

# Experimental Investigation and Development of Fuzzy Logic-Based MPPT for Photovoltaic Systems Across Varied Climatic Conditions

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**Abstract.** *The Fuzzy-based photovoltaic (PV) Maximum Power Point Tracking (MPPT) algorithm is a sophisticated approach for enhancing the efficiency and performance of solar photovoltaic systems. It uses fuzzy logic principles to dynamically track and maintain the optimal operating point related to PV panel, ensuring that the determined available power is extracted under varying environmental conditions. Unlike traditional MPPT techniques, the Fuzzy-based PV MPPT algorithm excels which adjusting to changing rapidly the weather surroundings and is more robust in partial shading scenarios. It employs linguistic variables and rule-based decision-making to continuously adjust the voltage which related to the current at which the PV panel operates. This enables the system to efficiently respond to factors such as cloud cover, shading, and temperature variations, optimizing energy production and reducing energy losses. The adaptability and robustness of the Fuzzy-based PV MPPT algorithm make it a valuable tool for harnessing renewable solar energy, contributing to sustainable power generation and reducing reliance on conventional energy sources. The Fuzzy-based MPPT algorithm presents a compelling solution to address the shortcomings of conventional MPPT controllers and increase 2. operational effectiveness of solar power systems.*

## Keywords:

Fuzzy, MPPT, PV, Converter, MATLAB

## 1. Introduction

In the realm of solar energy utilization, the need for a reliable and efficient (MPPT) controller in (PV) schemes takes become increasingly evident. PV systems are vital for harnessing solar energy, which is an abundant and sustainable power source. However, their performance can be significantly hampered by variations in environmental conditions, such as sunlight intensity, shading, temperature, and other dynamic factors [1-2]. Traditional and conventional MPPT controllers, although widely used, have certain disadvantages that limit their effectiveness in enhancing the energy creation of PV systems. Conventional MPPT controllers, often based on techniques

are PO, have been the go-to choose for many PV systems. These controllers typically rely on a simplistic approach of adjusting the  $V_{\text{Operating}}$  and its  $I_{\text{PV panel}}$  to determine the point at which the system extracts the most power [3-4]. Although they do improve energy output compared to fixed-voltage systems, they have inherent limitations.

One of the primary disadvantages of conventional MPPT controllers is their susceptibility to rapid changes in environmental conditions. Sudden cloud cover or shading can lead to frequent and unnecessary perturbations in the operating point, causing the scheme to operate far from the maximum power point for extended periods [5-7]. This results in energy loss and inefficient power generation, particularly in regions with highly variable weather patterns. Furthermore, conventional MPPT controllers often struggle to achieve accurate tracking in partial-shading scenarios. When portions of a PV panel are shaded, the controller may misinterpret the conditions and select an incorrect operating point, further decreasing the overall system efficiency. Furthermore, under specific circumstances, they might show steady-state oscillations near the maximum power point, causing wear and tear on the PV system components and reducing their lifespan [8-9]. The fuzzy-based MPPT algorithm, on the other hand, offers a convincing remedy to report these shortcomings and increase the performance of PV systems. Fuzzy logic is a computational approach that incorporates linguistic variables and rule-based decision-making, allowing for more nuanced and adaptive control. When applied to MPPT, fuzzy logic enables the controller to respond dynamically and intelligently to changing environmental conditions [10]. One of the benefits of the Fuzzy-based MPPT algorithm is its adaptability to rapidly changing weather conditions. It can swiftly and accurately adjust the operating voltage and its current towards the PV panels in response to sudden changes in sunlight intensity or shading, ensuring that the scheme consistently operates near the peak value. This adaptability suggestively decreases the loss in energy and increases the Energy generation capacity of the Solar system [11]. By considering linguistic variables and rules, it can better discriminate between partial shading and true changes in the maximum power point, mitigating the risk of

erroneous decisions. This capability is crucial in urban environments, where shading from nearby buildings or trees is common [12]. In this study, the need for efficient MPPT controllers in PV systems is indisputable, given the increasing reliance on solar energy as a sustainable power source. Conventional controllers, although widely used, have shortcomings that limit their effectiveness, particularly in rapidly changing weather and uneven shadowing scenarios. The FL offers a promising alternative, leveraging principles to provide adaptive and accurate control, ultimately maximizing energy production and reducing reliance on conventional energy sources [13]. In order to maximize the potential of solar energy, which is still essential to our shift to greener and further environmentally friendly energies, sophisticated MPPT algorithms such as fuzzy must be used.

