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AN ASYMMETRIC FUZZY LOGIC CONTROLLER BASED MPPT ALGORITHM FOR PV SYSTEM

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AN ASYMMETRIC FUZZY LOGIC CONTROLLER BASED MPPT ALGORITHM FOR PV SYSTEM

By Sarmad Khalid Waheeb ALDOORI

June 2023

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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Sarmad Khalid Waheeb ALDOORI

ABSTRACT

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Master of Science in Electrical and Electronics Engineering

Advisor: Prof. Dr. Murat ARI

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Renewable solar energy systems with photovoltaic modules convert solar thermal energy into electricity, making sunlight a viable renewable energy source. Sunlight is available in surplus amounts and can be replenished naturally. Conventional solar systems with advanced maximum power point tracking (MPPT) features cannot utilize all power supplied by the photovoltaic system due to nonlinear properties of the PV cell. Optimized control algorithms and powerful MPPT controllers are essential for efficient and organized solar energy systems. It has the significant advantage of utilizing all the power with minimum energy loss. Another advantage of using an MPPT controller is that it is very cost-effective. The main objective of this study is to compare various powerful technology-based techniques to implement MPPT control and to obtain a regulated production with better results. MPPT control algorithm has been used to maintain the PV array's route of greatest power with an effective and optimum output response. In order to assure a quick and precise MPPT algorithm and to extract the most energy and power possible from the PV array, an effective DC-DC Boost converter has been used. Maximum power-delivering mechanism for solar power systems has been analyzed. In this study; PI controller, fuzzy logic and Adaptive-Network Based Fuzzy Inference System (ANFIS) has been used for MPPT. The results of three algorithms has been compared which each other.

2023, 75 pages

Keywords: Asymmetric, Maximum power point tracking, PI controller, Fuzzy logic controller, Photovoltaic, Neuro fuzzy

ÖZET

PV IÇIN ASIMETRIK BULANIK MANTIK DENETLEYICI TABANLI MPPT ALGORITMASI

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Yenilenebilir güneş enerjisi sistemleri, fotovoltaik modülleriyle güneş termal enerjisini elektriğe dönüştürür ve böylece güneş ışığını kullanılabilir bir yenilenebilir enerji kaynağı haline getirir. Güneş ışığı fazlasıyla mevcut olup doğal olarak yenilenir. Gelişmiş maksimum güç noktası izleme (MPPT) özelliklerine sahip geleneksel güneş sistemleri, PV hücresinin doğrusal olmayan özellikleri nedeniyle fotovoltaik sistem tarafından sağlanan tüm gücü kullanamaz. Verimli ve düzenli güneş enerjisi sistemleri için optimize edilmiş kontrol algoritmaları ve güçlü MPPT kontrolörleri gereklidir. Bu, en az enerji kaybıyla tüm gücü kullanma önemli bir avantajdır. MPPT kontrolörünün kullanılmasının bir başka avantajı, çok maliyet etkin olmasıdır. Bu çalışmanın ana amacı, MPPT kontrolünü gerçekleştirmek için çeşitli güçlü teknoloji temelli teknikleri karşılaştırmak ve daha iyi sonuçlarla düzenlenmiş bir üretim elde etmektir. MPPT kontrol algoritması, PV dizisinin en yüksek güç yolu üzerinde etkili ve optimum çıkış tepkisiyle kalmasını sağlamak için kullanılmıştır. PV dizisinden mümkün olan en fazla enerji ve gücü çıkarmak ve hızlı ve hassas bir MPPT algoritması sağlamak için etkili bir DC-DC Boost dönüştürücü kullanılmıştır. Güneş enerjisi sistemleri için maksimum güç sağlama mekanizması analiz edilmiştir. Bu çalışmada; MPPT için PI kontrolörü, bulanık mantık ve Adaptive-Network Based Fuzzy Inference System (ANFIS) kullanılmıştır. Üç algoritmanın sonuçları birbiriyle karşılaştırılmıştır.

2023, 75 sayfa

Anahtar Kelimeler: Asimetrik, Bulanık mantık denetleyici, Maksimum güç noktası takibi, Fotovoltaik, Nöro-bulanık, PI denetleyici

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Sarmad Khalid Waheeb ALDOORI
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LIST OF SYMBOLS

A	Ampere
C	Capacitance
CE	Change error
ΔD	Change in duty ratio
I	Current
Impp	Current at maximum power point
°	Degrees
DC	Direct current
D	Duty cycle
η	Efficiency
E	Error
L	Inductance
irr	Irradiance
RL	Load resistance
Pmax	Maximum power
Ω	Ohm
Voc	Open circuit voltage
Iph	Photo current
P-n	P-n junction
P	Power
R	Resistance
m^2	Square meters
tem	Temperature
V	Voltage
Vmpp	Voltage at maximum power point

LIST OF ABBREVIATIONS

ANN	Artificial neural network
ANFIS	Adaptive network fuzzy inference system
FLC	Fuzzy logic control
IC	Incremental conductance
ISC	Short circuit current
MPP	Maximum power point
MPPT	Maximum power point tracking
P&O	Perturb and observe
PSO	Particle swarm optimization
PV	Photovoltaic
PWM	Pulse width modulation
STC	Standard test condition
PI/P	Power extracted from the photovoltaic panel
PPV	Theoretical photovoltaic power of the panel

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1. INTRODUCTION

1.1 Background and Overview

One of the most significant sources of renewable energy is solar energySolar energy is an endless, cost-free, and environmentally friendly energy source in contrast to traditional nonrenewable energy sources. Photovoltaic system has many applications and one of the main applications include either stand alone or grid connected configurations. Stand-alone applications include street lighting, water pumping, domestic, electric vehicles, military and space applications while grid connected configurations include power plants and hybrid system. However, two major problems with photovoltaic generation system are that electric power conversion efficiency is too low and it happens especially in low irradiation conditions. Another problem is continuous changes in electric power produced by solar arrays with conditions of the weather. Nonlinear characteristics of photovoltaic output and change in the cell temperature with solar irradiation requires using the maximum power point tracking (MPPT) approach to obtain the most energy possible out of the solar array. There are many MPPT techniques and their performance can be evaluated by using Simulation tool. In the presence of variations in solar irradiance, the behaviour of each technique is different (Ocran *et al.* 2005).

In all aspects of everyday life energy is required and due to depletion of gas reserve and fossils combined with global warming growing concern, there is urgent need for alternate energy the resource to meet the demand for energy nowadays. The demand for electrical energy is continuously rising, and the number of power plants now in operation cannot meet it. Photovoltaic cells are the tools that are used to convert the sunlight energy into electricity but due to low efficiency and high cost there is strong need of flexible and effective model, the characteristics of which resemble the actual PV cell so that maximum possible performance can be obtained by small manipulation of data. The specific and non-linear characteristic of solar panel depending on the solar panel's temperature and solar radiation. There are several advantages to get energy from solar panel which include no environmental pollution and very little maintenance. Solar panels have multiple applications such as solar power generation, charging batteries, solar power satellites and solar hybrid vehicles (Xiaoting *et al.* 2012).

The energy extraction process become more efficient now a days due to advancement in semiconductor physics. Techniques including perturbation and monitoring (P&O), constant voltage (CV), incremental conduction (INC), short current pulse, Fuzzy logic control and artificial neural networks have both been described as very effective power extraction techniques. However, by taking into account the By using the solar cells' current-voltage (I-V) properties, the efficiency of the energy extraction process may be increased. Power voltage (P-V) or I-V curve has a unique point of solar array which is called as maximum power point (MPP). At this point, the entire photovoltaic system is operating at maximum efficiency and maximum output power is produced. Therefore, to improve the efficiency and to obtain maximum power, the MPPT technique can be used in PV system. Multiple While MPPT methods based on microcontrollers and Arduino have been established, maximum power point tracking methods have not. It enables the system to become more efficient, simplest and highlflexible (Aneka 2008).

Figure 1.1 Fuzzy logic MPPT to improve PV system performance

In the last few years, the conventional energy resources and fossil fuels have been exhausted and it has led to produce energy from renewable energy sources. The promising solution for green and clean energy is distributed energy resources with higher efficiency to minimize the environmental issues as well as to minimize the world energy. The most attraction is directed towards photovoltaic arrays due to their higher efficiency. A PV panel harvest amount of energy mostly influenced by the environment's temperature and sun radiation. To maximize the output of a photovoltaic (PV) system, Maximum Power Point Tracking (MPPT) is frequently utilized.

In photovoltaic (PV) power system, major role has been played by Tracking Maximum Power Point (MPPT). Regarding the variations in temperature and sunshine irradiance, the generation of power by photovoltaic system changes. Different MPPT techniques have been developed to improve the MPP in PV system. MPPT controller are classified into two major types such as direct and indirect MPPT controller. For offline analysis of photovoltaic system performance, indirect Maximum Power Point Tracking (MPPT) techniques are used while direct methods are developed by use of fuzzy logic controller in order to track MPP of photovoltaic (PV) system. It is easy and robust method and no mathematical model required to design controller (Zadeh 1963).

Figure 1.2 Temperature based MPPT algorithm to increase PV system efficiency

Solar energy is a plentiful and cost-free energy source, however photovoltaic system adoption is significantly hampered by high capital costs and poor efficiency. The major variables that impact the output voltage of a PV system are panel temperature and solar irradiation. Consequently, it is required to produce the most power possible utilizing the MPPT technology. A few of the available MPPT methods INC, NN, PO, fuzzy logic, current/voltage feedback-based techniques and ANFIS. The most accurate MPPT techniques are those based on artificial intelligence and incremental conductance, although the design is difficult. Most extensively used technique in commercial MPPT systems is PO which have moderate accuracy. Voltage/current feedback (VF/CF) is simpler than PO since it compares panel voltage or current feedback to pre-calculated current or a reference voltage. Adjusting the duty ratio of dc-dc converters continuously to ensure that functioning is near to the MPP (Spiers 1998).

The importance of Photovoltaic solar energy is emerging as source of replaceable energy to human being due to rapid depletion of conventional energy sources. It is inexhaustible, pollution-free and clean source and much attention has been received to power generation by photovoltaic system in multiple applications. Due to continuous increasing efficiency and decreasing cost by PV arrays, it would become the main source of power generation by mankind in near future. MPP of power generation by photovoltaic system depends upon solar insolation as well as array temperature. So, continuous tracking of solar array MPP is necessary (Lorenzo 1994).

Due to increasing requirements of scalable space-based and flexible power to avoid electric propulsion power system and redesign of spacecraft, concepts have been emerged in an effort to offer expandable methods like Maximum Power Point Tracking and parallel converted power converters. This approach leads to multiple options such as modular, commonly used, parallel-connected power converters. The purpose of this design is to offer a single power design system that can accommodate a variety of power requirements for spacecraft and electric propulsion systems. Under conditions in which MPPT systems guarantee that the maximum amount of power is provided from solar arrays when the output voltage of the power system has lost regulation (Himanshu and Tripathi 2012).

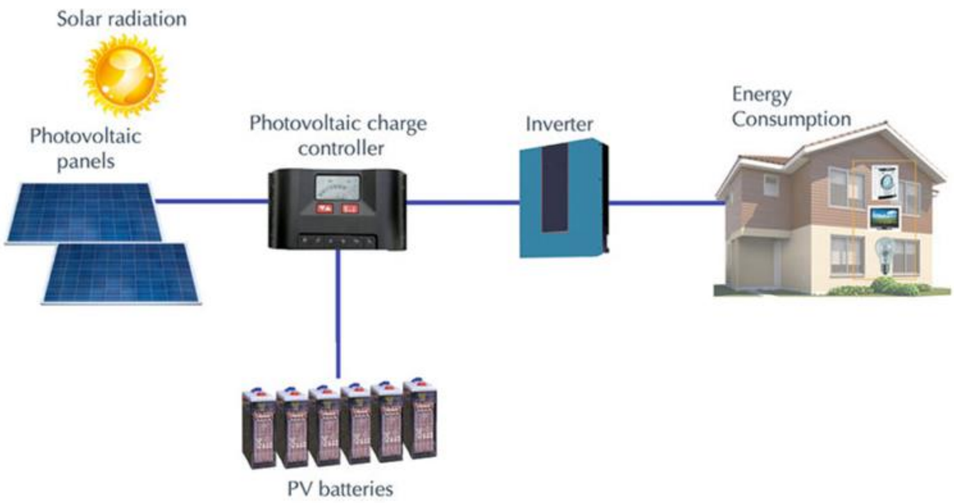


Figure 1.3 Isolated photovoltaic system applications

In the last decades, the solar energy use has attained great attention and this source of energy is defilement-free. It is employed in remote locations for lighting, pumping, etc. However, it is crucial to maximize PVG's power output at all times of the day. due to the non-linear properties of PVG that make the location of the leading power point difficult. Therefore, to maximize the output power, It is necessary to use a maximum power point tracking approach. Solar energy is highly recommended in an effort to to provide enough water for human consumption. There are two main reasons for this need, first one is that solar energy is pollution free and inexhaustible source of energy and second one is the areas for pumping water don't have access to electricity grid and transmission lines installation and expensive transformers. PVG turns solar radiation's light energy into electricity. Time-varying weather elements affect the amount of electrical energy PVG generates to power the water pumping system (Blue Sky Energy 2009).

The solar photovoltaic voltage generation depends upon the intensity of sunlight. As, sunlight direction changes during day so intensity of sunlight also changed that results in reduction of voltage. In order to maintain voltage, the direction of the should be in so that it continues to face the sun in order to receive the most intense light possible. Hill Climbing algorithm is used to find the best position of the board that provides maximum effort. The most optimal conditions are saved and explored by this algorithm and its updates in case of new situations. A maximum power point tracking (MPPT) algorithm is implemented that guides the board to generate the maximum voltage. To interpret the algorithm, Arduino microcontroller is used and to instruct DC motor to set the panel position most optimal. Due to lifetime of device and simplicity of energy conversion, solar photovoltaic is prospective for energy generation future applications (Kondawar *et al.* 2012).

To meet the rapidly growing demand for load, renewable energy source plays an important approach. The imperative concern among renewable energy is solar energy that is eco-friendly, noise free easy maintenance requirements with impressive lifespan. It is tough to guess solar power as it is non-linear. Solar energy that hits a solar photovoltaic system may be converted exactly into electricity. Current is affected by temperature and radiation and voltage enormously which are the main cause of non-linearity. There is need to minimize the cost of PV system, to increase its efficiency and to reduce the size. The extraction of power from solar cell is maximum power point (MPP) under special circumstances. Load current depends primarily upon ambient temperature, radiation and cell temperature. To track maximum power by load resistance optimization properly in any condition of environment is Maximum power point tracking (MPPT) (Orozco *et al.* 2009).

Due to sustainability of alternative renewable energy, it has gained a great attention as well as importance now a days. Due to industrial revolution, the demand of energy has been increase very much. The simple and reliable technology is photovoltaic (PV) solar panel that convert directly solar energy to electrical energy for industrial and home utilization. By the use of MPPT controller, maximum power can be obtained from photovoltaic system (Chouder *et al.* 2008).

Under normal operating conditions, using maximum power points methods for temperature conditions and solar irradiation, oscillatory behaviour is displayed. There is no response of the system to changing in temperature and irradiance. Conventional PI controller are considered as fixed feedback gain controller. They don't compensate the variation in parameters and cannot adapt the environmental changes. Intelligent based schemes are introduced now a days. One of the intelligent based methods is Fuzzy logic having its own merits which include easy formulation of algorithm. Membership function shape can be adjusted so that gap between maximum power point and the operation point can be optimized. (Chouder *et al.* 2008).

The objectives of the thesis are divided into, to compare different technical based robust techniques for Implementing Maximum Power Point Tracking (MPPT) control ensures that output is under tight control and produces the best possible outcomes, to design and implement To maintain the PV array's maximum power point track with efficient and optimal output response, one MPPT control algorithm, to design efficient DC-DC Boost converter to assure fast and accurate algorithm of MPPT to get maximum energy and power from PV array and to analyse maximum power delivering mechanism for solar power system and implementation of system for comprehensive system design.

1.2 Problem Statement

To convert solar heat energy to electrical energy, renewable solar energy system with PV solar modules is being introduced now a days. Because of non-linear characteristics of PV cell, conventional solar system without optimized and advanced MPPT featured do not utilizes all power supplied by photovoltaic cell. It is essential to design and implement optimized control algorithm with highly organized, efficient, powerful and optimistic MPPT controller as it has ability to utilize all power with minimum loss of energy. Another advantage of using MPPT controller is that it is very cost effective.

1.3 Thesis Arrangment

The thesis is organized into six chapters, whose presentation is given herewith. Chapter 2 briefly review discuss the literature review. Chapter 3 cover the Modelling of a Photovoltaic Module. Chapter 4 presents Simulink model design Solar PV based on MPPT. Chapter 5 presents the simulation Based Testing and Results and chapter 6 is the conclusion and future of works of the thesis.

2. LITERATURE REVIEW

In this chapter, a group of similar papers related to our topic will be discussed and presented as the following categories are examples of MPPT algorithms: PO approach, IC methodologies, Fuzzy logic, neural networks, and alternative methods.

Kouzaev *et al.* (2008) the study is based on a comparison of different MPPT techniques by using MATLAB tool Simulink. by taking into consideration the Partially shaded conditions are not considered here and the radiation is assumed to be uniformly scattered over the PV array. The mathematical model of each component is taken into account in the implementation of the photovoltaic system in addition to the specification of the actual component. Attention has focused on the grid-connected photovoltaic system generated by the primary single-ended DC/dc connection (SPEIC) between the grid and the solar panel. Ten different MPPT techniques are compared here. Solar isolation of twelve different types are considered and energy is calculated that is supplied by complete PV system. It is concluded that PO and IC algorithm are most efficient MPPT technique among all analyzed techniques.

Faizal *et al.* (2016) described that the P& amp; Oc method efficiency is low unlike other P&O methods and the reason for its low efficiency is lack of speed while tracking MPP. The greater efficiency of the ICb method does not justify the cost of using more than one sensor compared to the Ica method. IC techniques are almost having similar efficacy. Good results are produced by TP temperature technique but inconveniences produced by this are variations in certain parameters that create error in the evaluation of optimal voltage Vop. And its effect on the measured temperature by a phenomenon unrelated to solar insulation. There is need of further research on comparison of cost of these techniques especially under shadow conditions.

Rokonuzzaman *et al.* (2017) based on the use of The fuzzy logic way to find it maximum power point of solar panels the major advantage of fuzzy logic is that these are robust, efficient and relatively In order to get maximum power from the solar panels when changing radiation levels, a buck-boosted DC-DC converter is used as a regulator of the output voltage from the solar panels. It is concluded in this research article that if conditions of solar irradiation are changed, output of the photovoltaic system can be kept at its maximum value by using a complete power point tracking system (MPPT). An average increase of output voltage value to 17% from 11.6V to 13.94V after installation of MPPT system during changed solar irradiation conditions. Power output increased by 28% from 35.13 W to 48.9W after MPPT installation under changed solar irradiation conditions. Under changed temperature conditions, the output voltage of photovoltaic modules can be maintained by MPPT system at maximum desired value of12 V. As the load current is not able in order to accept, system output power is still not maximized.

Allah Hamadi *et al.* (2018) related to the design and implementation of microcontroller base MPPT controller technique by using Arduino microcontroller. The system proposed in this article demonstrate its low power consumption, low cost and high-power efficiency and control unit base on microcontroller. It is based on microcontroller as it allows customized and easier system modifications and it also facilitate the date storage remote monitoring, continuous displaying of system status and external device charging. The results of experiment from 30W prototype system presented and validated. It is concluded that charge controller average efficiency is 91.45%and it is satisfying fully the regulations of technical standard committee (TSC) of infrastructure development company limited (IDCOL). It can be interfaced to power grid converter as well as can be coupled to other renewable energy resources.

Venkateshkumar (2018) based on the comparison of different MPPT methods in order to determine the most robust and most efficient system in the presence of changing conditions in climate such as temperature and irradiance. The article work is related to successful implementation of perturb, observe and fuzzy logic. DC-DC photovoltaic panel boost converter model using fuzzy logic and traditional Maximum Power Point Tracking (MPPT) method for P&O controllers was created in the MATLAB Simulink environment, and Simulink results were compared. The boost transformer is connected to increase the voltage of the PV panel. The load receives enhanced voltage from the DC-

DC converter. In order to track the maximum power from the solar panels, the Maximum Power Point tracking block regulates the boost converter's operating ratio. On the basis of this research article, it is concluded that the performance of Fuzzy logic controller is rapid, accurate and better than P&O under varying atmospheric conditions.

Karanjkar *et al.* (2014) grid integration of photovoltaic (PV) power system with intelligent controller-based energy management is demonstrated in an effort to improve power quality. This objective is achieved by mathematical design modelling of photovoltaic system and simulation In different weather conditions of PV system with foggy MPPT system. The fuzzy based management system was created, put through testing under various power demands, and had its battery charging and discharging function analyzed. Finally, MATLAB is used to simulate the suggested grid integration goal for PV systems and analyze system performance under various operating scenarios. The efficacy of the suggested method is then demonstrated by comparing the power quality simulation improvement with the 1547 standard.

Pongratananukul *et al.* (2003) related to the comparison of three different control algorithms of MPPT to determine their effectiveness. These methods include incremental conductance method (IncCond), Constant voltage and turmoil monitoring method and control method (P&O). investigation of proposed system has been done via simulation and efficiency evaluation experiment of the methods. Analysis of transient and steady state characteristics of control algorithm with efficiency measured. Finally, incremental conductance method and constant voltage control methods are combined and a novel control algorithm two-mode MPPT control is proposed in an attempt to improve the efficiency of 3kW photovoltaic power generation system in different insolation conditions. Under rapidly changing solar insolation conditions, the P&O and IncCond MPPT control approaches fail to follow the maximum power point. Due to the implementation of a modified constant voltage control mechanism, the two mode Maximum power point tracking control algorithm suggested in this paper performs excellently.

Sun *et al.* (2002) based on presentation of DSP-based improved MPPT approach is utilized for multiple solar array applications. Here, a parallel current-mode DC/DC converter regulation technique called "shared bus" current sharing is used. the increased system power brought about by modular design. With two solar arrays and a 500-W prototype, the proposed system's MPPT performance and current sharing are validated. This article presents an expandable power system with reliable and effective multiple power point tracking (MPPT) features. DSP controller is incorporated to track multiple power peak points of plurality of solar arrays. The proposed system performance evaluated and validated.

