FUZZY LOGIC - BASED MAXIMUM POWER POINT TRACKING OF PHOTOVOLTAIC SYSTEM

by

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A thesis
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CERTIFICATE OF APPROVAL

The thesis entitled as **"Fuzzy Logic - Based MPPT of Photovoltaic System"** submitted by **Md. Shakhawat Hossain** bearing Matric **ID. ET171054** and **Mahmudul Kabir** bearing Matric **ID. ET171061** of session **Autumn 2020**, to the Department of Electrical and Electronic Engineering, International Islamic University Chittagong, has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering and approved for the examination held on **16 April, 2022.**

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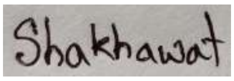
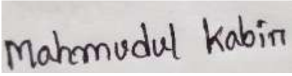
DECLARATION

It is hereby declared that this work has been done only by ours and no portion of the work contained in this Thesis has been submitted elsewhere for the award of any degree.



Md. Shakhawat Hossain



Mahmudul Kabir

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Author

ABSTRACT

In this modern era, the use of Solar energy is increasing day by day. Keeping in mind the needs of the future demand of Solar energy, it is very essential for us to get maximum power tracking point in order to utilize Solar energy properly. So, in this thesis work, we proposed a Fuzzy Logic Controller system to track maximum power point. This system is used to get the Maximum Point of a PV array. It is the most suitable way for the human decision making mechanism, providing the operation and showing every step on the basis of Boolean logic system. This technique contact about on the artificial intelligence with the help of membership function which is inspired on the basis of human perception. We knew that there are some techniques to find the maximum power point, but our proposed system has better effectiveness among these techniques. In this work, we compared with classical PI, PD, PID, FPID controllers and also compared performance analysis with P&O and INC method of maximum power point technique. In our study, a Boost converter is used with fuzzy sets method. In our proposed system, we also showed how to design a fuzzy system combining with boost converter and find maximum power of a PV array on fixed temperature and fixed irradiance. At finally we get a result, that the fuzzy controller has an excellent performance to track solar MPPT over P&O, INC method and others controllers.

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LIST OF ABBREVIATIONS

MPPT	Maximum Power Point Tracking
PV	Photovoltaic
FLC	Fuzzy Logic Controller
P & O	Perturbation and Observation
INC	Incremental Conductance
COG	Centre of Gravity
BOA	Bisector of Area
MOM	Mean od Maximum
FIS	Fuzzy interference System
IGBT	Insulated Gate Bipolar Transistor

CHAPTER 1

INTRODUCTION

1.1 Introduction

Global warming is a major environmental issue that the world is now dealing with. One of the most effective ways to address this issue is to use renewable energy [1]. So with a growing awareness of the depletion of classical energy sources and the damage of environmental caused by increased carbon dioxide emissions from coal-fired power generation, the use of renewable energy has emerged as the preferred energy source [2]. Renewable energy is derived from natural processes that are still in progress, as well as energy from natural processes that has been turned into usable forms. Sunlight, wind, flowing water, biological processes and geothermal energy are all examples of renewable energy sources. Because of fossil fuels are very limited, rapidly exhausted, pollute the environment, and cause of climate change, the usage of renewable energy sources is rapidly increasing. Another element that contributes to the increased usage of renewable energy sources is that they may be deployed anywhere and produced utilizing a variety of technologies. For that solar and wind energy are the most popular renewable energy sources. In order to achieve wind energy, wind turbines must be sited in such a way that they receive maximum exposure to the wind. However, not every state in Bangladesh, it can give such conditions. Furthermore, wind turbines must be ready to better from residential areas, as the sound of wind turbines is quite bothersome to humans. The photovoltaic (PV) system integration with the grid is spreading globally, increasing the proportion of generation of PV to overall power generation of global. So, among renewable energy sources, the most appealing system is solar energy, and it may be considered one of the most valuable sources because it has many advantages, such as pollution free operation and maintenance expenses, and it is expected to expand in popularity in the next future [4].

The definition of fuzzy logic is, a lots of valued logic form is described as one in which the truth values of variables can be any real number between 0 and 1. We can’t tell whether the assertion is true or incorrect in actual life. Fuzzy logic provided a lot of freedom for reasoning at the time. To attain the best outcomes in terms of maximum power as well as growing performance, a control strategy based on theory of fuzzy control was presented as well as compared to a traditional PI controller / Homer for validation of performance. The system of fuzzy logic is simple and straightforward. The system may easily be tweaked to increase or change its performance. In computational challenges, logic of fuzzy allows for the inclusion of hazy human judgments. The system of Fuzzy logic has gotten a lot of attention. The system of fuzzy logic has been used to work on wind energy, solar energy and a variety of other energies. However, there are significant gaps in the process of employing a controller of fuzzy logic to link to the solar energy with a grid. We used a controller of fuzzy logic to try to limit the greatest variations of solar energy with a system of grid connection. Because it provides the highest production while also including an intelligence system. The modelling and design of a controller of a fuzzy to track the PV module maximum power point is presented in this study, which makes use of the fuzzy logic characteristics to represent a problem through language terms [5]. The environmental variables such as sun irradiation and operational temperature influence and planned RES power output. The control system of maximum power point tracking approach is primarily utilized to extract the RES's most capable power with the respect to sun irradiation and thermal temperature at a suitable time point. The controller of MPPT will use virtually all of the available power. The algorithms of MPPT have attracted a lot of attention in early years [1]. They have been studied, improved as well as implemented. The goal of MPPT is to match the MPP voltage to the actual operating voltage of the solar panels.

1.2 Background of the Study

We know that the Photovoltaic (PV) energy is one of the most important energy source among all energy sources and this system is becoming increasingly important as the most available renewable source of energy since it is clean and noise free. So it is important to get maximum output from this system. To get maximum output PV energy conversion systems should be in Maximum Power Point. MPPT control is necessary to extract maximum power from a PV array. In recent years, a large number of techniques have been introduced for tracking the maximum power point. Different MPPT techniques such as the Perturbation and Observation (P & O), Incremental conductance (INC), Short Circuit technique and Open circuit technique are mainly used. But in all above techniques there are some limitation like these techniques are vary in complexity, costly, speed of convergence, oscillating in output etc. But our proposed Fuzzy Logic Controller to find maximum power can be best solution to overcome these type of limitation. Because our proposed system is low cost, there is no oscillation in output so its output is more accurate from all the system, however in this controller we can vary the membership function for getting more accurate result in any other sector. So in this work, the attention will be on Fuzzy Logic Controller to get Maximum Power Point and showing a comparison among P&O and INC method between Fuzzy Logic System.

1.3 Objective

The objectives of this thesis work are

- To demonstrate a photovoltaic system based on fuzzy logic.
- To study of fuzzy logic controller design and comparison with other conventional controllers.
- To establish the Fuzzy Logic technique as the most effective method for obtaining MPPT of Photovoltaic system while comparing with other techniques like as P&O, INC.

1.4 Overall methodology of the Fuzzy Logic Controller and PV system

Fig. 1.1 shows that overall methodology of the fuzzy logic controller and PV system. We used MATLAB Simulink for completing our overall task.

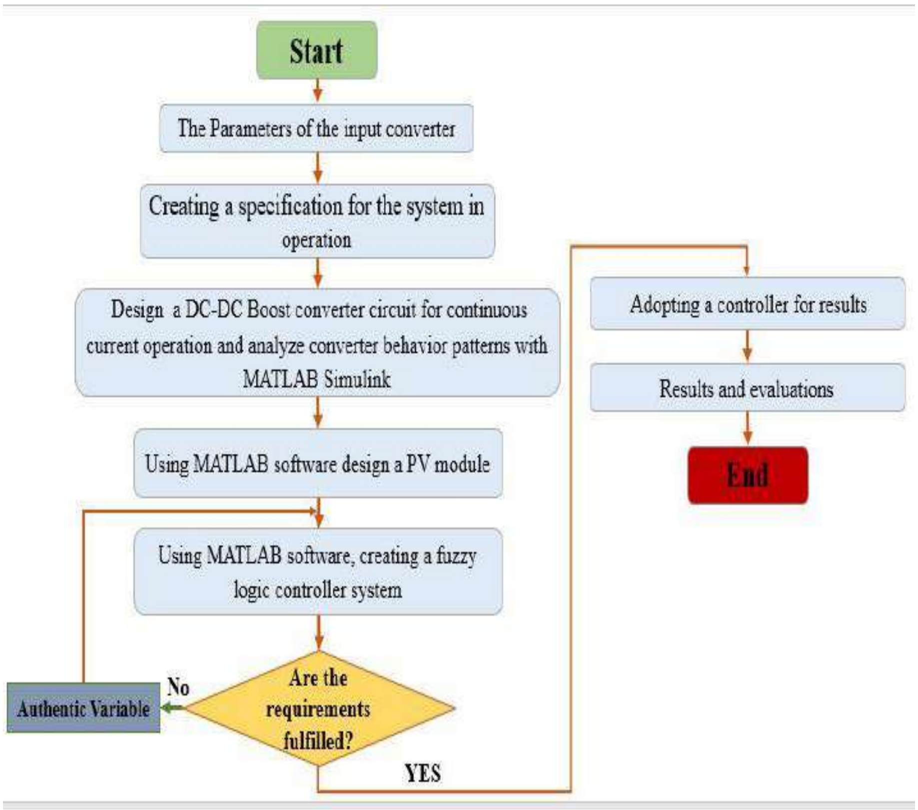

Fig. 1.1 Overall methodology of the Fuzzy Logic Controller and PV system.

1.5 Thesis Layout

- ✓ The thesis is organized by five different chapters.
- ✓ **Chapter one** provides a general introduction and objectives of this study.
- ✓ **Chapter two** discusses about Literature Review, Introduction of Solar Energy, DC-DC Boost converter, A summary on various types of controller, introduction on Maximum Power Point Tracking System (MPPT System) and different types of MPPT techniques, Solar Photovoltaic Cell (SPV)cell, Introduction on Fuzzy Logic Controller System (FLC) system.
- ✓ **Chapter three** gives a brief explanation of Methodology of our thesis work and Simulink of proposed Fuzzy Logic Controller (FLC) with Solar Photovoltaic system.
- ✓ **Chapter four** provides the result of this experimental work and output of various controller system.
- ✓ **Chapter five** presents the summary on this thesis work and suggestion for future works on Fuzzy Logic Controller system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, we discussed about Solar energy and various types of converter. Because we are running low on fuel and energy, we must instantaneously prepare for a third transition, such as solar power. The sun hits the planet with approximately 430 quintillion joules of energy every hour. This amount of power is capable of supporting all energy related activities. In today's (2022) climate of growing energy demand and increasing environment concern. As a result, solar energy can be a perfect substitute for satisfying energy demands while also preserving the environment. In solar power systems, DC-DC Boost converters are significant because they enhance the voltage level of a solar array for a specific set of conditions. But in our work we used DC-DC Boost converter combining with Fuzzy logic controller and Solar system to get maximum output.