### 1.1 Literature Survey

An enhanced control scheme is introduced for solar photovoltaic (PV) systems Grid-tied, incorporating (MPPT). The algorithm, known as PO, suffers from several limitations including suboptimal efficiency, prolonged settling time, and increased ripple. Additionally, P & O is also associated with a critical issue of grid current ripple. Furthermore, the voltage regulation of solar PV in the conventional method relies on the proportional gain value, which poses challenges in ensuring stability in the constant current region. In consideration for resolving these concerns is a two-phase solar PV grid system. A contemporary FLC is implemented to accomplish rapid dynamic response and minimize disturbance in the grid current. The feedback-driven linearization-based volt controller is employed to address voltage instability in contrast to the traditional PI voltage controller, in the solar PV's constant current zone. [14]. (MPPT) used to make sure that photovoltaic systems work at their best and get the most power from any level of sunlight. This is done because solar energy is constant. In stand-alone photovoltaic systems, batteries are often used as a backup for power control. This makes sure that load always has power, even when the sun isn't shining. We present a new battery management system (BMS) and MPPT controller for a solar system without any external connections that uses fuzzy logic. The logical control method and the conventional perturbation and observation technique are put side by side to see how well the suggested fuzzy logic control system works. By creating a BMS with a new system that considers a number of restrictions, it is possible to protect both the workload and the battery properly. Depending on the amount of irradiance, different parameters are measured, such as the output voltage, the maximum power, and the state of the battery status are (100W/m<sup>2</sup>, 500W/m<sup>2</sup>, 1000W/m<sup>2</sup>) [15]. A (FLC)-based grid-tied photovoltaic solar power system is shown that can handle changes of voltage at CPI by controlling the  $DC_{linkV}$  in a reactive way. Solar power from PV panels is taken in by a boost converter using the MPPT method transferred to the PV generator's DC circuit. The conversion device for voltage

sources lets the PV transformer send power to the grid. When the voltage changes quickly at the CPI, the MPPT method gives better dynamic performance than other ways. MATLAB/SIMULINK is used to build and test the recommended FLC MPPT solar PV system [16].

The study proposes a fuzzy logic-based MPPT modeling and management technique for a grid-connected hybrid energy system that includes a solar power plant, a DC to DC converter, and a storage module. MATLAB simulations demonstrate that the suggested approach is more dependable and effective at tracking loads than PID MPPT controls. The study proposes an artificial intelligence-based fuzzy reasoning MPPT modeling and control approach for a grid-connected hybrid power system with a PV system, a DC-DC converter, and a power storage module. Suggested method applies seven fuzzy groups with seven linguistic variables to the DC-DC converter and includes a battery module as a way to store energy when there is extra power and/or as a backup when the load demand is high. The fuzzy logic-based MPPT controlling and modeling method used seven fuzzy sets with seven language variables on the DC-DC converter. It also used a battery module as a way to store energy when there was extra power and/or as a backup device when the load demand was high. This work adds to the study of MPPT methods for PV systems in hybrid power systems. It focuses on fuzzy logic-based controllers using MPPT as a promising way to control a nonlinear PV system [17].

The newly developed intelligent artificial system in this study depends on a Mamdani inference fuzzy type FL controller and was tested in normal ways. The system works with a photovoltaic panel that has a battery store that is controlled by a bi converter. The suggested controller, which is responsible for determining the maximum power point, was thoroughly tested using the MATLAB/Simulink software. The two input sources for the system are a battery and a photovoltaic module. It also features a fuzzy logic driver, a bidirectional converter, and a boost converter. The outcomes, which originate from several steady instances such as varying loads (such as full load and no load) and irradiation levels ( one thousand Weber/meter<sup>2</sup>, six hundred Weber/meter<sup>2</sup>, four hundred Weber/meter<sup>2</sup>, and 200 Weber/meter<sup>2</sup>), unequivocally demonstrate that the fuzzy logic controller functions as intended. The outcomes also demonstrate that, in terms of flexibility, speed, and economy, the artificially intelligent controller performs better than the standard controller in the same system. [18].

The study is mostly about controlling voltage, which is an important part of both transmitting and distributing electricity. Voltage and frequency mismatches can happen when solar cell power goes into the low voltage distribution grid. This is because non-linear loads can cause harmonics. The FACTS controller device D-STATCOM is used in this study to make voltage regulation and power system safety better. The model was looked at in a number of different working situations and