Assahout *et al*. (2018) based on introduction of photovoltaic energy system controlled by single phase bi-directional PMW converter and DC-DC converter to realize inversion. A current controlling maximum power point tracking (MPPT) method It has the capacity to monitor maximum power and compels the system to function near the point of usage. In MPPT system, The usage of artificial neural networks and intermittent environmental and weather conditions increases robustness and insensitivity. Inversion current controller used is UC3854 which has maximum performance in power factor and in harmonics as well.

Ulinuha *et al.* (2020) based on photovoltaic water pumping system. A DC-DC boost converter, PVG, and a DC motor connected to a centrifugal water pump make up its three primary components. A new MPPT algorithm is proposed in this article that is built on an Artificial Neural Network with Fuzzy Logic to enhance the system's performance. The optimal voltage of PVG is predicted by use of ANN A fuzzy controller is used to manage a DC-DC boost converter under various temperature and sun irradiation circumstances. The comparison of the proposed method is done with perturbation and observation method MATLAB/Simulink Simulation is used to test the efficacy of the system. Duty cycle D converter value is provided by a fuzzy controller. On the basis of Simulation results, Maximum power point tracking (MPPT) based on Artificial Neural Network and Fuzzy logic is shown to be much more efficient. It is proved from this algorithm that the performance by this system is much better, this system is highly accurate and robust to varying environmental conditions and response time is fast.

Sahu *et al.* (2018) Based on a hill climbing optimization technique, maximum power point tracking is used to improve solar photovoltaics. An Arduino microcontroller used here for interpretation of algorithm. To maintain the power generated by photovoltaic system at its constant level, The panel should be moved to a new location so it will always face the sun. A maximum power point tracking system is used to drive the panel to its maximum power. The power obtained is utilized as the foundation for driving the motor for rotor rotation after the Arduino microcontroller calculates the voltage and current feedback. The position of panel is determined by Hill Climbing algorithm. The main application of this concept is to allow system to provide more energy and power. As, the system is equipped with MPPT that employs actuator and microcontroller. It should be considered that how much power is consumed by these devices. It is concluded that energy reduction due to use of actuator and microcontroller is higher even for the system with the most advanced MPPT.

Goshwe *et al.* (2018) based on Incorporate a DC-DC boost converter and maximum power point tracking into your off-grid solar system designs MPPT. MPPT technique based on tuned PID is used to harness the solar system's highest amount of electricity under different circumstances such as varying temperature and irradiance. PID controller design parameters play imperative aspect to increase the system performance. Ant lion Optimizer (ALO) algorithm has been adopted in this research article to optimize PID parameters to provide pertinent duty cycle to DC-DC boost converter output power and voltage maximization. MPPT technique PO based is implemented for validating superiority of PID-based MPPT to improve system responsiveness. in this article The suggested ALO optimized PID controller's underlying MPPT method is finished. performance is better as compared to conventional PO technique by conceding time response, oscillation, settling time, current and power of the solar system and maximum values of voltages.

Attia *et al.* (2019) based on a single-ended primary inductor (SEPIC) converter is switched using fuzzy logic to offer maximum power point tracking management and collect the most power from a photovoltaic (PV) system. The FLC MPPT proposed here at varying irradiances of 1000, 900, 700 and 500 W/m2. The Temperature varying from 30, 25, 20 and 180C. The single-ended primary inductor (SPEIC) converter has output voltage 58.70 V for 1000 W/m2 at temperature 18C. For SPEIC fuzzy controller MPPT scheme indicate good transition of current and keep voltage constant with acceptable limits, in varying conditions of temperature and irradiances. This research concludes that solar PV systems using SPEIC dc-dc converters work better with no ripples or oscillations at PV module output voltage. Fuzzy logic controllers are used to maximize power under fluctuating temperature and irradiation. According to this module, at a 1000 W/m2 PV system, output power increases while cell temperature decreases, which is consistent with.

Kottas *et al.* (2006) based on the presentation of an innovative freestanding photovoltaic (PV) system that can power a direct current water pump but is challenging to supply with utility electricity. In order to achieve the best power point tracking operating circumstances, a system's ANN is employed in conjunction with PI controller function softening to regulate the system. A parallel-connected PV array is created to provide the water pump with the necessary electricity. In order to avoid the complicated behavior of an alternating current (AC) pumping system, the design suggested a permanent magnet DC motor (PMDC) of 48 volts and 500 Watts as well as the adoption of a direct current (DC) pump. AC system components were thus avoided. To produce reference voltage for MPPT PV system functioning, a feed forward ANN algorithm adopted. The insertion of Proportional Integral (PI) controller to soften performance of PV controller. The design of the system, Simulation results and analysis of results is presented in this article.

Shiau *et al.* (2015) related to Fuzzy set theory for maximum power point tracking in order to improve energy conversion efficiency. By using fuzzy cognitive network, a new system is proposed here and this is in close cooperation with presented Fuzzy controller. the new method provides a vey good operation of photovoltaic array at maximum power under varying conditions such as temperature as well as changing insolation. The simulation study present the proposed algorithm effectiveness. The article is based on combining Fuzzy MPPT with designed appropriately FCN to speed-up procedure to reach accurate maximum power point of PV system under environmental changing conditions. The concluded results show 0.78% error in production of energy when comparison done with expected theoretical production of photovoltaic array available commercially. The data simulated on whole year climatic data. Therefore, this method has guaranteed performance independent of variations.

Femia *et al*. (2006) based on detailed determinations and Fuzzy rules, as well as merits and demerits of MPPT algorithm based on properties of photovoltaic cell. There is finite range of input variable of Algorithm maximum power point (MPP) conditions are well defined at steady conditions and thus it can be utilized for multipurpose controller design. To verify the design, computer simulations are conducted. This article summarizes the six fuzzy MPPT algorithms by using different input variables. Algorithm (Vi) which utilized the sum of angles of arctangent of conductance and incremental conductance arctangent as input variable, considered most promising algorithm for MPPT by keeping in view our considerations as conditions for MPP have well-defined range for sum (1800) as well as range of sum (90-2700). To determine the range of universe of discourse, associated membership function for maximum power point tracking (MPPT) algorithm, the algorithm (Vi) made it easier. The better MPPT performance by Algorithm (Vi) confirmed by computer simulations.

Abdel Rahim *et al.* (2011) based on the use of One-cycle-control (OCC) for power factor correction (PFC) and maximum power point tracking (MPPT) in grid connected photovoltaic applications. Operating parameters as well as circuit of one-cycle based controller single-staged cost-effective inverter optimized to obtain good performance of system under different levels of irradiance. First of all, formulation of design constraints which allow to obtain highly efficient OCC operation in terms of extracting maximum power from PV array, PFC and stability. By means of suitable heuristic approaches, such constraints utilized to perform parametric optimization of one cycle controller. The article is related to deep study of optimization process of OCC for single-staged inverter associated to PV grid-connected system. The design constraints analysis done, then systematic procedure to optimize the controller is build up. The performance indices defined in an attempt to classify set of parameters that are meeting the design constraints. Advanced heuristic technique used for non linear constrained optimization. Validation of results by time domain simulation under varying conditions of irradiance. Maximum performance shown by optimized controller in terms of drawn power from PFC capability and PV field.

Goshwe *et al.* (2018) proposed single-stage high gain buck-boost grid-connected system. The system proposed consists of high efficiency-high voltage gain-switched inductor buck-boost converter (SIBBC), H-bridge folded cascade inverter. Sinusoidal modulation derived proposed converter switch so than rectified sine wave is output voltage, it requires folded cascade as second stage. So, the converter output voltage is folded by H-bridge to fundamental frequency that eliminate the loss of switching. The article is based on the system proposed that is used to connect grid to PV module with achieving MPPT control; AC module. Operation of converter in DCM to inject sinusoidal current with unity power factor into grid. Merits of proposed dc-ac system include small size, low cost and simple control. In addition, MPP, grid connection and unity power factor control executed through only single switch, the converter switch. For validation, protype built and tested. Simulation and experimental results provided.

Amirullah *et al.* (2016) The research article is based on different types of PV system, power electronic converters usage and maximum power point tracking control algorithms, various controller, filters in order to reduce harmonic content battery system usage for photovoltaic system. Attempts are being made to highlight the present and future issues which are involved in development of PV system with improved performance. It is concluded in this article that perturbation and observation (P&O) and incremental conductance are simple methods that have low utilization efficiency and slow tracking. To overcome this drawback, fuzzy as well as neural network techniques are being used to increase the efficiency. There is reduction of harmonic content from DC-

DC converter output by using filter circuits. Better AC outputs are produced by PMW inverter technique which are utilized to connect grid interconnections and standalone AC loads. In hybrid system, Grid tied inverter with backup of battery are used even if grid goes down for off grid and grid tied systems.

Nayak *et al.* (2017) related to the power quality enhancement under three phase grid low voltage for three phase grid that is caused by PV generator integration under varying solar irradiance level under constant temperature and load. The MPPT method P and O and MPPT fuzzy on varying irradiance integration PV generator level producing unbalanced voltage with value stable at 0%. Average grid voltage and current THD increased as the level of solar radiation increases. Using MPPT fuzzy method, the current THD and average grid voltage reduced. Therefore, Fuzzy Logic Controller method for maximum power point tracking (MPPT) improve the profile of grid voltage and current THD due to number of PV generator integration to three phase grid.

3. MODELLING OF A PHOTOVOLTAIC SYSTEM

3.1 Introduction

In the chapter of the thesis dedicated to photovoltaic systems, the pros and downsides of employing solar systems were explored. Photovoltaic PV systems and how they respond to environmental conditions are technically complex. This study constructed and assessed a MATLAB/SIMULINK PV model. The model was developed using PV cell equivalent circuit equations. The manufacturer's datasheet and a maximum power point tracking system were utilized to simulate the PV installation MPPT.

As fossil fuels run out, alternative energy sources are gaining attention. Renewable energy sources are eco-friendly and durable. Sun, wind, water, biomass, geothermal heat, and ocean currents are renewable energy sources. Renewable energy sources emit nearly little carbon dioxide compared to fossil fuels, natural gas, and uranium, mitigating global warming and the greenhouse effect.

Non-renewable resources pollute, while fossil fuel reserves are diminishing, causing price hikes. Renewable energy is pollution-free and free. Renewable energy is a possible alternative for fossil fuels and other non-renewable sources. Figure 3.1 (Ren 2016) shows the percentage of global renewable energy production.

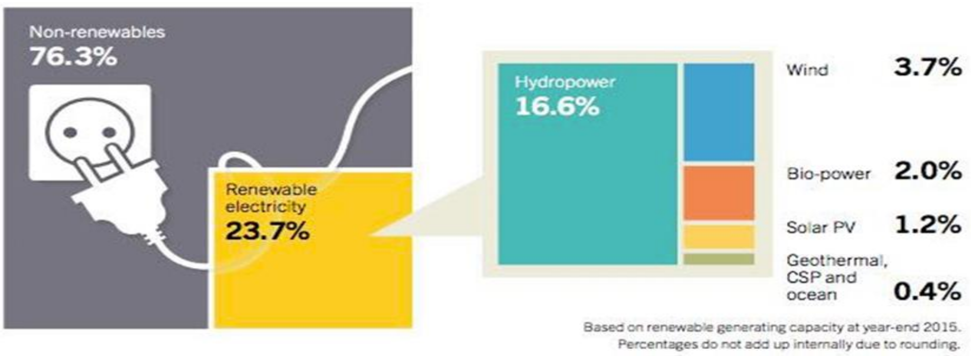


Figure 3.1 2015 percentage of renewable energy used to generate power globally (Ren 2016)

3.2 Photovoltaic Systems

3.2.1 Solar power generation systems

Sunlight is transformed directly into electrons and volts to generate photovoltaic energy. Photovoltaic cells convert light into electricity (Figure 3.2). Solar photovoltaic (PV) cells are built of light-sensitive diodes like transistors and computer chips. PV cell steps: Semiconductors convert photons to electrons. Positively charged "holes" produced by light recombine with high-energy electrons to produce heat in semiconductors. The link between the two semiconductor types in a PV cell creates an electrical field, a voltage differential is formed. Cell current is drawn via the two terminals.

Photovoltaic (PV) cells create power like chemical batteries. A PV cell's output is limited by parameters such as irradiance, and temperature (Spiers 1998).

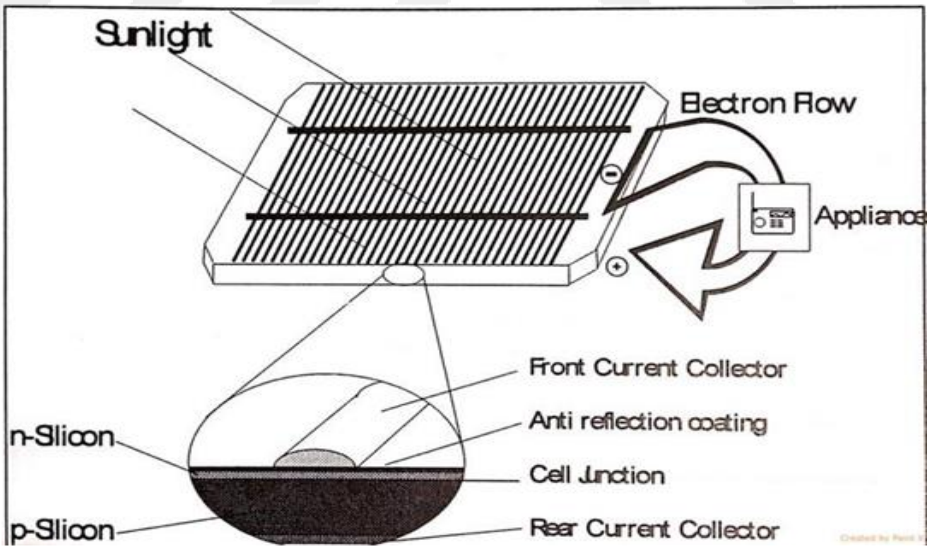


Figure 3.2 PV cell showing PV effect (Spiers 1998)

3.2.2 PV cell types

- **Monocrystalline (single-crystalline) cells**

Figure 3.3 shows single-crystal silicon cells that are very smooth to the touch. Monocrystalline cells are the most effective, but expensive to produce.

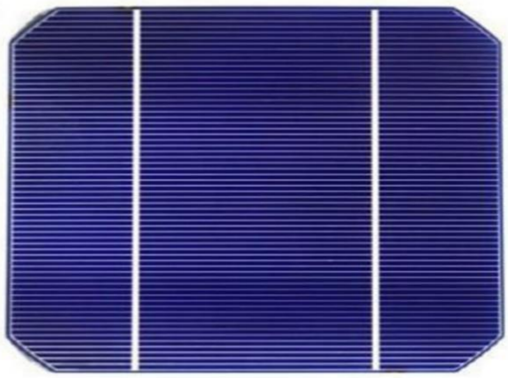


Figure 3.3 Monocrystalline PV cell (Goetzberger *et al.* 2005)

- **Polycrystalline cells, also known as multi-crystal cells**

Named after its multi-crystal structure, "polycrystalline cells" Figure 3.4 illustrates that they're formed of silicon. Poly-crystalline solar panels are cheaper than mono-crystalline due to their lower efficiency.

Figure 3.4 Poly-crystalline PV cell (Goetzberger *et al.* 2005)

- **Amorphous cells includes**

Figure 3.5 shows amorphous cells created by depositing thin layers of non-crystalline silicon on different substrates.

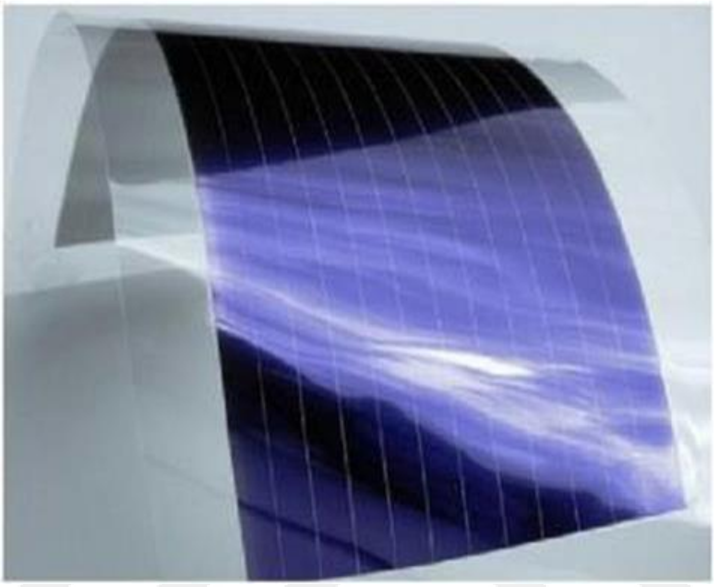


Figure 3.5 Non-crystalline (amorphous) PV cell (Goetzberger *et al.* 2005)

3.2.3 PV cell characteristics

The backside is positive electric field and the front is negative electric field of the typical silicon semiconducting resources. Solar cells, wires, shields, and supports make up a photovoltaic PV generator. Solar photons clash with a solar cell, breaking atomic bonds and releasing electrons. This "loosening" creates electron-hole pairs, which positive and negative electrical conductors connect to. Moving electrons produce an Iph symbolized electric current in an electrical circuit. Solar cells operate like diodes when dark. It's a p-n junction that blocks voltage and current. Connecting the cell to a high-voltage external source generates an ID current. Figure 3.6 shows that a solar cell's electrical activity commonly resembles a single diode. This kind of circuit may be used in single cells, modules, and arrays (Lorenzo 1994).

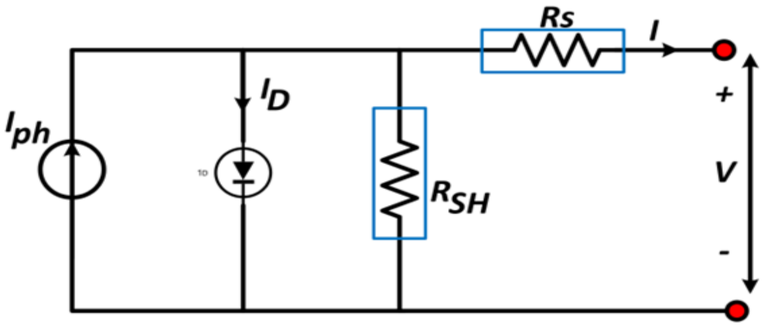


Figure 3.6 Single solar cell module

The model comprises a current source (Iph), series resistance (RS), and a diode that simulates cell resistance. Figure 8 shows the diode's outside and interior shunt resistance. Equation (3.1) present the net current is the diode current minus the photocurrent, Iph.

$$I = I_{ph} - I_D = I_{ph} - I_o \left\{ exp \left[\frac{e(V+IRs)}{KTc} \right] - 1 \right\} - \frac{V+IRs}{R_{SH}} \quad (3.1)$$

Load resistance is generally higher than series resistance, little electricity "disappears" in the cell. We may determine the net current by deducting the photocurrent (Iph) from the typical diode current (ID) and disregarding these two resistors. To illustrate, have a look at the equation below.

Figure 3.7 portrays a solar cell's temperature (T), irradiance (Gt), and I-V (current-voltage) curve (TC). The amount of current generated by a photovoltaic (PV) cell depends on how much sunlight it absorbs, external voltage and internal resistance of the cell. In a short circuit, cell voltage drops to zero and current increases Isc. After a PV cell's circuit is open (and the leads aren't connected), The open circuit voltage (Voc) of the cell has been reached, but the current does not change. In both open and short circuits, the current and voltage product is 0, hence no electrical charge is formed. Between open and shorted circuits. Figure 9 depicts a typical current voltage curve for potential current and voltage. Since the sun creates positive current when touched, a sign convention gives the sun positive voltage (Lorenzo 1994). Positive voltage is always at cell ends.

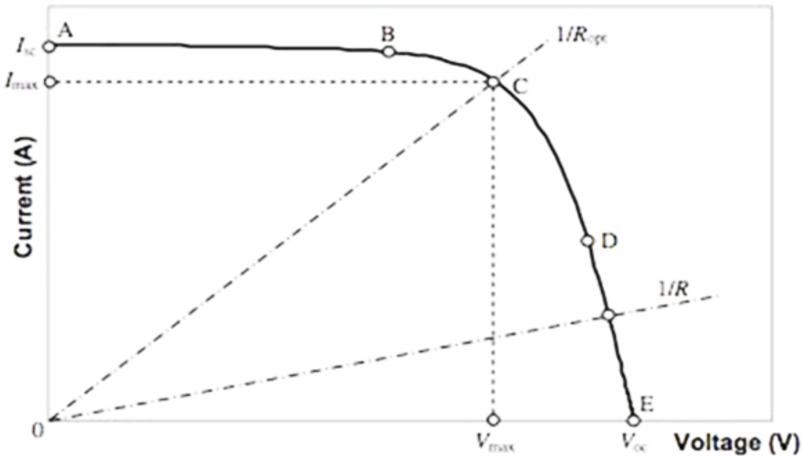


Figure 3.7 Representative voltage curve for photovoltaic cells (Lorenzo 1994)

The functioning point is defined as the location where the solar cells' terminals make contact with the variable resistance, R. Efficiency has run its course. The load with the slope (1/V=1/R) is shown in Figure 3.8. Load line seen above. As load resistance lowers, the cell advances toward AB. Continuous battery current are similar to short circuit current. In the DE area of the curve, when load resistance is high, the cell provides a constant voltage source around the open-circuit voltage. Because DE voltage is near to open-circuit voltage, they are basically the same. "Power" here means "voltage times current." Figure 3.8 shows potential workout outcomes on a P-V graph. Figure 10 displays peak power above maximum power at point C.

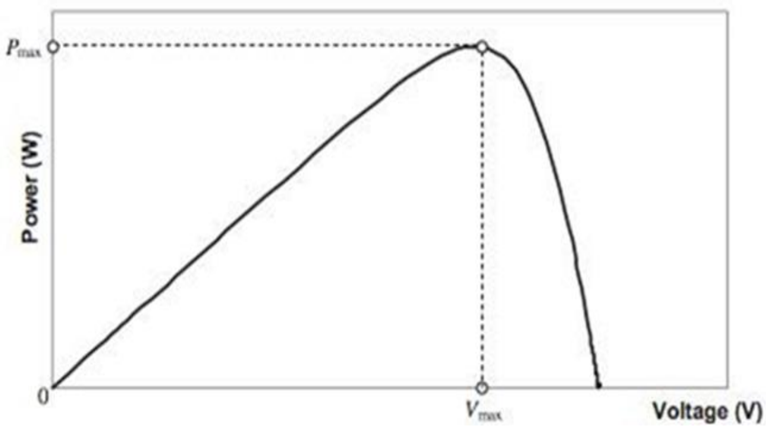


Figure 3.8 Delegating power–voltage curve for photovoltaic cells (Lorenzo 1994)

Ropt will have achieved its ideal value, and the power Equation (3.2) that has "disappeared" due to the resistive load will be at its peak.

$$P_{max} = I_{max} * V_{max} \tag{3.2}$$

Maximum power point C in the same figure separates Pmax, Imax, and Vmax. The maximum point is C. Equation (3.3) present the places have the most power. When computing Pmax, the fill factor (FF) might be considered, as shown in the Equation (3.4).

$$P_{max} = I_{sc} * V_{sc} * FF \tag{3.3}$$

or

$$FF = P_{max}/I_{sc} * V_{sc} = I_{max} * V_{max}/I_{sc} * V_{sc} \tag{3.4}$$

The fill factor is the true I-V characteristic, according to research. Healthy cells have a fill factor over 0.7, but it falls as cell temperature rises. As a result, the output power of a PV cell is raised when it is lighted and loaded to reach its Vmax. Resistive loads, electrical loads, batteries, and other electrical loads may be used to load the cell.