2.2 Solar Energy

Solar energy is not a new thing. Solar energy has been used in the 7th century B.C. by humans. The sun's energy has been cherished and used just about as long as man has appeared on earth in its most primitive form. Solar power was first used to start fire for cooking by concentrating the sun's energy through a magnifying lens. Greeks and Romans adopted "burning mirrors" to sunlight reflected to ignite sacred torches for religious events by the third century B.C. Sunrooms were constructed in ancient times to capture the sun's organic warmth. From the mythic Roman bathhouses to Native American red clay, these typically south-facing rooms have captured and absorbed sunlight, and are still popular in many present residences. In Greek solar history, the scientist Archimedes is said to have gone out to invade sailing ships as from Romans. According to Archimedes, he deployed bronze shields to reflect the sun's light energy, focusing the rays and destroying the enemy before they made landing. Consider it a solar laser shot from the distant past. It is unknown whether or not this occurred during Archimedes' time. However, the Greek navy took this solar power experiment to the test in the 1970s. They were capable of transporting them to a timber test ship 50 meters away utilizing only the fabled bronze shield and solar light energy. While experimenting with a cell constructed of metal electrodes in a conducting fluid in 1839, French physicist Edmond Becquerel developed the photovoltaic concept. He observed that when the cell was exposed to light, it generated more energy. Willoughby Smith identified that selenium could be used as a photoconductor in 1873. In 1876, three years after Becquerel's discovery, William Grylls Adams and Richard Evans Day implemented the photovoltaic principle to selenium. They discovered that when exposed to light, it could produce electricity. In 1883, nearly 50 years after the invention of the photovoltaic effect, American inventor Charles Fritz invented the first operational selenium sun cell. Despite the fact that modern solar panels employ silicon in their cells, this solar cell was a crucial forerunner to the technology used today. Many physicists led to the advancement of solar cells in some way. Becquerel is credited with creating the photovoltaic effect's potential, whereas Fritz is credited with inventing the ancestor of all solar cells. Solar energy is the radiating energy and heat from the Sun that is captured and used to generate electricity using a variety of technologies such as solar power. Solar energy is still the most environmentally friendly and freely accessible renewable energy source. Based according to how they absorb and transmit solar energy or transform it into solar electricity, their methods are classified as passive solar and active solar. The whole energy is well-known for a range of applications, including generating electricity, lighting, and water heating for household, corporate, and professional use. We can also use solar generation to produce our electricity needs. Solar radiation is directly transformed to DC power using solar photovoltaic (SPV) cells.

2.3 DC-DC Boost Converter

In our work, we used a DC-DC Boost Converter with IGBT switch to increase the output efficiency. Basically boost converter is used to step up voltage. In order to change in input voltage of the panel to fulfill our demand we used a boost converter and this is done by varying the duty cycle. A DC-DC Boost converter circuit diagram and waveform of a Boost converter shown in **Fig. 2.1** and **Fig. 2.3**.

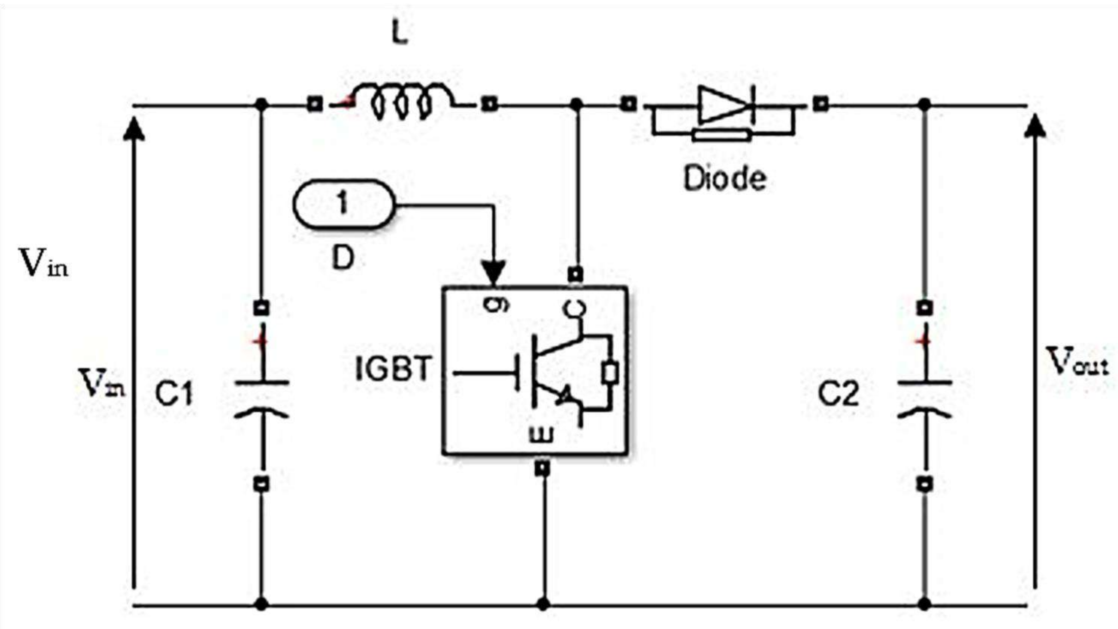

Fig. 2.1 Circuit diagram of a Boost Converter [6].

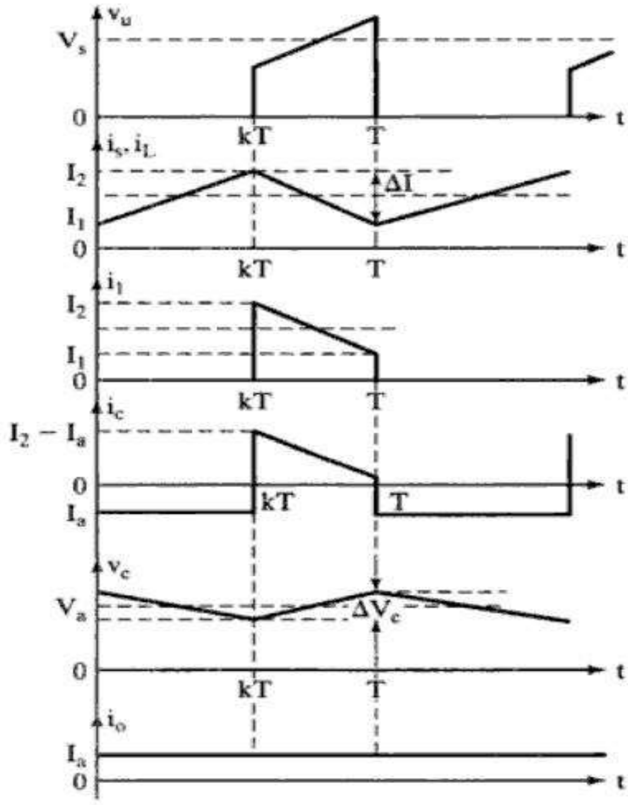

Fig. 2.2 Waveforms for a Boost Converter [7].

2.4 Classical Controller

Fig. 2.3 depicts a general feedback control system. A sensor or transducer in the feedback element measures physical factors like speed and heat and transforms them to voltage. Many control problems have the primary purpose of making the output follow the reference input and creating the transfer function. As indicated in equation 2.1, the transfer function, which is the ratio of the Laplace transform (LT) of the system's output to the LT of the reference signal, is set to 1.

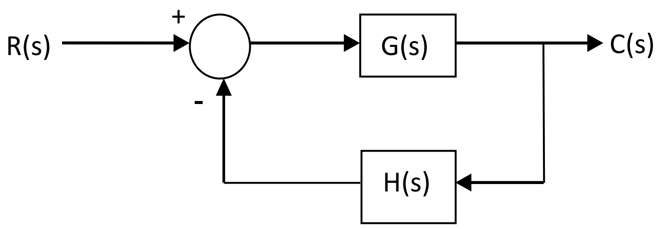

Fig. 2.3 General Feedback Control System [8].

In **Fig. 2.3**, R(s) and C(s) are the Laplace Transform of the output. H(s) is feedback factor. G(s) is open-loop gain. E(s) is the error between feedback factor and open-loop gain. In (equation 2.1), C(s) and R(s) are the LT of the output and the reference signals respectively.

$$T(s)=\frac{C(s)}{R(s)}=1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2.1)$$

2.4.1 PI Controller

The major purpose of the PI controller is to eliminate the steady state error caused by the P controller. However, it has a negative impact on the system's overall quickness of response and general the stability. This controller is typically utilized in applications where system speed is not a concern Because the PI controller lacks the ability to forecast future system failures, it is unable to reduce the rise time and remove oscillations. Any amount of I, if used, ensures set point overshoot. Because of its capacity to compensate for most practical industrial processes, the PI controller has been employed in numerous industrial applications. PI and PID controllers are used to control most low to medium order processes. Most processes of low to medium order are controlled by using PI and PID controllers. More than 85% of control loops are controlled by single input and single output that have led them to use PI and PID controllers [9].

2.4.2 PD Controller

A PD controller is a proportional-derivative controller that responds to the rate of change in process error. A PD controller can affect a control system by improving the damping, decreasing the maximum overshoot, and also decreasing the rise and setting time; however, and show noise at higher frequencies [9].

2.4.3 PID Controller

One of the first typical industrial controllers is the PID (Proportional-Integral-Derivative) controller. It offers numerous advantages, including low cost, simplicity, and ease of tuning. Most controllers employed single-loops and a single variable in the past. Multi-loop and multi-variable controllers are now widely employed in a variety of applications. The PID controller serves as the foundation for these control schemes. A proportional element, an integral element, and a derivative element make up this system. Figure 2.4 shows a PID controller block diagram in any system with all three PID components connected in parallel. The gains of P, I, and D elements are represented by Kp, Ki, and Kd, respectively. The error sigma is used as a PID controller's input.

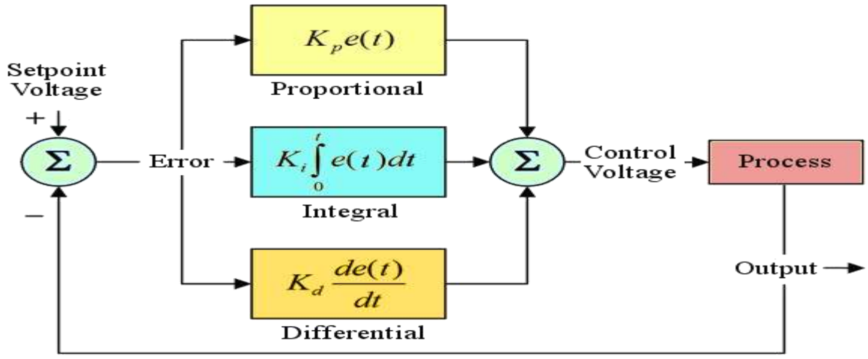

Fig. 2.4 Logical diagram of a PID Control Loop [10].

Kp, Ki, and Kd represent proportional gain, integral gain, and derivative gain, respectively, as shown in **Fig. 2.4**.

2.5 Maximum Power Point Tracking System (MPPT System)

A Maximum Power Point Tracker, or MPPT, is an electronic DC to DC converter that optimizes the match between the solar panel and the electric grid. Simply described, they convert a higher voltage DC output from a solar panel to a higher voltage AC output. Maximum power point tracking is a type of electrical usually digital tracking. The maximum power point tracking controller is a critical component of photovoltaic systems, and its algorithm is utilized to extract the greatest power from a PV unit under a variety of conditions. Generally, MPPT controllers could be considered an essential and efficient part in photovoltaic systems. They possess the advantages listed below [11].

• They increase the power (depending on weather conditions).

• They are more adaptable, as they can link PV modules in series, in order to raise the system's voltage up. Wiring gauge is reduced as a result of this operation.

• They are cost effective since they eliminate the need for transmission wiring when installing a PV system.