judged using the MATLAB SIMULINK program. [19]. The study comes up with phase response-based lag, mercury, lead, and lead-lag regulators for supporting the stability of boost converter systems connected to green sources of energy and the grid/load. In terms of setting time, rise time, and peak overshoot, fuzzy logic controllers do better than linear controllers. Boost converters can use frequency response-based lag, lead, and lead-lag controls to keep things stable and match phase margin, bandwidth, and cross-over frequency needs. The lead-lag control has better overshoots rise time, as well as settling time than the lag and lead controllers, as shown by the models. The study talks about the fuzzy logic system, which is better than linear controllers at peak overshoot, setting time, and rising time. That proves that the fuzzy logic device could manage a boost converter system connected to clean sources of energy and the grid/load. [20]. Voltage and a distinct maximum power point (MPP) exist. To ensure optimal power delivery to the load during operational changes, a MPPT controller is required. Traditional controllers, like P&O and incremental, struggle to provide quick responses for fuel cell operation. This research analyses and enhances PEM fuel cell efficiency utilizing several intelligent controller strategies based on MPPT. MATLAB is used to design and implement intelligent controllers for PEM fuel cell power systems. Simulated results are compared and analysed. The optimal intelligent controller was selected for its ability to enhance fuel cell efficiency in nonlinear operating situations [21]. This piece talks about the maximum power point track of smart controller-based fuel cell power systems. A lot of MPPT methods were looked at. The performance of the final fuzzy logic-based MPPT technique for the fuel cell system is looked at. In this study, we looked at how the electrical characteristics of PEM fuel cells changed with the flow rate of fuel. A fuzzy logic-based MPPT method was modeled in MATLAB Simulink software to look at how well it works with clever control and find the best way to use fuel. The evaluated patterns show that the system works well. [22]. A boost chopper-based cascaded dc/dc converter is shown. Configurable parameters include converter settings and PV cell layout. The entire system is optimized. To optimize boost chopper components, semi-empirical models of losses and volumes were created. Optimization uses sequential quadratic programming. To optimize, loss and boost volume models were created. The best depends on many factors. A flexible converter has been tested to handle these variances. Experiments confirm the converter's modularity and efficiency [23].

The essay proposes integrating AI with a standalone photovoltaic power plant to optimize energy production. Suggested ANFIS-based MPPT provides fast and precise dynamic response. Feed through the ratio of duty and modulation index are controlled by the qZSI's closed-loop system to effectively manage injected power and preserve current, frequency, and voltage [24].

For MPPT in partially shaded photovoltaic (PV) systems, the firefly approach is employed. The method has the

advantages of simple calculation, fast convergence, and inexpensive microcontrollers. For two PV array designs in partially shadowed situations, the tracking performance of the proposed technique is compared to that of particle swarm optimization and perturbation and observation [25]. (MPPT) is applied to solar cells with a low gear ratio. Determine the array's junction conductance and current voltage. The array junction current is then estimated using an ANFIS solar cells framework based on the array's observed voltage and current. Two more sensors are required due to the difficulties of monitoring cell temperature and sun radiation, which increases measurement noise and system circuits.

An analytical model using wavelets for denoising is presented. One voltage sensor is all that's needed for MPPT to save hardware installation time and boost array power [26]. In this study, they explore the application of a multilevel topology and a medium-frequency ac link to incorporate utility photovoltaic (PV) plants onto a medium-voltage grid. Two series-connected arrays are often used in a megawatt-scale PV facility's multiple zone. Every zone's medium-frequency transformer contains three secondaries that link to the medium volt grid's three phases. The MF transformer gets its juice from an inverter that uses a full bridge of insulated-gate bipolar transistors. Three full-bridge ac-ac converters are used to convert the transformer's secondary voltage to the three-phase line frequency ac. Because the dc bus is protected from the harmonic power of the second line frequencies, the capacitor's size can be decreased. Since the medium-voltage output is cascaded from several cells, it is of high quality. An alternative way of managing the cascaded multiple converter leads to lower switch ratings under partial shading. The suggested design optimizes the power factor and power yield by eliminating the isolation of the line frequencies transformer and reducing the size of the dc bus capacitor. In the present article, the results of an experimental prototype that was constructed smaller and powered by a 10-megawatts utility photovoltaic system. The novel energy management method uses a 4-kW hybrid photovoltaic (PV) power conditioning system with an energy storage device. A lithium-ion battery or other ESD boosts the system's energy efficiency based on time and weather. A new function for real-time energy management without weather forecasts, home load changes, and electricity price is suggested. By charging for nocturnal electricity, the suggested energy management system (EMS) can cut electricity costs. It reduces daytime grid voltage oscillations from high PV generation [28]. The gradient-wise optimization (GWO) technique is proposed for MPPT in PV systems to address issues like poor tracking efficiency, steady-state oscillations, and transients found in P&O and IPSO methods. Under partial shading conditions (PSCs), the GWO-MPPT demonstrates superior tracking performance compared to P&O-MPPT and IPSO-MPPT. Simulations using MATLAB/SIMULINK confirm GWO-MPPT as the most effective approach. [29]. This research provides the boost-multilevel inverter design with a built-in energy

storage system for use in stand-alone applications. This inverter design is more compact, less expensive, and more reliable as cascaded H-bridge multilevel inverters because it utilizes fewer power switches. By optimizing switching angles, the GA method may eliminate voltage harmonics at will, subject only to the constraints imposed by the fitness function. Batteries can be charged while the inverter is operating [30]. In this paper, we present an incremental conductivity (IC) for MPPT that uses fuzzy logic. In conditions when the weather is constantly changing, the proposed MPPT method excels above the industry-standard IC MPPT method. In simulations, IC MPPT controllers based on fuzzy logic respond to changes in solar radiation more quickly and oscillate less than their traditional counterparts. [31-32].