PV cell efficiency is often discussed. Efficiency is the ratio of electricity generated to light lost. When calculating efficiency, it's assumed the PV cell is 250 degrees Celsius and the incoming light has 1000 watts per square meter with a spectrum similar to solar noon. Solar system costs will reduce as solar cell efficiency improves. Each step of solar production has undergone R&D. Equation (3.5) present the efficiency of a solar cell manufactured from a single crystal of crystalline silicon in mass manufacturing lines has climbed to 14-15 percent (Lorenzo 1994).

$$\eta_{max} = \frac{P_{max}}{P_{in}} = \frac{I_{max}V_{max}}{AG_t} \tag{3.5}$$

3.2.4 PV system feature

Changes in operational conditions including sun irradiation, moisture levels, and temperature affect photovoltaic system performance. The amount of solar irradiation a PV receives is directly connected to the amount of electricity it produces, and the amount of power produced is inversely proportional to temperature. Changing temperature or solar energy changes the maximum power point. DC-DC converters must be used to alter array terminal voltage and monitor maximum power point. In the third chapter, we'll discuss ways to find the greatest power point see Figures 3.9 and 3.10.

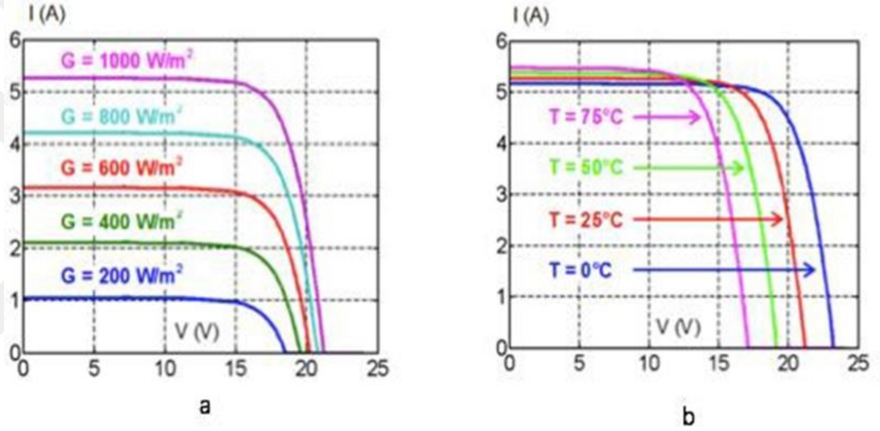


Figure 3.9 The influence of temperature fluctuations on I-V curves and the impact of changes in solar radiation (Guo *et al.* 2011)

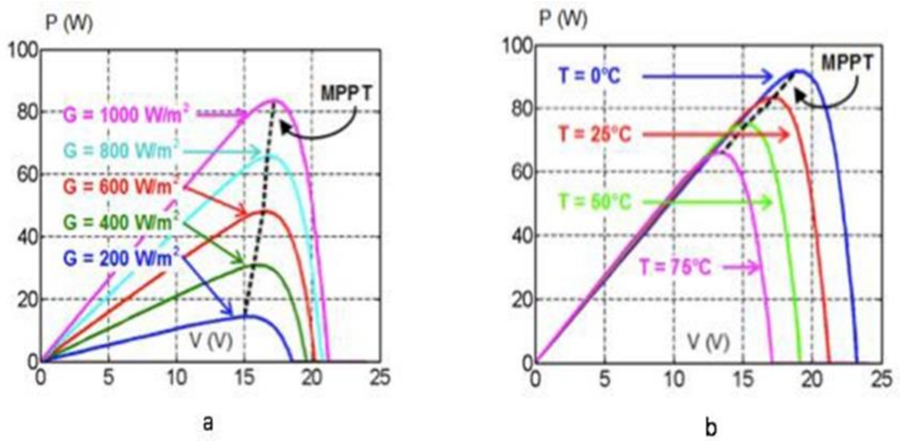


Figure 3.10 a) The impact of changing solar radiation on PV curves, and b) how temperature variations affect PV curves (Guo *et al.* 2011)

Solar energy is converted into electricity via photovoltaics. The generation of electron-hole pairs with energies greater than the semiconductor's bandgap occurs when it is exposed to sunlight. To create a solar cell, a p-n junction is attached to a semiconductor wafer. The analogous circuit of a solar cell is shown in Figure 3.11.

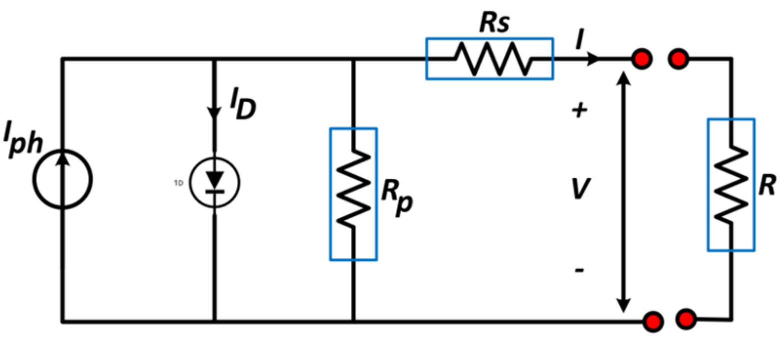


Figure 3.11 Photocell styled diode circuit

Iph signifies the cell's photocurrent in the diagram. Rsh stands for the shunt resistances inherent in the cell, while Rs represents its resistance series. The number of Rsh is generally significant, but the value of Rs is negligible; you may leave them out to simplify the study. PV modules are clusters of PV cells that may create PV arrays. Solar panels produce power.

Equation (3.6) present the current for the module photos

$$I_{ph} = [I_{SCR} + Ki(T - 298)] * \frac{\lambda}{1000} \quad (3.6)$$

And the current for the Module in Reverse Saturation presents in Equation (3.7).

$$Irs = I_{SCR}/[\exp\,(q.V_{oc}/Ns.k.A.T)] \quad (3.7)$$

The unit saturation current oscillates with cell temperature, as illustrated in the following Equations (3.8) and (3.9):

$$I_s = I_{rs} * [T/Tr]3\exp[q * Ego\{(1/Tr) - (1/T)\}] \quad (3.8)$$

The current drawn by PV modules is thus

$$I_{pv} = Np * I_{ph} - Np * I_s[\exp\{(q * V_{pv} + I_{pv} * Rs)/NsAKT\}] \quad (3.9)$$

Where Vpv = Voc, Np=1 , Ns=36 (Diab *et al.* 2012).

3.3 Solar PV

3.3.1 The global spread of photovoltaic cells

Solar energy is not geographically limited, unlike wind and water. Solar energy can be created practically anywhere on Earth. Photovoltaics are gaining popularity since they produce the most solar-based power. Figure 3.12 shows 2015 renewable energy growth. Figure 3.13 shows that photovoltaic capacity increased in three years (Ren 2016). Photovoltaics grew faster than other renewable energies.

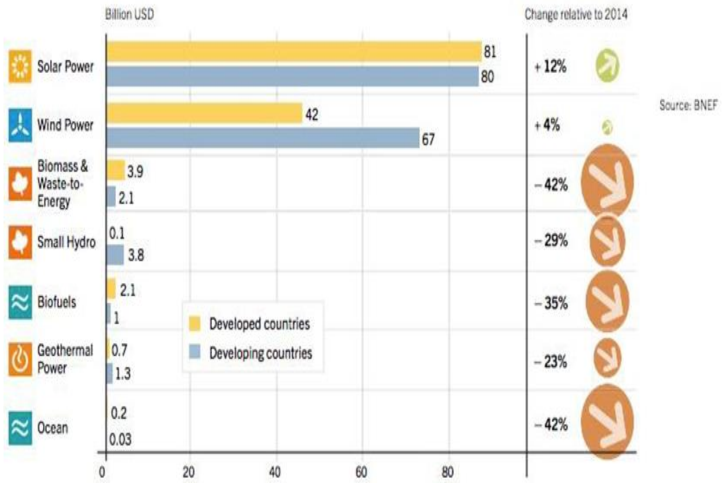


Figure 3.12 2015 yearly averages for the expansion of renewable energy capacity and the production of biofuels (Ren 2016)

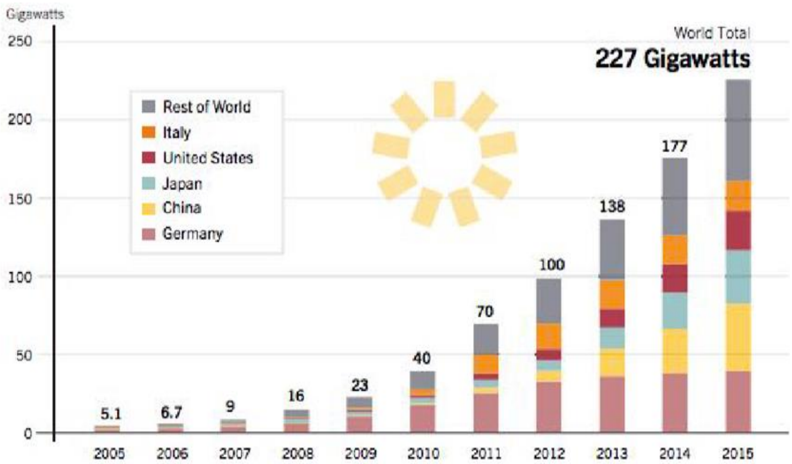


Figure 3.13 Global PV solar capacity, 2005–2015 (Ren 2016)

3.3.2 PV system benefits

PV systems are superior to other types in many ways (Goetzberger *et al.* 2005).

1. Pre-packaged PV systems are ready to install. The modules are low-maintenance since they have no moving parts.
2. The systems' breadth of sizes and outputs makes them useful in many scenarios. Lightweight photovoltaic (PV) systems are easy to move.
3. Systems may be expanded by adding modules. This may be done in series or parallel (to boost current) (i.e., to strengthen the voltage).
4. System components can withstand high winds and hot or cold temperatures. They can endure salt and dampness. Photovoltaic (PV) systems may offer steady, high-quality electricity even when there is no sunlight, such as at night or during severe weather, due to their storage capacity.
5. The systems don't emit noise or carbon; therefore, they don't contaminate the environment.

PV systems offer benefits and drawbacks, including the following:

1. PV systems are expensive to manufacture because to high material and labor expenses.
2. Concerns remain about the maximum power point.
3. Clean the systems regularly to reduce dust build-up.
4. Systems remain ineffectual.

3.4 Various PV Systems

3.4.1 Country remain regulations

A system consists for a PV panel, an inverter to convert direct current to alternative current, and a battery bank (Diab *et al.* 2012, Wang *et al.* 2010) Figure 3.14 displays a freestanding system appropriate for minimal energy needs and plentiful solar insulation. When overcast or dark, a fossil fuel-powered system may charge the PV battery. The hybrid technology reduces the generator's fuel and maintenance demands and extends the battery's life.

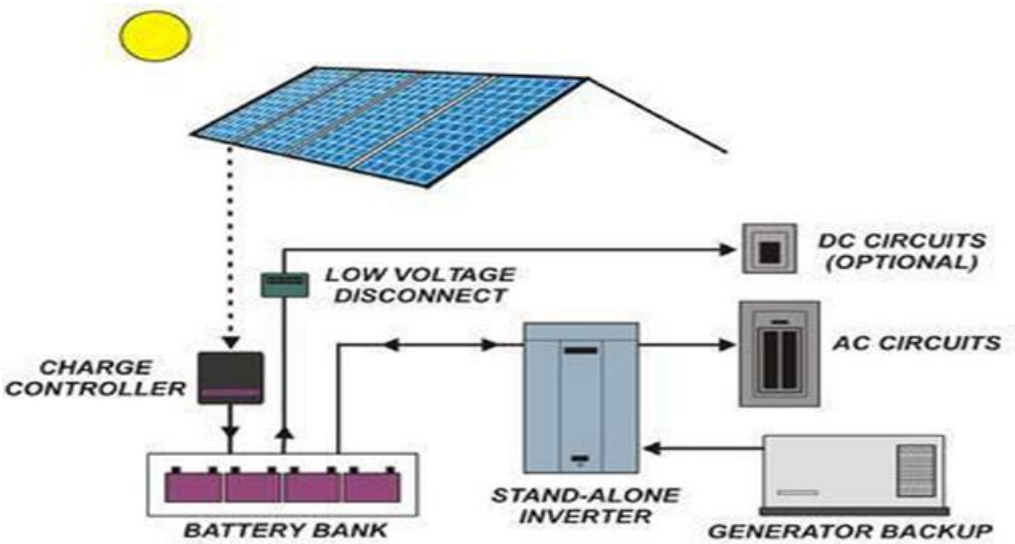


Figure 3.14 Standalone PV system (Diab *et al.* 2012)

3.4.2 Grid connected systems

This depict at Figure 3.15, employ a better inverter and are directly linked to power lines, unlike stand-alone systems. Independent systems don't need inverters. In PV systems that are grid-connected, the inverter, converts DC to AC (Guo *et al.* 2011). PV-based generating stations are called grid-connected systems since they provide electricity into the grid. This is a crucial truth. This has more promise than stand-alone ones. Grid-connected users may sell excess power to utilities for a charge. In a shortfall, they may use the utility's supply.

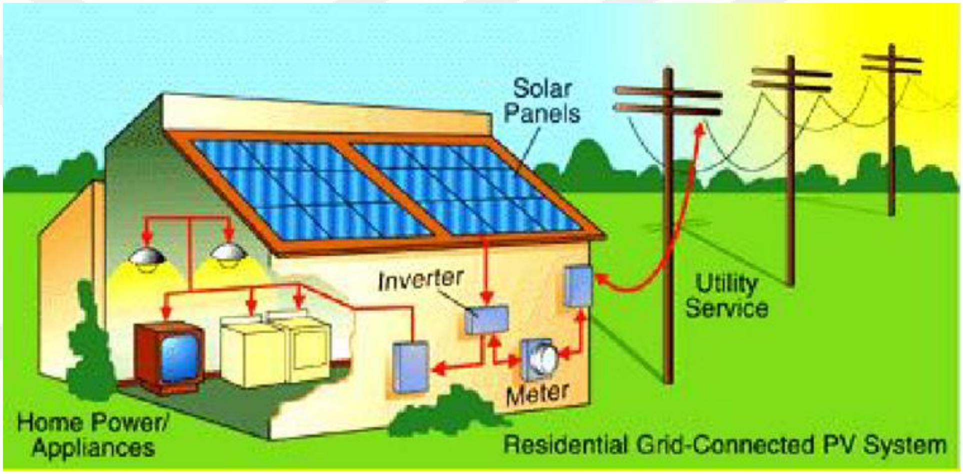


Figure 3.15 Grid-connected PV system (Guo *et al.* 2011)

3.5 Maximum Power Point Traking and DC-DC Converter

3.5.1 DC-DC converter

Nonlinear PV systems fluctuate in output power due to changing environmental conditions. A dc-dc converter is the best instrument for altering a PV source's voltage and current (Himanshu and Tripathi 2012). Figure 3.16 shows a DC-DC converter. The converter changes the direct current output value from the direct current input voltage. This adjustment must be done with low converter losses; thus, the transistor will act as a switch and apply the control signal d (t). Figure 3.17 shows that the control is permitted to remain high for ton and toff (Himanshu and Tripathi 2012).

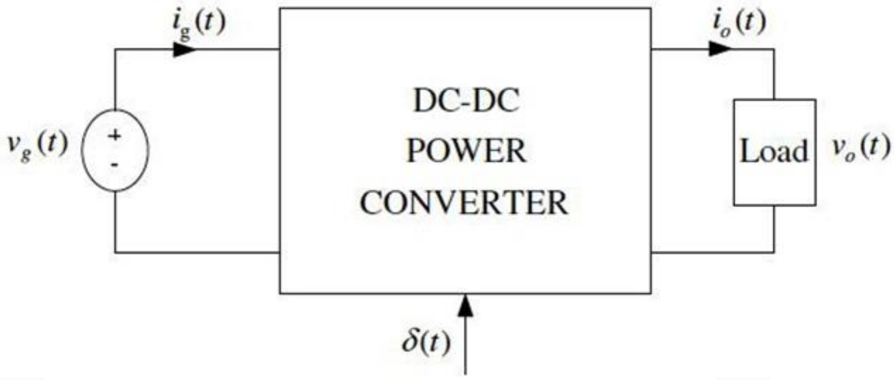


Figure 3.16 DC-DC converter structure (Himanshu and Tripathi 2012)

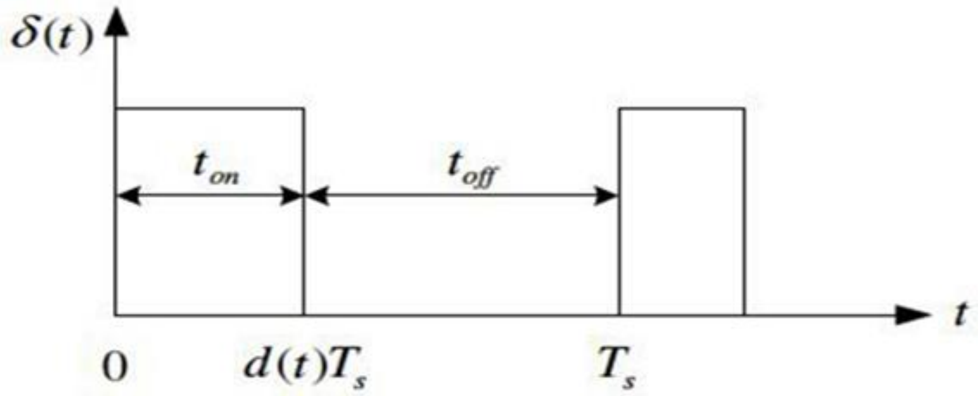


Figure 3.17 Transistor control signal (Erickson *et al.* 2001)

The on-device voltage drop reduces the transistor's power loss. Turning off the transistor reduces both the current and electricity wasted. Changing the pulse width while keeping Ts constant changes the average output voltage. With *d (t) = ton/Ts*, the duty cycle is a real value from 0 to 1. Duty cycle equals pulse width/switching time.

Due of capacitors and inductors' low losses. Electrical components may be simply combined (topologies), each with its unique properties. The most common types of converters are buck, boost, and buck-boost. Boost converters have higher output voltages than buck converters, where buck boost output voltage is high (Erickson *et al.* 2001).

Because the transistor's on-state voltage is low, it causes essentially little power loss. Since the transistor's current is so low, it loses essentially little power when turned off. Pulse width influences average voltage output, not switching time Ts. The duty cycle *d(t)* is proportional to the ratio of pulse width to switching period (Erickson *et al.* 2001).

Resistors aren't utilized in DC-DC converters to decrease loss. Inductors and capacitors are used since they don't produce losses under ideal circumstances. Electrical components may be linked and integrated in a number of topologies, each with distinct features. Most transformers are buck-boost, buck, or boost. Buck transformer raises the input voltage, whereas boost converters reduce it. Buck-boost systems produce both voltages.

3.5.2 Maximum power point tracking

The output power of a PV module is influenced by the operating voltage of the load, cell temperature, and solar radiation. The functioning point of the module may be determined by connecting a variable load resistance R across its terminals. The operational point is determined by comparing the load's I-V characteristic to the junction of the module's I-V curve. Figure 3.18 shows PV module functions. Zone II is a source of voltage, while Zone I is a source of current. The module's internal impedance is high in Zone I and low in Zone II. Pmp is situated at the power curve's knee. As temperature rises, internal impedance decreases as a result of solar radiation. Rise in short-circuit current. The open circuit's voltage has dropped. Only when the source and load impedances are equivalent can the maximum power transfer theory be used. The load characteristic may be approximated by the slope of the line that I/V = I/R produces. The module operates around Isc since it is a continuous current source in AB; as a result, R is low. When the module is used to produce a steady voltage around Voc, R becomes important (Erickson *et al.* 2001).

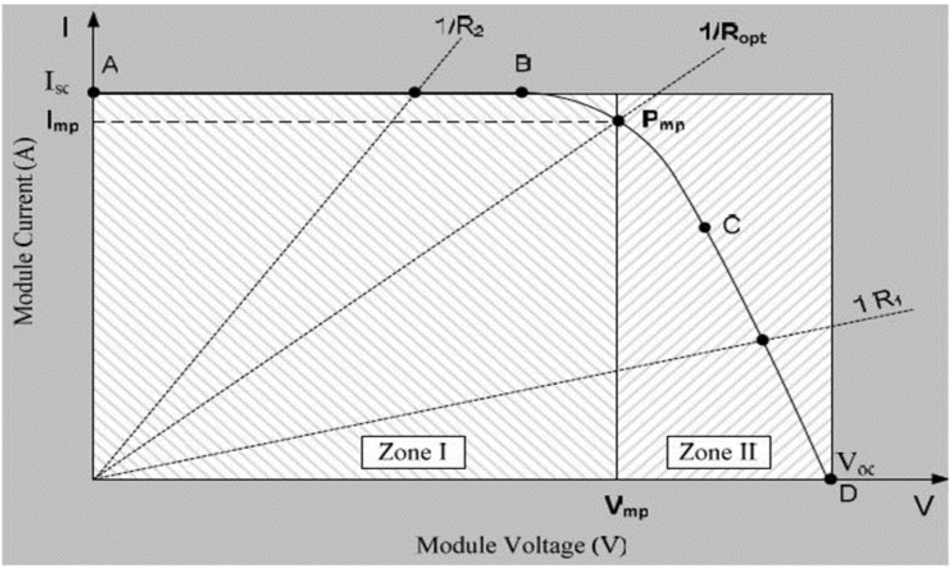


Figure 3.18 Monitoring the PV module's maximum power point (Erickson *et al.* 2001)

3.6 Determining the Optimal Transformer Topology for Tracking the Maximum Power Point

In this portion, we examine converter topologies based on their performance and appropriateness for MPPT in the necessary system.