It is also used to control (increase or decrease) power output under the required conditions of the system [12].

2.5.1 Different MPPT techniques

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1) Perturbation and Observation method (P & O method)
2) Incremental Conductance method (INC method)
3) Short circuit current
4) Open circuit voltage
5) Neural networks
6) Fuzzy logic

In our work, we used Fuzzy Logic system and compared it with P & O and INC and improved INC method.

2.5.2 Perturbation and Observation (P&O) Method

The simplest way is P & O method, which involves repeatedly increasing or decreasing the PV array voltage to shift the operating point toward the maximum power point. If the power grows, the perturbation will continue in the same direction in the following cycle; otherwise, the direction of the disturbance will be reversed. This means that every MPPT cycle, the array terminal voltage is disrupted, and when the P&O is reached, the P&O algorithm will oscillate around it, resulting in a loss of PV power, especially in circumstances when atmospheric conditions are stable or slowly varying [13], **Fig .2.5** shows an example of P & O method.

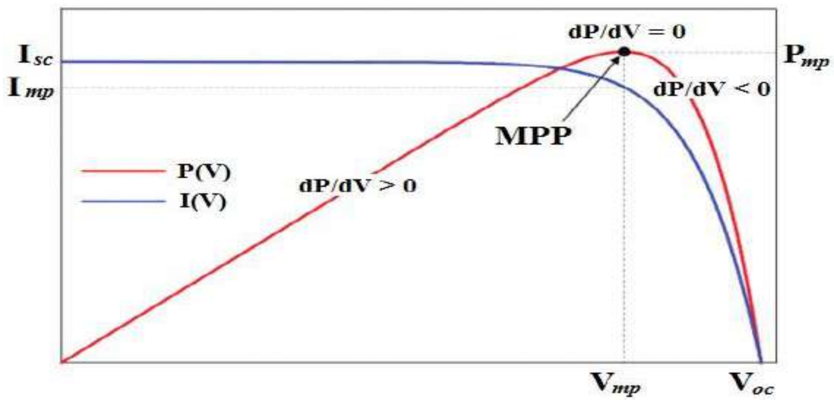

Fig. 2.5 Example of Perturbation and Observation method technique Block diagram of PV system [12].

2.5.3 Incremental Conductance (INC) Method

The incremental conductance (INC) method has been proposed to improve tracking accuracy and dynamic performance under rapidly varying conditions. It is based on the fact that the slope of the PV array power versus voltage curve is zero at the MPP [14] [15] and **Fig. 2.6** shows the power and slope of power versus voltage curves of INC method.

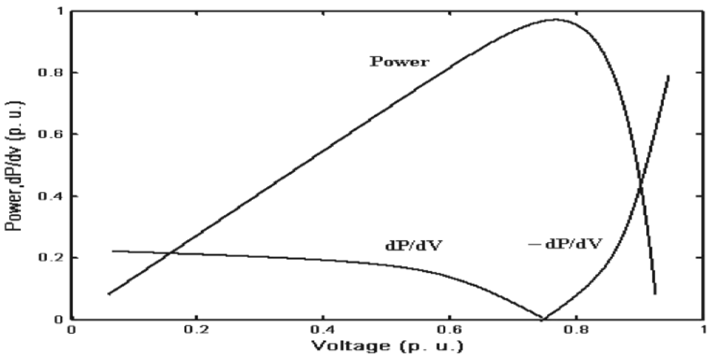

Fig. 2.6 Variation of the normalized power and slope of power versus voltage Curves (INC method [16].

2.5.4 Modified incremental conductance (INC) Method

A flag value of zero "0" is placed at the start to indicate that the MPP is reached when the flag is set to "1." If the flag is set to "0," the INC is applied using Equation (2.2); when this condition is met, the PV system operates at its maximum, and the algorithm sets the indicator to "1," switching to the modified method. The software still checks the condition in equation in this enhanced approach (2.2) [17]. If the irradiance and load resistance are kept unchanged, no variations are made to the duty cycle; when the irradiance or load changes, the algorithm sets the flag to “0” and there is a change in P_{PV} and I_{PV}. If the algorithm detects that the voltage and current have been increased, then the duty cycle increases too; and INC algorithm is modified to overcome the imprecise response during the increase in solar irradiance. The duty cycle is unchanged if the irradiance and load resistance are maintained constant; if the irradiance or load changes, the algorithm sets the flag to "0," and the Ppv and Ipv are modified. The INC method is updated to overcome the imprecise reaction during the rise in solar irradiation [18], if the algorithm recognizes that the voltage and current have increased. In **Fig. 2.7**, modified INC method in various irradiance is shown.

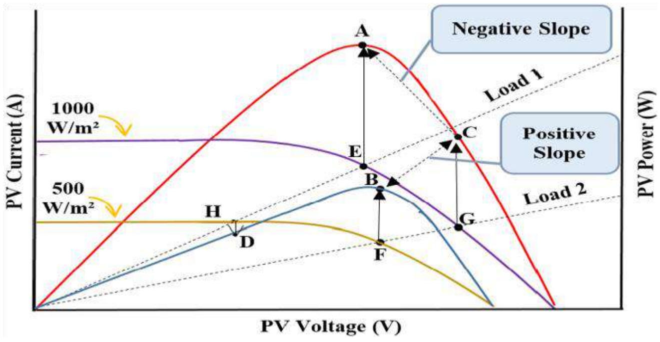

Fig. 2.7 Modified INC method in various irradiance [19].

$$E(K) = [P_{pv}(K) - P_{pv}(K-1)]/[V_{pv}(K) - V_{pv}(K-1)] \ldots\ldots\ldots\ldots\ldots (2.2)$$

2.6 Photovoltaic (PV) cell

A photovoltaic systems or solar cell is a device that uses the photoconductivity, a physiochemical occasion, to transform light into electricity. So when sunlight passes a solar cell electrons evacuated, leaving holes – the voids left by the fleeing electrons. The electric field will transfer electrons to the n-type layer and holes to the p-type layer. If the n-type and p-type layers are connected with a metallic wire, electrons will flow from the n-type layer to the p-type layer by traversing the depletion zone and then passing via the n-type layer and finally a flow of electricity will be created. A solar cell, on the other hand, is not the same as a photodiode. A photovoltaic system is always forward biased because light hits on the n channel of the semiconductor junction and is turned into a current or voltage output.

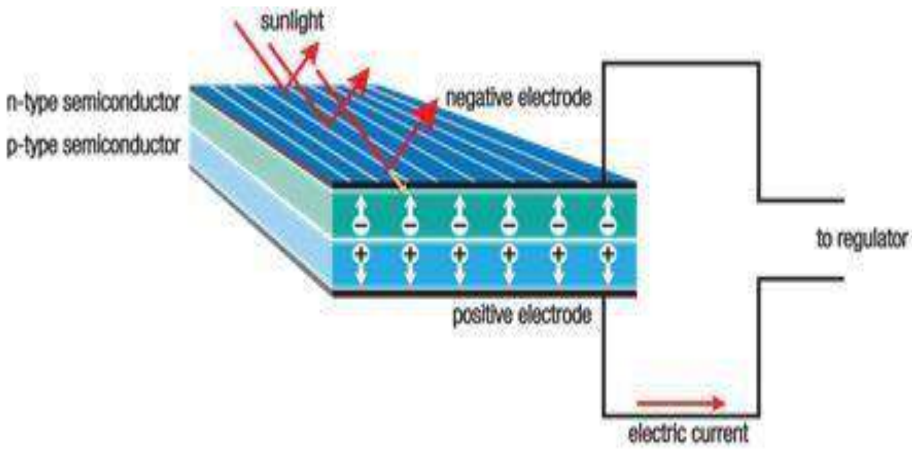

Fig. 2.8 Basic Structure of a PV Cell [20].

2.6.1 PV Modelling

A solar array is made up of multiple photovoltaic cells connected in series or parallel. The configuration is capable of raising the current inside the array, meanwhile the series connection is crucial for stimulating overall voltage of panel. A current source and an inverting diode parallel connection can be used to imitate a solar panel. It has its own resistance in series and parallel. The leakage current causes series resistance, whereas the impediment in the direction of electron transport from the n to the p junction causes parallel resistance.

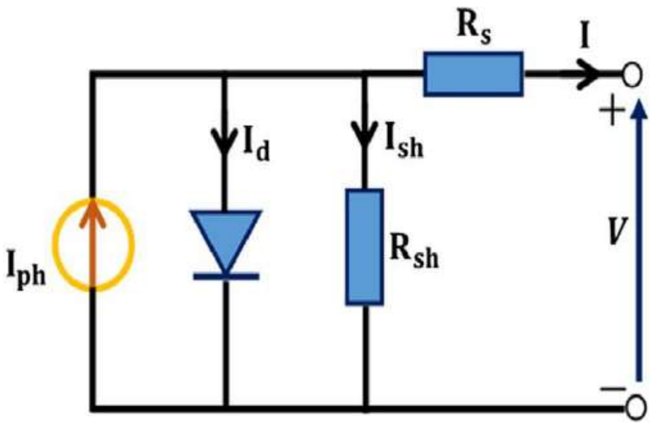

Fig. 2.9 Single diode model of a PV cell [19].

In above **Fig. 2.9** we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$$I=I_{sc} - I_d \qquad (2.3)$$

$$I_d = I_o\,(e^{qVd/kT} - 1) \qquad (2.4)$$

In equation (2.4), I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38 * 10^{-19} J/K) and T is the junction temperature in Kelvin (K)

From eq. 2.3 and 2.4

$$I = I_{sc} - I_o\,(e^{qVd/kT} - 1) \qquad (2.5)$$

Using suitable approximations,

$$I = Isc - Io\,(eq((V+IRs)/nkT) - 1) \qquad (2.6)$$

In equation (2.6) I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n is the diode ideality factor

In order to model the solar panel accurately we can use two diode model but in our project our scope of study is limited to the single diode model. Also, the shunt resistance is very high and can be neglected during the course of our study.

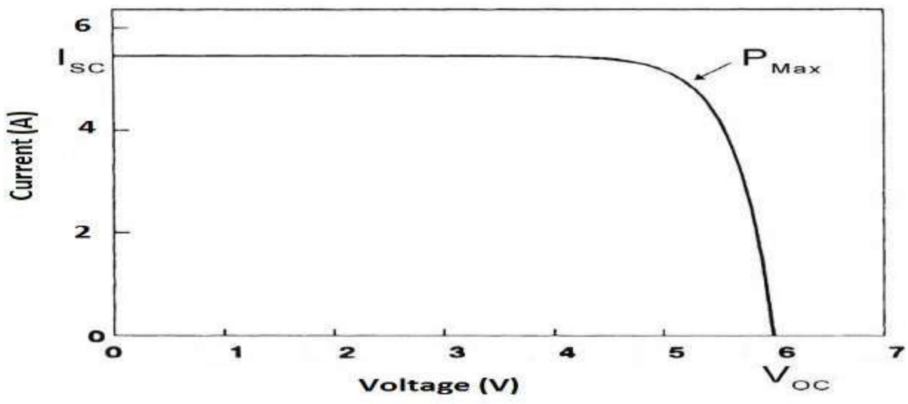

Fig. 2.10 Solar Panel I-V characteristics curve [21].

The I-V characteristic of a typical solar cell are as shown in the **Fig. 2.10**.

When the voltage and the current characteristics are multiplied, we get the P-V characteristic as shown in **Fig. 2.11**. The point indicated as MPP is the point at which the panel power output is maximum.

