated, using the current and previous voltage and current values. The primary check is then performed with the aid of the relationships in the equations described above. If the condition satisfies the above-mentioned inequality equation, it is assumed that the operating point is on the left side of the MPP, so the module voltage must be increased to the right. Similarly, if the condition satisfies the equation of inequality, it is assumed that the operating point is on the right side of the MPP and must therefore be shifted to the left by reducing the voltage of the module.

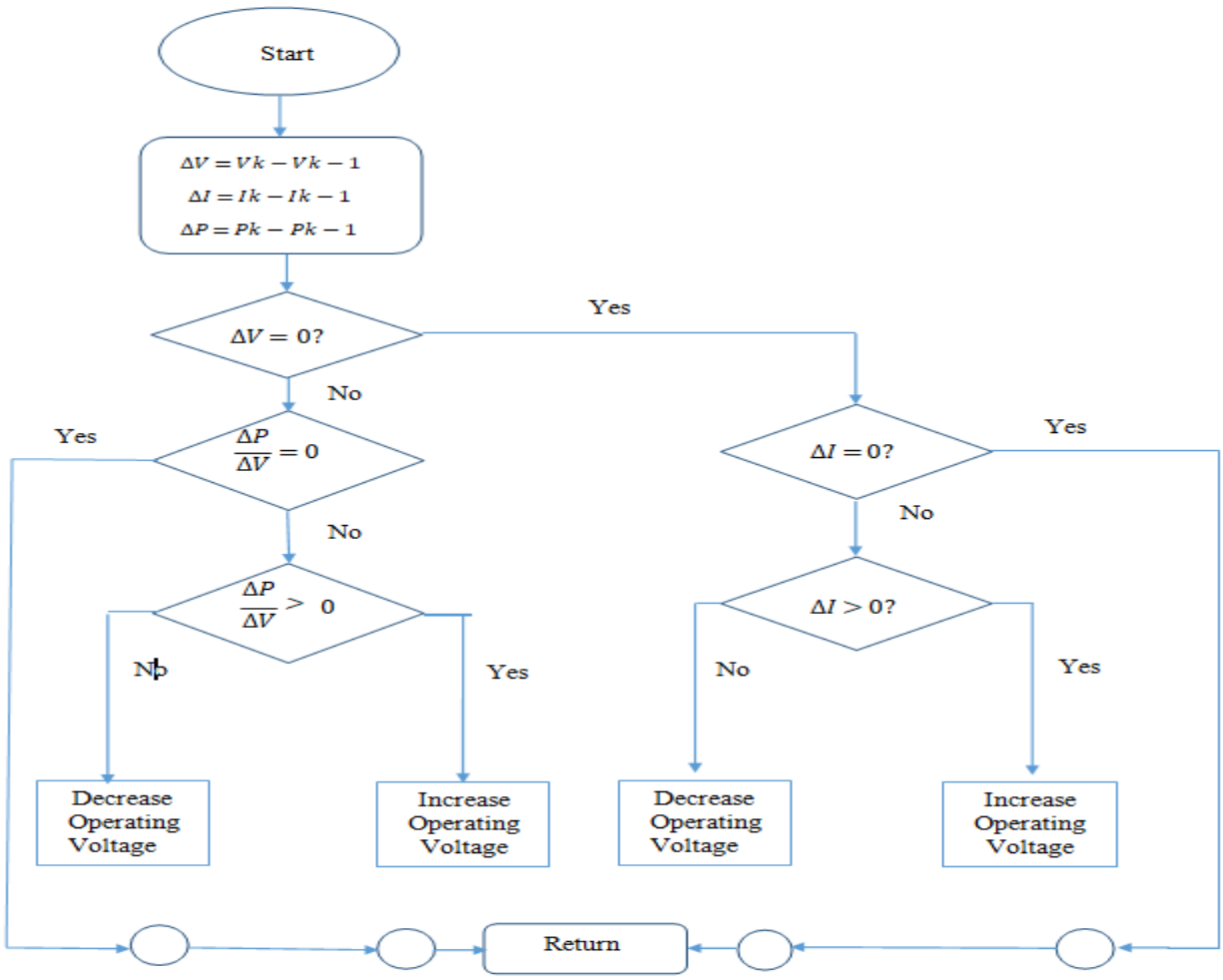


Figure 4.5: Flowchart of Incremental Conductance Method Algorithm

4.3.3. Fuzzy Logic Controller

In the field of artificial intelligence known as fuzzy logic, reasoning systems that mimic human cognition and decision-making are studied. These algorithms are employed in contexts where it is impractical to express process data in binary form. Fuzzy logic demands information in order to reason. An entity that is stored in the fuzzy system and is knowledgeable about the procedure or computer provides this information (the expert). Fuzzy Logic is an environment that helps a computer system to reason with ambiguity through a series of computer techniques. It is distinguished by its Membership Feature (MF), dealing with humanistic systems whose Human interpretation, decision-making, and judgment have a significant impact on behavior. Systems for making fuzzy inferences are made up of a number of "if-then" rules that are specified over fuzzy sets. In their field of expertise, fuzzy sets are connections that may be utilized to simulate the

linguistic variables employed by human specialists. The distinction between fuzzy sets and logic (crisp) sets is that the membership function can take any value from 0 to 1 for elements of a fuzzy set, but logic sets only take 0 or 1. Too often unambiguous situations correspond to the fuzzy, where it is difficult to determine whether or not anything belongs to a certain class. Fuzzy Logic Controllers (FLC) has been used as diagnostic and classification of many control problems because they can accommodate the difficult reasoning of experts. Setting the limits, assigning the linguistic variables and setting the rules for the controller are the procedures for creating the control designs.

In the following figure, the synoptic of the design is depicted. Four key components are included in the basic structure of the fuzzy rule-based system: the fuzzification interface, where input values are calculated, fuzzified and the input range is mapped into the appropriate discourse universe, the knowledge base, which includes a numeric portion of the 'database' and a fuzzy (linguistic) rule base section, the fuzzy inference mechanism.

4.3.3.1. Fuzzy Inference System

The input universes must be big enough for the inputs in order to stay inside the restrictions (no saturation). Each input family should contain a number of terms that are constructed in such a way that the total membership values for each input are known. This is possible when the sets are triangular and cross their neighbour sets at the membership value = 0.5; Then, the peaks would be evenly separated. Any input value can therefore belong to no more than two sets, and the membership of each set is a linear function of the input value. The number of rules in each family is determined by the number of terms because they must be the AND (outer product) combination of all terms to assure completeness. Ideally, the output sets should be singletons; they can alternatively be triangles with symmetric peaks, but singletons make defuzzification easier. To guarantee linearity, the connective AND's algebraic product will be selected. Since all firing strengths sum up to 1, the denominator is eliminated when utilizing the weighted average of rule inputs for the control signal (equivalent to center of gravity defuzzification).

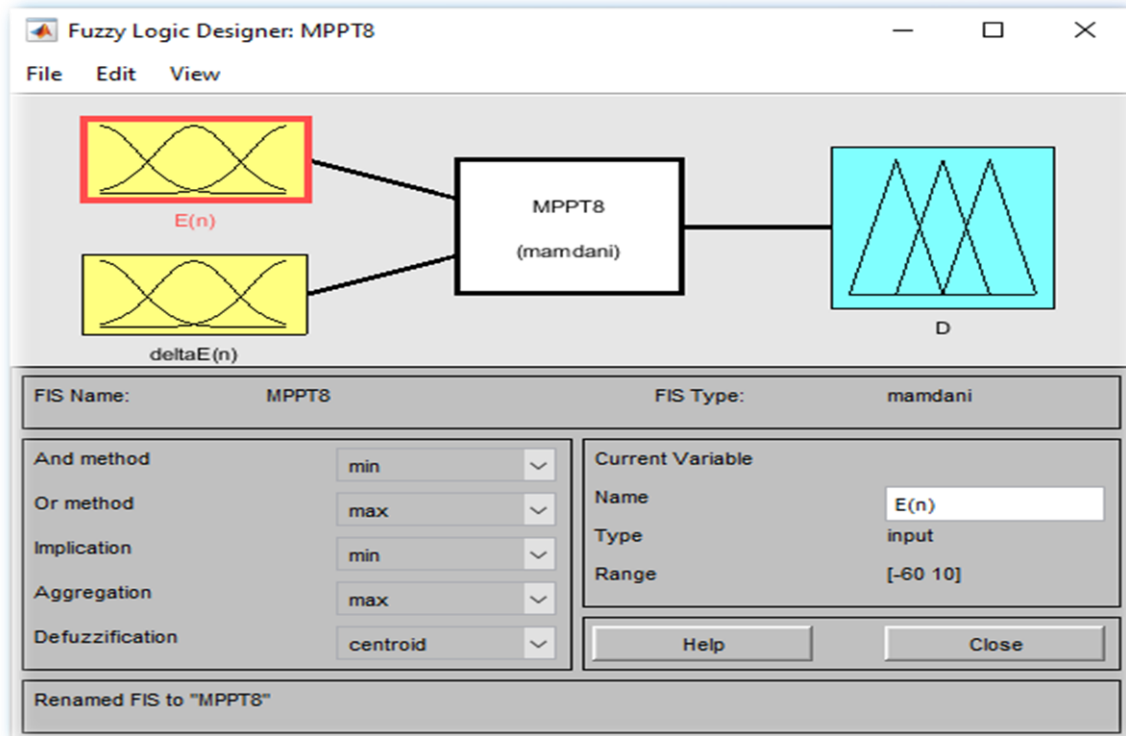


Figure 4.6: MATLAB implementation of the Fuzzy logic control system

4.3.3.2. Fuzzier Design

1. Two trapezium and three triangular forms of fuzzy input membership functions are employed for duty cycle ratio error and change in duty cycle ratio.
2. Five fuzzy linguistic values are assigned a degree of membership of a crisp value: NB, NS, ZE, PS, and PB. Membership Function of error of duty cycle ratio is one of the input linguistic variables having five linguistic variables called **NB** [-60 -50 -45 -35], **NS** [-45 -35 -25], **ZE** [-35 -25 -15], **PS** [-25 -15 -5] and **PB** [-15 -5 49 75].

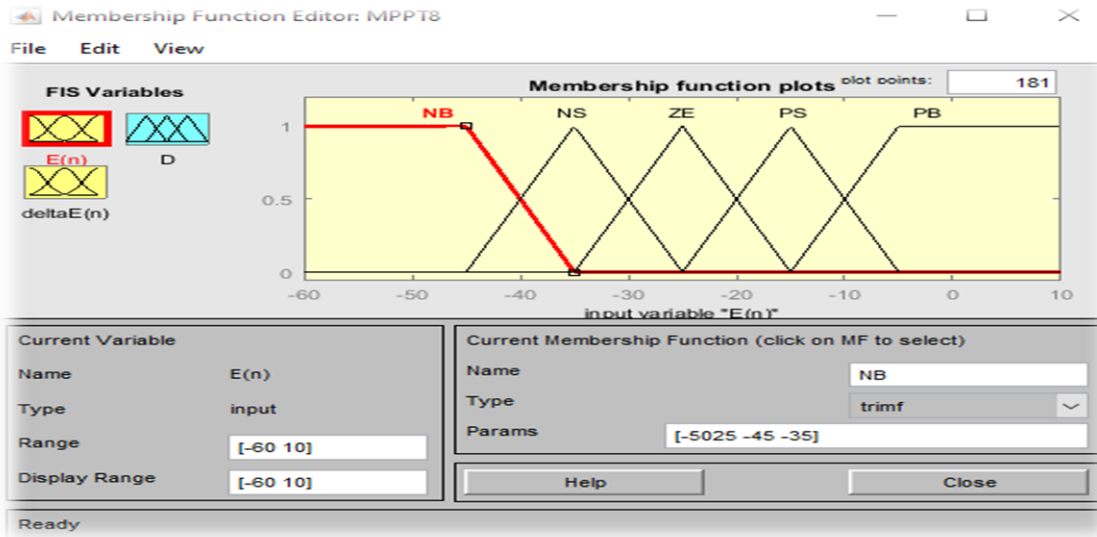


Figure 4.7: Membership functions for error of duty cycle ratio

- Membership Function of change of error of duty cycle ratio is one of the input linguistic variables having five linguistic variables called **NB** [-1808 -272 -80 -40], **NS** [-80 -40 0], **ZE** [-40 0 40], **PS** [0 40 80] and **PB** [40 80 500 600].

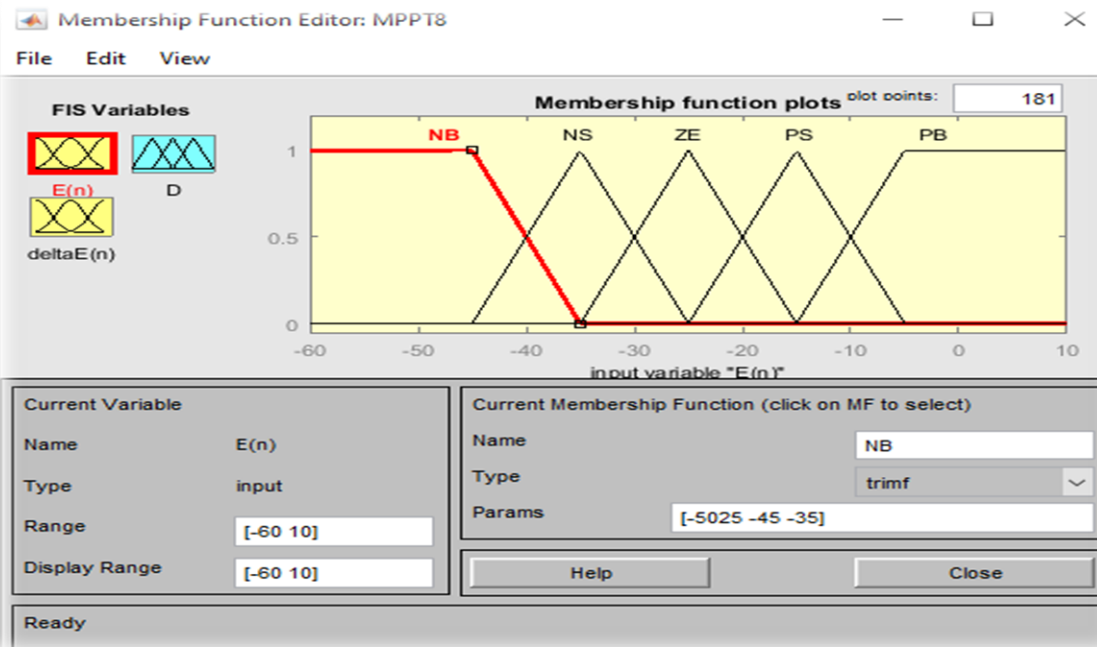


Figure 4.8: Membership functions for change of error of duty cycle ratio

4..Five linguistic variables are used in the Membership function of duty ratio of the output variables: NB [-1.45 -1 -0.5 -0.35], NS [-0.68 -0.3 0], ZE [-0.35 0 0.3], PS [0 0.3 0.35], and PB [0.3 0.6 1 1]. .47]