### 1.2 Research Gap and Objective

This research focuses light on the shortcomings of conventional MPPT controllers, such as their susceptibility to rapid changes in the surrounding environment; imprecise tracking in scenarios where there is partial shading; and steady-state oscillations. The purpose and aim of the research are to solve these restrictions and enhance the efficiency of PV systems by providing a fuzzy-based algorithm for PV (MPPT). Therefore, the research need in this study can be deduced as the need for a more adaptive and resilient MPPT algorithm that is able to successfully handle quickly changing weather conditions, partial shading scenarios, and enhance overall system efficiency.

### 1.3 Maximum Power Point Tracking

On average, about 30 to 40 percent of incident radiation from the sun is converted into electrical energy by a solar panel. The efficiency of solar panels is increased with the use of MPPT technology. Because it fluctuates over time on Earth, the sun is not a reliable supply. We must monitor a solar cell's maximum power under a variety of circumstances in order to employ MPPT controllers. There are numerous MPPT strategies utilized in photovoltaic power systems.

#### 1.3.1. Integration-Reset Technique

The method is a not a linear MPPT one. It has a single-phase inverter that has been consolidated, and the output  $I_{\text{Inverter}}$  may be measured by altering the  $V_{\text{Inverter}}$  with the assistance of the L and C parameters

#### 1.3.2. Current and Voltage Feedback Method

This technology is typically utilized in conjunction with a photovoltaic power system that lacks storage. In this procedure, the real output voltage or current principles from the PV panel have to be linked with the  $V_{\text{reference}}$  and  $I_{\text{value}}$ , and then error needs to be determined.

The duty cycle of DC/DC converter's is optimized with an error value in mind, operating the PV panel near its current set point and increasing it incrementally by  $\Delta I$ . This results in a higher output power, which is then added to the current set point.

#### 1.3.3. Feedback of Power Variation with Rate of Change of Voltage and Current

When it comes to monitoring power fluctuations with voltage or current (dP/dV) or (dP/dI) equal to zero under power feedback, this approach is similar to the feedback voltage and current method.

## 2. Proposed model Intelligent Control Based MPPT Method

Fig.1 shows the proposed block diagram, Due to the technology that allowed us to develop a fuzzy logic system, the proposed method can explore the electrical properties of PV cells while they were exposed to diverse atmospheric circumstances. The fuzzy logic controller gets one  $V_{\text{actual}}$  and one reference  $V_{\text{reference}}$  via its two inputs. We used fuzzy rules that are reliant on the input value, and the index of modulation was computed as the fuzzy controller's output. Since the trapezoidal approach makes it possible to produce the largest output with the fewest number of fuzzy rules like low, medium and high, it is employed in the construction of the fuzzy interference. The centre of gravity approach is employed throughout the defuzzification process to establish the converter's output modulation index and approximate maximum power point tracking.

### 2.1. Solar Cell Characteristics

#### 2.1.1 Voltage Below Open Circuit State:

When the photocurrent  $I_p$  is transverse to the diode (p-n junction), or towards the produced current  $I = 0$ , voltage is equivalent to the voltage reduce towards the diode. It displays the cell's voltage when there is no sunlight. and it can be statistically expressed as

$$V_{(\text{opencircuit})} = \left( \frac{n_1 K_1 T_1}{q_1} \right) \ln \left( \frac{I_1 - I_{\text{saturation}}}{I_{\text{saturation}} + I} \right) \quad (1)$$

Where

$n_1$  - diode ideality constant  
 $K_1$  - the Boltzmann constant  
 $q_1$  - electron charge

$I_{\text{saturation}}$  - diode current saturation

Like  $I_{ph}$  (A),  $I_L$  =light-generated current.

$T_1$  - temperature

#### 2.1.2 Electron-Hole Pairs Generation

$$I_l = (G_r / G_{\text{reference}}) * (I_{\text{reference}} + \alpha_{\text{Isc}} (TC - T_{\text{panel}(\text{reference})})) \quad (2)$$

Where

$I_l$  - Light generated current (Radiation)

$I_{\text{reference}}$  Photoelectric current under standard condition

$T_{\text{panel}(\text{reference})}$  the panel temperature under standard condition

$G_r$  - radiation in W/m<sup>2</sup>

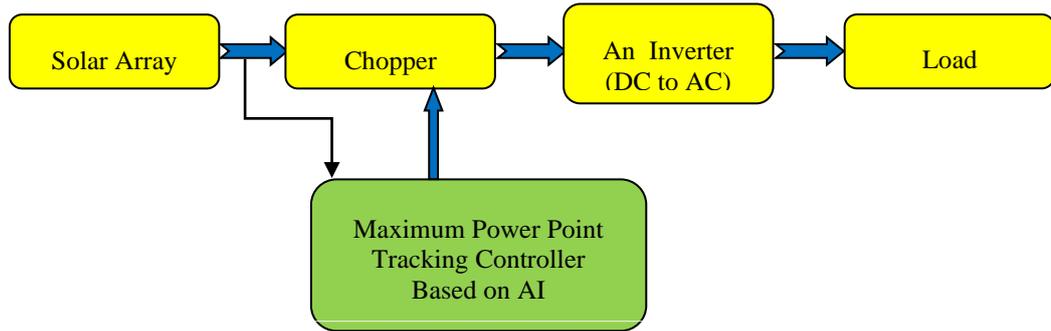


Fig.1 Proposed model

$G_{reference}$  - radiation in normal circumstances.