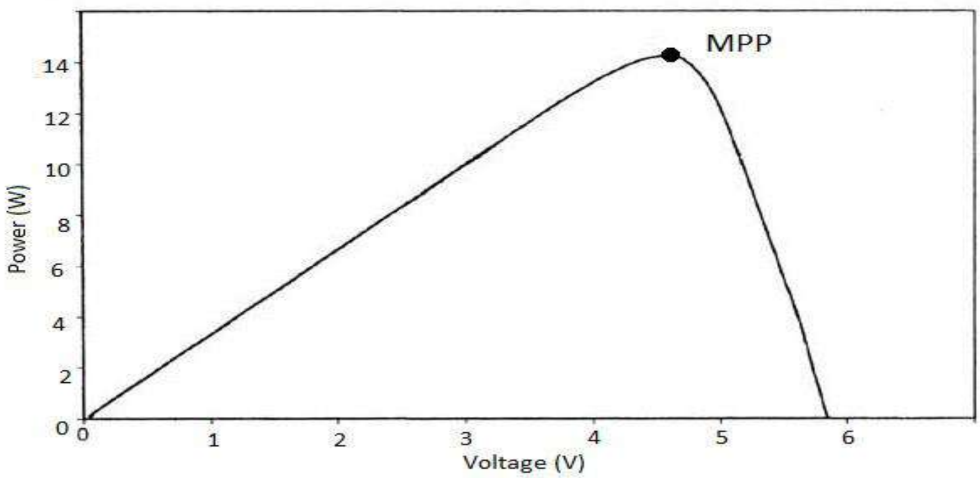

Fig. 2.11 Photovoltaic cell V-I characteristics curve [21].

2.7 Fuzzy Logic Controller (FLC)

Initially, Lotfi Zadeh established the Fuzzy Logic (FL) concept. He was professor at the University of California in Berkeley who recognized that traditional computer logic was incapable of manipulating data representing subjective or ambiguous human thoughts, but it was presented as a data processing method rather than a control methodology. In human decisions, Fuzzy Logic, unlike other computers, consists of a range of possibilities between True and False, according to his observation. This strategy was not used until the 1970s due to a lack of small-computer capacity at the time. Professor Zadeh came to the conclusion that humans don't require precise numerical knowledge but can still exercise great adaptive control. If output systems, which are quantitative systems that assess input values in terms of conceptual variables, can be configured to accommodate noise and imperfect input, they can be significantly much more effective and easier to manage. Fuzzy set theory can be used in a variety of systems of various sizes and abilities. A variety of macro to macro interfaces should be available for use. Furthermore, it can be applied in machine intelligence as technology, program or combination of both. From control systems to all, fuzzy algorithms have been used in a variety of domains. It was created so that a computer could distinguish between data that was either true or untrue. It is akin to how humans think. As an example, a small darkness, a small lightness, and so forth. The control of fuzzy logic is broadly employed in a variety of industries, including the production of domestic products like dishwashers and televisions as well as industrial applications. FLC is also widely used in control systems. The capacity to modify knowledge in a language from rather than a quantitative form is one of the reasons behind the control system of fuzzy is growing popularity. FLCs are not interdependent predictable computational formalism; they are designed to accommodate any model. It is the most important nonlinear system control approach [8]. It's the term used to describe the concept of incomplete truth. In real life, we may encounter a circumstance in which we are unable to determine if a statement is either true or false. The fuzzy logic method aids in the solution of problems by taking into account all relevant facts. Then it makes the best decision feasible based on the input. The fuzzy logic control technique mimics how humans make decisions by considering all of the choices between digital values of True as well as False.

2.7.1 Feature of a Fuzzy Logic Controller

The following are some key aspects of fuzzy logic:

- Machine learning is a versatile and simple to use approach.
- It can assist you in simulating human mind reasoning.
- Two alternative solutions may be represented by logic's two values.
- For unclear or imprecise reasoning, this strategy is ideal. Inference is viewed as a process of spreading elastic in fuzzy logic.
- Fuzzy logic views inference as a process of propagating elastic constraints.
- Anyone can create nonlinear system of any complexity using fuzzy logic.
- Specialists should be involved in the development of fuzzy logic [22].

2.7.2 Fuzzy Logic Example

Take a look at the following **Fig. 2.12**. It demonstrates that the elements of the system of Fuzzy are represented by a 0 to 1 integer. In this case, 1 represent perfect truth, whereas 0 represent total falsity.

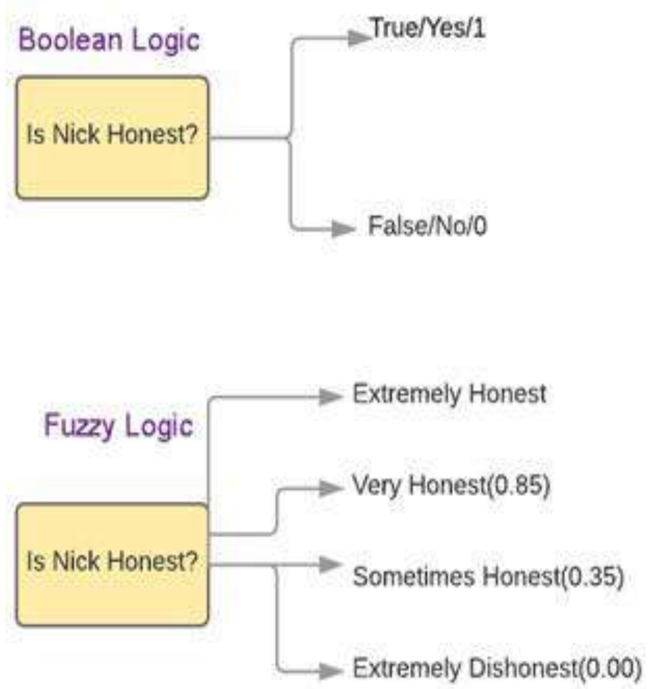

Fig. 2.12 Example of fuzzy logic [22].

2.7.3 Fuzzy Logic System Architecture

The controller of fuzzy logic has three main components. The fuzzification module(fuzzifier), the rule base, and the defuzzification module are the three pieces (defuzzifier). A basic block diagram of fuzzy controller is shown in **Fig. 2.13.**

- **Fuzzification**

The state parameters that indicate the devices transient behavior determine the level of fuzzification. The input parameters indicate to regulate determines the transient behavior of the network. Instead of employing a mathematical simulation method, the control of fuzzy logic analysis emphasizes language variables like high, huge, positive, negative, little, zero, low, medium and so on. Transforming a number of data (decimal digits or sharp numbers). Corresponding membership function that encompass the entire field discourse identify fuzzy sets. Fuzzy sets come in various shapes and sizes, such as triangular. Trapezoidal, parabolic and so on [23].

- **Rule base**

The criteria concerning rule is described as an IF-Then structure function. Under the guidance of a software program capable of executing the instructions as well as calculating a control signal. The Error (E) as well as The change of error (DE) of monitored input data are unmistakably used in the computation. [23].

- **Defuzzification**

Defuzzification is a bidirectional Fuzzification method. The output in a attribute values is required to operate the controller of fuzzy logic (Fuzzy number). The input parameters must be translated into crisp output depending on the real conditions [24] [25]. The Center of Gravity (COG), Bisector of Area (BOA), and Mean of Maximum are the most often used Defuzzification algorithms (MOM).

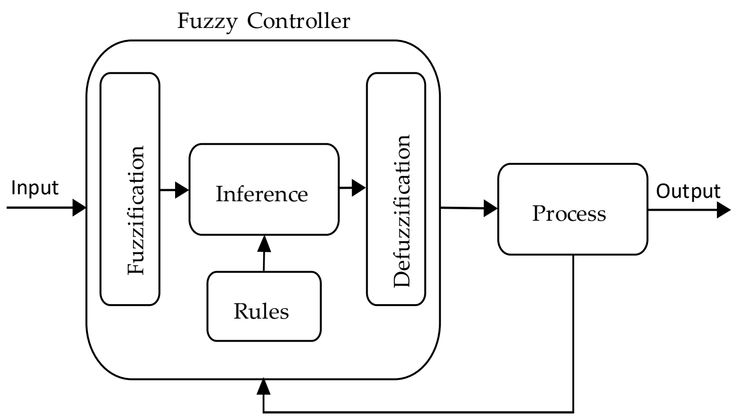

Fig. 2.13 Basic Block diagram for a fuzzy controller [5].

2.7.4 Membership function types

Trapezoidal MFs, Gaussian MFs, and extended bell MFs are all examples of membership functions used throughout fuzzy set theory. **Fig. 2.14** depicts the many forms of membership functions.

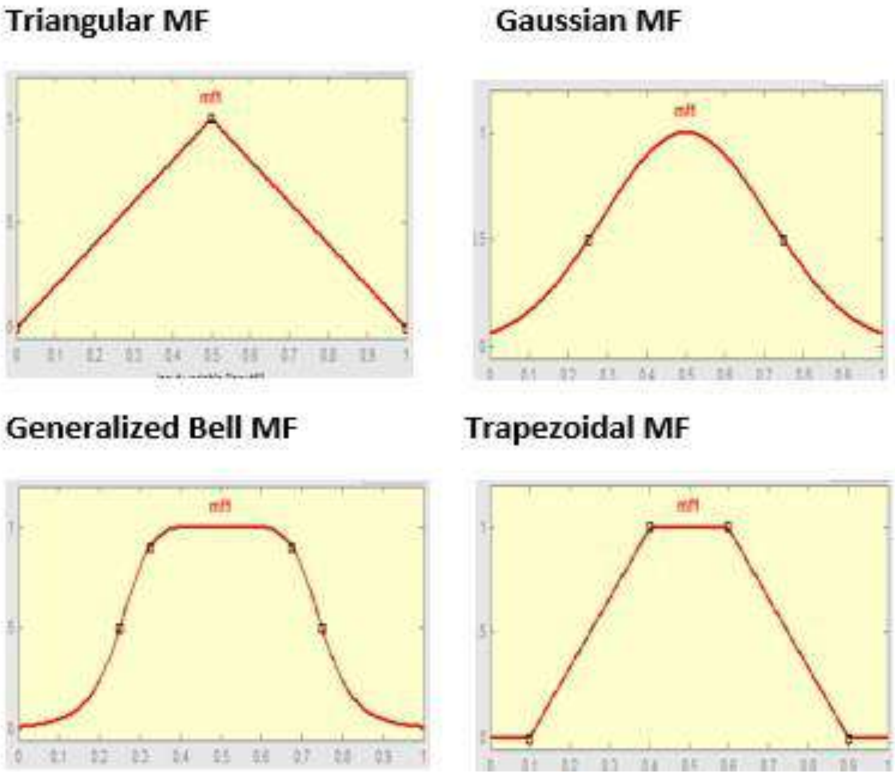

Fig. 2.14 Fuzzy Logic Control Membership Functions [8].

CHAPTER 3

METHODOLOGY

3.1 Design of a Fuzzy Logic Controller

Fuzzification is the process of converting numerical input variables into language variables. The error (E) and the change of error (DE) are typically the controller's input variables (CE). The error depicts the PV system's working point in terms of MPP, which should be zero, and its fluctuation depicts how this point changes along the power-voltage curve. The conversion is performed by utilizing membership functions to several input variable ranges, with a value of ranging from 0 to 1. The interface is process of executing the rule-based operations that determine the controller's operations. The controller's output will become a language variable that sets the converter's duty ratio and the number of iteration reduces the error to near zero. The membership functions are used to acquire the numerical output values during the defuzzification step.