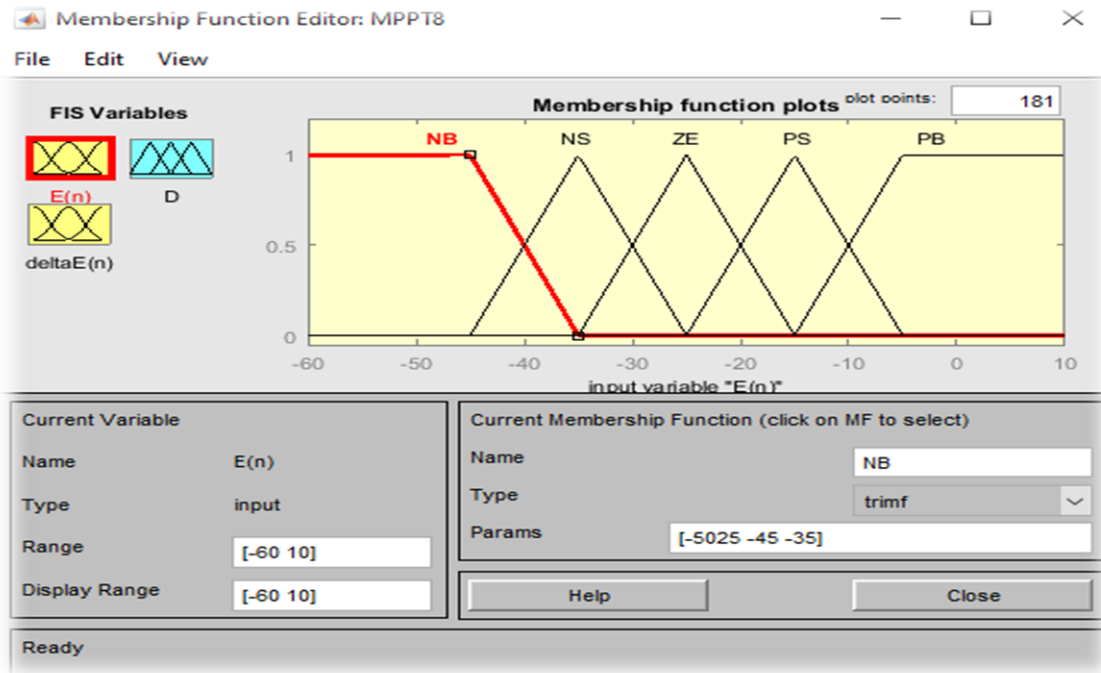


Figure 4.9: Membership functions for output duty ratio

4.3.3.3. Rule base construction

The Mamdani fuzzy abstract thought system was backed by the rules that define the regulation of our system. Since these input parameters that define membership functions (MFs) must be fuzzified, it is important to gamble on the specific membership degree values, duty cycle ratio error, and duty cycle ratio change.

Table 4.1: Rule Table Matrix

E/CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

The Min-Max technique of fuzzification is employed to line the fuzzy rules of the controller

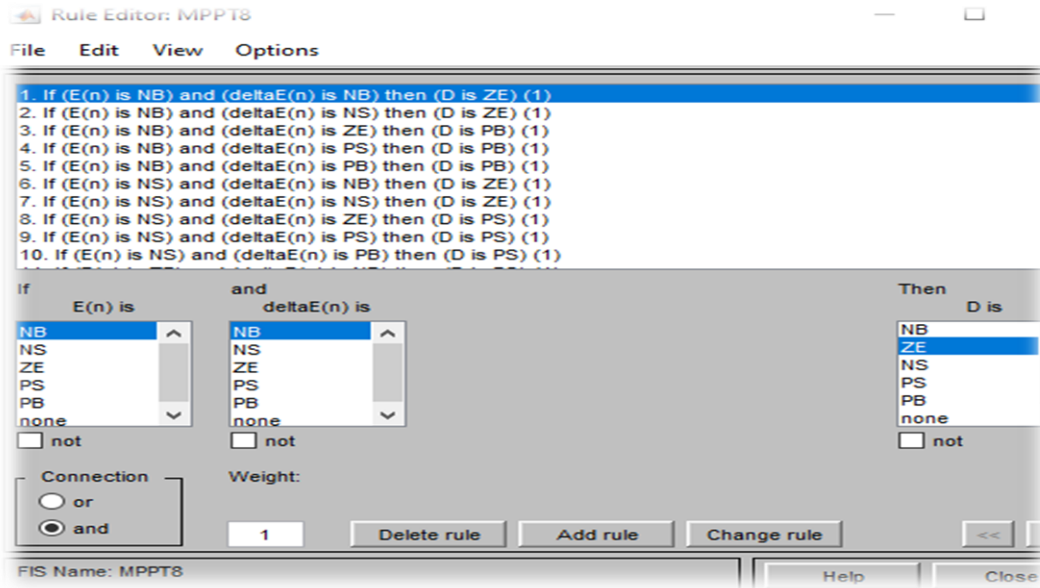


Figure 4.10. fuzzy. Rule Base of a proposed model



Figure 4.11. Rule Viewer Of Fuzzy logic Control Matlab Model

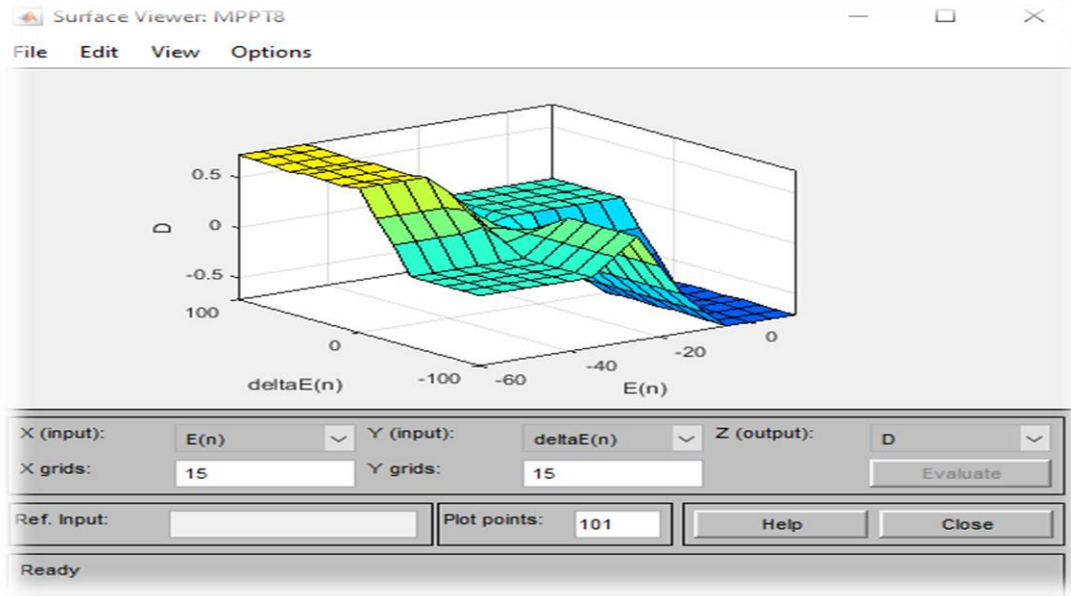


Figure.4.12.Surface Viewer Of Fuzzy logic Matlab Simulink Model

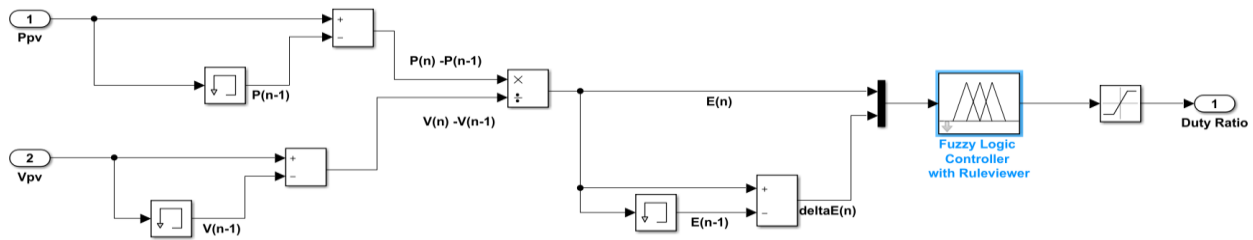


Figure 4.13: Simulink Model of Fuzzy Logic Controller

4.4. Overall System Design of A Proposed Model

The essential components of the system design include PV array solar cells, a DC-DC boost converter with an MPPT controller, and fuzzy logic control (FLC). This paper proposes a fuzzy logic controller for intelligence control. Monitoring the maximum power point (MPP) of a PV system and comparing the suggested intelligent control fuzzy logic under partial shading conditions using the two MPPT conventional controller methods of perturbing and observing (P&O) and incremental conductance (INC). Figure 4.14, which is below, illustrates the proposed design's nine single (3×3) PV array layout in various connectivity schemes that are explained in more detail in the private chapter (Total cross tie). and BL (Bridge linked) and different shading pattern the DC-DC Boost converter is linked between the PV array and the output Load the Fuzzy controller designed to tracking and control MPP of a proposed system.