3.6.1 Buck converter

The ideal buck converter connectsI_g,I_o , V_g and V_o priested in the Equations (3.10) and (3.11).

$$V_o = V_g D \tag{3.10}$$

$$I_o = I_g D \tag{3.11}$$

The steady-state duty cycle D. By using Ohm's law, calculate the converter's dc R load presented in Equation (3.12).

$$R' = \frac{R_L}{D^2} \tag{3.12}$$

To increase the source's workload, adjust 0 to D1. For the buck converter the beginning load must be smaller than the PV module's maximum power point current in order to draw the most electricity possible.

3.6.2 Converter boost

Equations (3.13) and (3.14) present the average boost converter output, input, and current values after optimization:

$$V_o = V_g/(1 - D) \tag{3.13}$$

$$I_o = I_g(1 - D) \tag{3.14}$$

The load resistance R' on the input side may be stated as Equation (3.15):

$$R' = R(1 - D)^2 \tag{3.15}$$

Adjusting D between 0 and 1 reduces the source's load.

3.6.3 Boost converter, buck

Optimized buck-boost converter output, input, and current averages are (Mohan *et al.* 2007) as in Equations (3.16) and (3.17).

$$V_o = V_g\left(\frac{D}{1-D}\right) \tag{3.16}$$

$$I_o = I_g\left(\frac{D}{1-D}\right) \tag{3.17}$$

The analogous expression for R' is present in Equation (3.18):

$$R' = R\left(\frac{1-D}{D}\right)^2 \tag{3.18}$$

By altering D, the source's apparent load may be boosted or lessened. The buck-boost converter may work in Zone I or II. According to the study, the optimized buck-boost converter is superior than the other two.

Figure 3.19 shows a buck-boost circuit with Q, T, L, and C. Modelling must include non-ideal system aspects. Here, an ideal inductor L is series-coupled with a resistance RL. Next, we model RC in series with a perfect capacitor; RL and RC may be used to measure inductor and capacitor power loss. Forward voltage drop (VT) is measured in volts, whereas transistor on-site resistance (Rt) is in ohms. The converter has three modes. (Mohan *et al.* 2007) Describes each mode's state space.

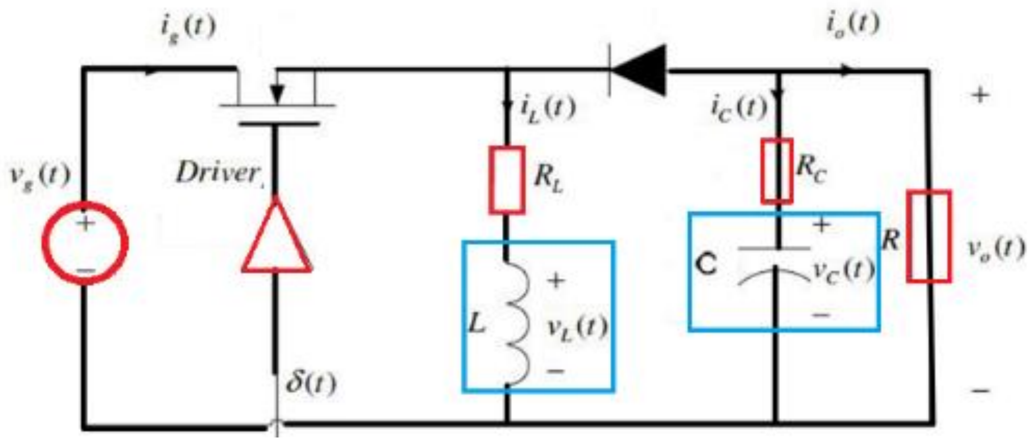


Figure 3.19 A circuit for buck-boost conversion

The converter is modeled by averaged converter theory as a linear time-invariant system. This model ignores the conversion's switching dynamics. Due to this, the state space model is averaged, providing the conventional converter model.

The converter's input fluctuates slower than the switching frequency, therefore this transition only happens at intrinsic frequencies. The converter operates differently Whether the transistor is on or off or when there is no current to the inductor. During non-switching times, converters may transition between time-invariant periods. The converter is thus a dynamic system model. Using this knowledge, a linear continuous-time time-invariant system may be estimated for this time-varying system (Middlebrook and Slobodan 1976), determine the median. Most models are nonlinear and time invariant; hence the duty cycle control signal is *d(t)*. (Modabbernia *et al.* 2013) describes an averaged converter state space model.

3.7 Batteries

Furthermost photovoltaic (PV) need a battery to generate power at night or when cloudy. During darkness, a PV system cannot provide enough power. Product strain and battery availability determine battery size and type. Batteries are generally stored in cooler, well-ventilated areas. Load and product availability influence battery type and size. Batteries are kept in just above-freezing, well-ventilated places. Batteries should be used to store extra power or in low-power scenarios. Batteries can store extra energy for usage during low solar irradiance. Unreliable PV output may need batteries. The term "qmax" refers to the maximum amount of ampere hours (Ah) a battery can produce under specific conditions. The ratio of the quantity of charge lost from a battery during discharge to the amount needed to recharge it is a battery's efficiency (SOC) charging rate, and discharging rate all affect battery life and efficiency Equation (3.19).

$$SOC = \frac{q}{q_{max}} \tag{3.19}$$

SOC levels are 0-1 If the SOC number is one, If the battery shows a charge of 0, it is dead. The battery's lifetime and charging/discharging technique are other necessary. The battery's charge (or discharge) regime defines the relationship between its nominal capacity and charging current (or discharged). To determine a battery's usual lifespan, we may look at how many times it can be charged and drained before losing 80% of its original capacity Equation (3.20) (Lorenzo 1994), say after a 40-hour discharge at 5 A and 200 Ah. As shown in Figure 3.20.

$$V = E - I * R_o \tag{3.20}$$

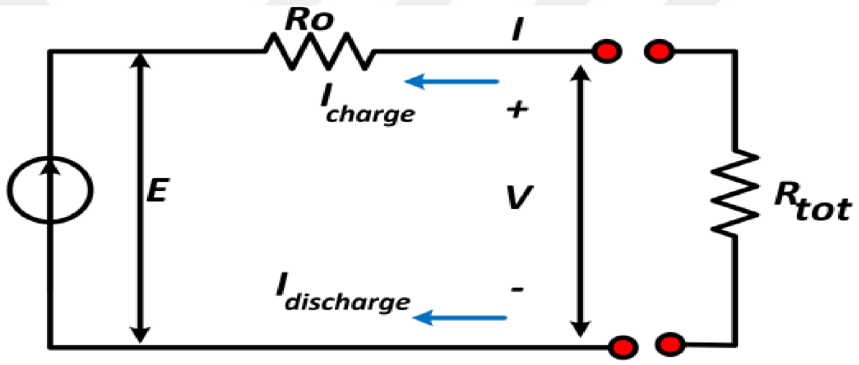


Figure 3.20 Schematic diagram of a battery

3.8 Outline to Fuzzy Logic

Focusing on AI thinking systems (AI), Machine applications aim to closely simulate human cognitive processes and decision-making skills. If binary data cannot be utilized, fuzzy logic techniques are extensively employed. Using ambiguous terminology to describe temperature or age isn't beneficial to the reader. "It's 90 years old" and "It's 70 degrees" are facts. Fuzzy logic transforms inaccurate statements such as "she's pretty" or "she's old" into more specific logical concepts. A PLC with fuzzy logic may indicate the temperature range and the link between cold and hot if we were talking about how chilly it was. Knowing the cold-to-hot ratio helps determine that "warm" is between the two extremes. In binary logic, 'cold' denotes logic 1, while 'hot' denotes the other value (here denoted by logic 0). Figure 3.21 (Aneka 2008) shows that "warm" is meaningless.

Fuzzy logic, unlike binary logic, depicts values on the boundary between two categories. Fuzzy logic produces a range of data by assigning 1 and 0. values (the lowest degree). (Minimum) In Figure 2a, temperatures below 70 degrees Fahrenheit are given a value of 1 for "cold air." "Hot" temperatures are above 80°F, while "cold" temperatures are below 60°F. "Cool" temperatures are 60 to 80 degrees. Figure 2b depicts "cold" temperatures in another manner.

Dashed line indicates when it's no longer cold. Half cool and half chilly represents 650 F in fuzzy logic. This threshold indicates coolness. Fuzzy logic defines "cold" as temperatures below 600 Fahrenheit.

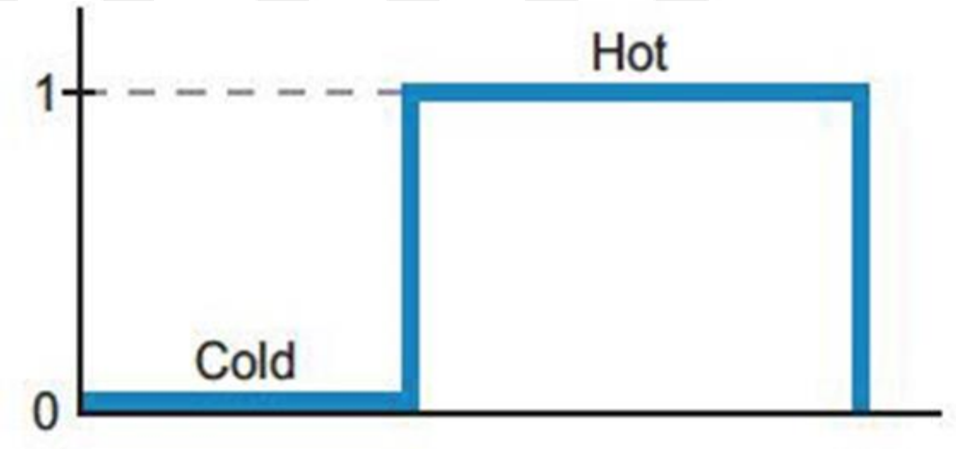


Figure 3.21 A discrete temperature value represented in binary logic (Aneka 2008)

Real-world situations may benefit from fuzzy logic. It's perfect here. Fuzzy logic temperature approach may assist you pick weather-appropriate clothes. Temperature "input" and range affect what to wear. As shown in Figure 3.21, a shirt with short sleeves and a light fabric may be suitable around 70 degrees Fahrenheit, while a shirt with long sleeves and a heavy fabric is better at 65 degrees or lower. Before wearing a sweater over a shirt, consider the temperature and coolness rating. If the input has a 25 percent coolness rating and a 75 percent coldness rating (for example, 62 degrees Fahrenheit), a sweater may be the best option. An infinite number of inputs may alter a fuzzy system's output (e.g., temperature, precipitation, etc.). The fuzzy logic network's knowledge base must be considered for every output option. Fuzzy logic needs data to "think." The fuzzy system stores information from the procedure expert. If a steam heating system's temperature rises, the "expert" in control may urge to "slightly" turn the steam valve clockwise. May he realize the mysterious system "slightly" as an exact degree of turn (8 degrees), reducing traffic by 4%. "Somewhat" is a fuzzy descriptor since it lacks a single, objective value

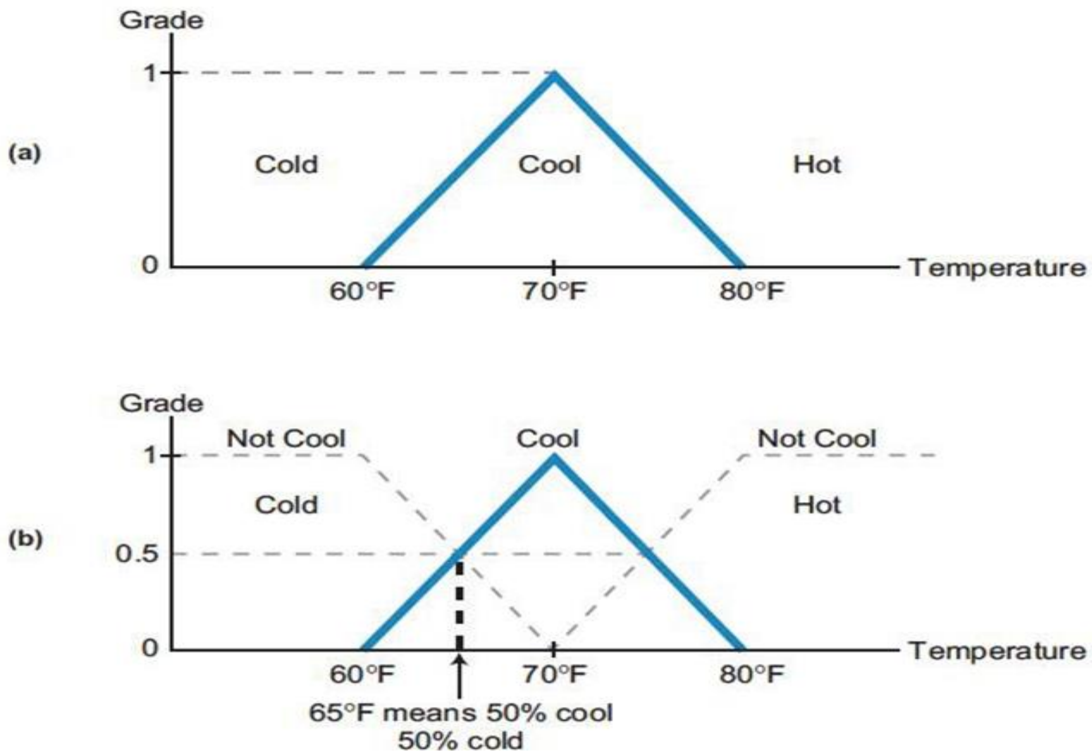


Figure 3.22 (a) The temperature range of cool air ,and dotted lines (b) not cool air temperature range

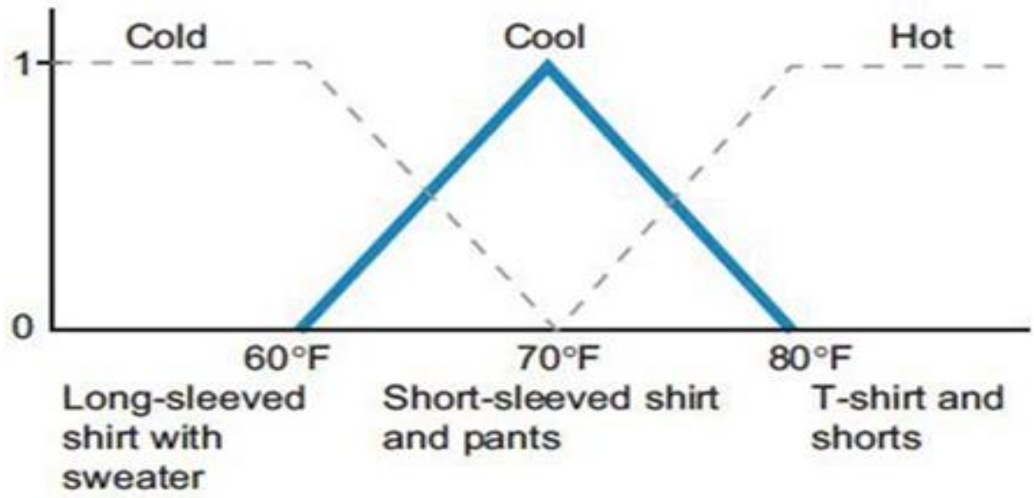


Figure 3.23 Temperature-driven clothing options shown on a fuzzy-logic temperature-based clothing choices graph (Aneka 2008)

An expert's inputs are combined with desired outputs using fuzzy logic. In reality, fuzzy logic's applicability is dictated by its four components: Figures 3.23 show the overall design of fuzzy logic systems, and the next sections describe each variety.

1. Rule-based systems use if-then statements as illustrated in Figure 3.21. Fuzzy logic is used to quantify expert opinion on optimum control, like in the rules we just discussed.
2. An inference technique that replicates how experts make judgments by first "comprehending" information and then utilizing that knowledge to regulate input components.
3. Inputs are processed using a fuzzy logic interface to give information for rule formulation and application (component #2).
4. A direct decompilation interface "feeds" the algorithm results of inference (part 2).

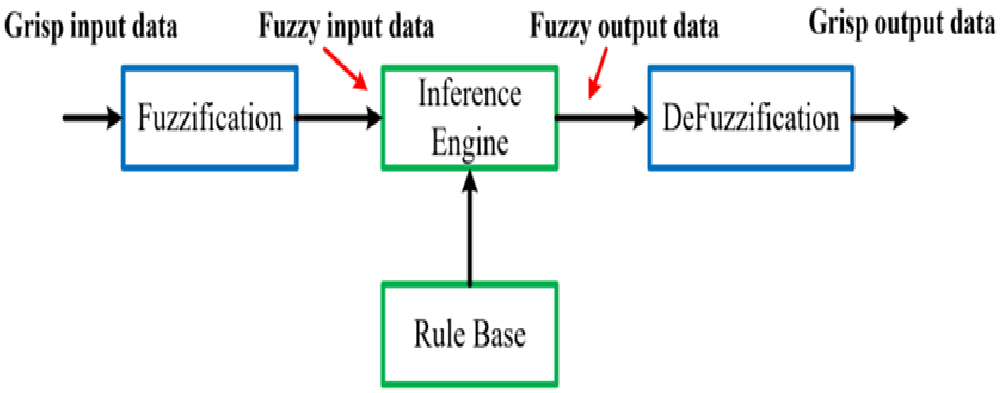


Figure 3.24 Fuzzy logical system structure

3.8.1 Fuzzification

Obfuscation blurs well-defined values. To achieve ambiguity, identify language components and phrases. In this technique, natural language words and/or phrases are input and output variables. Before starting, we breakdown a linguistic variable into phrases. Consider central air conditioning. "Temperature" (or "T") specifies the area's temperature. The example in (Zadeh 1963) shows how membership functions may transform "crisp" (non-fuzzy) input data into fuzzy linguistic ideas.

3.8.2 Membership functions

This procedure values inputs that may be functional overlaps. The membership function affects the final outcome. Configuration, or "form," is an important membership function defining component. Figure 3.25 shows membership functions, definitions, and graphs.

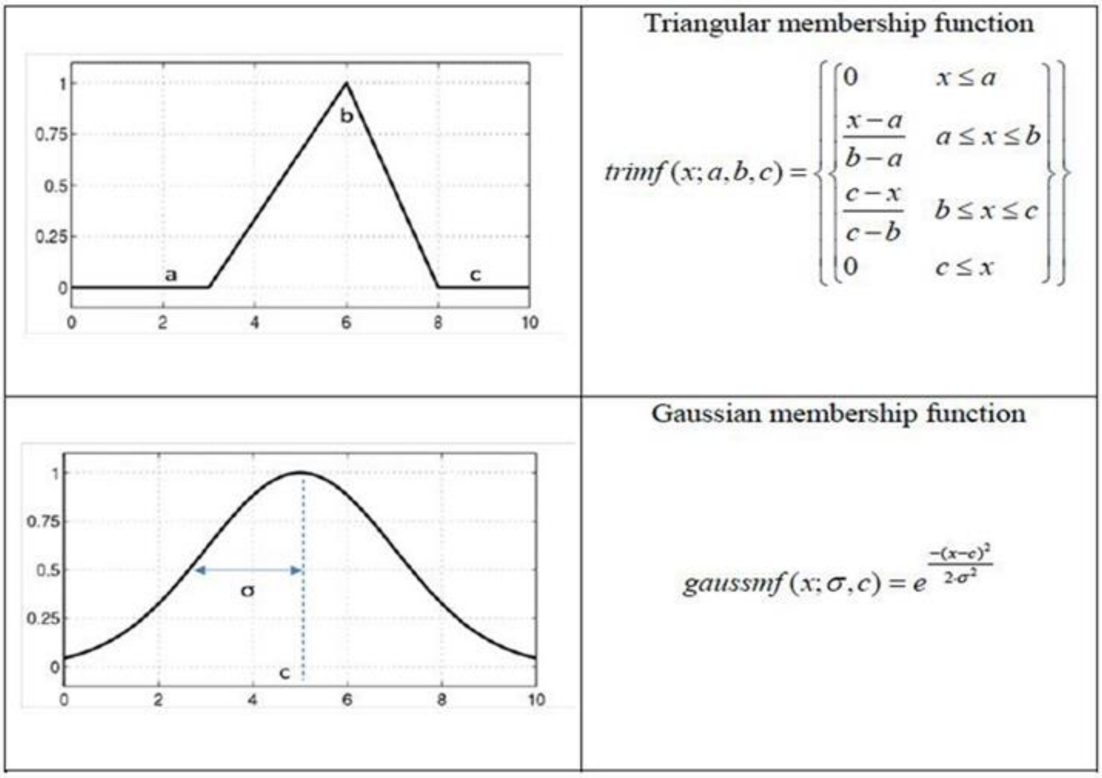


Figure 3.25 Different types of membership function (Zadeh 1963)

It may distinguish between discrete and continuous set items. Continuous form membership function may be a mathematical function or programming. Discrete is usually preferable over continuous.

Since triangle membership functions are all straight-line segments, fuzzy control makes building them easy. Gaussian membership function produces smooth, continuous output.

3.8.3 Fuzzy rules

We briefly discussed this. Fuzzy systems help form logical inferences and connect ambiguous terms of reference. Approximation reasoning is used in fuzzy logic systems. Fuzzy sets and fuzzy operators are "If-Then" rule statements used in fuzzy logic. "If-then" conditional statements are fuzzy logic's building blocks. trademark fuzzy logic as discussed; fuzzy logic systems use rule bases to manage output variables. Fuzzy systems aim to draw logical conclusions and connect fuzzy jurisdictions. Fuzzy logic systems call this approximate logic. Fuzzy sets and fuzzy operators serve as nouns and verbs in fuzzy logic. These are the elements that make up "If-Then" statements in fuzzy logic.

First, fuzzy logic control gathers input data from sensors. The control system "eats" this data. "Fuzzification" turns discrete input variable values into a wide range. This modifies input variables. Last, control instructions "defuzzify" the output data (Zadeh 1963).