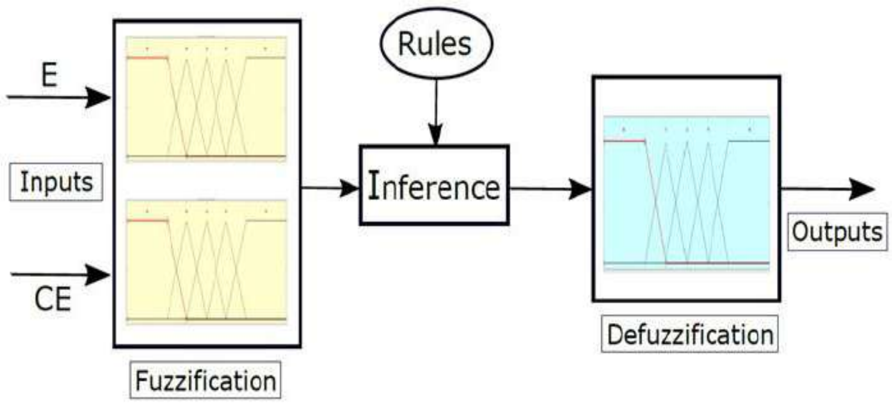

Fig. 3.1 Fuzzy Logic controller structure [1].

Fig. 3.1 shows fuzzy logic controller structure. The design of a fuzzy controller for such a job is described, taking into consideration the foregoing. Error (E) as well as Change of Error (CE) are the two input variables, as illustrated in Equations (3.1) as well as (3.2).

$$E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} = \frac{\Delta P}{\Delta V} \tag{3.1}$$

$$CE(k) = E(k) - E(k-1) = \Delta E \tag{3.2}$$

Where P (k) and V (k) represent the PV panel's power and voltage at sampling time k. Membership functions, which should be discussed in the next section, are used to transform these input values to linguistic terms. Linguistic factors are classified into five categories in our work: H (High), VH (Very High) (VH), N (Neutral), L (Low), VL (Very Low). The P-V curve slope is input E(k), which determines where the MPP is located in the Photovoltaic panel. The CE(k) input indicates if the system response is moving in the MPP directions. The increase in duty cycle (D) is the output variable, which might be positive or negative depending on where the operational point is located. The load is driven by this output, which is supplied to the dc-dc converter. Finally, as indicated in Figure (membership output fig no), the fuzzy controller's outputs (D) are transformed to numerical values, and duty cycle D(k) is determined using the equation:

$$D(k) = D\,(k - 1) + \Delta D(k) \qquad (3.3)$$

3.2 Modelling of Fuzzy Controller

The MATLAB Fuzzy Inference Toolbox was used to simulate the controller. The centroid defuzzification approach was employed with a Mamdani controller. The fuzzy system editors (FIS editors) was used to carry out this method. The Simulink model of the controller is shown in given **Fig. 3.2**.

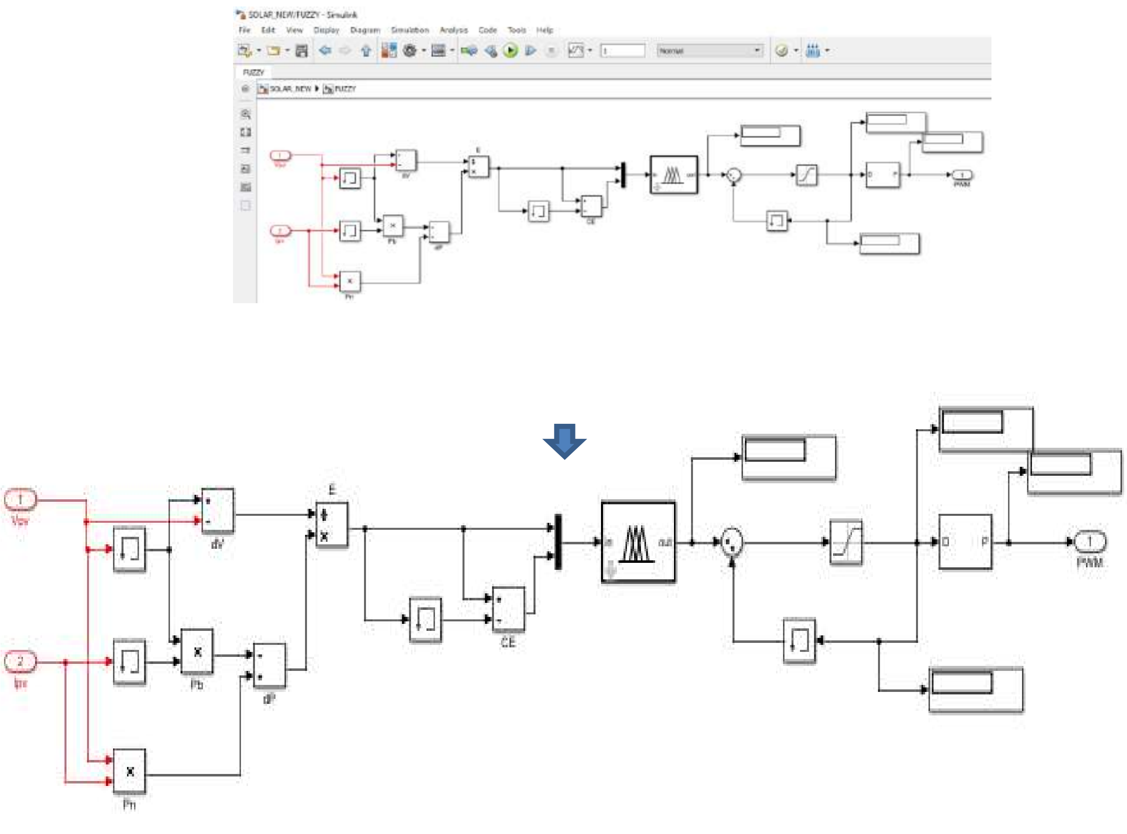

Fig. 3.2 Simulink Model of Fuzzy Logic Controller.

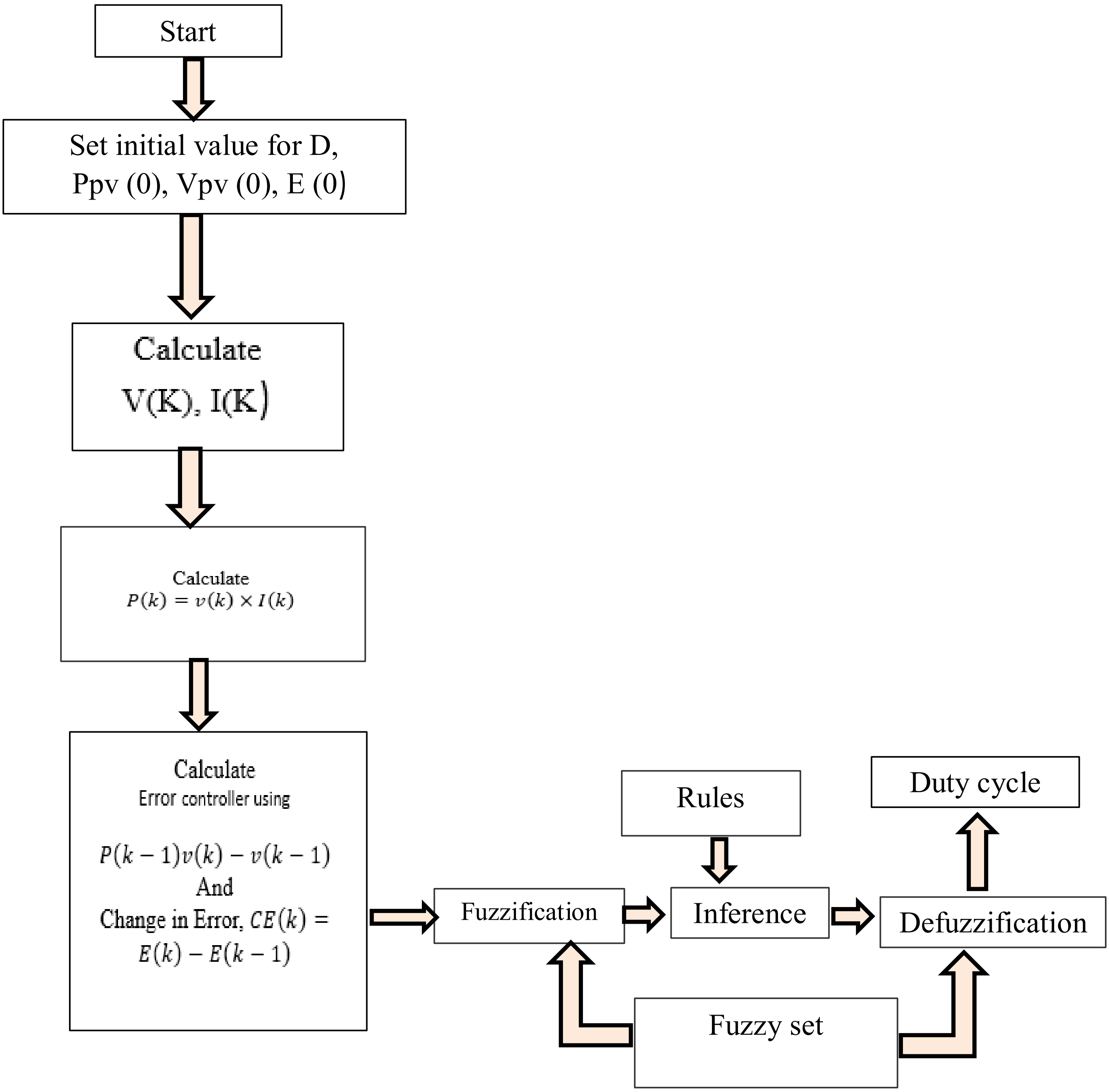

Fig. 3.3 Flowchart of fuzzy logic controller design.

3.2.1 The Membership Function of Fuzzy Controller

In our thesis, we employed triangular membership function parameters for the fuzzification procedure. Five membership functions were developed in terms of the various linguistic variables for the inputs E, CE, and output D: High (H), and Very High (VH), Neutral (N), Low (L), Very Low (VL) are the four levels of difficulty (VH). The error range is (60 to 100), the change in error range is (10 to 10) and the duty cycle increment range is (0.01 to 0.01). Several membership functions for such controller's inputs and outputs are shown in **Fig. (3.4)**.