4.4.1. Fuzzy logic design of MPP controller for PV system partial shade condition

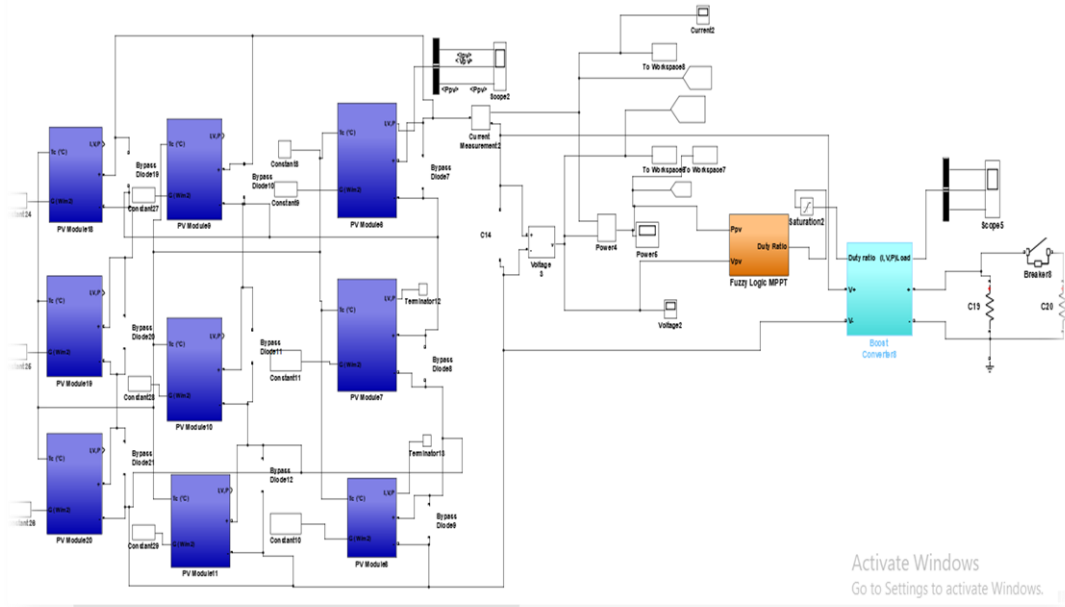


Figure 4.14. Design of MPP for PV system PSC in fuzzy logic controller

4.4.2. Design of an MPP controller using the P&O method for partial shading of a PV system

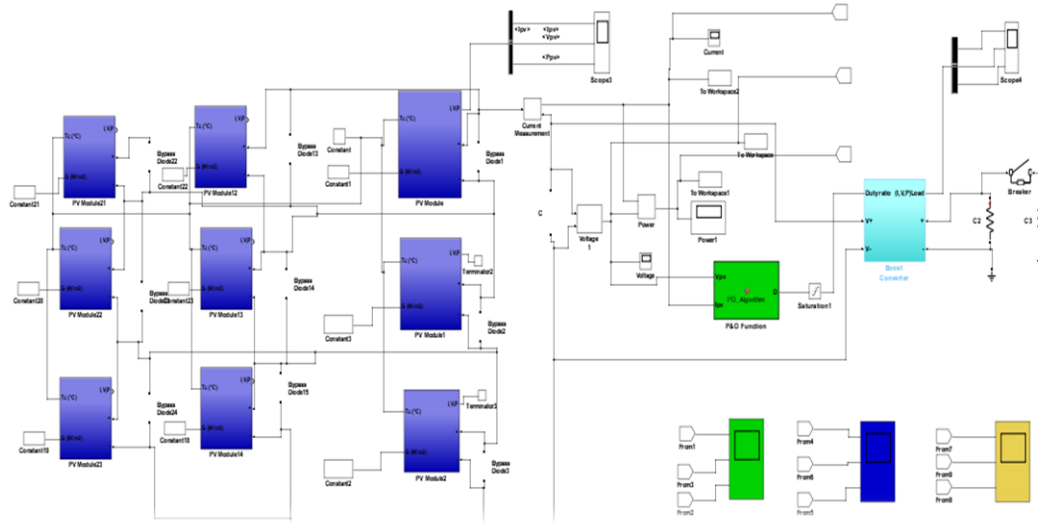


Figure 4.15. Design of MPP for PV system PSC in P&O method

4.4.3. Design of an MPP controller using the INC method for a PV system with partial shading condition

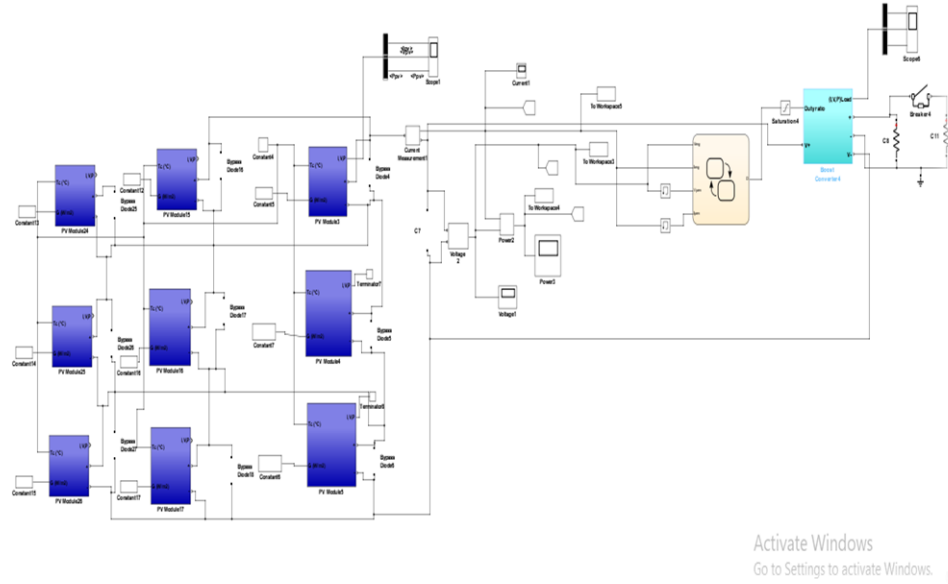


Figure 4.16. Design of MPP for PV system PSC in INC method

4.4.4. Design of DC-DC Boost Converter

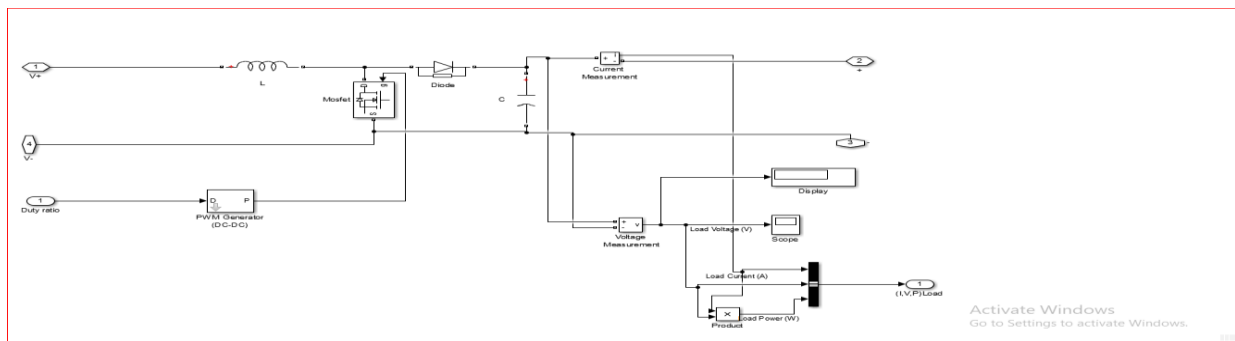


Figure 4.17.sub Simulink model of DC-DC Boost Converter

Control design conclusion

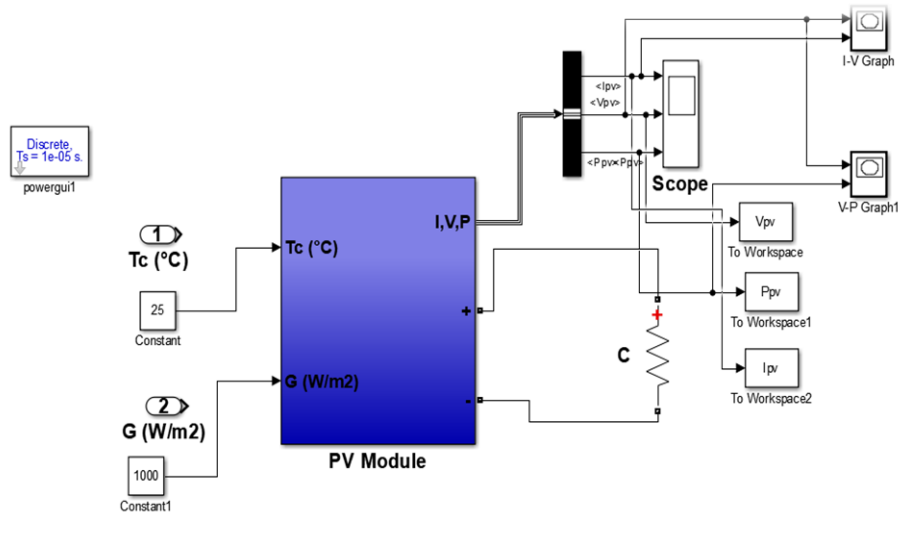
In this study, fuzzy logic intelligence controller Extract maximum power point Compared to the traditional methods of MPPT of PV system P&O and INC methods a design was created to maximize PV solar system power in conditions of partial shade.,

CHAPTER FIVE

5. Simulation Results and Discussion

5.1. PV module characteristics

Simulink diagram of single PV solar system



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Figure 5.1. simulink model of Single PV solar module

Simulation Result of Single PV module

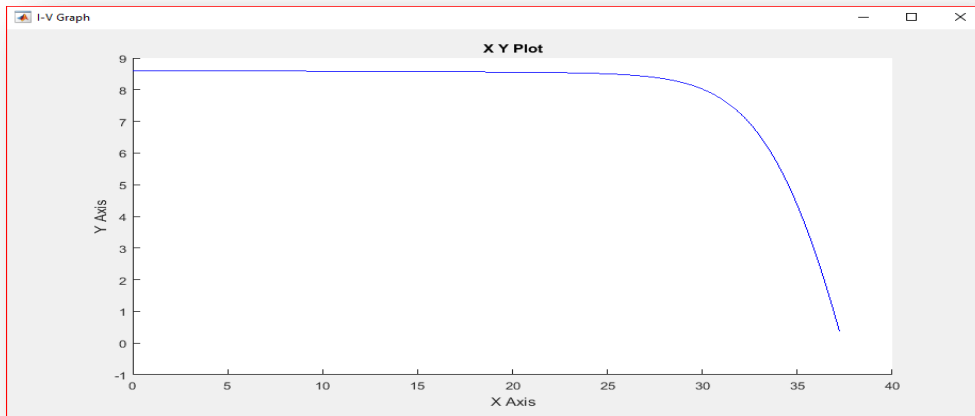


Figure 5.2. I-V curve of a single PV module at STC (1000W/m2 and 25°C)

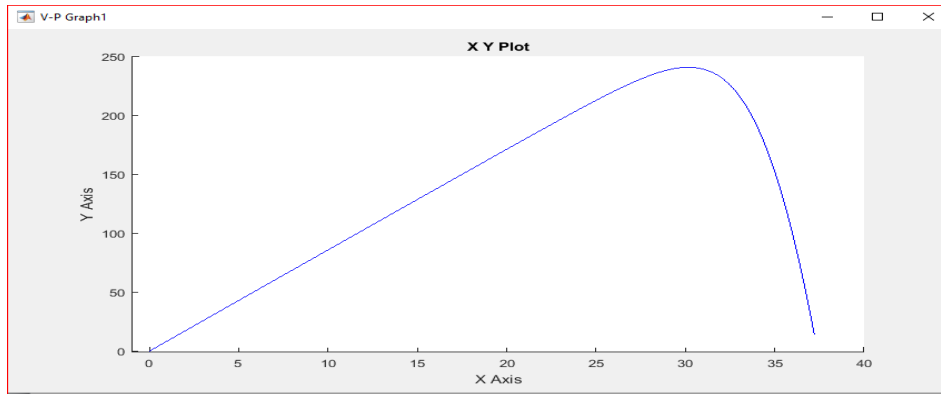


Figure 5.3. PV module P-V Curve at STC (1 000 W/m² and 25 °C)

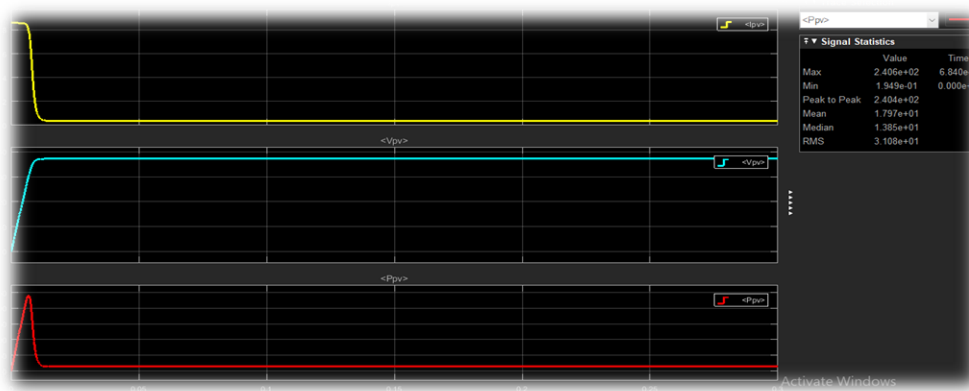


Figure 5.4. The output power voltage and current of a single PV module

The single PV module solar cell that is being suggested, as shown in figure 5.1, includes the following features.

Table 5.1.: Electrical specification of PV Module Data

parameter	value
Peak Power Pmax (Wp)	250W
Maximum Voltage Vmpp (V)	30.6V
Maximum Current Impp (A)	8.17A
Open Circuit Voltage Voc (V)	37.5V
Short Circuit Current Isc (A)	8.7A

According to the data, the maximum power output of a PV module was 250W at STC (1000W/m² irradiance and 25°C Temperature). The results of MATLAB Simulink show that this power is around 246W, or 98.4% of the maximum power of a PV module.

$$P=I \times V = 30.6 \times 8.17 = 250W$$

5.2. A proposed PV module's partial shading characteristics model, without controller.

Simulink diagram of partial shading characteristics of a PV module Configuring Nine single PV module in various shading patterns.

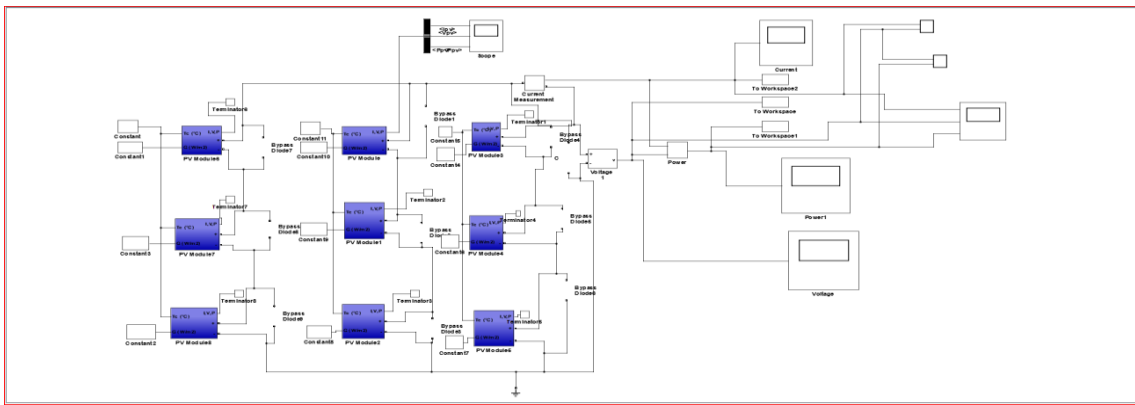


Figure 5.5. Simulink diagram of a PV module's partial shading characteristics without a control design

Case1. PV cell solar module PSC (Partial shade condition) 3×3 series parallel connected at STC (1000W/m² irradiance and 25°C temperature)

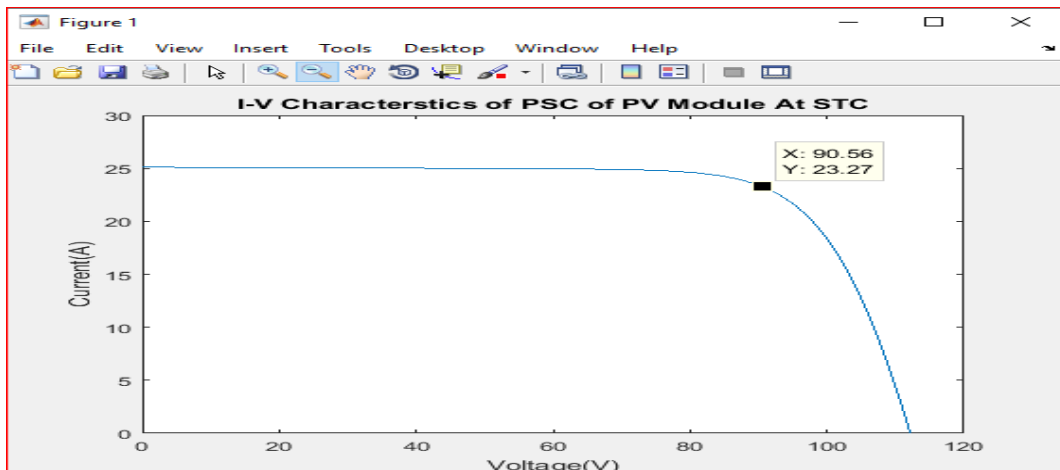


Figure 5.6. I-V curve of PV module at STC (1000W/m² and 25°C temperature)

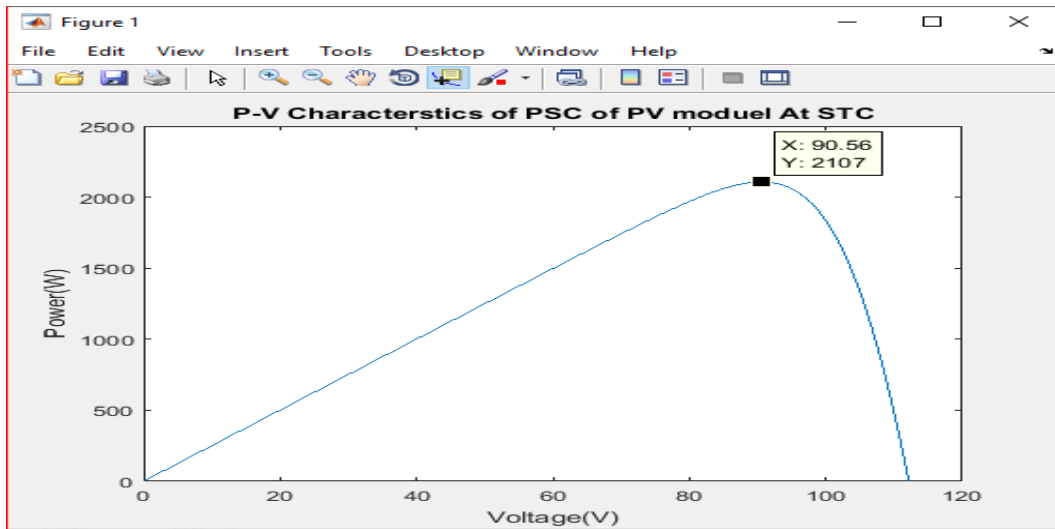


Figure 5.7. P-V curve PV module at STC (1000W/m² and 25°C temperature)

Discussion

Analyze how effective maximum power Point Tracking (MPPT) Efficiency of a PV module will be determined by of a PV solar system as

$$\text{Efficiency of PV module} = \frac{MPPT}{\text{Expected maximum powe}} \times 100$$

$$\text{Expected maximum power } P_M = V_M \times I_M = 91.8V \times 24.51A = 2250W$$

$$\text{MPPT in Simulink Result} = 2107W$$

$$\text{Then the Efficiency of output power} = \frac{2107W}{2250W} \times 100 = 93.64\%$$

Case2. I-V and V-P characteristics of a 3×3 Series parallel linked (1000,800,600)W/m² irradiance arrangement of PV modules under PSC shown above in figure 5.5.