3.8.4 Inference engine

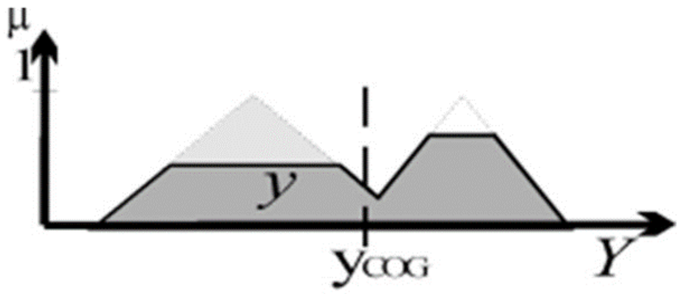
It means deducing new knowledge from existing facts or evidence. "Inference" describes the process used in fuzzy logic control systems to integrate all the results of fuzzy rules. This helps determine the end outcome. Mamdani and Takagi-Sugeno-Kang are popular inference methods. Mamdani method invented by Ibrahim H. Mamdani in 1975. Lofti Zadeh 's (1936) research on fuzzy algorithms influenced Mamdani's (1975) control technique. In (Zedeh 1936) technique, Rc handles fuzzy implication and max-min generates composition. Let's suppose the form below follows a rule for this case.

IF input x = A AND input y = B THEN output z = C

3.8.5 Defuzzification

This refines confusing inference engine findings (crisp). Determining which defuzzification approach is suitable for a given application is more art than science (Figure 3.26).

The Centroid of Gravity (COG) approach has supplanted prior methods due to its simplicity. COG is



$$y_{COG} = \frac{\int_{y \in Y} y \mu_y(y) dy}{\int_{y \in Y} \mu_y(y) dy}$$

Figure 3.26 Defuzzification method of center of gravity method (COG)

4. SIMULINK MODEL DESGIN SOLAR PV BASED ON MPPT

4.1 Energy Management System

Figure 4.1 provides a high-level overview of the whole MPPT solar PV controller model created in the MATLAB/Simulink environment. It is made up of a battery, a micro grid, an MPPT charge control block, a solar PV array, and a DC-DC converter.

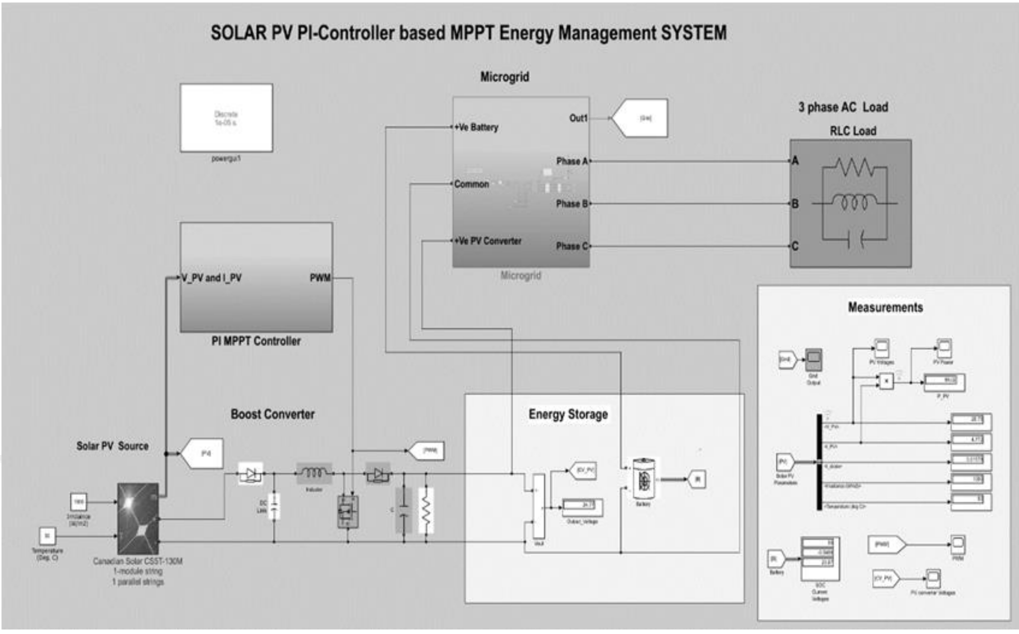


Figure 4.1 Complete simulink model design solar PV based on MPPT

4.1.1 Solar PV boost converter unit

Figure 4.2 present the solar PV source and the boost converter unit. A grid-tied inverter or batteries can be powered by using the boost converter as a power transfer medium, solar panels. In a boost converter, the energy absorption and injection operation is carried out by a combination of four separate components: an inductor, an electrical switch, a diode, and an output capacitor.

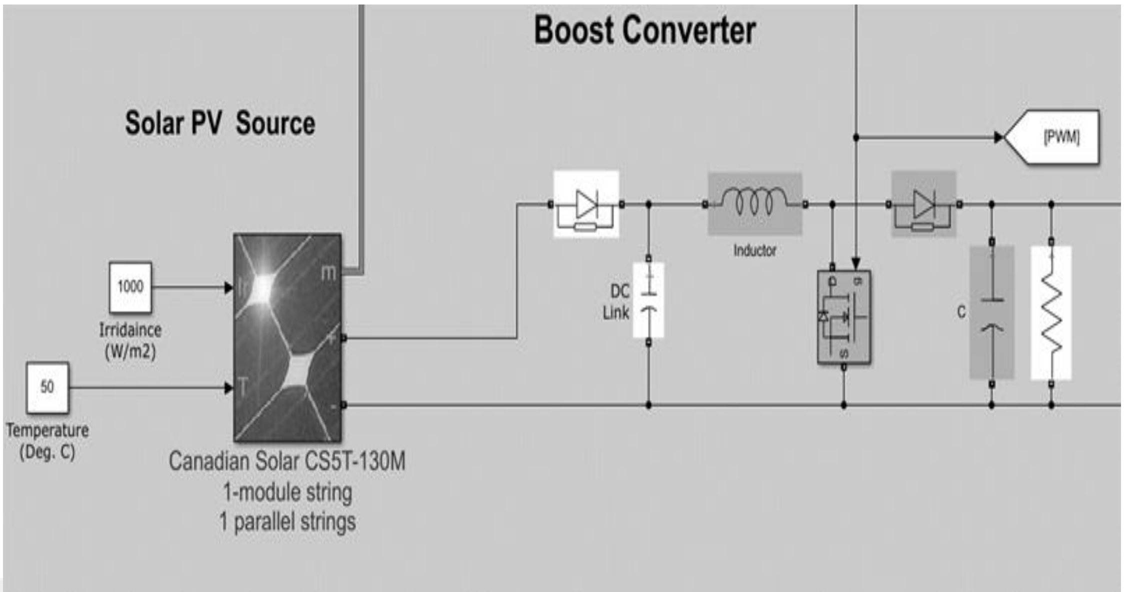


Figure 4.2 Solar PV source and boost converter

4.1.2 Solar energy storae section

A crucial aspect of a photovoltaic system is that electricity is only produced when there is sunlight. Since only a few types of systems, such as those that power cooling fans, can precisely match the amount of sunlight available with the load, storage is frequently required for systems where photovoltaics serves as the only source of generation. In hybrid or grid-connected systems, batteries may usefully be included for load balancing or power conditioning even when they are not strictly essential.

The most common type of storage is chemical storage, which takes the shape of a battery, however other types of storage can be employed in certain situations. A flywheel or capacitor can be used for small, short-term storage, or storage in the form of water or ice can be used for specialized, single-purpose photovoltaic systems like refrigeration or water pumping. The energy storage device for our simulation system is seen in Figure 4.3.

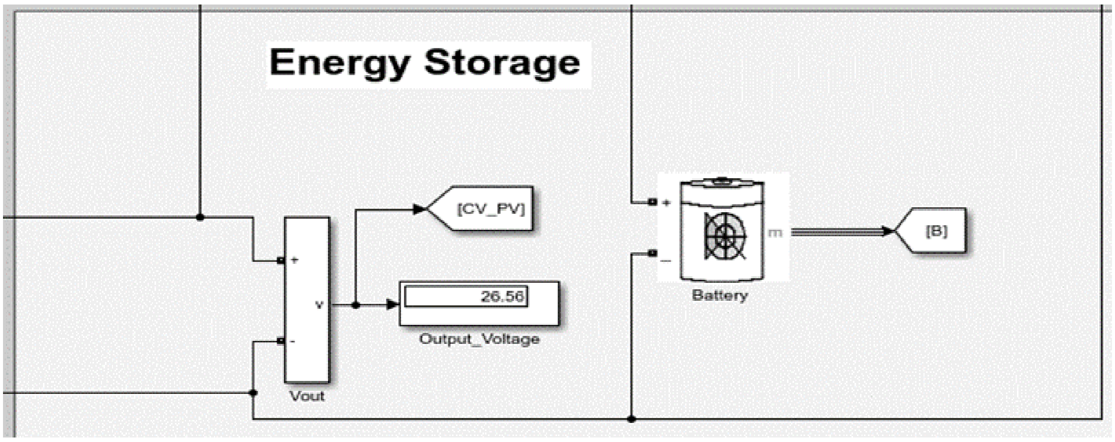


Figure 4.3 Energy storage unit for the simulation system

4.1.3 Microgrid and three-phase DC to AC inverter block

A micro grid in Figure 4.4 is a tiny power grid that can run by itself or in cooperation with other tiny power grids. Distributed, dispersed, decentralized, district, or embedded energy generation are terms used to describe the use of micro grids.

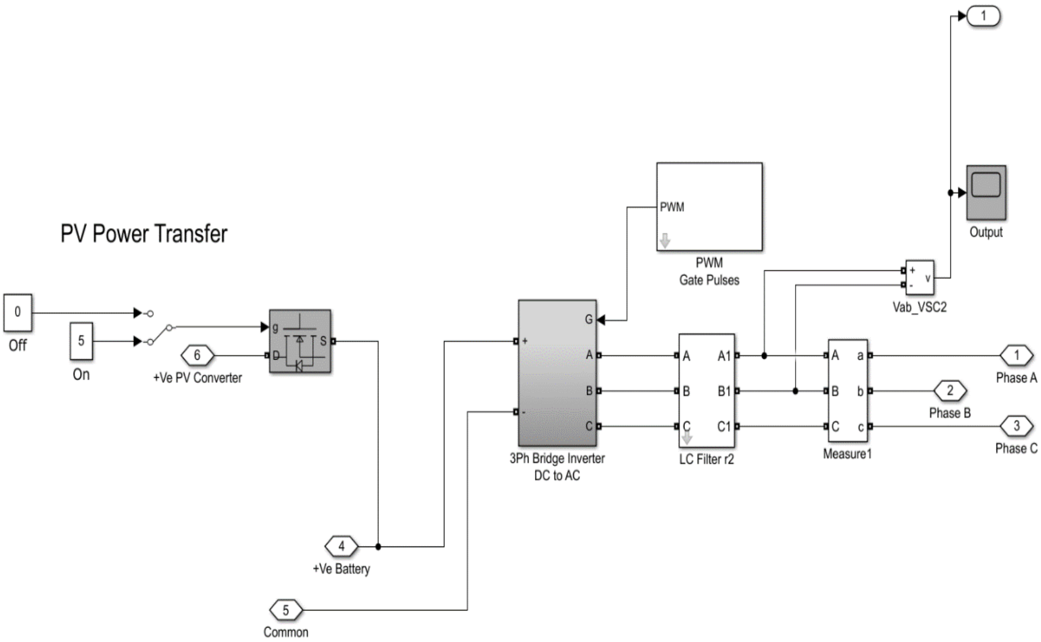


Figure 4.4 Microgrid block daigram

An inverter produces a three-phase AC output from a DC input. A three-phase AC supply is produced by delaying its three arms at an angle of 120°, as seen in Figure 4.5. The ratio of each inverter switch is 50%, and switching takes place every T/6-time T 60° angle interval.

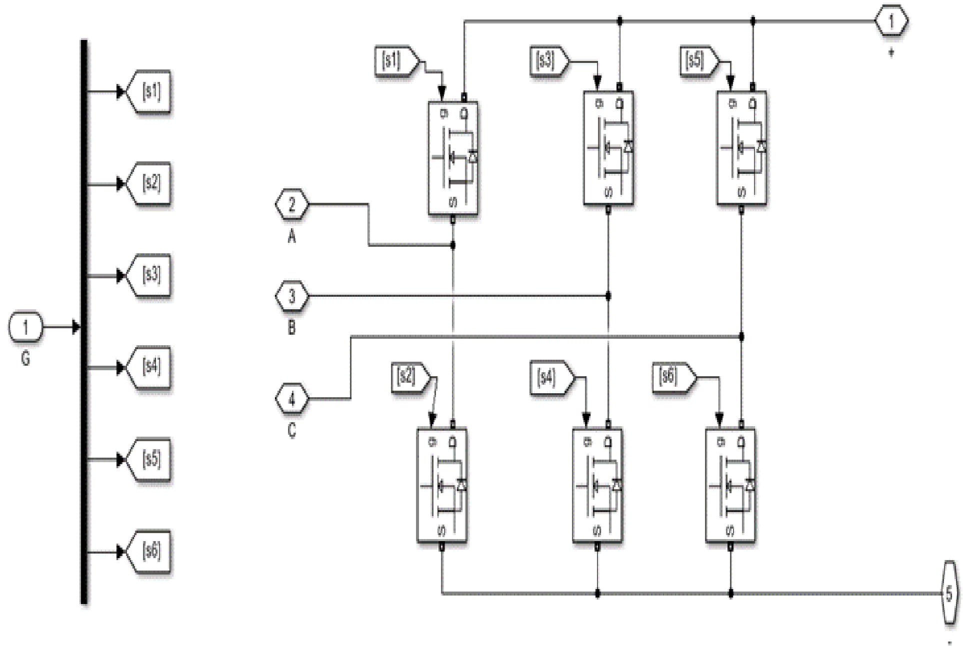


Figure 4.5 Three-phase inverter unit for the simulation system

4.2 Measurement Section

Figure 4.6 shows the main section to display all the results of the system designed in this thesis

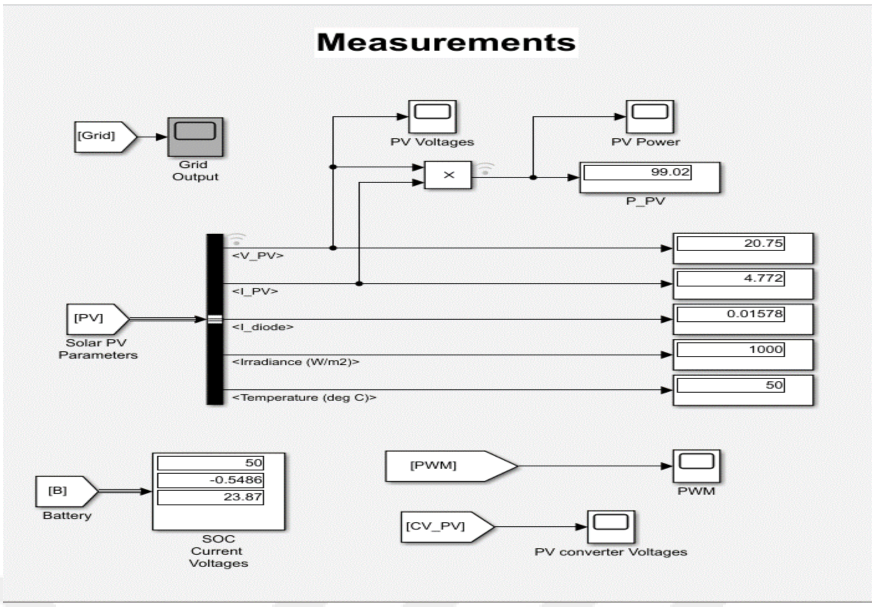


Figure 4.6 Monitoring section part in the simulation software

4.3 Types of MPPT Control Systems

4.3.1 MPPT and PI controller section

Figure 4.7 shows the MPPT and PI Controller Section and the differential change in power and voltage block diagram and the error generating block diagram are presented in Figures 4.8 and 4.9 respectively.

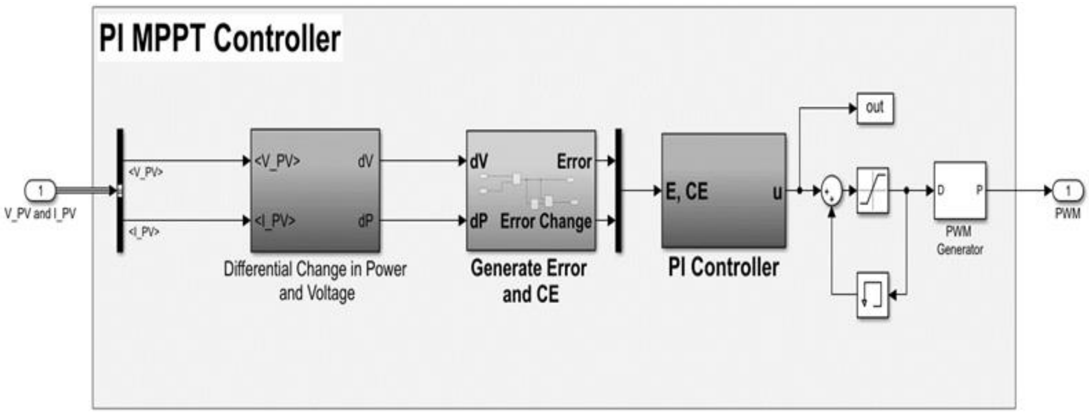


Figure 4.7 PI controller section

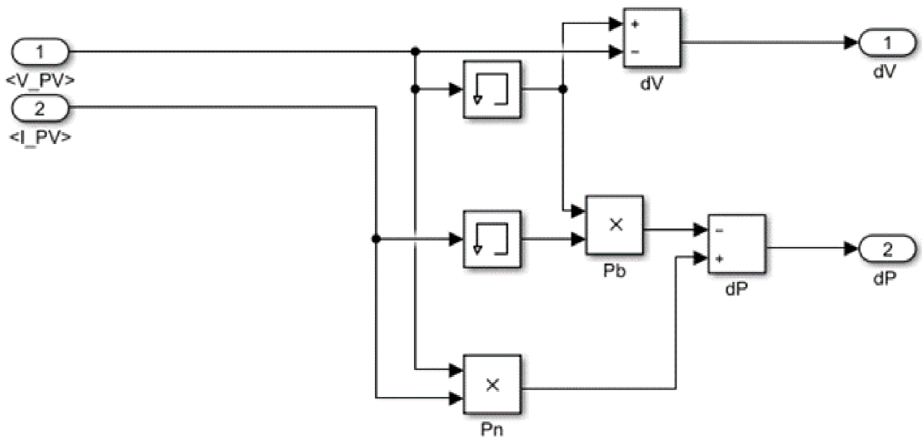


Figure 4.8 Differential change in power and voltage block diagram.

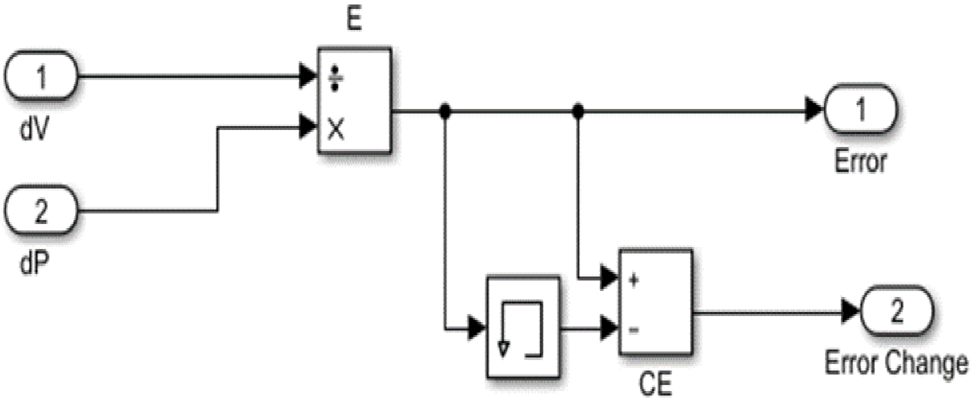


Figure 4.9 Error generating block diagram

4.3.2 MPPT and fuzzy controller section

The fuzzy logic-based Mppt controller is employed in this method to increase the voltage of the PV module (Figure 4.10). The recommended approach employs fuzzy logic-based control (FLC) to start the control command to the output buck-boost converter when there is a change in the voltage and current across the PV panel.

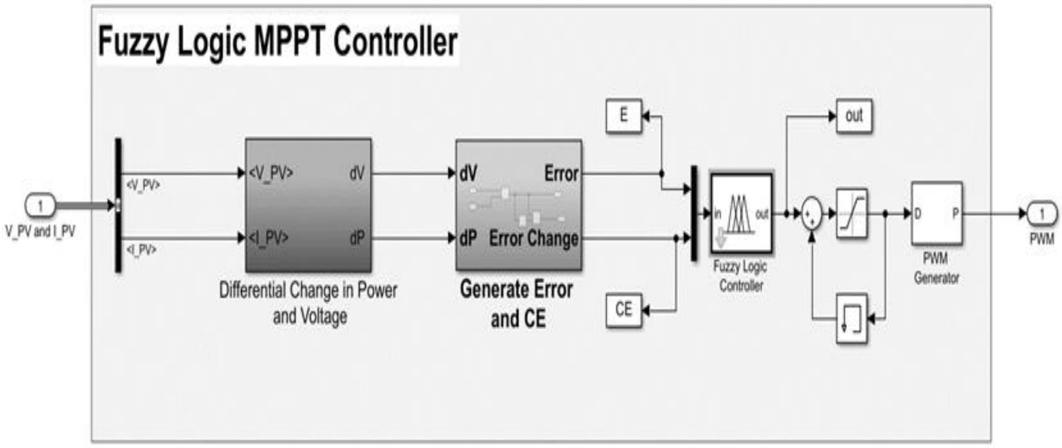


Figure 4.10 Fuzzy logic controller system block diagram

4.3.3 MPPT and ANFIS controller section

This is a proposal for an ANFIS logic-based MPPT controller to expand the PV module (Figure 4.11). When there is a change in the voltage and current across the PV panel, the suggested technique uses the ANFIS logic-based control (FLC) to begin the control command to the output buck-boost converter.command to the output buck-boost converter.