$A_{Isc}$  - temperature co-efficient of the  $I_{sc}$

$\alpha_{Isc}$  - Short circuit attenuation

2.1.3 Negative Current Produced by a Reverse Bias:

$$I_{Rev \text{ saturation}} = I_{saturated} (T_1/T_{reverse})^{3} \exp((qE_{bgs}) / (K_1 * n_1)) * (1/T_{reverse}) - (1/T_1) \tag{3}$$

Where

$K_1$  - Boltzmann constant

$T_1$  - temperature

$I_{saturated}$  - saturation current

$n_1$  - ideality factor

$E_{bgs}$  - silicon's band gap

$q$  - Charge

2.1.4 Current under Short Circuit Condition

$$I_{short \text{ circuit}} = I_p$$

It refers to the highest possible current's value that is produced by a cell. It results from circumstances of a sc, which are:  $V = 0$

$$I_{sc} = I_l - I_o ((\exp(q_l (V - I_l R_s) / (n_1 K_1 T_1)) - 1)) \tag{4}$$

3.1. Define Input and Output Variables

- Determine which input variables have an impact on PV system performance. These typically include limitations such as solar irradiance, panel temp and voltage.

3.2. Fuzzy Input Variables

Apply linguistic labels to each input variable, dividing the range of possible values into categories. For example, "Low," "Medium," and "High" High for solar irradiance.

- Create membership functions that describe how each value belongs to each category. These functions are typically triangular or trapezoidal.

3.3. Define Fuzzy Rules

- Establish a set of if-then rules that map the combinations of linguistic labels of the involvement variables to linguistic labels of the output variable.

- These rules encode expert knowledge on how to adjust the PV system's operating point to achieve MPP under varying conditions.

- For example, a rule might be: "If solar irradiance is High and panel temperature is Low, then increase the duty cycle."

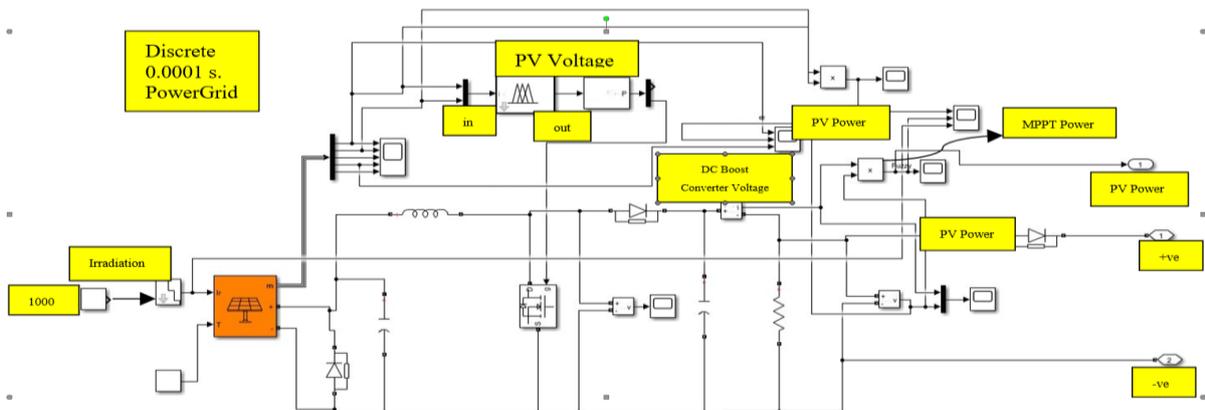


Fig.2 Model for simulating - fuzzy MPPT method for PV

### 3.4. Fuzzy Inference System

- Create a FIS calculates the level of each input variable's membership to each linguistic label and combines them according to fuzzy rules to determine the output.

### 3.5. Defuzzification

The fuzzy output (linguistic labels) is converted into an output value that is clear and reflects the intended control action.

- Common techniques for defuzzification include the centroid of the area or weighted average.

### 3.6. Implement the Controller

- Integrate the FLC into the PV system control structure. This may involve programming a microcontroller or a dedicated MPPT controller.

- Implement a control algorithm such that it continuously measures the input variables (solar irradiance, panel temperature, voltage, etc.) and uses the FLC to calculate the duty cycle or voltage reference for the PV inverter.

### 3.7. Testing and Fine-Tuning

- Test the fuzzy-based MPPT controller extensively in a range of environmental settings, including temperature and solar irradiation levels.

- Observe the system performance and fine-tune the membership functions and rules if necessary to optimize the controller response.