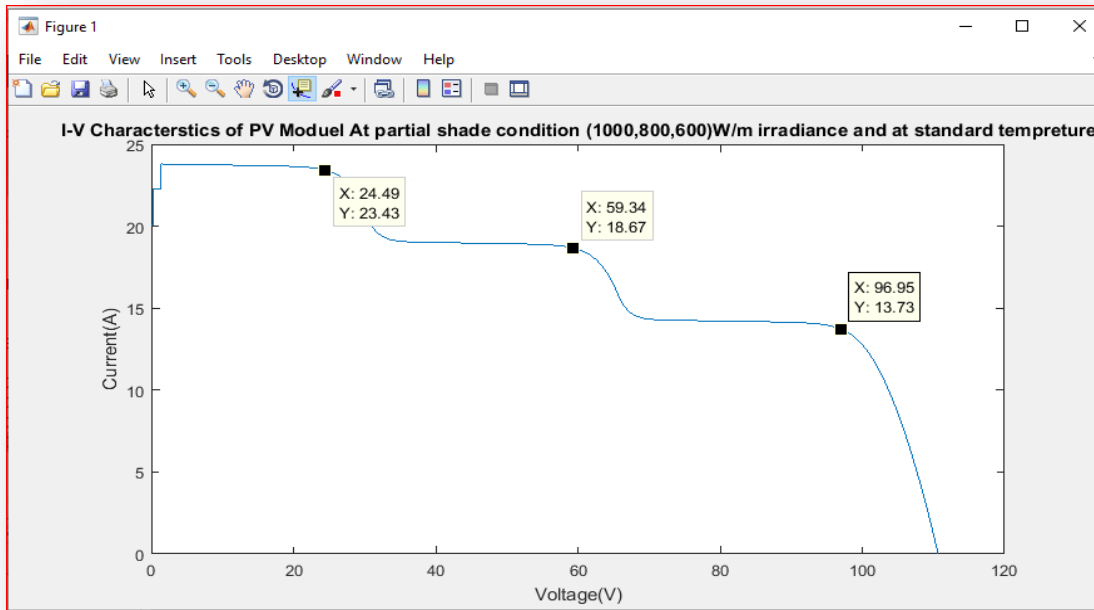


Figure 5.8. I-V Curve in PSC of PV module 3*3 SP connected
At a temperature of 25 c and irradiance of (1000,800,600) W/m²

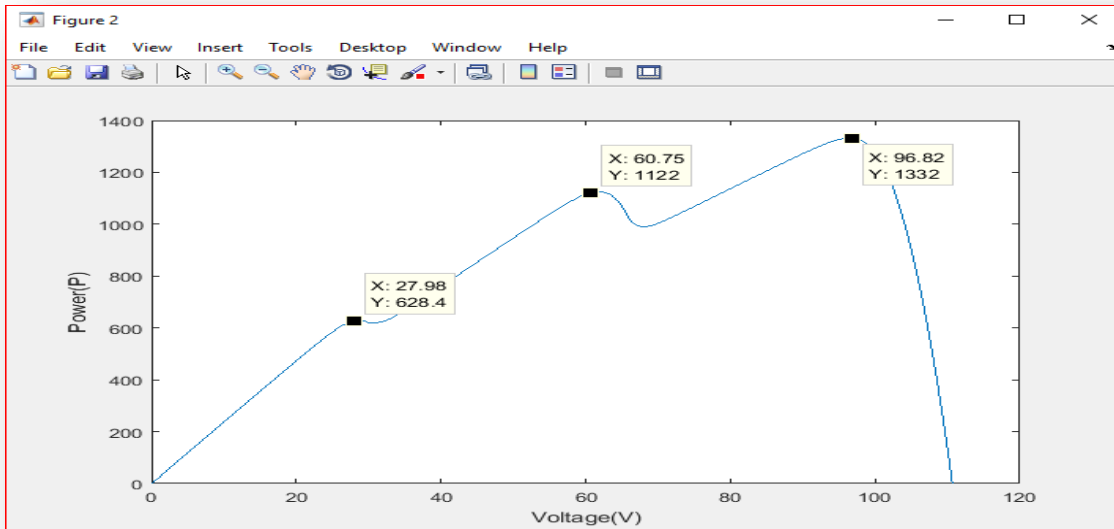


Figure 5.9. P-V Curve in PSC of PV module 3*3 S connected
At a temperature of 25 c and irradiance of (1000,800,600) W/m²

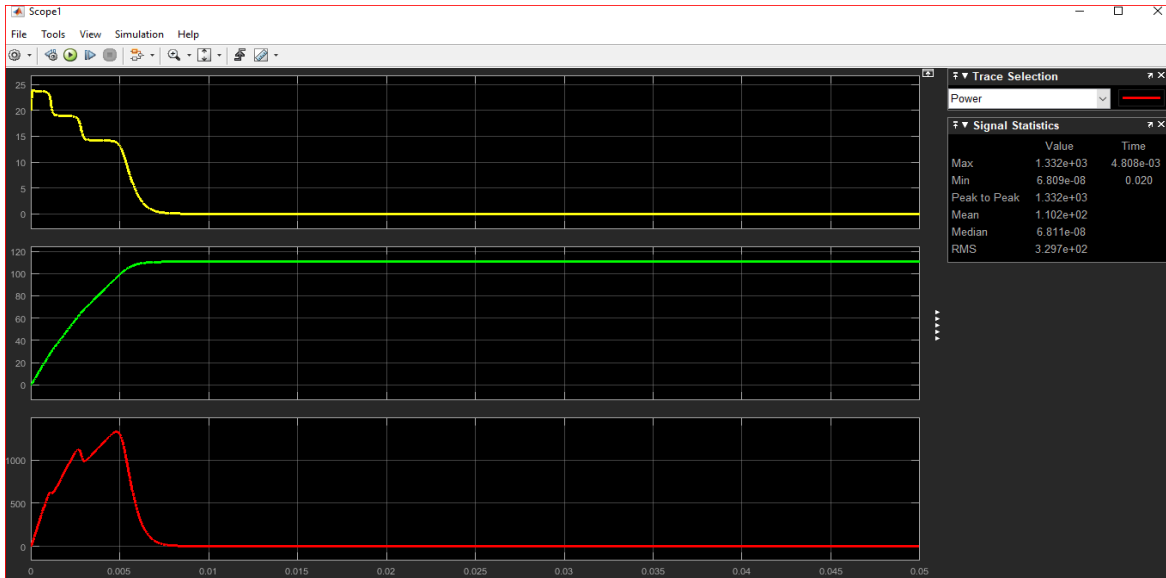


Figure 5.10. output of power voltage and current of 3*3 series parallel connected PV module under partial shade condition At (1000,800,600) W/m² irradiance and 25 °C temperature

Discussion

Figures 5.7, 5.8, and 5.9 display the output of Simulink for the I-V,P-V and I,V,P-T graphs, respectively. Irradiance of (1000,800.600W/m²) and 25°C ambient temperature with partial shadowing condition of PV module solar cell that is connected 3×3 series and parallel shown in figure 5.5.a determination of the result The anticipated power outcome will be made. The amount of solar radiation =1+0.8+0.6= 2.4Kw/ m²× (2250W÷3) =1800W is the expected maximum power under this shade condition but The maximum power point tracking (MPPT) Of a PV module Simulink result is 1333W.

Then the efficiency of the modules output = $\frac{1333W}{1800W} \times 100 = 74\%$ of the Expected Value.

When discussing the partial shade condition (PSC) of a Simulink PV MPPT result, three peaks are observed among those one global MPP with a value of 1333W at 1000W/m² and two local MPPs with values of 1122W and 628.4W at 800W/m² and 600W/m², respectively.

In order to determine the Simulink results according to the General objective of this thesis work the proposed Fuzzy logic controller in PV System. How to Extract GMPP during partial shading condition.

Fuzzy logic controller illustrates based maximum power point tracker it can be seen from the observation that the only two state variables are detected as inputs of fuzzy controller output voltage and output current of PV module V_m and I_m . the fuzzy logic controller from measurements gives a signal proportional to the converter duty cycle(D) to which is feed to the converter through a pulse width modulator(PWM) this modulator drives the value of D to perform pulse width modulation that generate the control signal for the converter switch.

Fuzzy logic structure based on fuzzy sets which a variable is a member of one or more sets a specified degree of membership benefits of using fuzzy logic is it allows to emulate the human Reasoning process in computer .

Fuzzy logic controller has Three stages fuzzification, inference and defuzzification

1.Fuzzification

In fuzzification numerical input variables converted into linguistic value based on a membership function in this MPPT the actual voltage and current measured continuously and the power can be calculated the control determined two proposed input control namely error(E) and change of error (CE) at the instant sampling n

$$\blacktriangleright \quad E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad \quad CE(n) = E(n) - E(n-1)$$

Where P(n) is the power and V(n) is the voltage of PV module

2.The inference engine

The inference engine applies a rule to fuzzy input to determine the fuzzy output therefore the rule can be evaluated before. The real input value must be fuzzified to obtain an appropriate linguistic value. In this thesis model has 25 rules of fuzzy controller depicted in chapter four the rules employed to control the DC-DC converter so the MPP of PV module is reached.

The main idea of base rules are to bring the operation point of a PV module to the MPP by increasing or decreasing the duty ratio of DC-DC converter.

A set of rules are used to governor the behavior of the control surface which relates the input and output variables of the system a typical rule would be if x is A THEN y is B if-then rule

3. Defuzzification

The DC-DC converter requires a precise control signal D at its entry. It is necessary to transform the output of the fuzzy controller from fuzzy information into deterministic information. This transformation is called defuzzification. In the defuzzification stage, the linguistic variable is changed into a numerical variable.

Defuzzification can be performed using two algorithms: the Center of Area (COA) and the Maximum Criterion Method (MCM). The most widely used defuzzification method is the determination of the center of gravity (COG) centroid method. This algorithm is used for this fuzzy design.

To generalize how the fuzzy logic controller extracts the Global Maximum power of the PV system in partial shading conditions. However, the fuzzy rules are extracted by analyzing the system behavior. Different operating conditions are considered in order to improve tracking performance in terms of dynamic response and robustness. The algorithm can be explained as follows.

The tracking process starts with an initial duty cycle $D=0$. The converter input current I_m and voltage V_m are then measured, and the duty cycle that can give the maximum power output of the converter at that time is determined based on predicted values that have already been entered into the fuzzy system. This operation repeats itself until the power reaches the maximum value and the system becomes stable.

5.3. Simulink Diagram of PV system with P&O MPPT Controller in partial shading condition

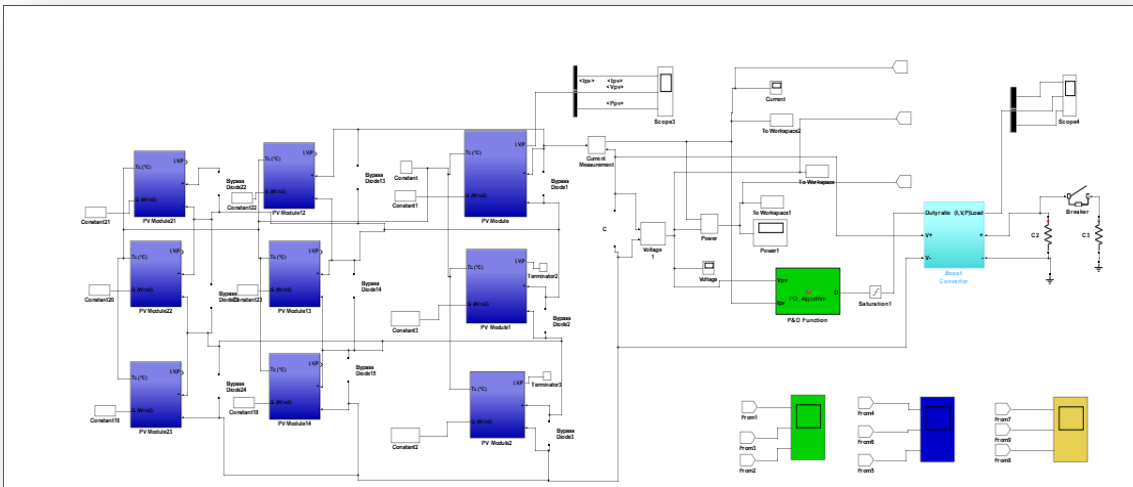


Figure 5.11. Simulink Diagram of PV MPPT in P&O controller and partial shade condition

Case.1 3×3 Evaluate performance of the PV module under PSC in Total Cross Tide (TCT) array configuration and 1000,800,500w/m² shading pattern using P&O MPPT controller.

Simulation Result of PV output power Voltage and Current in TCT array configuration

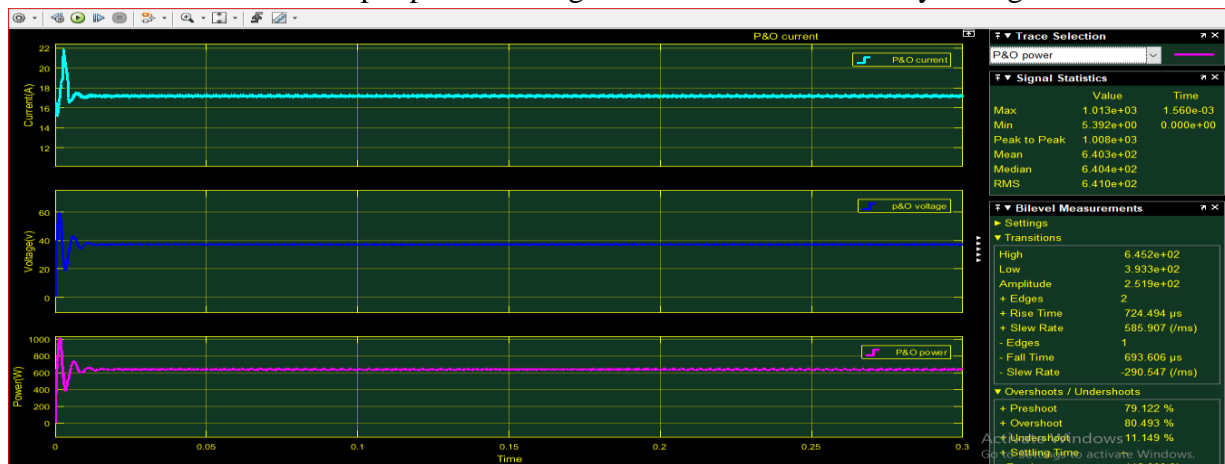


Figure 5.12. PV module output power Voltage and Current in the P&O Method with a TCT Interconnection Scheme without DC-DC Boost Converter.