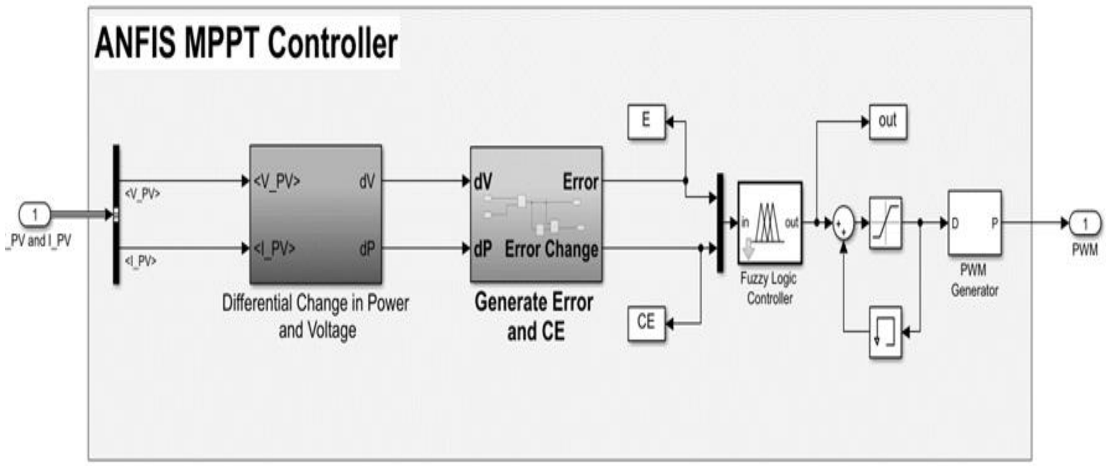


Figure 4.11 ANFIS controller system block diagram

4.4 Design of Fuzzy Logic Controller (FLC)

In MATLAB open the toolbox of the fuzzy logic by using the comment window, The fuzzy logic toolbox window will appear Figure 4.12.

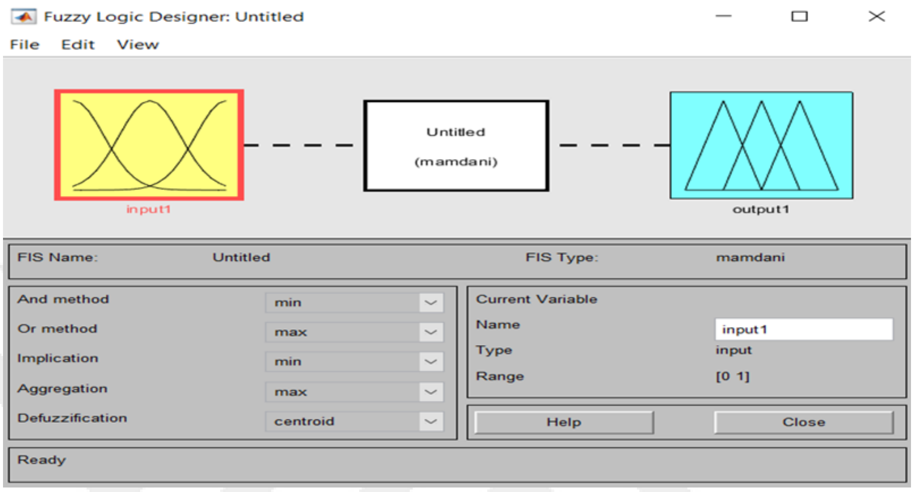


Figure 4.12 FLC toolbox window

4.5 Define the Input and Output of FLC

The Figure 4.13 present the mane window for define the input and output parameters for FLC. Voltage is the first input and energy are the second.

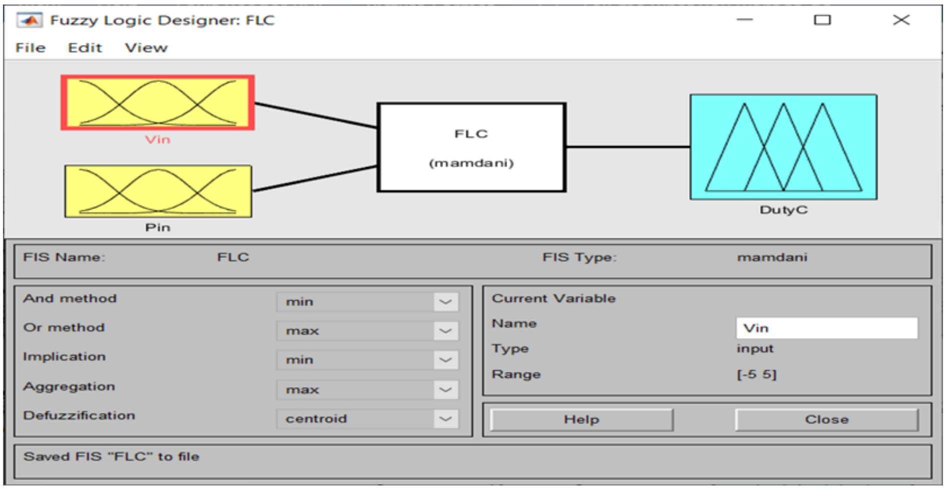


Figure 4.13 I/O of FLC window

4.5.1 Membership function assignment and input scoping 1

The Figure 4.14 present the mane window for define the range of the input 1 and relationship parameters for FLC. The first input is voltage values.

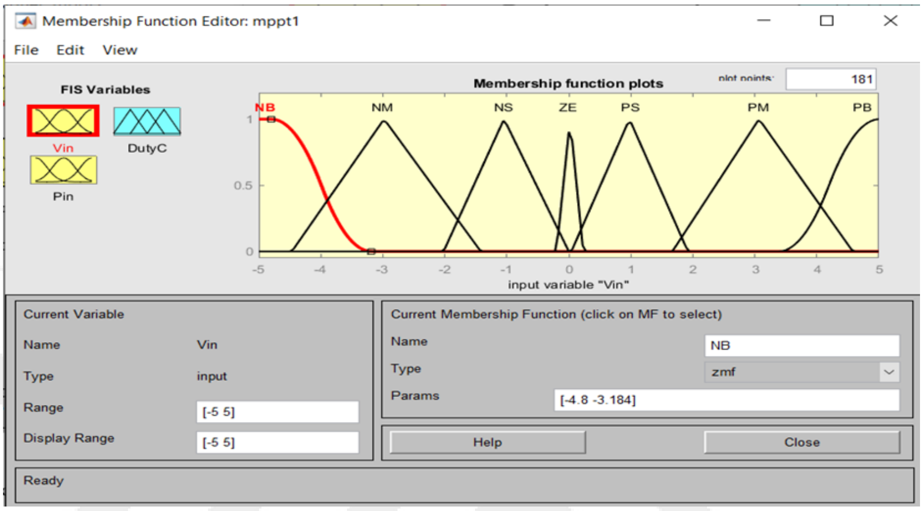


Figure 4.14 Membership entry function Vin

4.5.2 Power input membership function

The Figure 4.15 present the mane window for define the range of the input 2 and relationship parameters for FLC. The second input is power values.

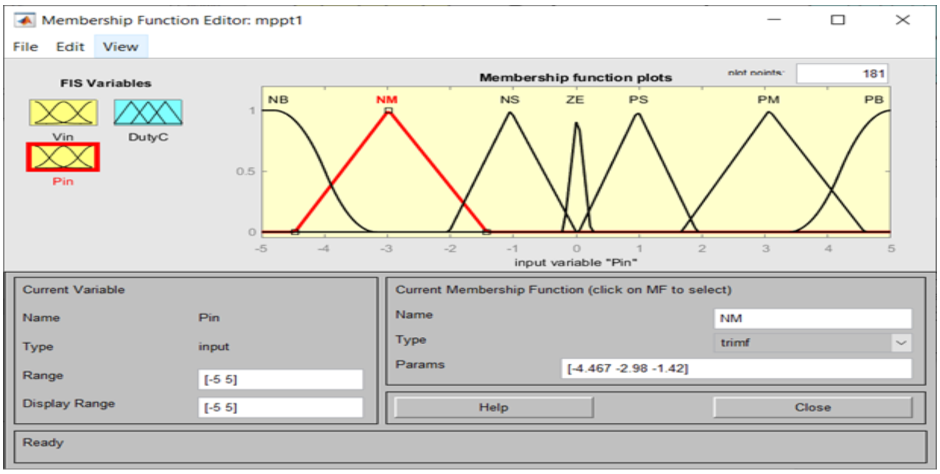


Figure 4.15 The ability to function organic

4.5.3 Service cycle output membership function

The Figure 4.16 present the mane window for define the range of the input 3 and relationship parameters for FLC. The third input is a duty cycle values.

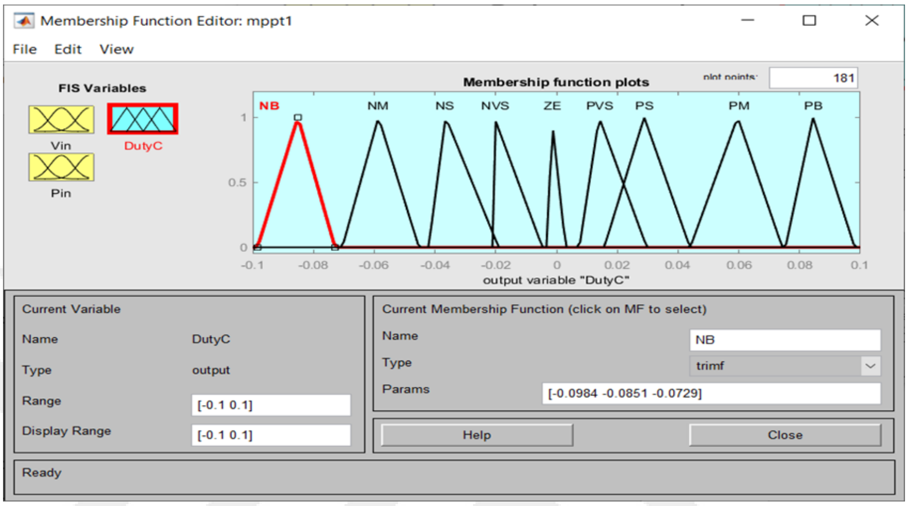


Figure 4.16 Membership function output

4.5.4 Set the rules

Figure 4.17 is shown the assign the rules of the FLC unit for the MPPT of the system

$$Rule\ No. = Mebership\ functions\ of\ first\ \frac{I}{O} * Mebership\ functions\ of\ second\ \frac{I}{O}$$

$$Number\ of\ Rules = 7 * 7 = 49$$

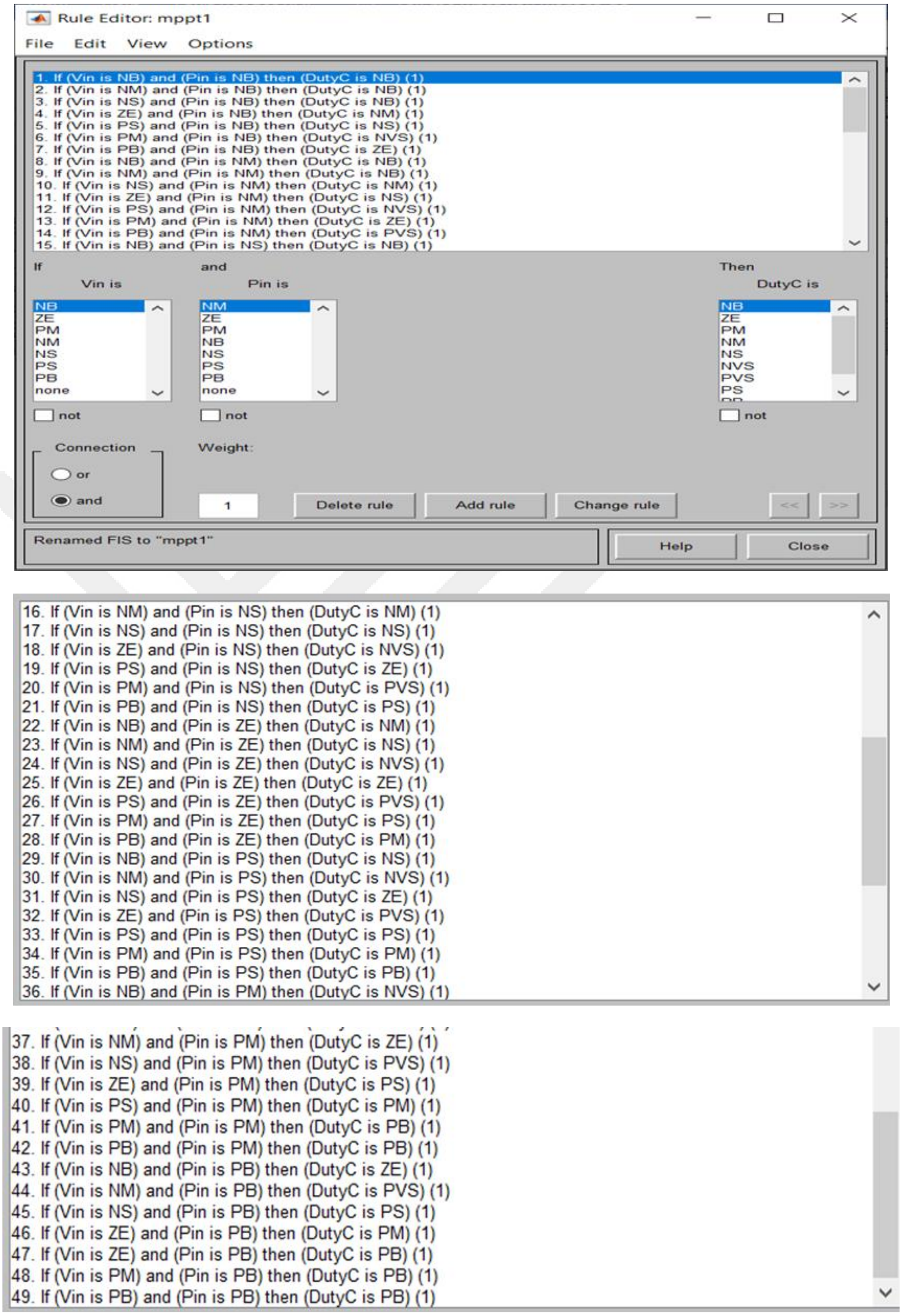


Figure 4.17 Assign the rules of the FLC unit

4.5.5 Check the validity of FLC with plots

For checking the validity of FLC with surface plots, Figure 4.19 shows the relationship between the duty cycle and Vin.

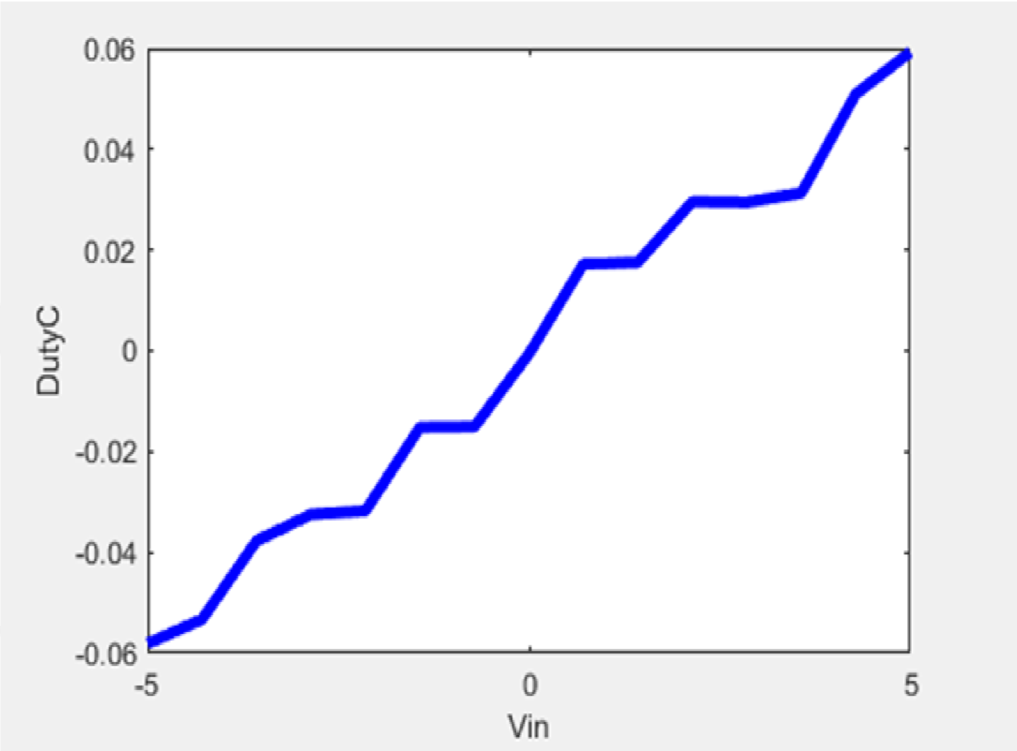


Figure 4.18 Vin and duty cycle

4.5.6 Surface plot operation cycle and access capacity

For checking the validity of FLC with surface plots, Figure 4.19 shows the relationship between the duty cycle and Pin. Figure 4.20 shows an FLC-based MPPT controller, an FLC rule viewer, and a surface viewer for triangular and trapezoidal membership functions.

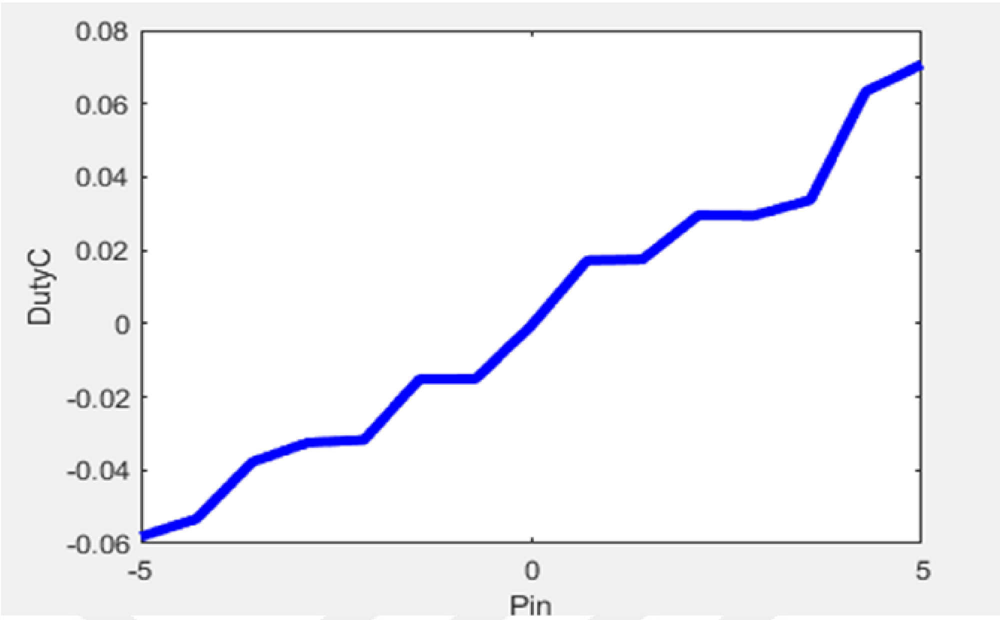


Figure 4.19 Surface widget, duty cycle and pin

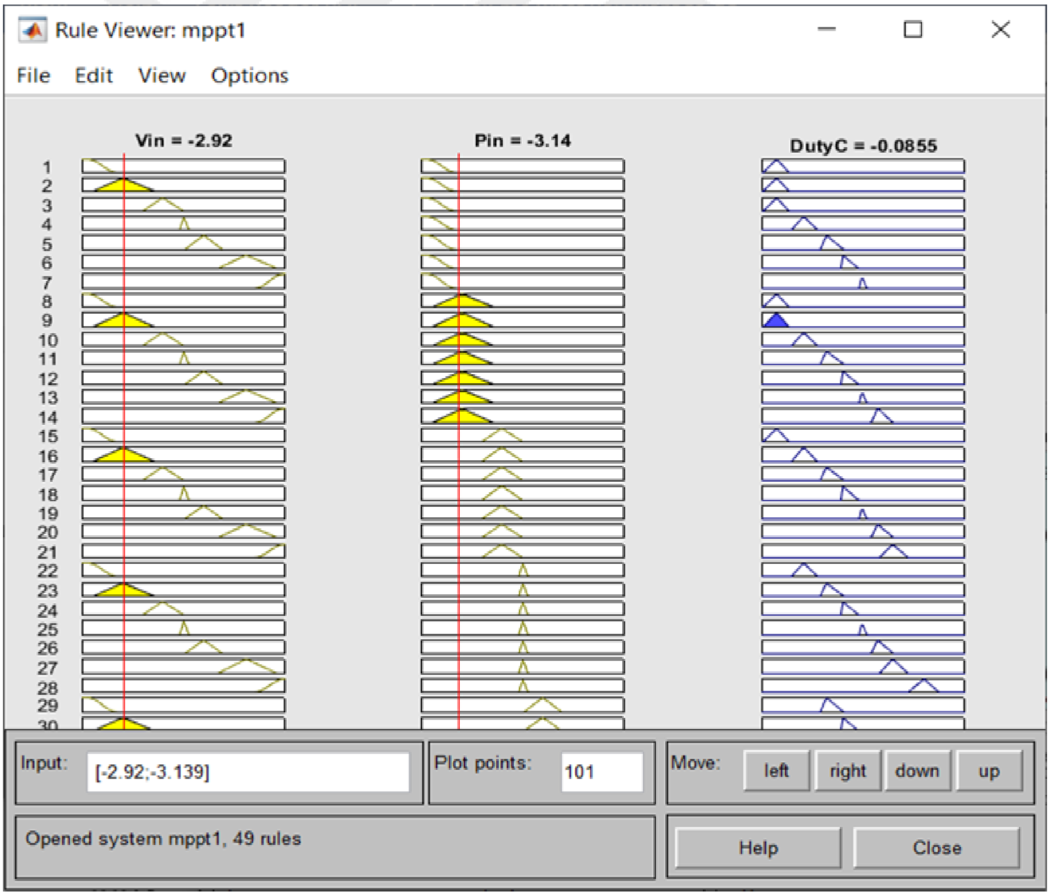


Figure 4.20 Viewer rules for FLC output monitoring

4.6 Neural Adaptive Fuzzy System Control Design

Export the input and output data for the Simulink fuzzy logic model system first.