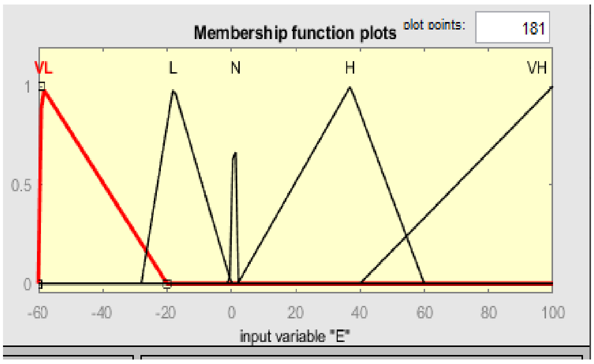

Fig. 3.4(a) Input parameter E shown in figure

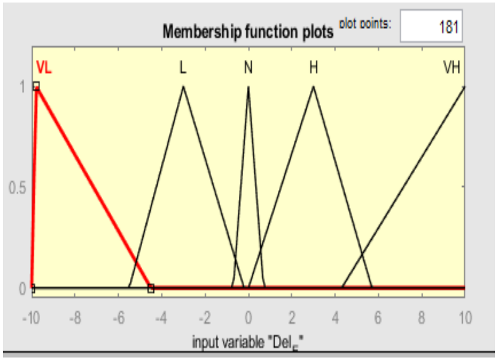

Fig. 3.4(b) Input parameter ΔE shown in figure

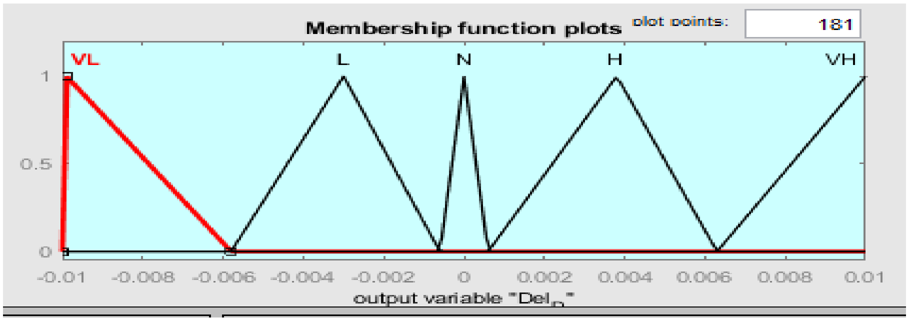

Fig. 3.4(c) Output parameter ΔD shown in figure

Fig. 3.4 Membership functions. **Fig. 3.4(a)** Errors; **Fig. 3.4(b)** Error Change; **Fig. 3.4(c)** Duty Cycle.

3.2.2 Rules of Fuzzy

The 25 fuzzy rules used in the controller are shown in Table 3.1. The two parameters E as well as ΔE are represented by the rows and columns. The parameter ΔD at the meeting of a row and a column is the output.

Table 3.1 Fuzzy conventional rules

E/ΔE	**Very Low**	**Low**	**Neutral**	**High**	**Very High**
Very Low	VH	VH	H	VL	VL
Low	H	H	H	VL	L
Neutral	H	H	N	L	L
High	H	H	L	L	VL
Very High	H	H	L	L	VL

1. If (E is VL) and (Del_E is VL) then (output1 is VH) (1)
2. If (E is VL) and (Del_E is L) then (output1 is VH) (1)
3. If (E is VL) and (Del_E is N) then (output1 is H) (1)
4. If (E is VL) and (Del_E is H) then (output1 is VL) (1)
5. If (E is VL) and (Del_E is VH) then (output1 is VL) (1)
6. If (E is L) and (Del_E is VL) then (output1 is H) (1)
7. If (E is L) and (Del_E is L) then (output1 is H) (1)
8. If (E is L) and (Del_E is N) then (output1 is H) (1)
9. If (E is L) and (Del_E is H) then (output1 is VL) (1)
10. If (E is L) and (Del_E is VH) then (output1 is L) (1)

11. If (E is N) and (Del_E is VL) then (output1 is H) (1)
12. If (E is N) and (Del_E is L) then (output1 is H) (1)
13. If (E is N) and (Del_E is N) then (output1 is N) (1)
14. If (E is N) and (Del_E is H) then (output1 is L) (1)
15. If (E is N) and (Del_E is VH) then (output1 is L) (1)
16. If (E is H) and (Del_E is VL) then (output1 is H) (1)
17. If (E is H) and (Del_E is L) then (output1 is H) (1)
18. If (E is H) and (Del_E is N) then (output1 is L) (1)
19. If (E is H) and (Del_E is H) then (output1 is L) (1)
20. If (E is H) and (Del_E is VH) then (output1 is VL) (1)

21. If (E is VH) and (Del_E is VL) then (output1 is H) (1)
22. If (E is VH) and (Del_E is L) then (output1 is H) (1)
23. If (E is VH) and (Del_E is N) then (output1 is L) (1)
24. If (E is VH) and (Del_E is H) then (output1 is L) (1)
25. If (E is VH) and (Del_E is VH) then (output1 is VL) (1)

Fig. 3.5 System of fuzzy logic by fuzzification rules.

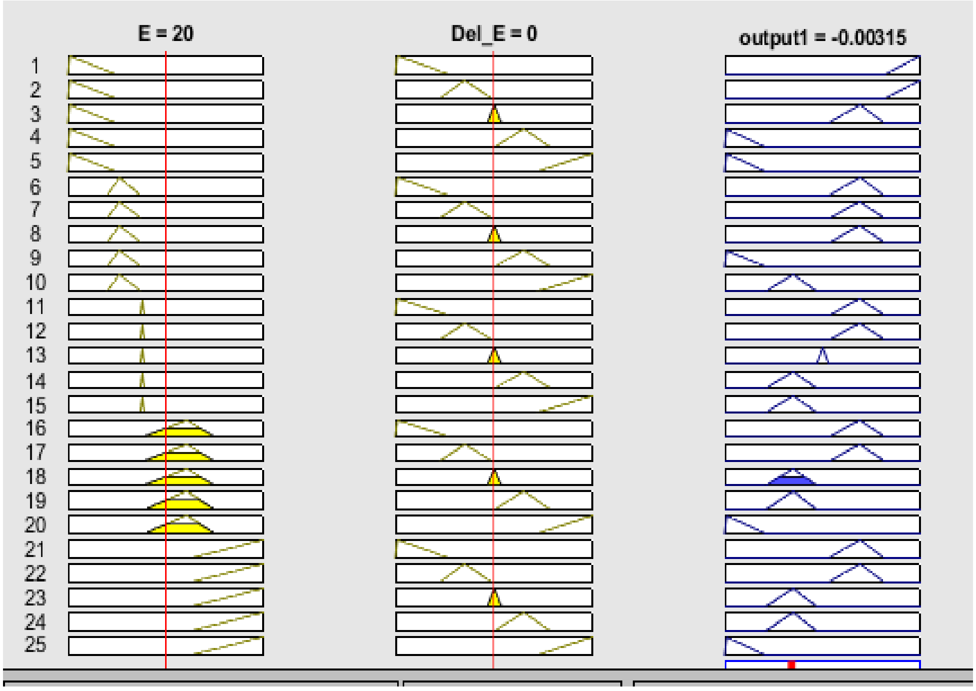

Fig. 3.6 View of fuzzy logic design system in rules viewer.

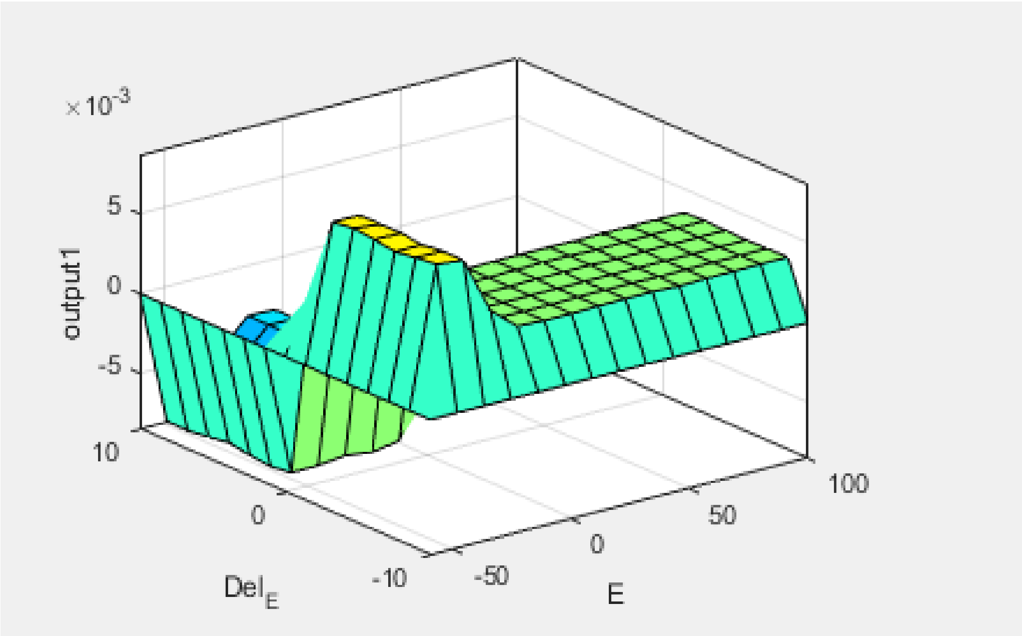

Fig. 3.7 View of fuzzy logic design system in surface viewer.

3.3 PV System Modelling

The PV system, which is made up of the Photovoltaic panel, the boost converter, and the fuzzy controller, is shown in **Fig. 3.8** in MATLAB/Simulink. To test the controller's operation, the signal generator block was being used to create temperature and irradiance inputs.

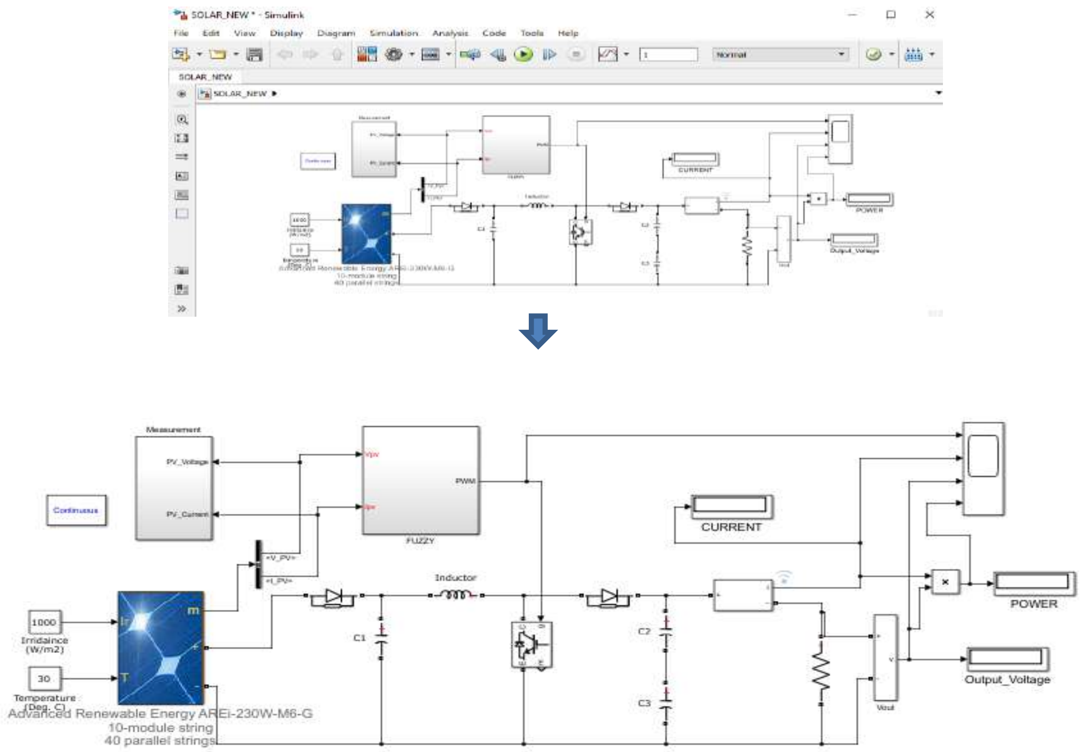

Fig. 3.8 Proposed PV system with fuzzy logic controller.