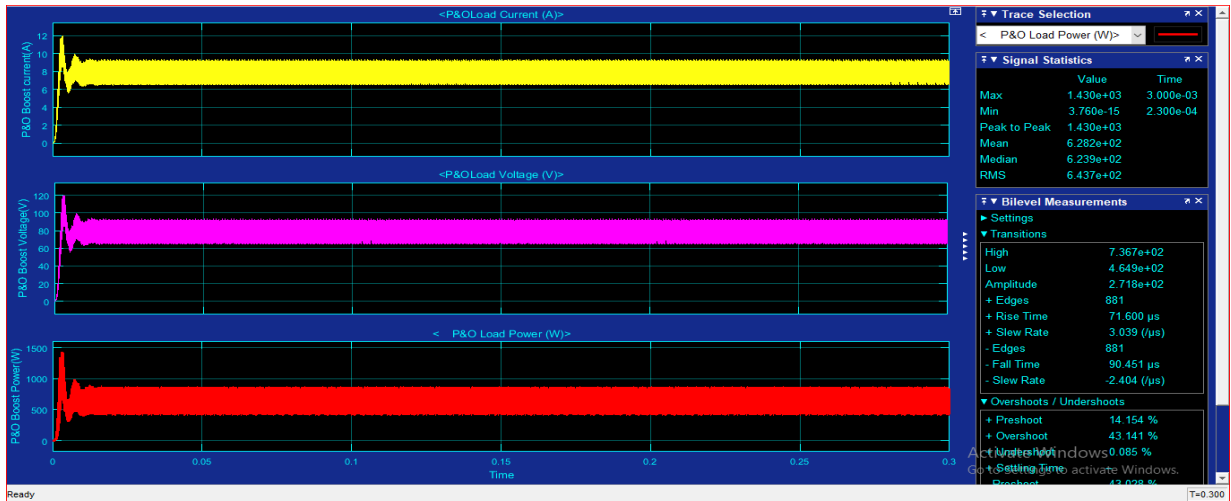


Figure 5.13. PV module output power voltage and current using the P&O method under PSC and TCT connection scheme using a DC-DC boost converter

Table 5.2. Performance Analysis of P&O MPPT Control in TCT connection Schemes of a PV Module under PSC

Connection scheme	MPPT controller	Response time	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
TCT	P&O	1.56ms	1725W	1430W	82.89%	-----	large

Discussion

The tracking of PV output power voltage and current under partial shade conditions is shown in Figure 5.12 using the traditional P&O algorithm in the TCT Interconnection scheme with a shading pattern for 1000, 800, and 500W/m² irradiance value. Evaluate the following Simulink values based on the outcome .PV output is 1013W with a tracking speed of 1.56 ms to extract the MPP, however there isn't selling time for the system to settle into a steady state.

The general performance of MPPT controller of the P&O method in PV solar cells under partial shade condition and TCT array configuration is determined by the MATLAB simulation results shown in Figures 5.12 and 5.13 and summary table 5.2. PV voltage was increased from 59.8V to 119.6V also a PV power increased from 1013W to 1430W which is 82.89 percent of the theoretical value. The tracking speed and settling time are listed in the summary Table.

5.3.2. PV MPPT system with P&O controller in BL array configuration and partial shade conditions

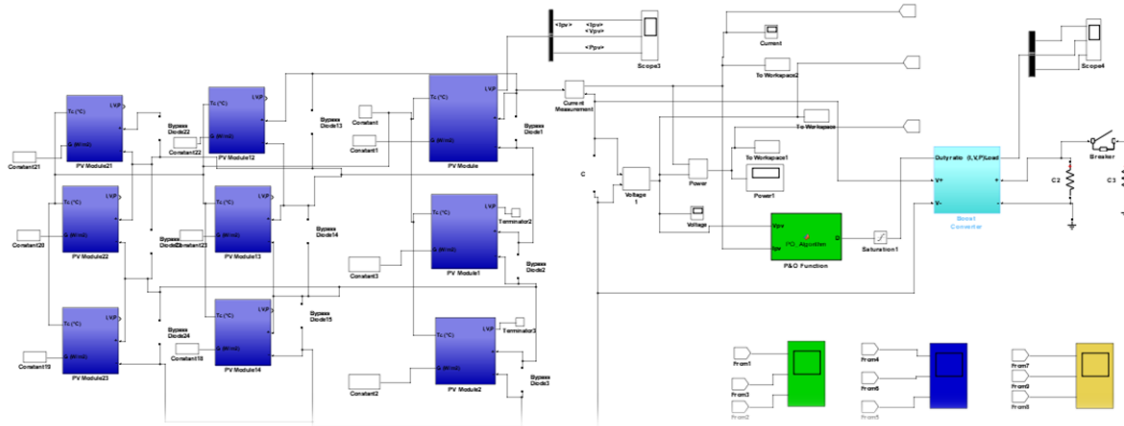


Figure 5.14. Simulink Diagram of P&O Control PV MPPT System with BL (bridge linked) Array Configuration under PSC

Case.2 The PSC performance of MPPT will be assessed using 3×3 PV module 1000,800,500w/m² shade pattern and Bridge Linked(BL) array configuration in P&O controller illustrated in Figure 5.14

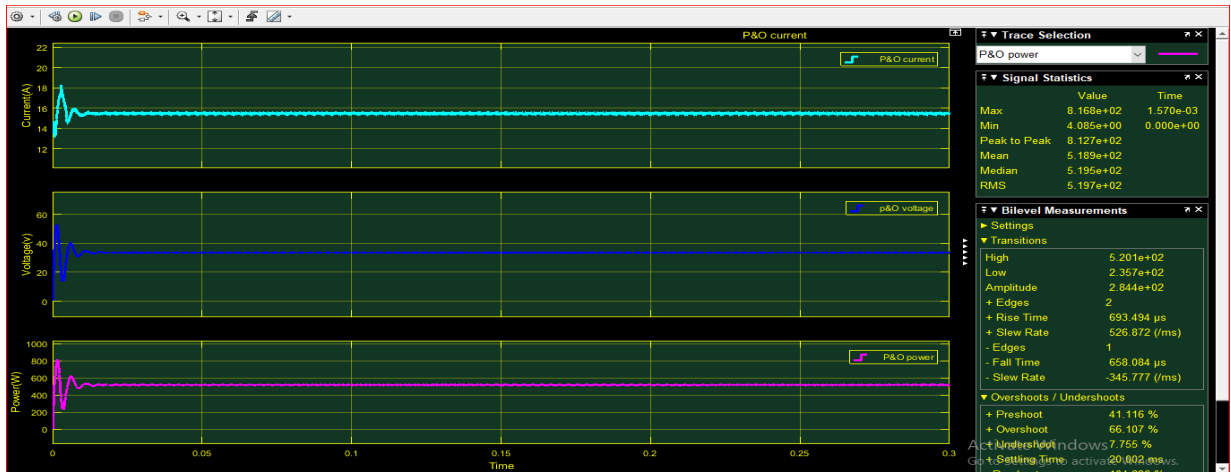


Figure 5.15. PV module output power voltage and current in the P&O method with BL (Bridge Linked) connectivity under PSC before DC-DC boost converter

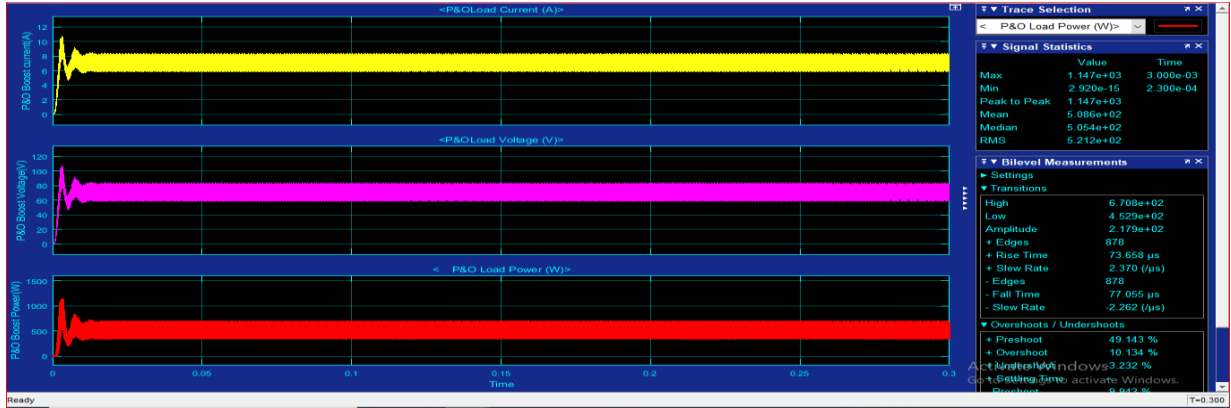


Figure 5.16. PV Module Output Power Voltage and Current in the P&O Method with a BL Interconnection Scheme with a DC-DC Boost Converter

Table 5.3. Performance Analysis of PV Module BL connection Schemes in P&O MPPT Controller under PSC

MPPT Controller	Connection Scheme	Response time	Expected Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
P&O	BL	1..57ms	1725W	1147W	66.4%	20.02ms	large

Discussion

According to the MATLAB simulation results shown in Figures 5.15 and 5.16 and the summary table 5.3, MPPT controller of the P&O method in PV solar cells operating in partial shade and BL array configuration. The MPPT of a PV has increased from 816.8W to 1147W 66.4 percent of the theoretical value as well as PV voltage increased from 52.86V to 107.1V.however the tracking speed and settling time specified in the summary Table.

The tracking of PV output power voltage and current under partial shade conditions is shown in Figure 5.12 using the traditional P&O algorithm in the BL interconnection scheme and shading pattern of 1000, 800, and 500W/m² irradiance value. When Evaluate the Simulink values based on the outcome. The PV's power output was 816.8W with a tracking speed of 1.57 ms to extract the MPP before Boosting.

5.3.3. PV MPPT system with P&O controller in series parallel array configuration and partial shade condition

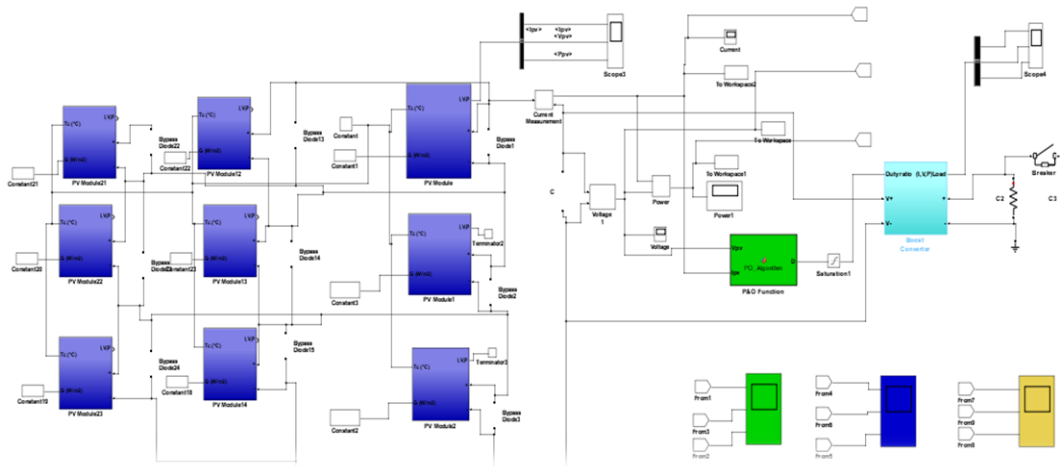


Figure 5.17. Simulink Diagram of PV MPPT system with P&O control under partial shading

Case.3.3x3 PV module 1000,800,500w/m² Irradiance and Series Parallel (SP) The scheme shown in Figure 5.17 will assess the MPPT's PSC performance.

Simulink Result of output power voltage and current of PV module in P&O and SP (Series Parallel) Interconnection scheme

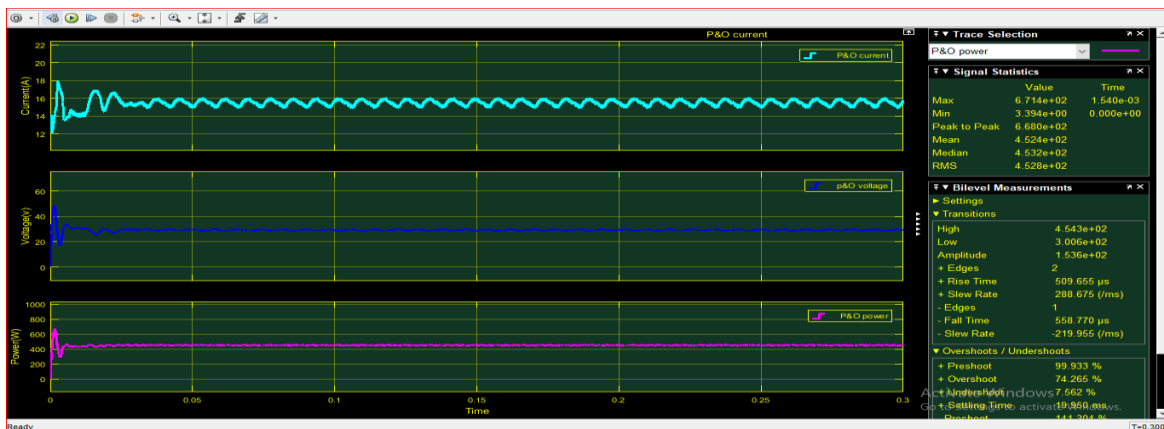


Figure 5.18. PV module output power voltage and current in the P&O method with an SP (Series Parallel) connection scheme prior to a boost converter

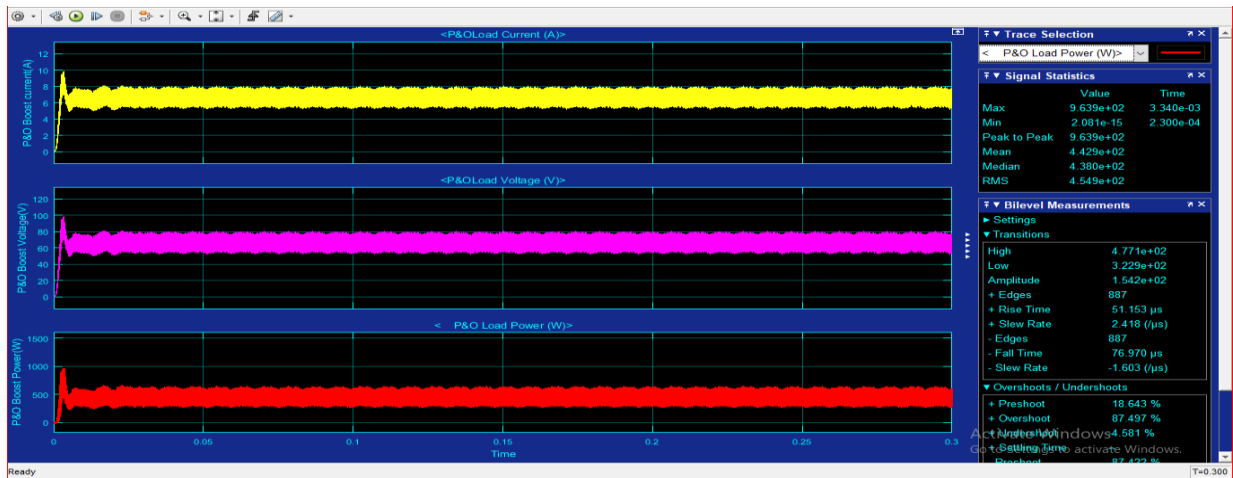


Figure 5.19. PV module output power voltage and current using the P&O method in PSC and SP connection scheme using a DC-DC boost converter

Table 5.4. Performance Analysis of P&O MPPT Control for PV Modules with SP connection Schemes under PSC

MPPT controller	Response time	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
P&O	1..57ms	1725W	963.9W	55.85%	19..50ms	large

Discussion

According to the MATLAB simulation results shown in Figures 5.18 and 5.19 and the summary table 5.4, MPPT controlling of the P&O method in PV solar cells operating in partial shade and BL array configuration. The MPPT of a PV has increased from 671.4W to 963.9W 55.85% of the theoretical value. The tracking speed and settling time were reported in the summary Table. The tracking of PV output power voltage and current under partial shade conditions is shown in Figure 5.18 using the conventional P&O algorithm in the SP Interconnection scheme and a shading pattern of 1000, 800, and 500W/m² irradiance value. The Simulink values of The PV's power output was 671.4W at a tracking speed of 1.54ms to extract the MPP before boosting.