4.6.1 MATLAB workspace

The ANFIS editor toolbox opens in MATLAB by using command window and writing anfisedit to loading the the workspace data to ANFIS editor (Figure 4.21)

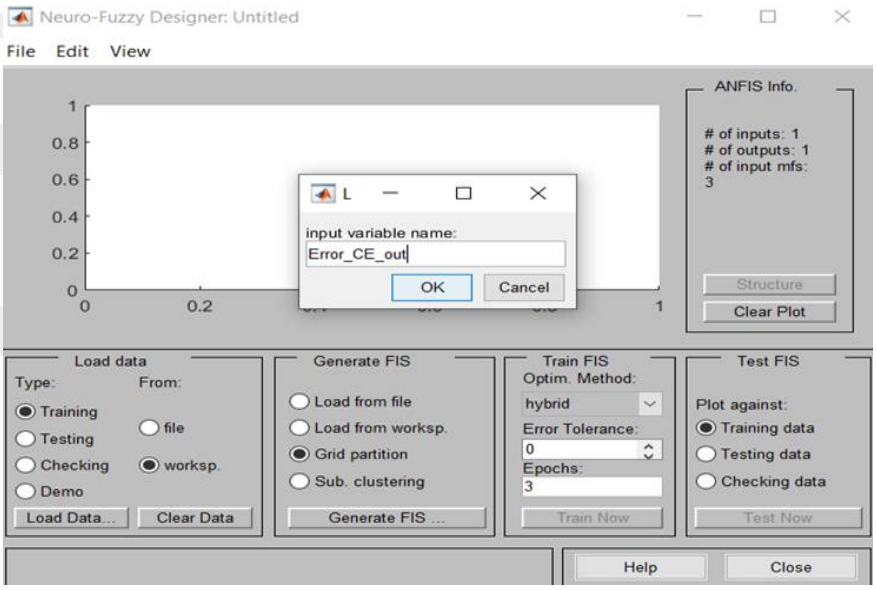


Figure 4.21 Import workspace data for the adaptive console design

The controller input data from the works space in form of error is loaded to ANFIS tool (Figure 4.22). Choose the kind of membership function and the kind of fuzzy logic membership function.

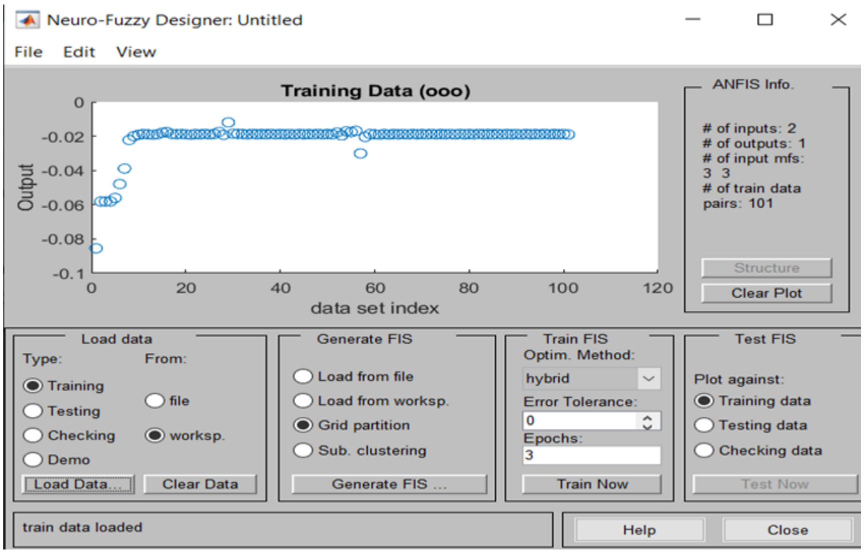


Figure 4.22 Uploaded data for ANFIS

5. TESTS AND SIMULATION-BASED RESULTS

5.1 System Simulation with a PI Controller

It is observed that the simulation of PI system delivers the battery output voltages of 23 V at state of charge of 50, and power of PV is almost 99 Watts, the voltages supplied by PV system is 20 v and current drawing through PV system is 4.7 amp, at applied solar radiation of 1000 W/m2 with solar heat up to 50°C Figure 5.1.

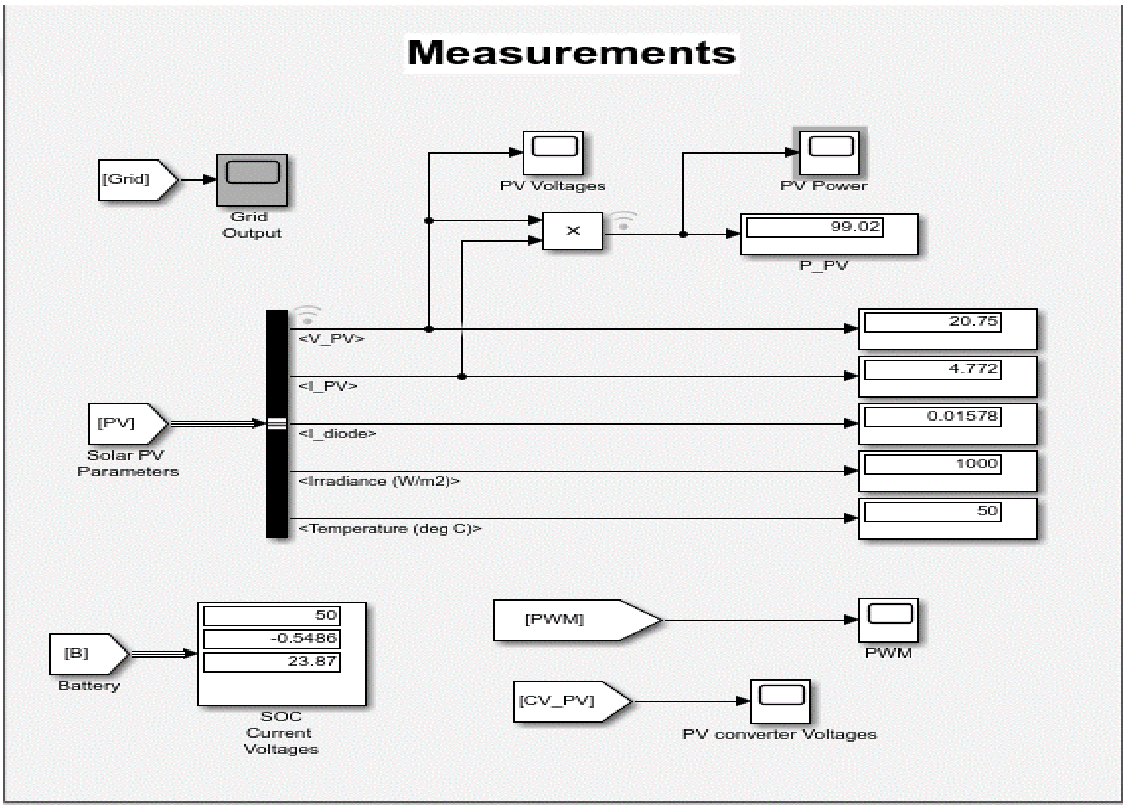


Figure 5.1 Measurements with PI controller results

5.1.1 PV Power with PI controller

The response indicates the output waveform of the solar PV system with maximum power delivered by PV system through MPPT with PI technique is shown in Figure 5.2.

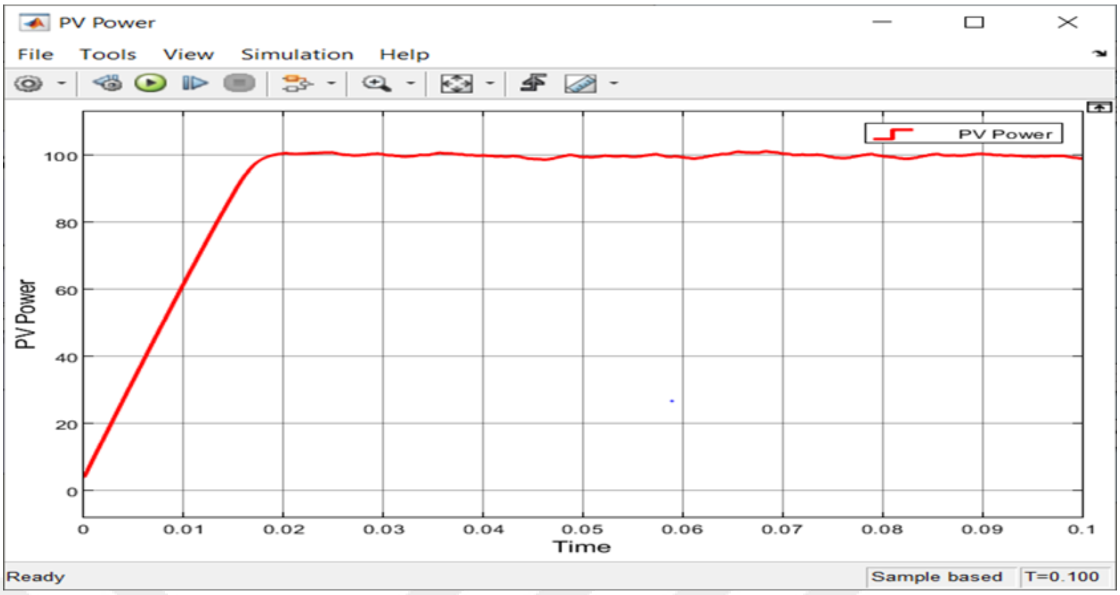


Figure 5.2 PV power with PI controller

5.1.2 PV Voltages signal

Figure 5.3 depicts the voltage waveform of a PV system along with the supplied voltages.

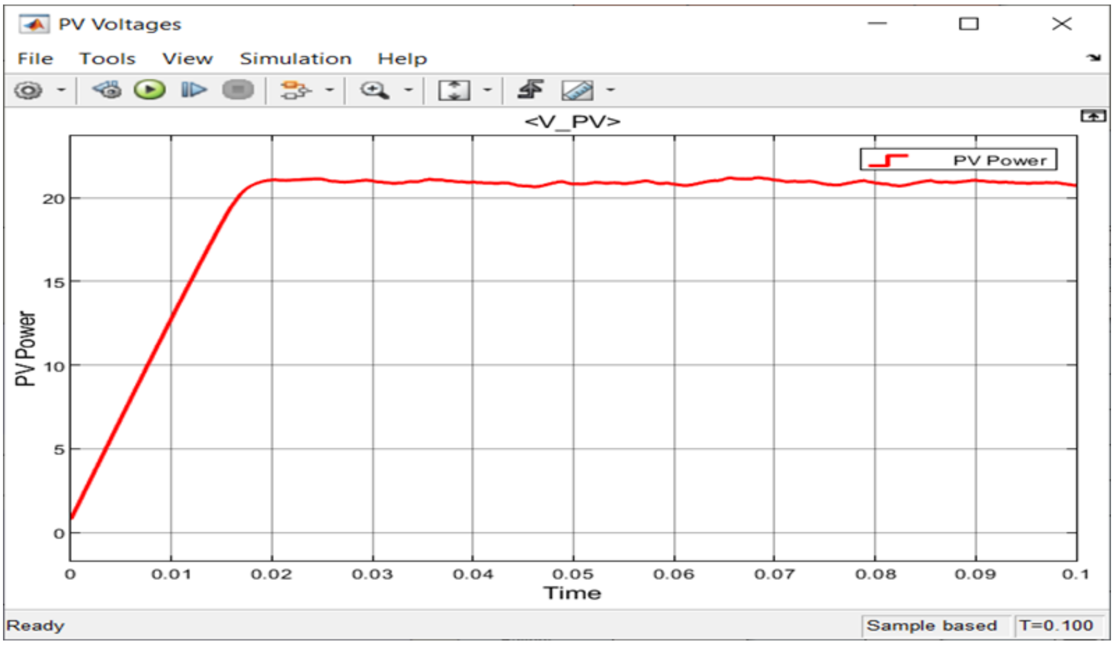


Figure 5.3 PV voltages signal

5.1.3 Grid output voltages

The grid output voltages are shown in Figure 5.4, the waveform is sinusoidal waveform but not pure.

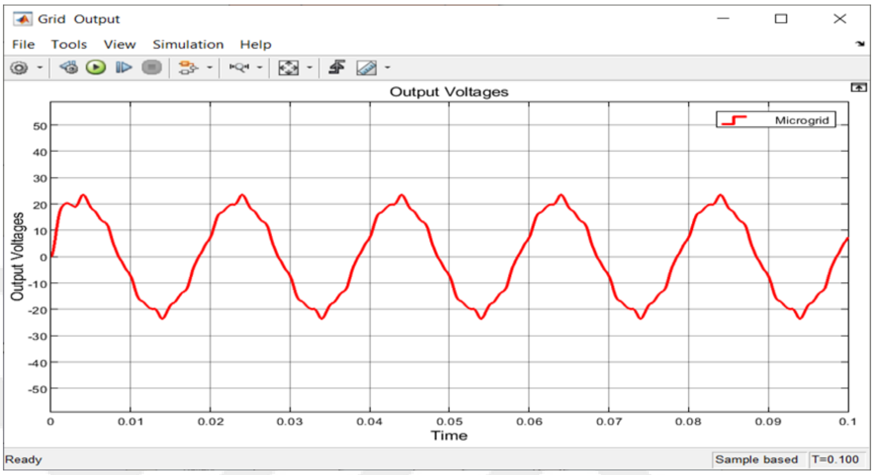


Figure 5.4 Grid output voltages

5.1.4 PV converter PWM signal

The PV converter PWM signal is shown by constant duty cycle interval in Figure 5.5. The duty cycle of PWM generator is shown as we can achieve the varying duty cycle of system.

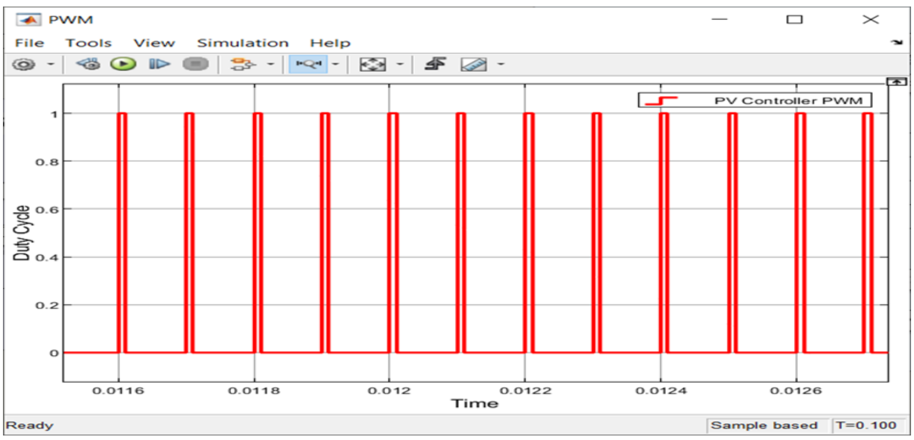


Figure 5.5 PV converter PWM signal

5.1.5 PV converter voltages with PI controlled MPPT

The output voltages of 25 v PV converter are achieved with implementation of PI controller is shown in Figure 5.6. The maximum power achieved with PI controller MPPT is 99.02.

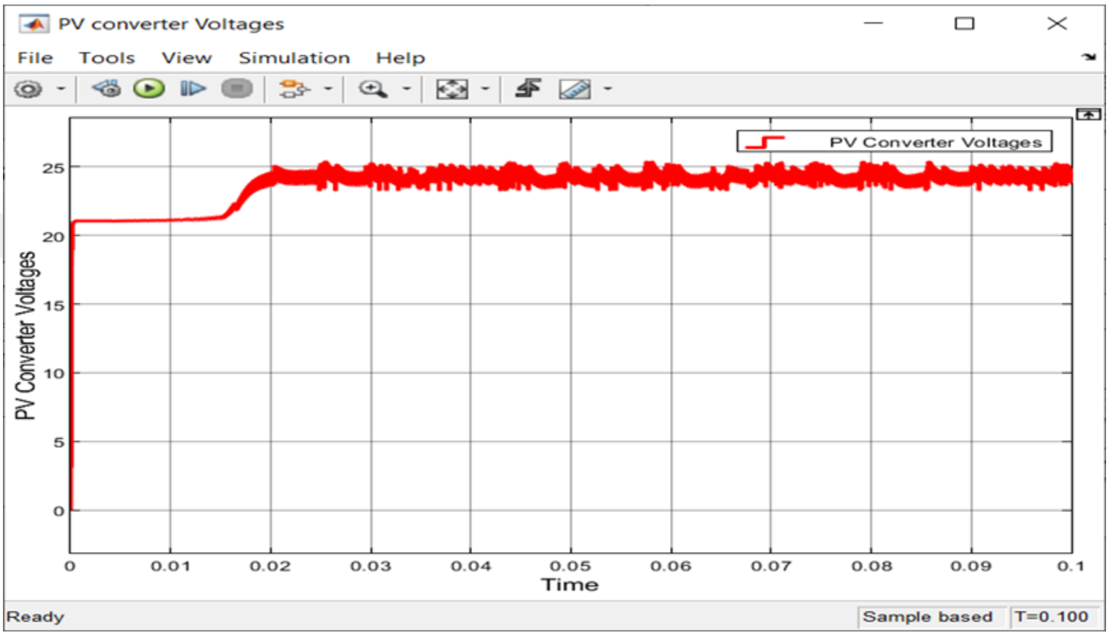


Figure 5.6 PV converter voltages with PI controlled MPPT

5.2 Results and Simulations with Fuzzy MPPT Control

It is observed that the simulation of Fuzzy system delivers the battery output voltages of 23 V at state of charge of 50, and power of PV is almost 106 Watts, the voltages supplied by PV system is 22 v and current drawing through PV system is 4.7 amp, At an applicable solar radiation of 1000 W/m2 with a solar temperature of 50°C (Figure 5.7).

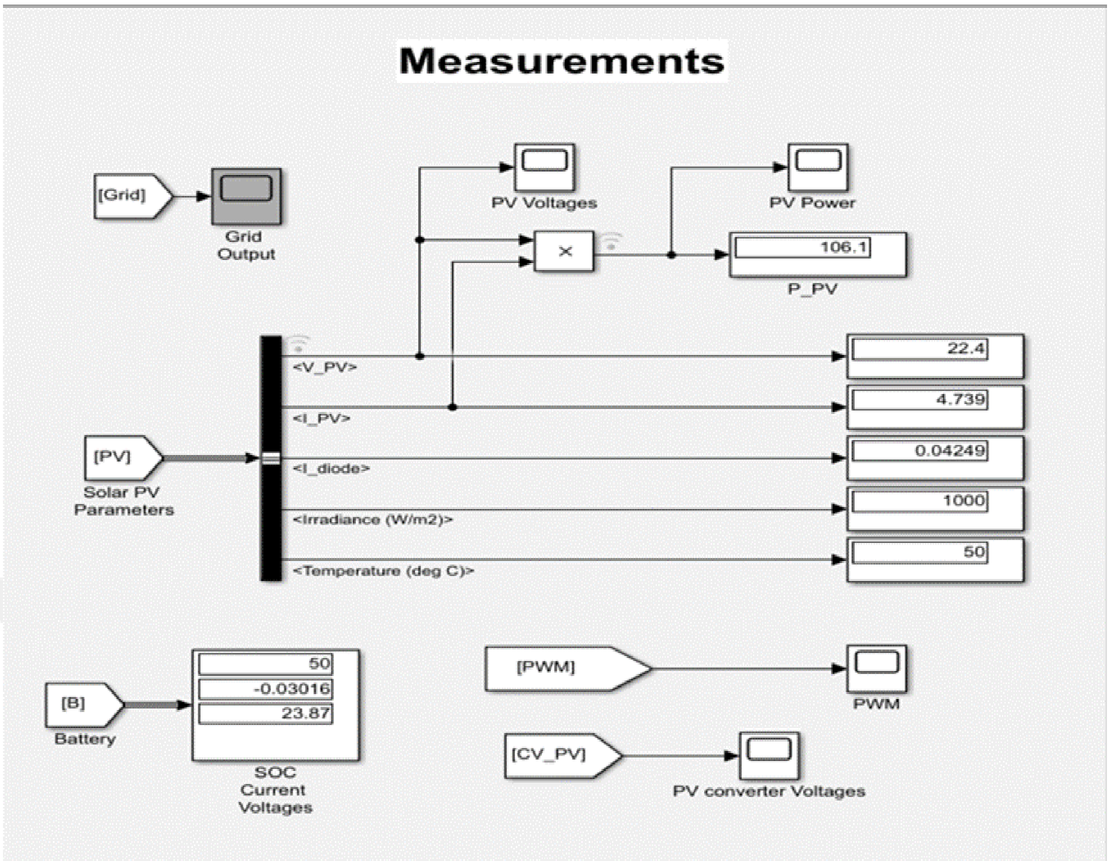


Figure 5.7 Measurements with fuzzy controller results

5.2.1 PV power response

Figure 5.8 in the answer shows the solar PV system's output waveform with the highest power supplied by the PV system utilizing MPPT with Fuzzy method.

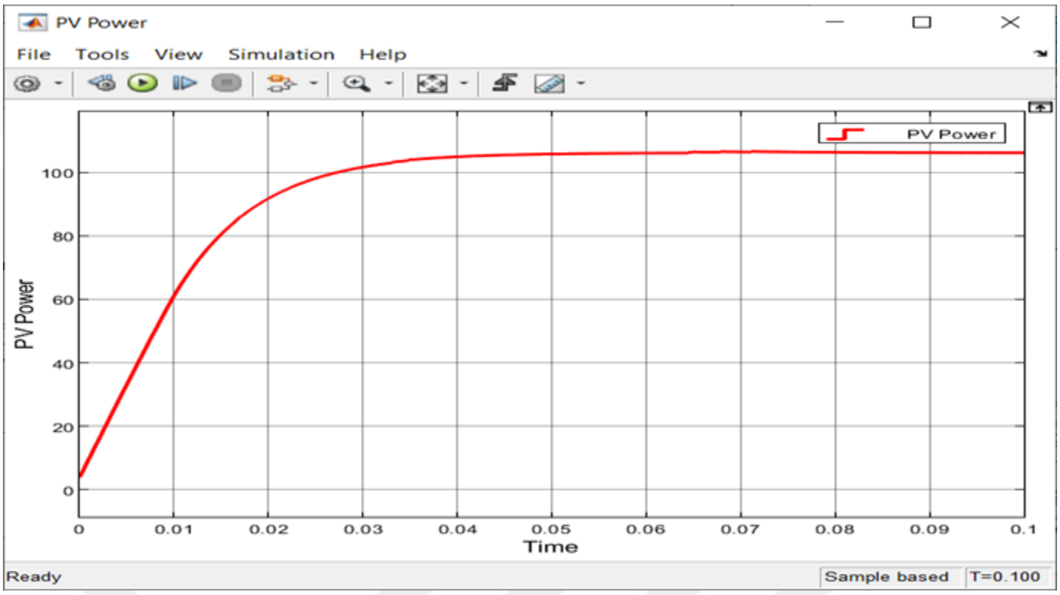


Figure 5.8 PV power with fuzzy control

5.2.2 PV voltages with fuzzy control MPPT

The voltage waveform of Figure 5.9 displays the PV system's voltage waveform. The PV converter PWM signal is shown in Figure 5.10 by constant duty cycle interval. The duty cycle of PWM generator is presented as we can achieve the varying duty cycle of system.