### 3.8. Validation and Evaluation

- Validate the FLC performance by comparing it with other MPPT algorithms, such as Perturb and Observe or Incremental Conductance, in real-world conditions.

- Evaluate the FLC's effectiveness in terms of energy yield and efficiency improvement.

### 3.9. Deployment and Monitoring

- Once validated, deploy the Fuzzy-based MPPT controller in your PV system.

- Continuously monitor system performance and make any adjustments or updates to the FLC as needed to ensure optimal MPPT under changing environmental conditions.

Developing a Fuzzy Logic Controller for PV MPPT requires a solid understanding of fuzzy logic principles, as well as expertise in programming and control systems. The effectiveness of the controller largely depends on the accuracy of the fuzzy rules and membership functions,

making thorough testing and fine-tuning critical for its successful implementation.

Fig.2 illustrates simulated model of the proposed fuzzy MPPT approach for the solar system is depicted in picture. The approach depicts algorithm's regulation framework and how the i/p and o/p variables interact. Using simulation models is essential for evaluating how well an algorithm performs in different situations. A summary of fuzzy MPPT model is given in Figure. 3. The algorithm's main elements and decision-making procedures are shown in this picture. The model's accuracy and adaptability in tracking the peak power point can be impacted by its complexity

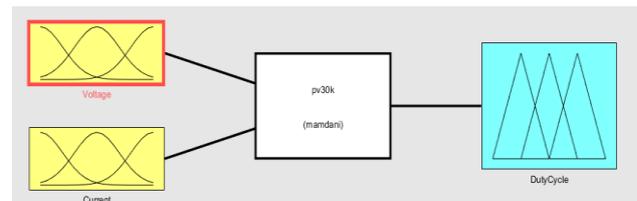


Fig.3 Fuzzy MPPT algorithm model

The input and output membership functions of the fuzzy MPPT algorithm are shown in Figures 4 and 5. The following diagrams show how the algorithm identifies the appropriate output, such the duty cycle, classifying input variables, like V and I, into a language labels (e.g., "Low," "Medium," and "High"). The algorithm's decision-making is influenced by the ranges and patterns of these functions of membership.

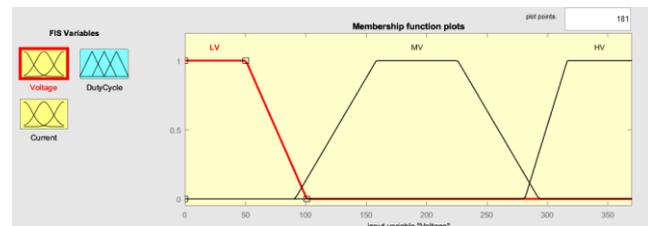


Fig.4 Fuzzy MPPT algorithm input membership function – Voltage

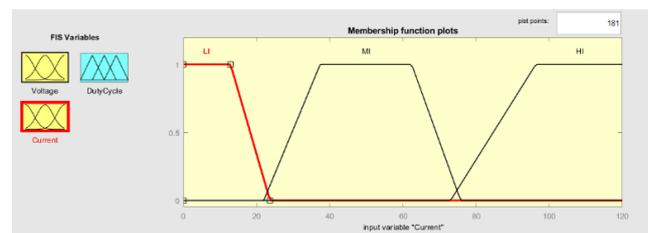


Fig.5 Fuzzy MPPT algorithm input membership function – current

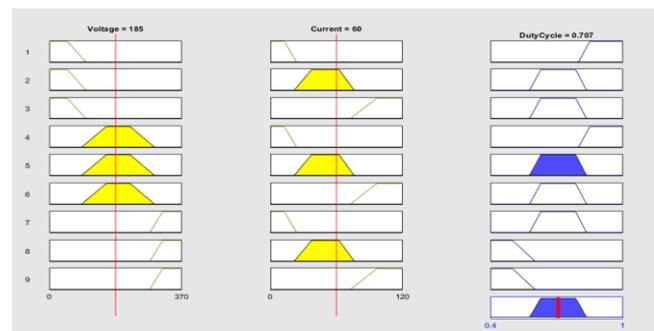


Fig.6 Fuzzy MPPT algorithm rule-based system

The fuzzy MPPT algorithm's rule-based framework is shown in Fig. 6. This picture shows how the algorithm creates an output by combining the linguistic labels of  $i/p$  variables.

Fig.7 demonstrate the Operational influence of the FLC approach on power generation. Fig. 6 shows the PV power production in different irradiation scenarios, highlighting the ability of the algorithm to adapt to changing sunlight intensity. This figure shows the impact of the approach in maximizing output.

Fig.8 shows the power waveform resulting from the FLC based MPPT for solar system. This shows how the algorithm minimizes fluctuations in power generation. and maintains the system's performance near its peak power point. A stable power waveform indicates efficient energy conversion.