Table 5.5. performance evaluation of P&O MPPT control method across three connection schemes.

No	Interconnection Schemes	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency
1	TCT	1725W	1430W	82.89%
2	BL	1725W	1147W	66.4%
3	SP	1725W	963.9W	55.85%

In Table 5.5 shown above TCT connections schemes extract the most power from the other two BL and SP connection scheme in P&O method.

5.4. MPPT control partial shading PV system using Incremental Conductance method

Simulink diagram of PV MPPT with INC method under PSC and TCT array configuration

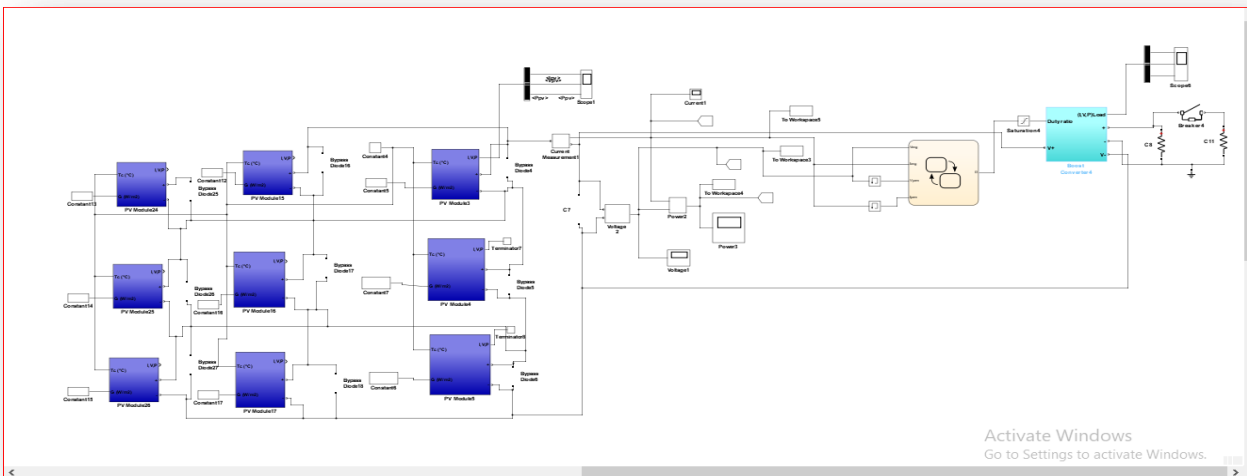


Figure 5.20 shows a Simulink diagram of a PV MPPT system with incremental conductance controller under partial shading.

Case.1 3x3 PV module linked with a Total Cross Tide connection scheme is shown in Figure 5.20. will evaluate the performance MPPT Controller of incremental conductance's under PSC

Simulation Result of PV output power Voltage and Current in INC method and TCT array configuration

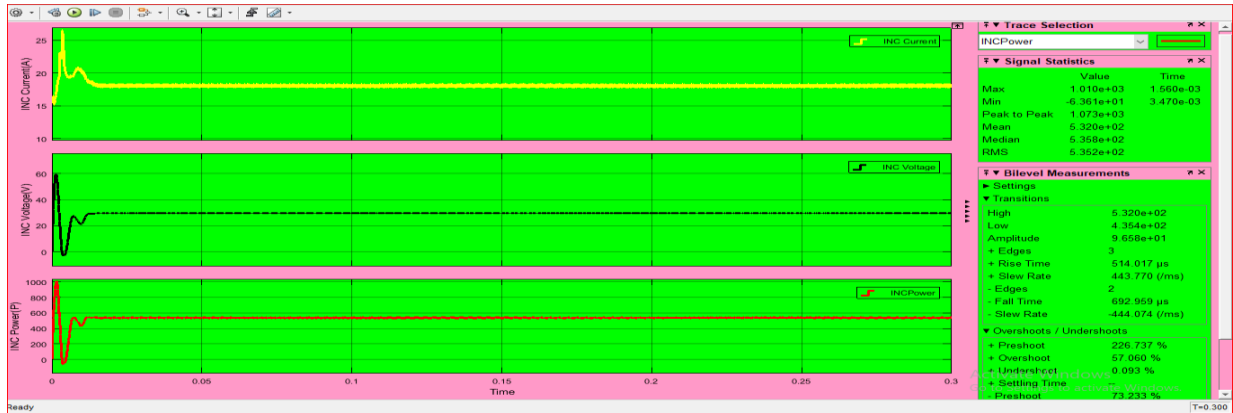


Figure 5.21., output power Voltage and Current of PV Module in INC Method under a partial shade condition before boosting a DC-DC converter



Figure 5.22.PV module output power voltage and current with INC method under PSC and the TCT connecting scheme Using the DC-DC boost converter

Table 5.6. Performance Analysis of INC MPPT Control for PV Modules in TCT Interconnection Schemes under PSC

MPP controller method	Connection scheme	Response time	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
INC	TCT	1.56ms	1725W	1010W	58.5%	-----	large

Discussion

The general performance of MPPT control of INC Method in PV Solar cell under partial shade situation and TCT array configuration is determined by MATLAB Simulation result shown in Figures 5.12 and 5.13 and summary table 5.2. The MPPT of a PV has increased from 960.7W to 1010W as well as the voltage increased from 59.4V to 98.1V. tracking speed and settling time indicated in the summary Table.

The tracking of PV output power voltage and current in partial shading condition shown in Figure 5.20 using the traditional Incremental conductance algorithm in the TCT Interconnection scheme and shading pattern for 1000, 800, and 500W/m² irradiance value. the Simulink values of .PV output was 960.7W with a tracking speed of 1.58 ms to extract the MPP before Boosting.

5.4.1. Simulink diagram of PV MPPT system with INC controller and BL array configuration

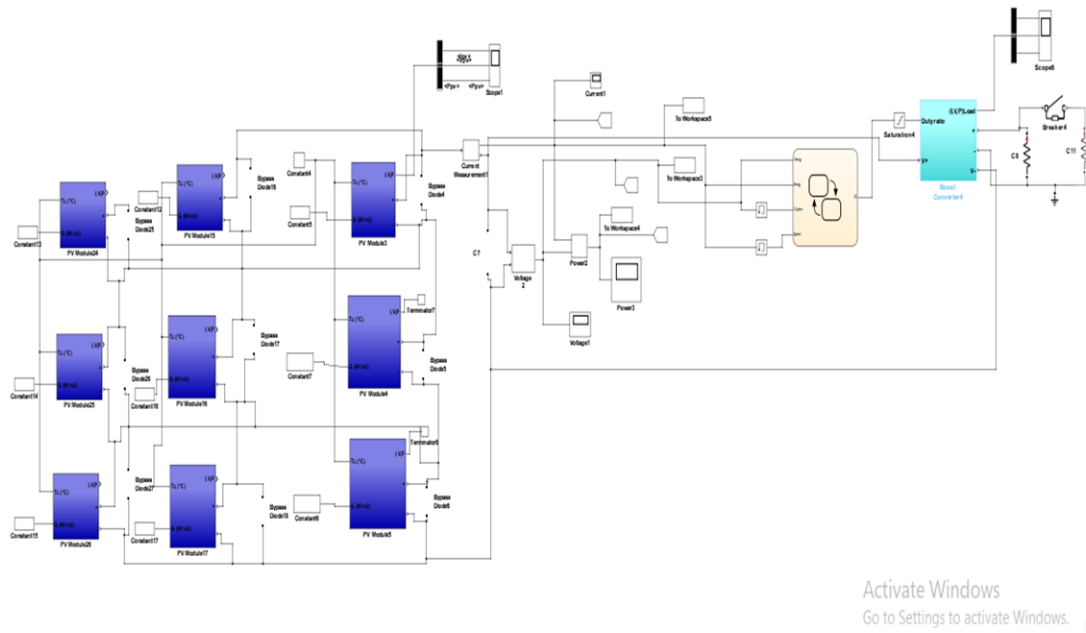


Figure 5.23. Simulink Diagram of PV MPPT system with Incremental Conductance controller under PSC and BL Interconnection Scheme

Case.2 Bridge Linked(BL) interconnection design shown in Figure 5.19 for a 3 by 3 PV module array rated at 1,000,800,500w/m².will evaluate the MPPT Control of incremental conductance's PSC performance

Simulation Result of PV output power Voltage and Current in INC method and BL array configuration



Figure 5.24. output power Voltage and Current of PV Module in INC Method under partial shade condition and BL interconnection scheme before boost of DC-DC converter

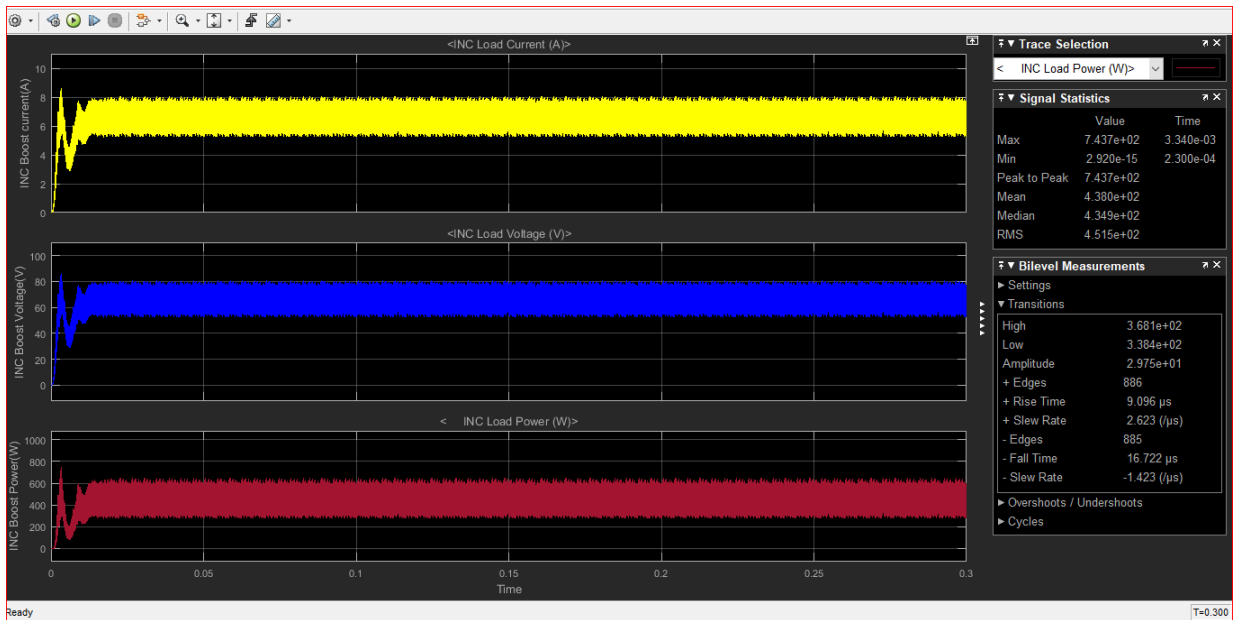


Figure 5.25. Output power Voltage and Current of PV Module under PSC in INC Method and BL connection scheme

Table 5.7. Performance Analysis of INC MPPT Control under PSC of a PV Module in BL interconnection schemes

MPP controller method	Connection scheme	Response time	Expected Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
INC	BL	1.56ms	1725W	743.7W	43.7%	-----	large

Discussion

According to MATLAB Simulation result the entire performance analysis will be able to view shown in Figures 5.12 and 5.13 and summary table 5.7. The MPPT of a PV has increased from 743.7W to 811.8W and in the same evaluation the PV output voltage rated from 52.46V to 98.1V. The tracking of PV output power voltage and current in partial shading condition shown in Figure 5.24 using the traditional INC (Incremental conductance) algorithm in the BL Interconnection scheme with a shading pattern for 1000, 800, and 500W/m² irradiance. Simulink values The power output of the PV was 743.7W at a tracking speed of 1.58 ms to extract the MPP, before Boosting.