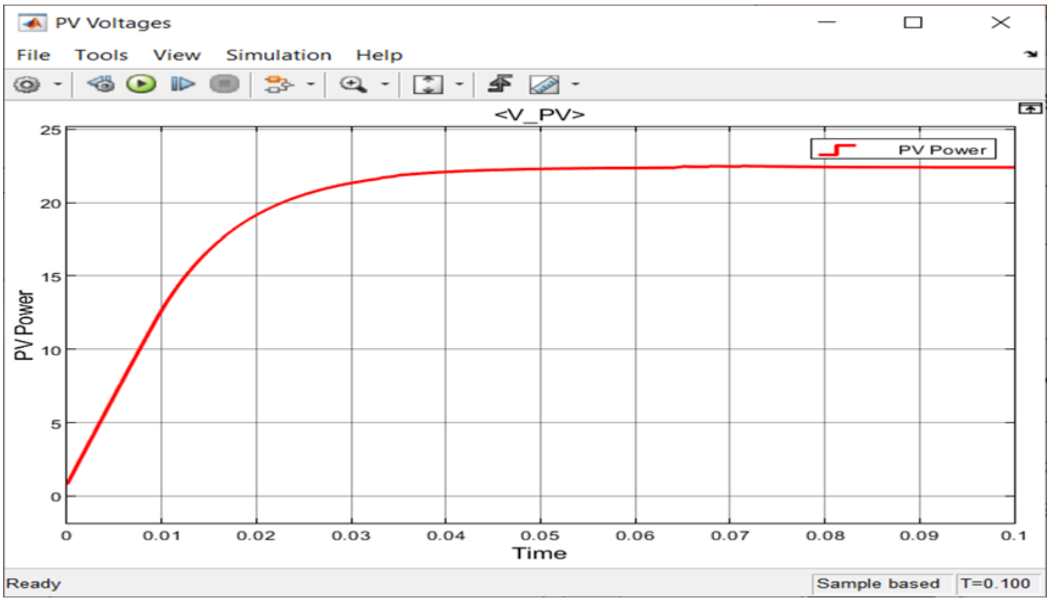


Figure 5.9 PV voltages with fuzzy control MPPT

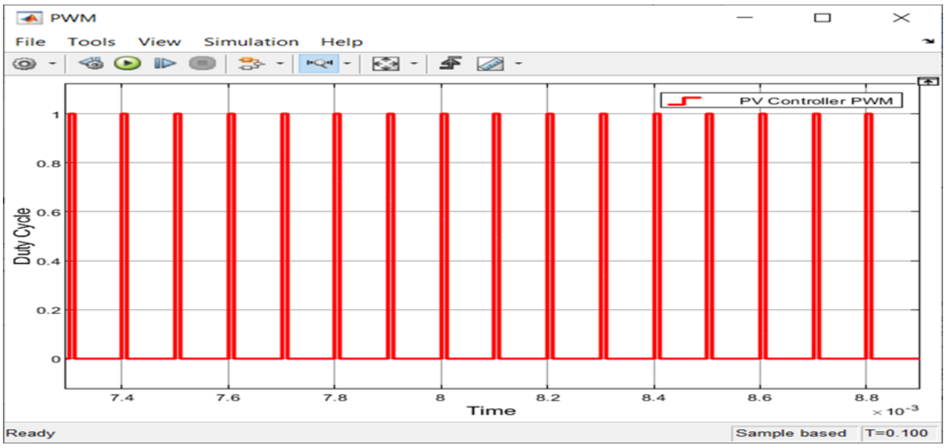


Figure 5.10 PWM with fuzzy controlled MPPT

5.2.3 Fuzzy controller with converter output PV voltages

The PV converter PWM signal is shown in Figure 5.10 by constant duty cycle interval. The duty cycle of PWM generator is presented as we can achieve the varying duty cycle of system.

The output voltages of 25V PV converter are achieved with implementation of PI controller is shown in Figure 5.11. Fuzzy controller MPPT can provide a maximum power of 106.1 watts.

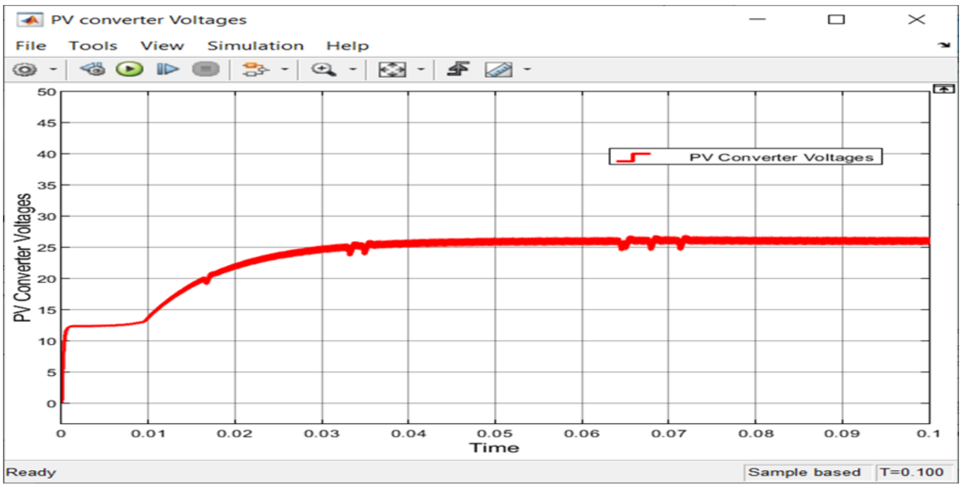


Figure 5.11 Converter voltages

5.3 Simulations and Results with ANFIS Controlled MPPT

It is observed that the simulation of ANFIS system delivers the battery output voltages of 23.8 V at state of charge of 50, and power of PV is almost 111 Watts, the voltages supplied by PV system is 23 v and current drawing through PV system is 4.6 amp, at applied solar irradiance of 1000 watt/m^2 with solar heat temperature of 50 degree centigrade (Figure 5.12).

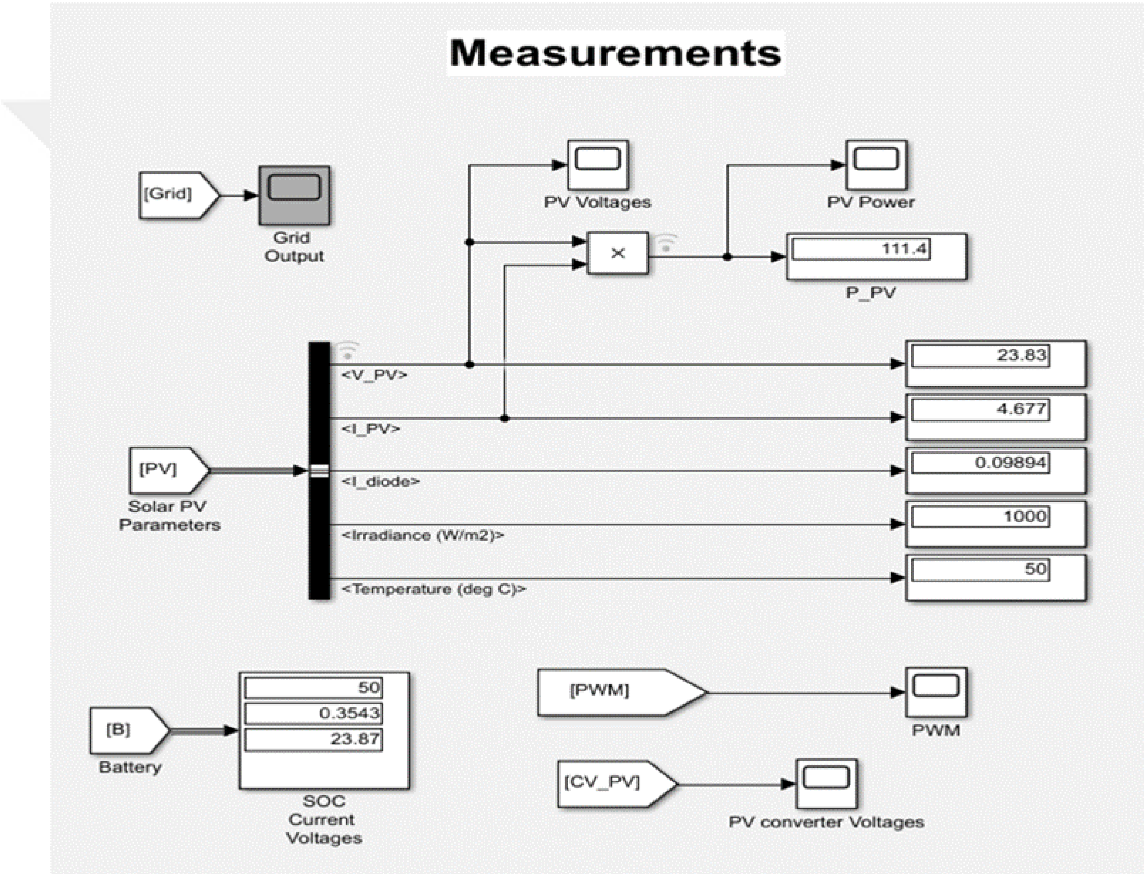


Figure 5.12 Measurements with ANFIS controller results

5.3.1 Maximum power achieved with ANFIS control

The response indicates the output waveform of the solar PV system with maximum power delivered by PV system through MPPT with ANFIS technique is shown in Figure 5.13.

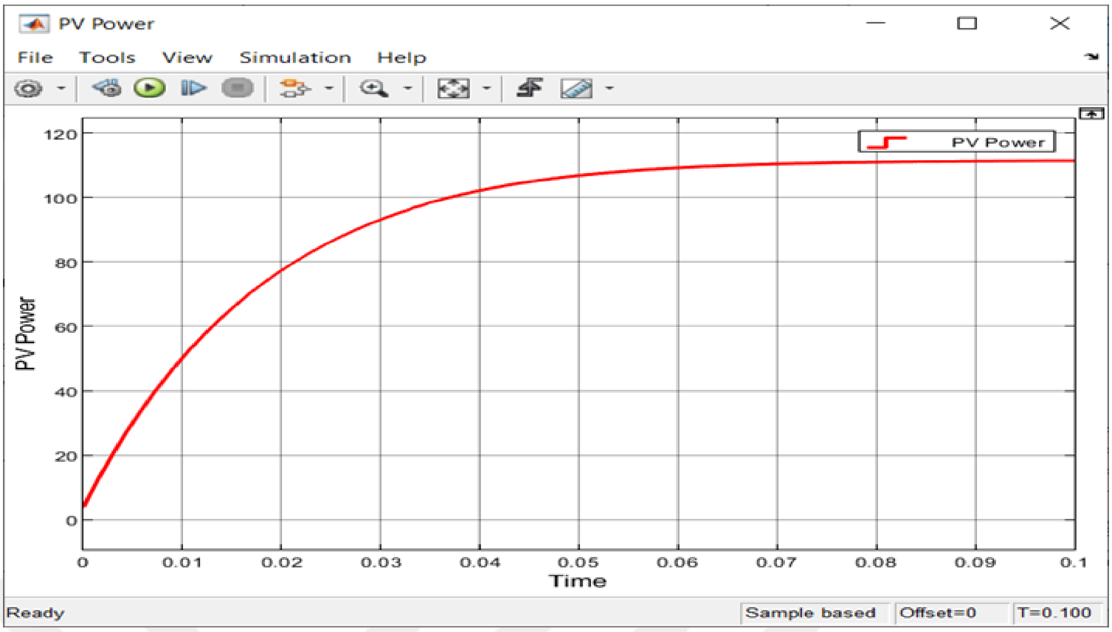


Figure 5.13 Maximum power achieved with ANFIS

5.3.2 PV voltages

The voltage waveform of PV system is shown in Figure 5.14.

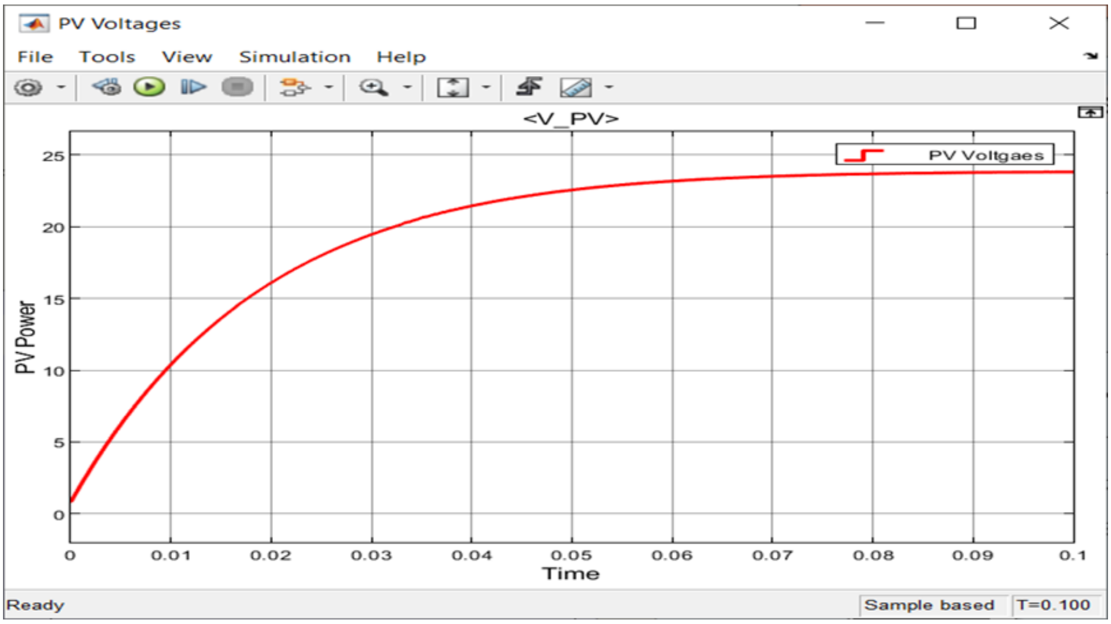


Figure 5.14 Controlled voltage of PV system

5.3.3 PWM duty cycle for ANFIS controller MPPT

The PV converter PWM signal is shown by constant duty cycle interval. The duty cycle of PWM generator is shown as we can achieve the varying duty cycle of system (Figure 5.15).

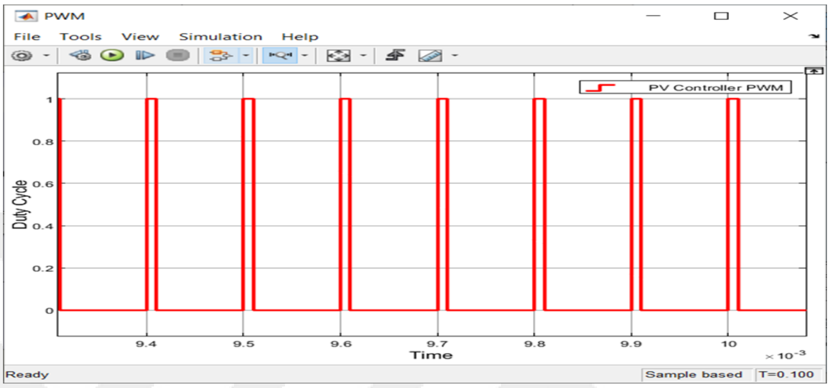


Figure 5.15 PWM duty cycle for ANFIS controller MPPT

5.3.4 PV controller voltages with ANFIS controlled MPPT

The PV controller Voltages with ANFIS controlled MPPT response indicates the output waveform of the solar PV system with maximum power delivered by PV system through MPPT with ANFIS technique is shown in Figure 5.16. The output voltages of 28V PV converter are achieved with implementation of ANFIS controller.

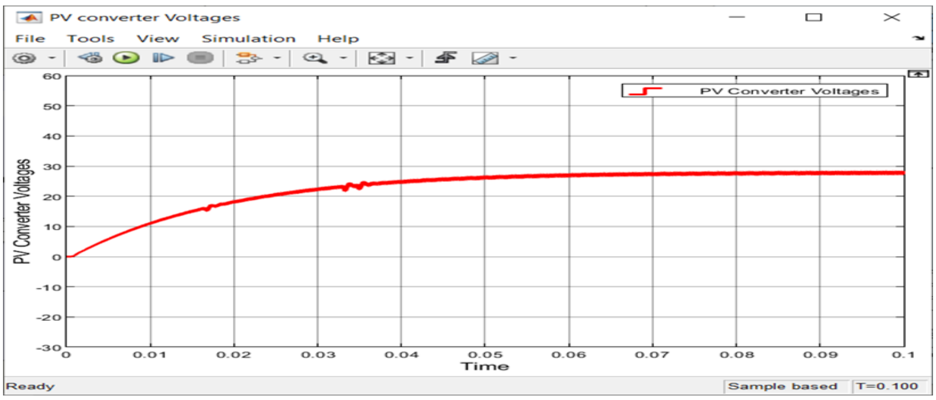


Figure 5.16 PV controller voltages with ANFIS controlled MPPT

Figure 5.17 shows the comparison among three MPPT algorithms - PI, Fuzzy, and ANFIS eveals distinct characteristics and power outputs. The PI algorithm demonstrates fast and stable performance with the lowest power value of 100W. The Fuzzy logic algorithm achieves a moderate power output of 111W, while exhibiting variable performance based on input conditions and fuzzy rules. On the other hand, the ANFIS algorithm yields the highest power value of 115W, although its need time to get to maximum power point tracking. The choice of the most suitable MPPT algorithm depends on specific application requirements and priorities, with the ANFIS algorithm offering the highest power output, the PI algorithm providing reliable stability, and the Fuzzy logic algorithm falling in between.

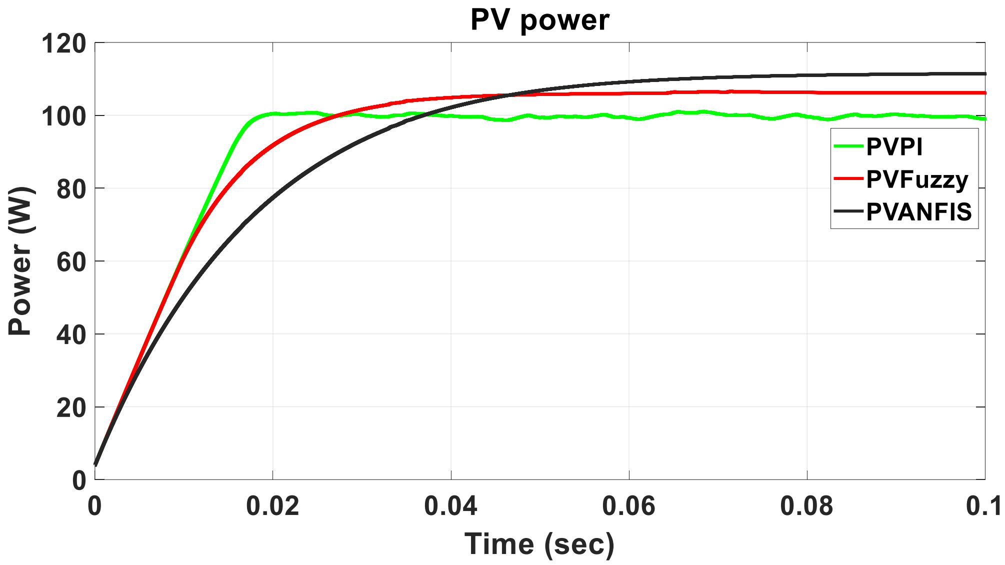


Figure 5.17 The compration among three MPPT algorithms (PI, Fuzzy and ANFIS)

Also, Table 5.1 shows the performance of proposed MPPT algorithms

Table 5.1 Performance of proposed MPPT algorithms

MPPT APPROACH	COMPLEXITY	COST	POWER
PI Controller-Based	Low	Low	99.02 Watts
Fuzzy Logic-Based	Moderate	Moderate	106.1 Watts
ANFIS-Based	High	High	111 Watts

Based on the simulation-based results presented in the study, it can be observed that all three methods, i.e., PI controller-based MPPT, fuzzy logic-based MPPT, and ANFIS-based MPPT, are capable of achieving maximum power extraction from the solar PV array under varying weather conditions. However, the ANFIS-based MPPT approach is observed to deliver the highest power output of 111 Watts, followed by the fuzzy logic-based MPPT approach with 106.1 Watts and the PI controller-based MPPT approach with 99.02 Watts. The ANFIS approach is more complex than the other two methods since it involves the use of a fuzzy logic system combined with neural network-based inference to achieve optimal control of the PV array. The ANFIS system requires more advanced algorithms and computations to be implemented, including the use of current and voltage sensors, the ANFIS editor toolbox, and the editor toolbox for fuzzy logic. Additionally, the ANFIS system involves a higher implementation cost due to the need for more sensors and sophisticated algorithms. While all three methods are capable of achieving maximum power extraction from solar PV arrays, the ANFIS-based MPPT approach has demonstrated superior performance in terms of power output. However, it is also more complex and costly to implement compared to the other two methods. The choice of the optimal MPPT approach will depend on the specific requirements of the application and the available resources.

6. CONCLUSION AND RECOMMENDATIONS

This comprehensive study on MPPT for solar modules underscores the importance of designing and implementing an efficient and reliable MPPT to handle uncertainties in solar temperature and power, and optimize control of solar modules. Different MPPT methods, including PI, fuzzy logic, and ANFIS controllers, were analyzed and tested, each demonstrating distinct advantages based on specific application requirements. While ANFIS produced the highest power output, it took more time to achieve maximum power point tracking, whereas the PI algorithm offered fast, stable performance at a lower power output, and the fuzzy logic algorithm exhibited variable performance based on input conditions. Additionally, the auxiliary conduction method showed promising results under varying weather conditions despite the higher implementation cost and complexity. The research findings provide valuable insights for the selection of the most suitable MPPT method based on application needs, balancing power output, stability, cost, and complexity.

Future work stemming from this study could focus on several key areas. The refinement of existing MPPT algorithms, particularly the ANFIS and fuzzy logic algorithms, is essential to optimize their performance under various conditions. Concurrently, efforts could aim to reduce the complexity and costs associated with the auxiliary conduction method and the use of both current and voltage sensors. Moreover, the simulation model used for testing these methods could be enhanced to encompass a broader spectrum of weather conditions and operational scenarios. Real-world testing of these MPPT methods is also a necessary next step to gain practical insights about their performance and resilience. Research could also extend towards integrating optimized MPPT methods with other renewable energy systems and exploring the development of adaptive MPPT systems that dynamically select the most efficient algorithm based on real-time conditions.

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