Table 3.2 Total Parameters of our Photovoltaic source

PARAMETERS	DESCRIPTION	VALUES
V_{ocr}**(V)**	The PV source's open circuit voltage	37.14
I_{scr}**(A)**	The PV source's short circuit current	8
V_{mppr}**(V)**	The PV source's voltage at MPP	30.72
I_{mppr}**(W)**	The max current that our PV source can provide	7.5
n_{iscT}	The Temperature coefficient of short circuit current	0.05535
n_{vocT}	The Temperature coefficient of open circuit voltage	-0.35339
P **(w)**	Maximum Power	230.4
N_{cell}	Cells per Module	60

CHAPTER 4

RESULT

4.1 Introduction

In this Chapter we discussed about the total output of our work. **Fig. 4.1, Fig. 4.2, Fig. 4.3, Fig. 4.4** are the output pulse, current, voltage and power respectively of our designed fuzzy logic controller.

4.2 SIMULATION OUTPUT

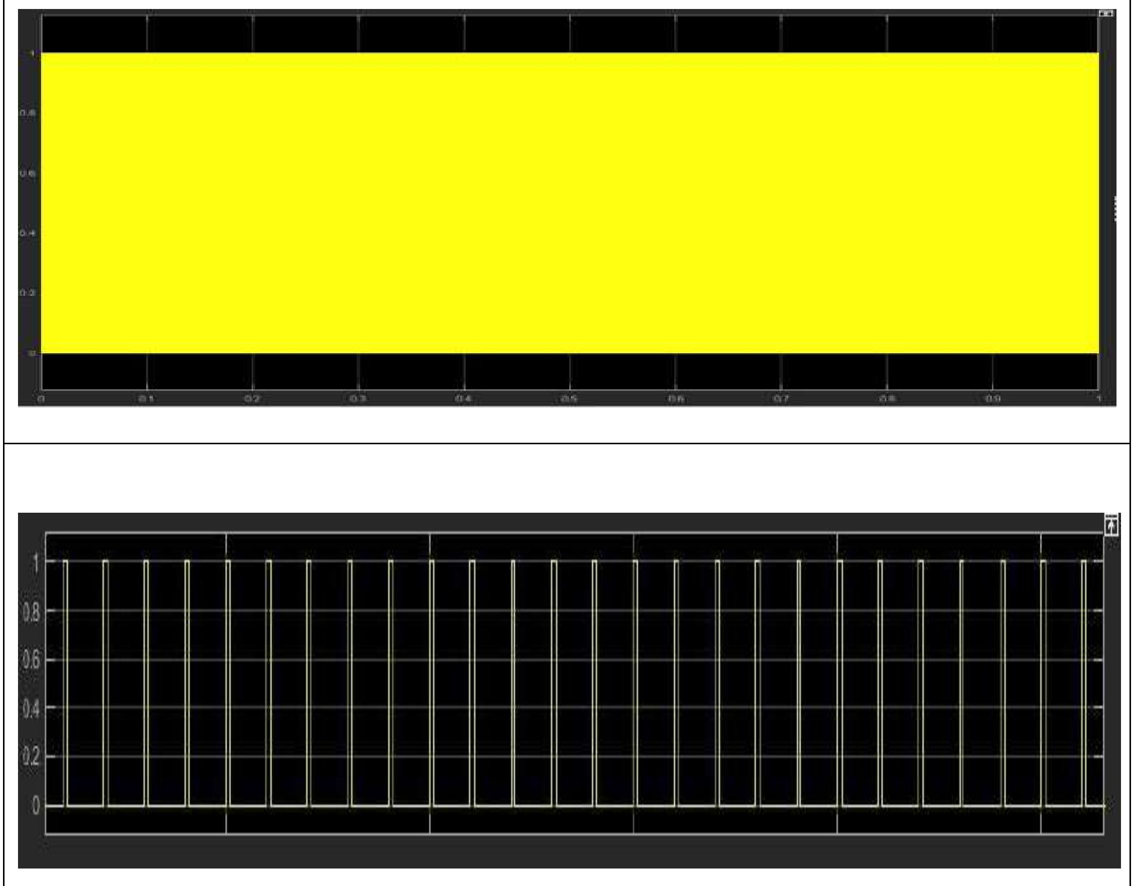

Fig. 4.1 Output Pulses of Proposed Fuzzy system.

Fig. 4.2 Output Current of Proposed Fuzzy system.

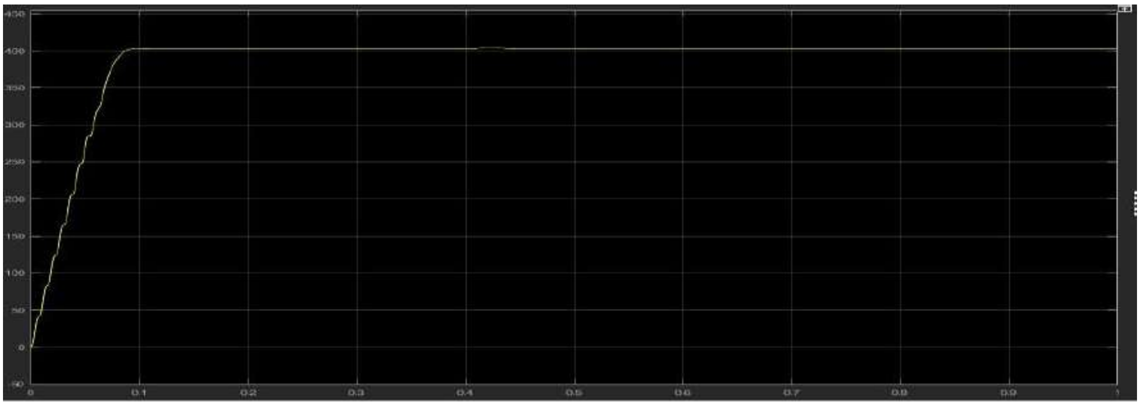

Fig. 4.3 Output Voltage of Proposed Fuzzy system.

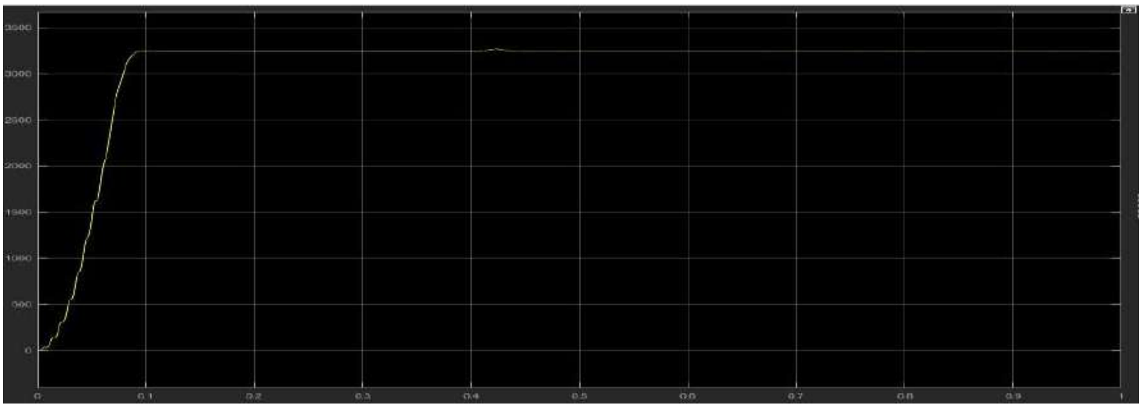

Fig. 4.4 Output Power of Proposed Fuzzy system.

Table 4.1 The table shows that the design of Fuzzy Logic resultant voltage parameters.

Controllers	Fuzzy
Rise time (sec.)	0.05833
settling time (Sec.)	0.07153
Maximum over shoot **(%)**	0.228
Oscillation (V)	0

Table 4.1 is the output parameters of our fuzzy system and this system will be compared with various controller output.

Table 4.2 Output of Various Controller

Controllers	PI	PD	PID	FLC	FPI	FPD	FPID
Rise time (sec.)	0.2460	0.3220	0.2170	1.5457	0.1200	0.1200	0.1200
Settling time (Sec)	1.3500	0	1.3450	2.5007	0.3713	0.1660	0.1580
Maximum over shoot **(%)**	1.2157	0	0.7318	No Applicable	0.2554	0.1304	0.228
Oscillation (V)	No Applicable	No Applicable	No Applicable	0.3941	0.255	0.13	0

Table 4.2 is the output of various controller; which are found from a paper. In that paper they said that their FPID (Fuzzy-PID) controller was very stable and showing good performance. But in table 1 we see that our Fuzzy design performance is better than their FPID design.

So to get better understand, we make a comparison between our fuzzy logic controller and various controller output, which are shown in next **Table 4.3.**

Table 4.3 Comparison between Fuzzy Design parameter & their FPID parameter given below

Controllers	Fuzzy (our design)	FPID (Paper's design)
Rise time (sec.)	0.05833	0.1200
Settling time (Sec)	0.07153	0.1580
Maximum over shoot (%)	0.228	0.0939
Oscillation (V)	0	0

We see above table, the rise time, settling time, maximum overshoot of our controller is better than other controllers output. That means our fuzzy design is faster and stable than the paper FPID design and our design showing good performance. We found better performance by using of only Fuzzy controller. So our objective 1 is fulfilled. In our work, we said fuzzy logic is best technique to get MPPT than other techniques (P&O, INC). At first we showed P&O, INC and modified INC method's output, which are collect from paper. In that paper they said their MPPT techniques are good. But in our work we proved that our MPPT technique using Fuzzy logic method is better than any other method.

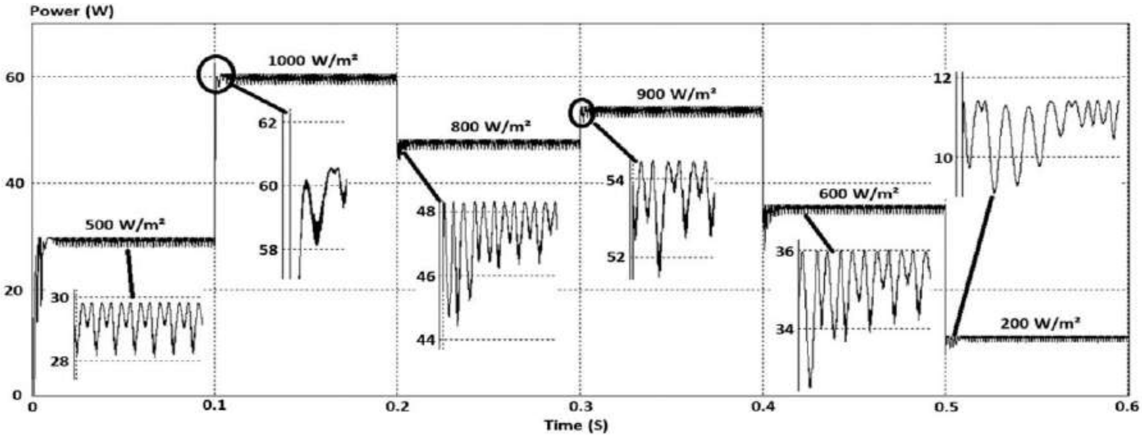

Fig. 4.5 P&O method simulation output [19].