5.4.2. PV MPPT system with controller INC in partial shade conditions and SP array configuration in a Simulink diagram

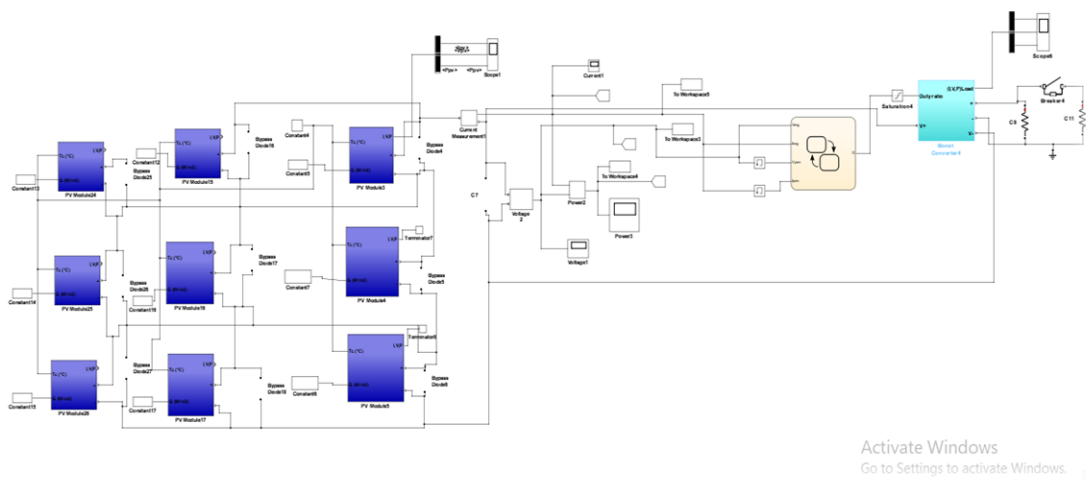


Figure 5.26. Simulink Diagram of PV MPPT system with Incremental Conductance controller in SP Interconnection Scheme under PSC

Case.1 Series Parallel (SP) interconnection arrangement for 3×3 PV modules with 1000, 800, and 500 watts per square meter is shown in Figure 5.24. will evaluate the MPPT Control of incremental conductance's PSC performance.

Simulation results PV output power voltage and current for the INC technique and SP array configuration

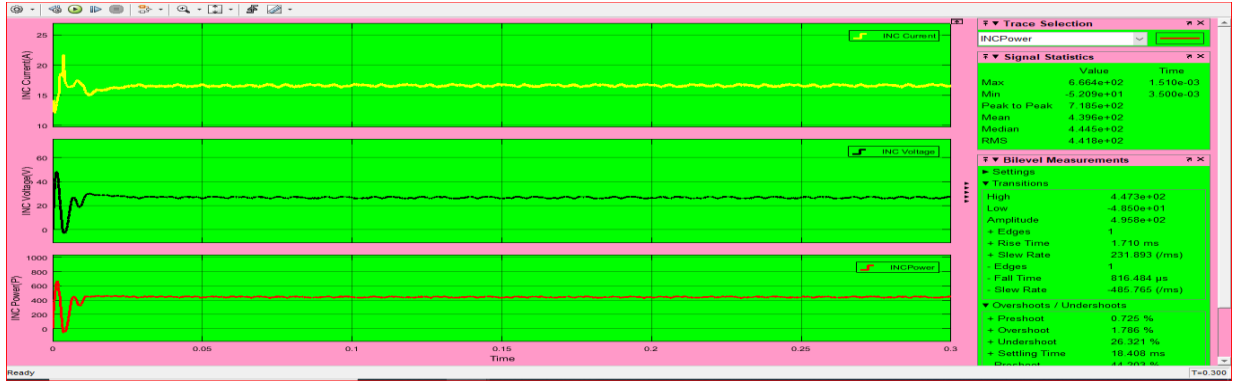


Figure 5.27. PV module output power Voltage and Current in the INC Method with an SP Interconnection Scheme before DC-DC Converter Boost

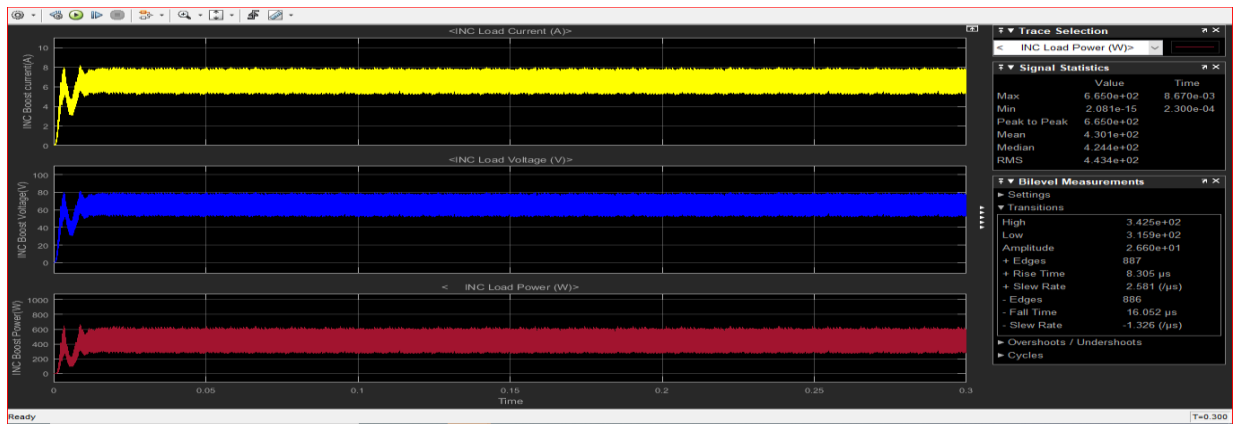


Figure 5.28. Output power Voltage and Current of PV Module in INC Method with SP Interconnection Scheme with Boost converter

Table 5.8. Performance Analysis of INC MPPT Control for a PV Module with Series Parallel Interconnection Schemes

MPP controller method	Connection scheme	Response time	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
INC		1.56ms	1725W	665W	38.5.7%	18.408ms	large

Discussion

Figure 5.26 illustrates the tracking of PV output power voltage and current under partial shade conditions With a 1000, 800, or 500W/m² irradiance shading pattern and the traditional Incremental conductance algorithm in the SP Interconnection Scheme. PV has a power output of 666.4W with a tracking speed of 1.58 milliseconds and a settling time of 18.04 milliseconds for a stable steady state before Boosting.

According to MATLAB Simulation result The general performance of MPPT control of INC Method in PV Solar cell under partial shade condition and TCT array configuration has shown in Figures 5.27 and 5.28 as well as in summary table 5.8 The MPPT of a PV has increased from 666.4W to 665.W in the same manner PV voltage boosted from 48.16V to 81.55V. the detail of tracking speed and settling time indicated in the summary Table. When have to come generalized The performance of PV MPPT in three interconnection schemes and shading pattern TCT array configuration has more effective than the two BL and SP connection schemes.

Table 5.9. Performance Evaluation of Three Interconnection Schemes Using INC MPPT Controller

No	Interconnection Schemes	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	
1	TCT	1725W	960.7W	55.6%	
2	BL	1725W	743.7W	43.7%	
3	SP	1725W	665W	38.5.7%	

5.5. Design of MPPT controller fuzzy logic control PV system with partial shading condition
 .PV MPPT system with FLC controller in partial shading condition and TCT array configuration

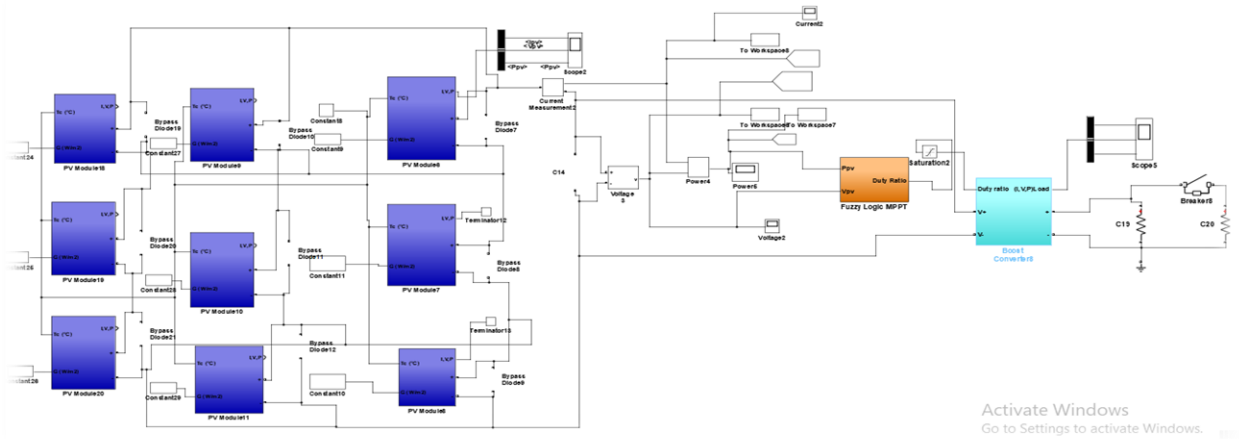


Figure 5.29. Simulink diagram of Fuzzy logic control PV MPPT system under PSC

Case.1 performance analysis of 3x3 PV module in Fuzzy Logic MPPT Control 1000,800,500w/m² irradiance level and Total Cross Tied interconnection scheme under PSC

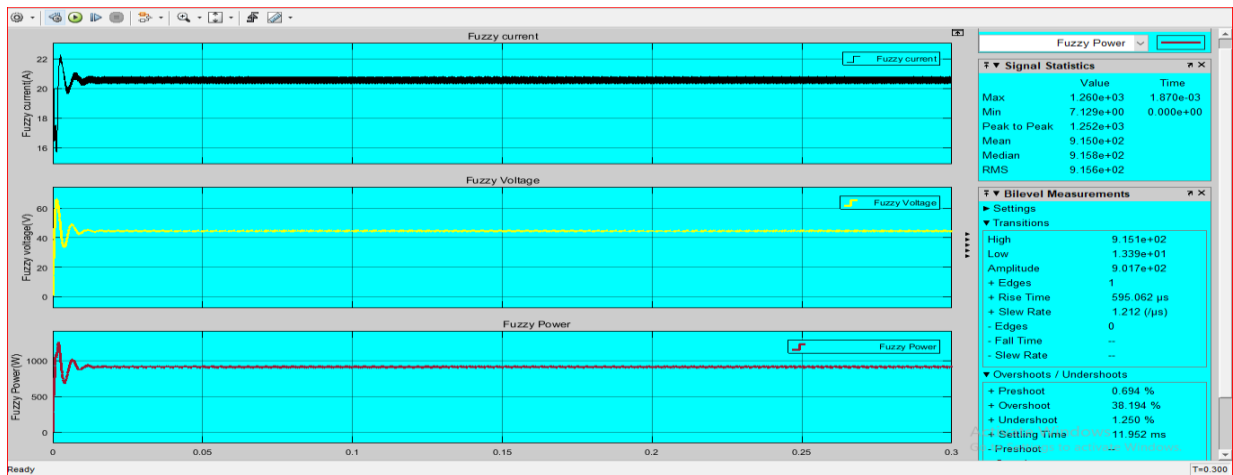


Figure 5.30. PV module output power Voltage and Current in FLC (Fuzzy Logic Controller) Method with TCT Interconnection Scheme before DC-DC Converter Boost

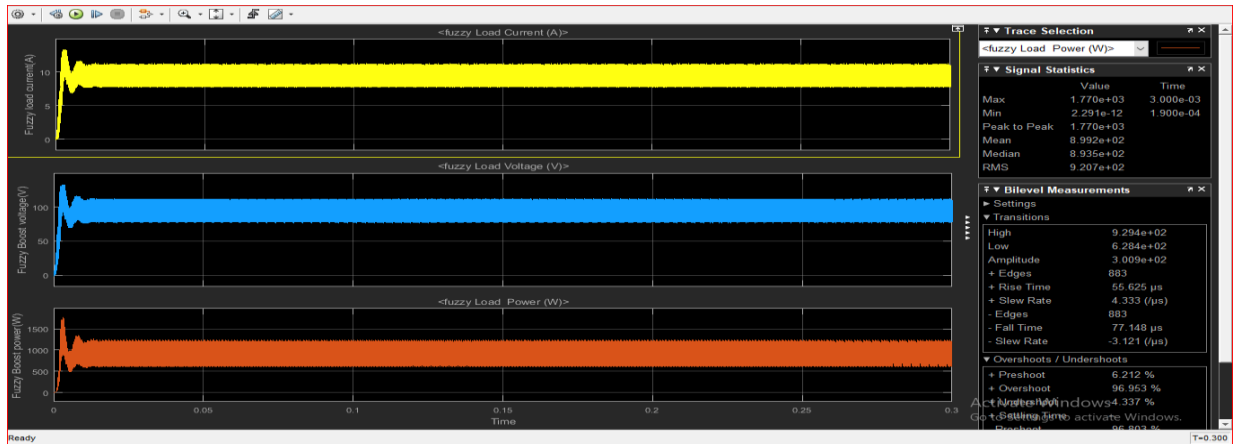


Figure 5.31. PV module output power voltage and current Using the FLC algorithm's and TCT connection scheme with DC-DC boost converter

Table 5.10. Performance Analysis of FLC MPPT Control for Modules in TCT Interconnection Schemes

MPP controller method	Connection scheme	Response time	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Settling time	Steady state oscillation
FLC	TCT	1.26ms	1725W	1770W	102.6%	11.952ms	medium

According to MATLAB simulation result shown in Figures 5.30 and 5.31 and summary table 5.10 Determine general performance of MPPT control of FLC method in PV solar cell under partial shade condition and TCT array configuration. MPPT of a PV with this shading pattern and array configuration has increased from 1260W to 1770W, as well as the PV voltage from 66.34V to 133V. The performance of the bridge linked (BL) and series parallel (SP) array configurations used in cases 2 and 3 are the same value to TCT connection Scheme. fuzzy logic MPPT controller performance is presented in Summary Table 5.11 below.

When evaluate the general performance of the three proposed PV MPPT controller under partial shading condition of PV system in order to Extract Global maximum power to overcoming the Local MPP. Fuzzy logic controller has best performance from the other two conventional controller P&O and incremental conductance but how performed this.

According to the General objective of this study Fuzzy logic controller exhibits based maximum power point tracker it can be seen from the observation that the only two state variables are detected as inputs of fuzzy controller output voltage and output current of PV module V_m and I_m . the fuzzy logic controller from measurements gives a signal proportional to the converter duty cycle(D) to which is feed to the converter through a pulse width modulator(PWM) this modulator drives the value of D to perform pulse width modulation that generate the control signal for the converter switch.

Fuzzy logic structure based on fuzzy sets which a variable is a member of one or more sets a specified degree of membership benefits of using fuzzy logic is it allows to emulate the human Reasoning process in computer .

Fuzzy logic controller has Three stages fuzzification, inference and defuzzification

Fuzzification

In fuzzification numerical input variables converted into linguistic value based on a membership function in this MPPT the actual voltage and current measured continuously and the power can be calculated the control determined two proposed input control namely error(E) and change of error (CE) at the instant sampling n

$$\blacktriangleright E(n) = \frac{P(n) - P(n-1)}{V(n) \cdot V(n-1)} \quad CE(n) = E(n) - E(n-1)$$

Where P(n) is the power and V(n) is the voltage of PV module

The inference engine

The inference engine applies a rule to fuzzy input to determine the fuzzy output therefore the rule can be evaluated before. The real input value must be fuzzified to obtain an appropriate linguistic value. In this thesis model has 25 rules of fuzzy controller depicted in chapter four the rules employed to control the DC-DC converter so the MPP of PV module is reached.