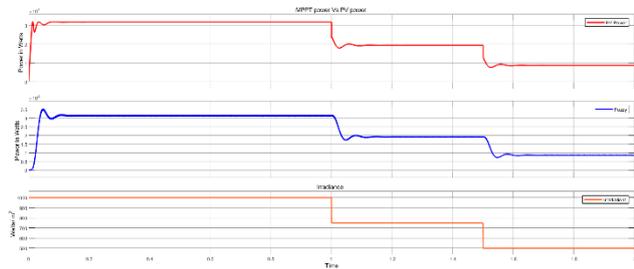


Fig.7 Power production of PV MPPT under diverse irradiance scenarios.

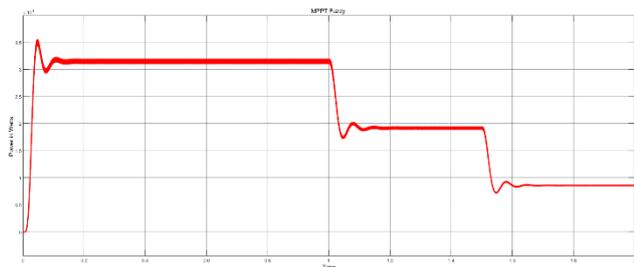


Fig.8 Fuzzy logic controller-based PV MPPT power waveform

Fig.9 displays the V and I waveforms of PV system under control of Fuzzy-based MPPT algorithm. These waveforms reflect the dynamic adjustments made by the algorithm to maintain the MPP. The PV properties under different weather scenario are displayed in Fig. 10. The figure is essential for evaluating how well the FLC handles challenges such as shading and temperature variations. The adaptability of the algorithm in maintaining optimal performance despite environmental fluctuations is a key takeaway. In the results and discussion section, it is crucial to analyze the data from these figures and compare the performance of the Fuzzy approach to traditional MPPT techniques. Examine the algorithm's ability to adjust to swiftly fluctuating weather conditions. Its accuracy in partial shading scenarios, and the overall improvement in energy production and system efficiency. Additionally, we consider the implications of these findings for the broader adoption of advanced MPPT algorithms in the context of sustainable energy generation.

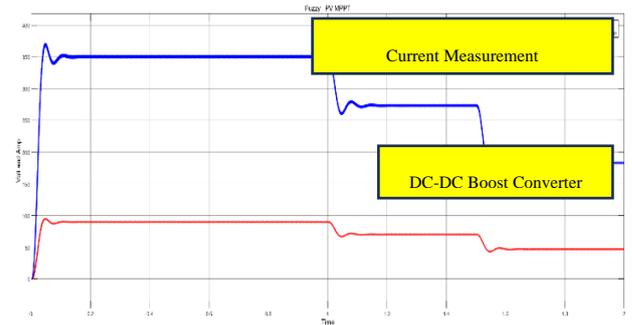


Fig.9 FLC based PV MPPT V and I waveform

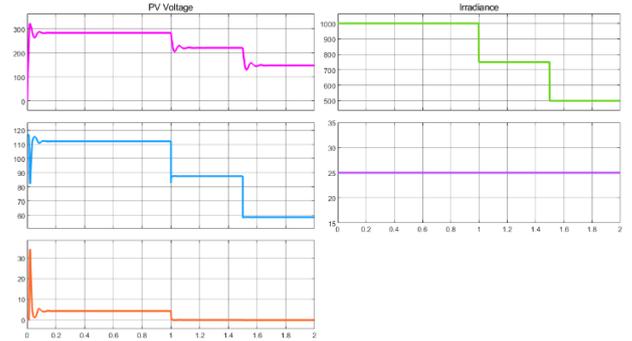


Fig.10 PV characteristics under various weather conditions

#### 4. Analysis of Traditional Methods Comparison of Mppt

P and O, INC method, HIL method of MPPT is simulated by considering the radiance as main parameter. The irradiance levels tested are: one thousand Weber per  $m^2$ , seven hundred and fifty Weber per  $m^2$ , five hundred Weber per  $m^2$ , four hundred Weber per  $m^2$

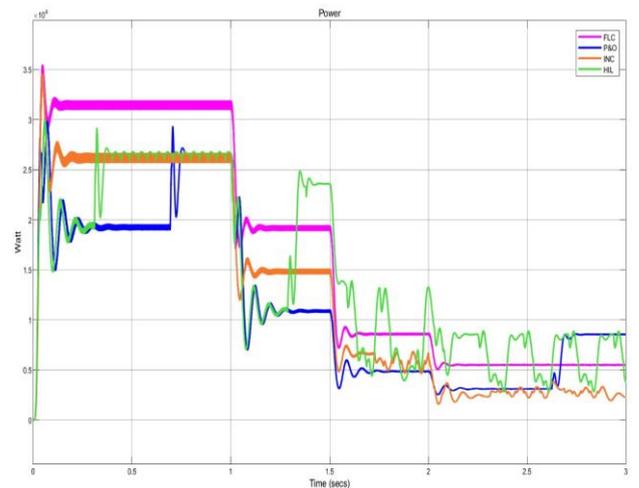


Fig.11 PV characteristics for different algorithms

In the simulation, the effectiveness of four Maximum Power Point Tracking (MPPT) algorithms—Hill Climbing (HIL), Incremental Conductance (INC), Perturb and Observe (P&O), and Fuzzy Logic Control (FLC)—in optimizing the power output of photovoltaic (PV) systems under various irradiance conditions is compared. The