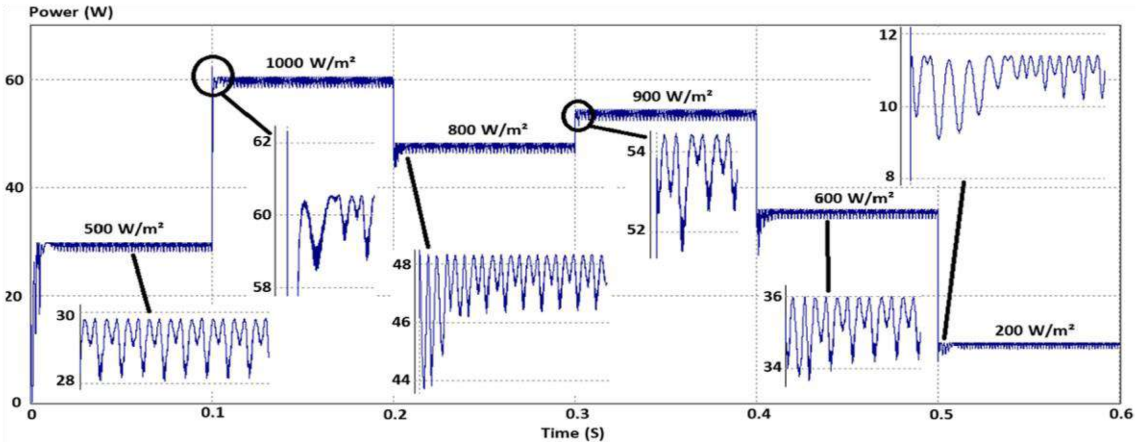

Fig. 4.6 INC method simulation output [19].

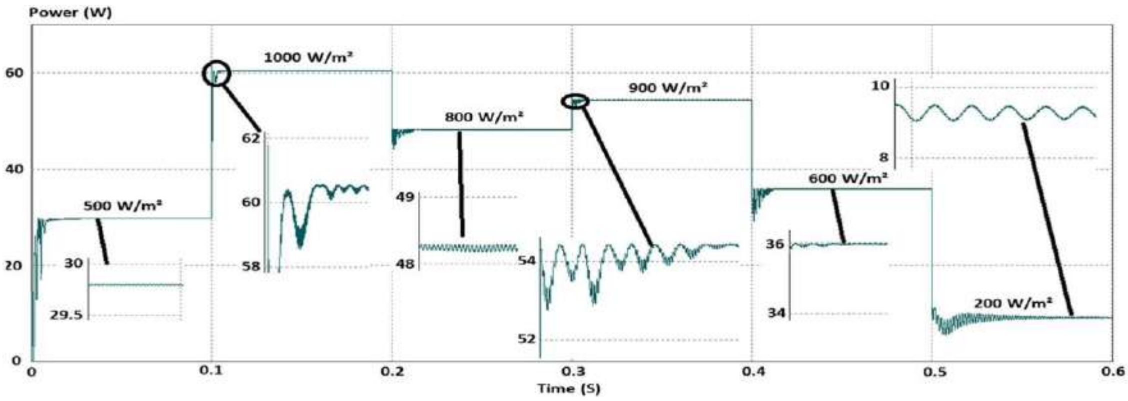

Fig. 4.7 Modified INC method simulation output [19].

In P&O and INC method oscillation is high, but in modified INC method the oscillation should be neglected that means there is small oscillation, but in Our designed fuzzy logic method there is no oscillation that means we get better output from fuzzy logic system to get MPPT. In solar PV system there is an impact of solar irradiation. There is a possibility to get incorrect decision under sudden increase solar irradiation in P&O and INC method. But in fuzzy logic method there is no possibility to get incorrect decision under sudden increase solar radiation. Because this fuzzy logic is an intellectual method to find MPPT and we can make irradiation at a fixed range. So finally we can say that Fuzzy logic system can fulfilled our demand.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In this study, a novel fuzzy controller is utilized to define that maximum point of a Photovoltaic panel, and its result is evaluated to that of traditional PI, PD, and PID controllers, as well as performance analysis using the P&O and INC techniques. For Solar MPPT tracking, we used a boost converter, MATLAB Simulink was used to model all of the PV system's components (PV module, boost converter, Fuzzy system). We designed this solar PV on specific temperature and irradiance. We defined some membership function to get result, these membership function and their rules can be varied to get more accurate result. It was shown that the fuzzy system output performance the Perturbation & Observation and INC methods and several other controllers, in detecting solar Maximum power point. In comparing to other methods such as INC and P&O, the modelling and execution results reveal that fuzzy controller has an improved operational power accuracy and operational performance.

5.2 Future Work

Fuzzy Controller is a versatile and simple machine learning technology that aids in computational models and allows anybody to manage machinery & consumer items. As a result, it will have a massive effect on the engineering sector in the future. The concept of Fuzzy method will be utilized to develop to allow tracking under shading conditions. It would also be an interesting subject to test their authenticity more on other effective converter systems. For improved results, anyone else optimization approach can be combined with fuzzy inference system. A more genuine temporal study that comprises a set of pre irradiance circumstances onto the PV array should be considered in future. It should also be done with a microcontroller or maybe altering the demand just on buck - boost converter even while permitting for fluctuations as in buck-boost converter's source voltage. In addition, various fuzzy system concepts with more sophisticated mappings should be used to enhance the productivity of a DC-DC buck-boost converter when used in combination with a photovoltaic (PV) panel. Fuzzy logic method will be incorporated on the reduced Arduino software in the near, highlighting that fuzzy system is simple to design in embedded systems.

REFERENCES

[1] H. F. A. S. Tatsuya Hinokuma, “Techno-Economic Analysis of a Fuzzy Logic Control Based Hybrid Renewable Energy System to power a University Campus in Japan,” *Multidisciplinary Digital Publishing Institute(MDPI),* vol. 14, no. 7, pp. 1-24, 1 04 2021.

[2] S. Karuppa Samy Anthony, “Fuzzy Logic Based Battery Power Management for PV and Wind Hybrid Power System,” *Asian Journal of Science and Applied Technology,* vol. 3, no. 1, pp. 21-27, 2014.

[3] G. G. Emre Kiyak, “Acomparison of fuzzy logic and PID controller for a single-axis solar tracking system.,” *SpringerOpen Journal,* vol. 3, no. 1, pp. 1-14, 2016.

[4] H. M. E. A. Mohamed El Amir ATTALLA, “Improving Solar Cell System Performance using Fuzzy Logic MPPT Technique under Environmental Condition Variations.,” *International Journal of Engineering Research & Technology(IJERT).,* vol. 10, no. 06, pp. 902-914, June 2021.

[5] J. T. G. O. R. A. Carlos Robles Algarin, “Fuzzy Logic Based MPPT Controller for a PV System.,” *Multidisciplinary Digital Publishing Institute(MDPI).,* vol. 10, no. 12, 2017.

[6] M. Boukasaim, M. Mekhfioui and M. Sifi, “Design and Implementation of Modified INC, Conventional INC, and Fuzzy Logic Controllers Applied to a PV System under Variable Weather Conditions,” *Multidisciplinary Digital Publishing Institute,* p. 71, 9 November 2021.

[7] M. H. Rashid, Power Electronics: Circuits, Devices and Operations, 3rd ed., India: Pearson, 2003.

[8] K. F. Hussein, “Hybrid Fuzzy-PID Controller for Buck-Boost Converter in Solar Energy-Battery Systems,” ScholerWorks at Western Michigan University (WMU), Michigan, 2015.

[9] G. R. S. Jay Stokes, “Implementation of PID controllers on the Motorola DSP560000/DSP56001. Part2. Microprocessors and Microsystems,” *Buuterworth-Heinemann Ltd,* vol. 15, no. 7, pp. 385-392, 1991.

[10] D. Gualtieri, “Google Chrome,” Scientific Consulting and Intellectual Property Creation, 19 October 2010. [Online]. Available: http://tikalon.com/blog/blog.php?article=control_freaks.

[11] H. M. E. A. Mohamed El Amir Attalla, “Improving Solar Cell System Performance using Fuzzy Logic MPPT Technique under Environmental Conditon Variations,” *International Journal of Engineering Research & Technology (IJERT),* vol. 10, no. 06, June 2021.

[12] J. A. A. V. d. B. V. G. M. A. Mohannad Jabbar Mnati, “Review Different Types of MPPT Techniques for Photovoltaic System,” in *International Conference on Sustainable Energy and Environment Sensing (SEES),* Baghdad, Iraq, 2018.

[13] D. S. B. A. K. B. J. Surya Kumari, “Design ans Analysis of P & O and IP & O MPPT Techniques for Photovoltaic System,” *International Journal of Modern Engineering Research (IJMER),* vol. 2, no. 4, pp. 2174-2180, July-Aug 2012.

[14] I. M. T. H. M. O. K. H. Hussein, “Maximum Photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions,” *IEEE,* vol. 142, no. 1, pp. 59-64, January 1995.

[15] Y. S. J. J. Y. G. S. K. G. J. Yu, “A novel two-mode MPPT control algorithm based on comparitive study of existing algorithms,” vol. 76, no. 4, pp. 455-463, April 2004.

[16] S. D. F. L. B. L. Y. K. Fangrui Liu, “A Variable Step Size INC MPPT Method for PV Systems,” *IEEE TRANSACTIONS ON INDUSTRIAL ELECRONICS,* vol. 55, no. 7, July 2008.

[17] M. M. M. N. S. Maroua Bouksaim, “Design and Implementation of Modified INC, Conventional INC, and Fuzzy Logic Controllers Applied to a PV System under Variable Weather Conditions,” *Multidisciplinary Digital Publishing Institute(MDPI),* vol. 5, no. 71, 9 November 2021.

[18] M. De Brito, L. Galotto, L. Sampaio and G. D. A. C. C. e Melo, “Evaluation of the main MPPT techniques for photovoltaic applications,” *IEEE,* vol. 60, no. 3, pp. 1156-1161, 2013.

[19] S. Motahhir and A. a. E. G. A. El Hammoumi, “Photovoltaic system with quantitative comparative between an improved MPPT and existing INC and P&O methods under fast varying of solar irradiation,” vol. 4, pp. 341-350, 2018.

[20] R. Electronics, “The Power of REDARC,” [Online]. Available: https://www.redarc.com.au/how-do-solar-panels-work.

[21] M. Villalva and J. R. F. E. Gazoli, “Comprehensive approach to modelling and simulation of photovoltaic arrays.,” *IEEE Transctions on power electronics,* vol. 24, no. 5, pp. 1198-1208, 2009.

[22] D. Johnson, “Guru99,” 18 December 2021. [Online]. Available: https://www.guru99.com/what-is-fuzzy-logic.html.

[23] G. H. Tien Anh, “A RESEARCH ON MARINE DIESEL ENGINE SPEED CONTROLLER BY FUZZY LOGIC CONTROL THEORY BASED ON EXPERIMENTAL INVESTIGATION,” *Journal of Mechanical Engineering Research & Developments (JMERD),* vol. 17, p. 19, 28 February 2019.

[24] H. Z. D. W. Y Bai, “Advanced fuzzy logic technologies in industrial applications,” *Springer,* pp. 17-36, 2006.

[25] E. Dadios, Fuzzy logic:controls,concepts,theories and applications, BoD-Books on Demand., 2012.