The main idea of base rules are to bring the operation point of a PV module to the MPP by increasing or decreasing the duty ratio of DC-DC converter.

A set of rules are used to governor the behavior of the control surface which relates the input and output variables of the system a typical rule would be if x is A THEN y is B if-then rule

Defuzzification

The DC-DC converter require a precise control signal D at its entry it is necessary to transform the output fuzzy controller from fuzzy information into deterministic information the

transformation is called defuzzification. In the defuzzification stage linguistic variable changed into numerical variable

Defuzzification can be performed in two algorithm; center of Area(COA) and max Criterion method(MCM) the most widely used defuzzification method is determination of the center of gravity(COA) centroid method then using this algorithm for this fuzzier design.

To generalize how the fuzzy logic controller extract Global Maximum power of PV system in partial shading condition. the fuzzy rules Extracted by analyzing the system behavior. The different operating conditions are considered in order to improve tracking performance in terms of dynamic response and robustness .the algorithm can be explained as follows.

The tracking process started with an initial duty cycle, $D=0$ the converter input current I_m voltage V_m are then measured and sense the duty cycle that can give maximum power output of the converter at that time based on predicted values that have already been entered into fuzzy system this operation repeats itself until the power reaches the maximum value and the system become stable. Then in this MPPT mechanism Fuzzy has performed best relatively compared to the conventional proposed algorithms.

Table 5.11. Performance Evaluation of Three Interconnection Schemes in FLC MPPT Controller

No	Interconnection Schemes	Excepted Maximum Power(W)	Tracking Power MPPT (W)	Efficiency	Response time
1	TCT	1725W	1770W	102.6%	1.26ms
2	BL	1725W	1770W	102.6%	1.26ms
3	SP	1725W	1770W	102.6%	1.26ms

According to Table 5.11.in Fuzzy MPPT controller's, the TCT BL and SP connectivity schemes are tracking the same maximum power of 1770W with the same reaction time.

5.6. Comparison of fuzzy logic, P&O, and INC control methods for MPPT control of PV PSC in various connection schemes and shading patterns.

The Simulink Diagram

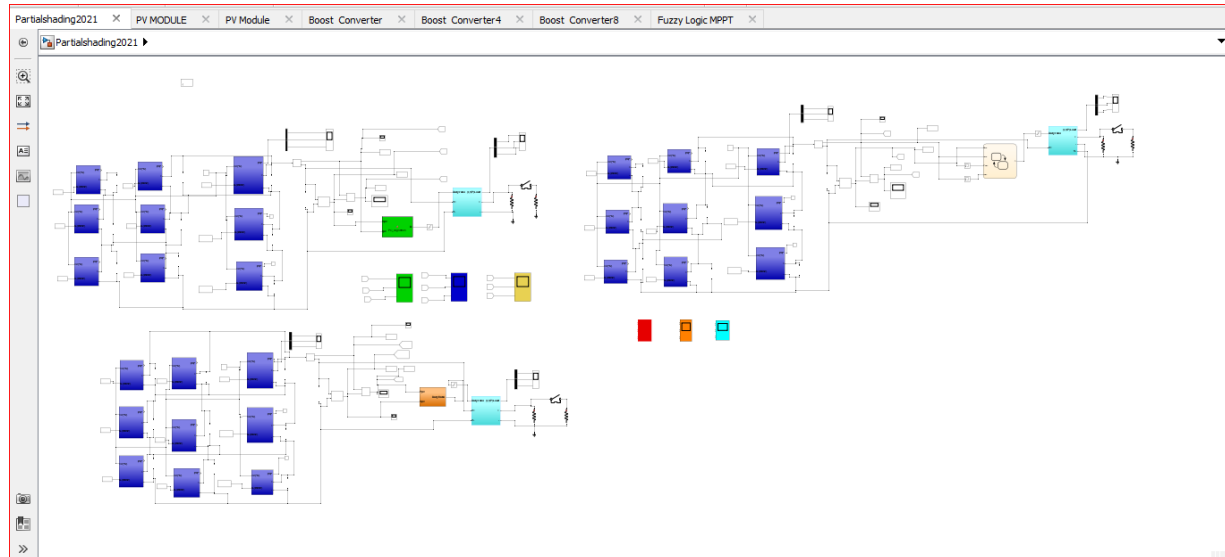


Figure 5.32. Simulink diagram of a PV system controlled by fuzzy logic, incremental conductance, and P&O under partial shade condition

5.6.1. performance comparison of PV MPPT controller P&O, INC, AND, FLC in TCT, BL and SP interconnection scheme under PSC.

Case 1. Configuration of a 3×3 PV array with irradiance values of 1000, 800, and 500 W/m² and a Total Cross Tide (TCT) connecting scheme

Case 2. Configuration of a 3×3 PV array with irradiance values of 1000, 800, and 500W/m² and a Bridge Linked (BL) connecting scheme

Case 3. Configuration of a 3×3 PV array with irradiance values of 1,000, 800, and 500 W/m² and a Series Parallel (SP) connecting scheme

Table5.12. Performance Evaluation of MPPT Control for PV PSC Using FLC, P&O, and INC Methods in TCT, BL, and SP PV Array Configuration

No	MPPT control method	PV array interconnecti on Scheme	Tracking Power MPPT (W)	Expected Maximum Power	Efficiency	Response Time	Settling time
1	P&O	TCT	1430W	1725W	82.89%	1.56ms	-----
		BL	1147W		66.49%	1.57ms	19.71ms
		SP	963.9W		55.8%	1.41ms	20.02ms
2	INC	TCT	960W	1725W	55.8%	1.56ms	-----
		BL	743.7W		43%	1.58ms	-----
		SP	665W		38.5%	1.25ms	19.61ms
3	Fuzzy logic	TCT	1770W	1725W	102.6%	1.26ms	11.952m s
		BL	1770W		102.6%	1.26ms	11.952m s
		SP	1770W		102.6%	1.26ms	11.952m s

Discussion

The comparison of three MPPT controller methods, fuzzy logic controller (FLC), perturbation and observe (P&O), and incremental conductance (INC), through various array configurations such as TCT, BL, and SP and shading Pattern of 3×3 1000, 800, and 500W/m² irradiances value of PV partial shading condition, is taken from the Simulink Result summary table 5.12. The MPPT Controller Fuzzy Logic Extract Maximum Power 1770W 102.6 percent of the Expected Maximum Power Value via TCT, BL, and SP array configurations, respectively, in a short time run and a good Settling time compared to the other two conventional methods P&O and INC under Partial shading condition. however, the P&O MPPT controller technique extracts 1430W in the TCT interconnection Scheme, 1147W in the BL interconnection Scheme, and 963W in the SP interconnection Scheme the same

item using INC MPPT control technique has extracted 960W maximum power in TCT array configuration.

Generally evaluation of the proposed PV in terms of extracted MPP with interconnection Schemes. Total Cross Tide connection scheme is better to get the Global Maximum Power in both MPPT controllers.

$$\text{Expected maximum output Power of PV} = \frac{\text{Sum of input irradiance value} \times \text{Maximum Output power of PV}}{\text{No of PV moduels}}$$

$$\text{Sum of irradiance value} = 1 + 0.8 + 0.5 + 1 + 1 + 0.8 + 0.5 + 1 + 0.8 + 0.5 = 6.9 \text{ kW/m}^2$$

$$\text{No of PV module} = 9$$

$$P(\text{Expected}) = \frac{6.9 \times 2250 \text{ W}}{9} = 1725 \text{ W}$$

OR $P(E) = \text{sum of irradiance Value} \times \text{Single PV module maximum output Power}$

$$P(E) = 6.9 \text{ kW/m}^2 \times 250 \text{ W} = 1725 \text{ W}$$

5.6.2. Performance comparisons of MPPT control of PV PSC Using P&O INC and FLC in TCT, BL, and SP PV Array Configuration and shading pattern,

1000w	900w	800w
800w	750w	450w
500w	300w	400w

PV Array shading pattern

Table 5.13. Performance Evaluation of MPPT Control for PV PSC Using FLC, P&O, and INC Methods in TCT, BL, and SP PV Array Configuration.

N	MPPT control method	PV array interconnection Scheme	Tracking Power MPPT (W)	Expected Maximum Power	Efficiency	Response Time	Settling time
1	P&O	TCT	1319W	1475W	89.4%	1.51ms	19.95ms
		BL	983.9W		66.64%	1.84ms	-----
		SP	902.9W		61.21%	1.41ms	-----
2	INC	TCT	844.1W	1475W	57.22%	1.97ms	-----
		BL	530.8W		35.98%	1.97ms	-----
		SP	536.62W		36.3%	1.5ms	-----
3	Fuzzy logic	TCT	1426W	1475W	96.6%	1.46ms	8.945ms
		BL	1407W		95.3%	1.46ms	11.64ms
		SP	1393W		94.4%	1.26ms	11.952ms

Discussion

The comparison of three MPPT controller methods, including fuzzy logic controller (FLC), perturbation and observe (P&O), and incremental conductance (INC), in various array configurations with TCT, BL, and SP and shading Patterns of 1000, 800, and 500W/m², 900, 750, and, 300W/m², 800, 450, and 400W/m² irradiances and 25°C ambient temperature is shown in Simulink Result and Summary Table 5.13. The fuzzy logic controller maintains greater performance. From the other two conventional control systems P&O and INC. Fuzzy Tracking maximum power of 1393W 94.4 percent of maximum predicted power in SP array configuration, 1426W 96.6 percent of maximum expected power in TCT array configuration, and 1407W 95.3 percent in BL array configuration simultaneously at 0.00146 seconds. while the traditional controller methods P&O and INC, which track 1319W (89.4 percent) at 0.00151 seconds and

844.1W (57.2 percent) at 0.00197 seconds, respectively in TCT interconnection schemes.in the BL and SP connection Scheme Extract Low Power.

$$\text{Expected maximum output Power of PV} = \frac{\text{Sum of input irradiance value} \times \text{Maximum Output power of PV}}{\text{No of PV moduels}}$$

$$\text{Sum of irradiance value} = 1 + 0.8 + 0.5 + 0.9 + 0.75 + 0.3 + 0.8 + 0.45 + 0.4 = 5.9 \text{ kW/m}^2$$

No of PV module = 9

$$P(\text{Expected}) = \frac{5.9 \times 2250 \text{ W}}{9} = 1475 \text{ W}$$

OR $P(E) = \text{sum of irradiance Value} \times \text{Single PV module maximum output Power}$

$$P(E) = 5.9 \text{ kW/m}^2 \times 250 \text{ W} = 1475 \text{ W}$$

For instance according to the Simulink result, the P&O MPPT Controller extracts the maximum power under partial shading condition (PSC) based on the array arrangement and the shading pattern. The INC MPPT Controller extracts the maximum power of 844.1W in TCT array configuration, 530.8W in BL configuration, and 536.6W in SP configuration, for a total power of 1319W, 983.9W in BL configuration, and 902.9W in SP configuration,

Conclusion on Simulink Results

When the simulation has taken In various shading pattern and array configurations of Simulink design, in the result fuzzy controller can better performed the other two traditional methods P&O and incremental conductance for tracking MPPT under partial shadow conditions.terms of Reduce steady state oscillation and stability time, quickly maintaining MPPT while doing so. According to the testing results; TCT connection scheme is preferable in the majority of conditions when used with the three proposed MPPT controllers Fuzzy, P&O. and INC. PV module connecting scheme and shading pattern determine MPPT tracking.

Finally determined the Simulink results according to the General objective of this thesis work the proposed Fuzzy logic controller in PV System. How to Extract GMPP during partial shading condition of the proposed design.

Fuzzy logic controller illustrates based maximum power point tracker it can be seen from the observation that the only two state variables are detected as inputs of fuzzy controller output voltage and output current of PV module V_m and I_m .the fuzzy logic controller from measurements gives a signal proportional to the converter duty cycle(D) to which is feed to the converter through a pulse width modulator(PWM) this modulator drives the value of D to perform pulse width modulation that generate the control signal for the converter switch.

Fuzzy logic structure based on fuzzy sets which a variable is a member of one or more sets a specified degree of membership benefits of using fuzzy logic is it allows to emulate the human Reasoning process in computer . the fuzzy rules Extracted by analyzing the system behavior. The different operating conditions are considered in order to improve tracking performance in terms of dynamic response and robustness .the algorithm can be explained as follows.

The tracking process started with an initial duty cycle, $D=0$ the converter input current I_m voltage V_m are then measured and sense the duty cycle that can give maximum power output of the converter at that time based on predicted values that have already been entered into fuzzy system this operation repeats itself until the power reaches the maximum value and the system become stable.

CHAPTER SIX

6. Conclusion and Scope For future work

6.1. Conclusion

This study successfully completes the task of constructing and modeling the solar PV system to extract the most power under partial shadowing conditions. The suggested system consists of four different types of MPPT: incremental conductance (INC) based MPPT, perturb and observe (P&O) based MPPT, and a DC-DC Boost converter developed at the level of the proposed design. The PV array was accurately modeled and built under the conditions of MATLAB/SIMULINK. By contrasting the model's output with the actual results, the PV module model's correctness was confirmed. According to the proposed thesis study and design, a PV array's maximum power point tracking (MPPT) has been determined Using a proposed MPPT controller's fuzzy logic under partial shadowing conditions and sudden changes in weather. In this thesis work proposed Fuzzy logic controller method has been selected in order to tracking global MPP under partial shade condition (PSC) comparison of the PV system's controller to the traditional perturb and observe (P&O) and incremental conductance approaches (INC).

However, the conventional controller failed to track the global MPP under partial shade conditions, failed to track the right direction of perturbation, and failed to detect steady state oscillation. The PV array structure and shading pattern are additional reduction factors for the PV MPP system under partial shading conditions. In this study, they are briefly explained and simulated to determine the PV system's maximum power tracking

The main objective of this work has been applying intelligence controller Fuzzy logic on PV MPPT system under partial shade condition, therefore testing and evaluating in MATLAB Simulink.as the Result how to extract maximum Global power under this condition. And Compared to the conventional methods it is clearly discussed in Simulink Result of the thesis work in chapter Five.

6.2. Scope for future work

Future research can be done to broaden the thesis's focus, which can be boiled down to the following topics. The modeling and design of fuzzy logic control for photovoltaic (PV) system maximum power tracking under partial shade conditions are covered in this thesis.

- Confirm the simulation results with various real-world trials.

- Other than the standard method, it is feasible to compare the model created using fuzzy logic and more intelligent MPPT techniques
- The fuzzy logic controller was integrated and modeled to other PV MPPT control systems to develop the PV MPP's performance under partial shadowing and sudden changes in weather.
- The study of a comparison between the traditional and fuzzy logic controls of MPPT with partial shade is the exclusive focus of this thesis.

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