magenta line, or FLC, represents the optimal overall performance with few oscillations and good stability, which makes it appropriate for sustaining a steady power output. The orange INC algorithm provides dependable performance by striking a compromise between responsiveness and stability. P&O, shown in blue, tracks well but is less efficient due to oscillations [Fig.11]. The least stable method is the HIL algorithm, shown in green, which struggles with varying irradiance levels. FLC and INC are suggested over P&O and HIL for applications where reliable and efficient power output is of utmost importance.

## 5. Hardware Result

The experiment for fuzzy logic was conducted using an experimental setup, with the waveforms being analyzed on a cathode ray oscilloscope.

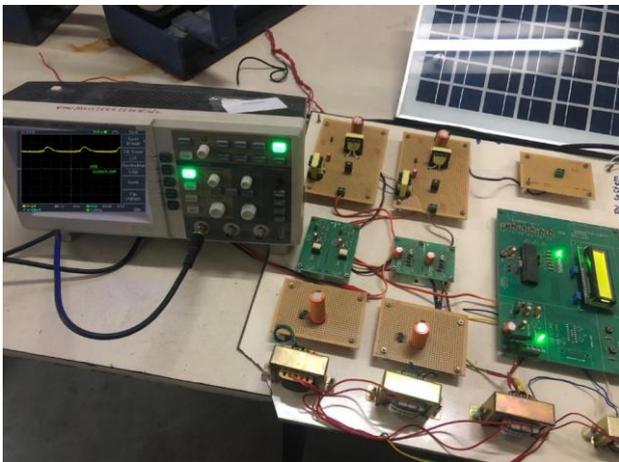


Fig.12 Irradiation analysis of PV on CRO

## 6. Results and Discussion

The results implicate the Fuzzy-based PV MPPT algorithm on solar photovoltaic systems. The model depicts how the algorithm regulates the input and output variables. Simulation models are critical for assessing algorithm performance in a variety of contexts. crucial algorithm components and decision-making techniques. The intricacy of the model influences its adaptability and precision in tracking the maximum power point. These diagrams explain how the algorithm identifies input variables such as voltage and current as "Low," "Medium," and "High" and calculates the duty cycle. Algorithm decisions are influenced by the shapes and ranges of membership functions. How the algorithm generates output from input variable linguistic labels. These rules, which include expert knowledge and control mechanisms, are critical to algorithm performance. The findings discuss how Fuzzy-based MPPT influences power generation. It also shows PV power generation under various irradiance conditions, proving the algorithm's versatility. This graph shows how successfully

the algorithm optimizes power output. The output shows the PV MPPT power waveform generated by a fuzzy-logic controller. This demonstrates how the algorithm smoothest power generation fluctuations and keeps the system close to maximum power as shown in Fig.12. Energy conversion is efficient when the power waveform is stable. These waveforms depict the algorithm's dynamic MPP maintenance changes. Energy yield is increased via effective voltage and current management. PV characteristics under various weather situations This figure is critical for evaluating the shading and temperature handling of the Fuzzy-based MPPT algorithm. The algorithm's ability to adapt to environmental changes and function well is a critical lesson. It is possible to compare the Fuzzy-based MPPT algorithm to normal MPPT methods in the findings and discussion section, as well as the algorithm's accuracy in partial shade conditions, flexibility to rapidly changing weather, and energy production and system efficiency improvements. We also talk about how these discoveries can effect the adoption of better MPPT algorithms for sustainable energy generation. Fuzzy Logic Control (FLC) is widely recognized for its ability to handle imprecise inputs and its robustness against system uncertainties. However, it also presents challenges, such as the difficulty of tuning and the requirement for expert knowledge to develop effective fuzzy rules.

## 7. Conclusion

The Fuzzy-based PV MPPT algorithm is a sophisticated approach for enhancing the efficiency and performance of solar photovoltaic systems. It uses fuzzy logic principles to dynamically track and maintain the optimal operating point of a PV panel, ensuring that the extreme available power is extracted under varying environmental conditions. Unlike traditional MPPT techniques, the Fuzzy-based PV MPPT excels in acclimating to rapidly changing weather conditions and is more robust in partial shading scenarios. It employs linguistic variables and rule-based decision-making to continuously adjust the voltage and current at which the PV panel operates. This enables the system to efficiently respond to factors such as cloud cover, shading, and temperature variations, optimizing energy production and reducing energy losses. The Fuzzy logic MPPT algorithm presents a compelling solution to address the shortcomings of conventional MPPT controllers and improve the performance of PV systems.

## Conflicts of Interest

There is no potential conflict of interest among the authors.

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