Jurnal Ilmiah
TELSINAS

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

Simulation of Fuzzy Logic Controller for Improving the Efficiency of PV Systems Using MATLAB

Muhammad Risky[1], Sitti Amalia[2], Taufal Hidayat[3], Sepannur Bandri[4]

Electrical Engineering Study Program, Institut Teknologi Padang, Indonesia
E-mail: 2024310033.risky@itp.ac.id

DOI:	Received:	Accepted:	Publish:
https://doi.org/10.38043/telsinas.v8i2.6817	07 June 2025	21 August 2025	25 September 2025

ABSTRACT: Solar Power Plants (SPP) are one of the main solutions in the utilisation of renewable energy. However, their efficiency is often hampered by the variability of solar radiation and ambient temperature. To overcome this, Maximum Power Point Tracking (MPPT) technology is required so that solar panels always operate at the maximum power point (MPP). This study develops a Mamdani fuzzy logic-based MPPT system using MATLAB Simulink on a 10 WP PLTS prototype. The fuzzy algorithm is designed with two inputs, namely power and voltage, and one output in the form of a PWM signal to regulate energy conversion efficiency. Five test scenarios were conducted with different input combinations to compare the results of MATLAB simulations and manual calculations using the centroid weighted average method. The results show that the difference between simulation and manual calculations ranges from 1 to 11 PWM units (average <5%), with output classification remaining consistent in the Low, Medium, and High categories. This demonstrates that the Mamdani fuzzy manual method is valid and reliable as an adaptive control solution for PLTS systems. This implementation is expected to significantly improve energy conversion efficiency and support the achievement of national clean energy targets.

Keyword: *PLTS; MPPT; Mamdani Fuzzy Logic; MATLAB Simulation; Energy Efficiency; PWM; Maximum Power Point*

I. INTRODUCTION

Solar Power Plants (PLTS) are one of the environmentally friendly forms of renewable energy utilization. However, the efficiency of PV systems remains a challenge since conventional solar cells are only capable of converting approximately 15–20% of solar energy into electricity [1]. Variations in irradiance and ambient temperature further exacerbate power output fluctuations, thus requiring an adaptive control system to maintain optimal performance [2].

One of the primary approaches to improving the efficiency of PV systems is the application of Maximum Power Point Tracking (MPPT) methods, which aim to keep the operating point of the solar panel at the Maximum Power Point (MPP). The Perturb and Observe (P&O) MPPT method is commonly employed due to its simplicity, but it has disadvantages such as oscillations around the MPP and slow response to rapid changes in irradiance [3].

As a solution to these limitations, the Mamdani fuzzy logic method is proposed for its capability to handle input uncertainty and deliver rapid responses without the need for training as required in Artificial Neural Network (ANN) methods. Several studies have demonstrated that the implementation of a Fuzzy Logic Controller (FLC) significantly enhances PV system efficiency and maintains stability under non-ideal conditions [4].

This research aims to develop an MPPT system based on Mamdani fuzzy logic with two main inputs, namely power and voltage, and one output in the form of PWM, using the MATLAB Simulink simulation platform. The results obtained from testing various validation scenarios indicate that the Mamdani fuzzy approach is effective, responsive, and can serve as a valid alternative to improve power conversion efficiency in small-scale PV systems.

II. LITERATURE REVIEW

Solar Power Plant (PLTS)

A Solar Power Plant (PLTS) is a system that converts solar radiation energy into electrical energy through the photovoltaic effect [5]. The system consists of solar panels, charge controllers, inverters (if

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

required), and energy storage units [6]. This technology falls under the category of renewable energy as it harnesses sunlight, which is naturally abundant, particularly in tropical countries such as Indonesia [7]

Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is a technique used in photovoltaic systems to ensure that solar panels always operate at their maximum power point (MPP) under varying irradiation and temperature conditions. Each solar panel has a current-voltage (I-V) and power-voltage (P-V) characteristic curve that changes depending on the intensity of solar irradiance and the ambient temperature. There is one optimal point on the P-V curve where the output power ($P = V \times I$) reaches its maximum value [8]. This point is known as the Maximum Power Point (MPP). Since irradiance and temperature conditions fluctuate throughout the day, the MPP also shifts dynamically. Therefore, a system capable of continuously tracking this point is required. MPPT works by adjusting the duty cycle of a DC-DC converter (typically a boost converter) to match the load impedance with the internal impedance of the solar panel at the maximum power point [9].

Fuzzy Logic

Fuzzy logic is a decision-making and control method that mimics human reasoning in dealing with uncertainty and imprecise or vague information [10]. The concept of fuzzy logic was first introduced by Lotfi A. Zadeh in 1965 as an extension of classical Boolean logic, which only recognizes two truth values: true (1) and false (0) [11]. In fuzzy logic, a variable does not only have binary values of "true" or "false" but can possess degrees of membership within a fuzzy set ranging between 0 and 1 [12]. For instance, the linguistic variable "warm" is not strictly categorized as "hot" or "cold" but may lie between them with a certain degree of membership.

Matlab

MATLAB is a numerical computing software widely used among academics and engineers for modeling, analyzing, and simulating complex systems. One of its important features is the Fuzzy Logic Toolbox, which provides both programming functions and a graphical user interface (GUI) for building and analyzing Fuzzy Inference Systems (FIS) [11]. With this toolbox, users can easily design fuzzy logic systems using various inference methods such as Mamdani and Sugeno, define linguistic variables, membership functions, fuzzy rules, and also conduct simulations and visualize results [13].

The design process of a fuzzy system in MATLAB begins with the creation of a new FIS, either through programming commands (scripts) or the GUI known as the Fuzzy Logic Designer. The interface includes several editors, such as the FIS Editor (to define the system structure), Membership Function Editor (to design membership functions such as triangular, trapezoidal, or Gaussian), Rule Editor (to define fuzzy rules in IF-THEN format), Rule Viewer (to visualize the inference process), and Surface Viewer (to map variable relationships in a three-dimensional surface) [14].

As an example, in a temperature-based motor speed control system, the input variable (motor temperature) can be categorized into fuzzy sets such as "Cold," "Medium," and "Hot" using triangular membership functions. Based on fuzzy rules such as "If the temperature is hot, then PWM is high," the system generates a PWM output to regulate the cooling fan speed. This entire process can be modeled, tested, and optimized in MATLAB before implementation into hardware such as microcontrollers or embedded systems [15].

III. RESEARCH METHODOLOGY

This study aims to design and simulate a Maximum Power Point Tracking (MPPT) system based on a Fuzzy Logic Controller (FLC) in order to improve power conversion efficiency in Solar Power Plants (PLTS). The design was carried out using MATLAB software by utilizing the Fuzzy Logic Toolbox to build a visual and computational MPPT control model.

The research stages began with a literature review to strengthen the theoretical foundation regarding PLTS, MPPT methods, and fuzzy logic. The focus of the review included the operating principles of solar cells, the influence of temperature and irradiance on panel efficiency, and the advantages of FLC in

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

handling input uncertainty without requiring complex mathematical modeling. MATLAB was chosen as the platform because it provides complete tools for modeling nonlinear control systems interactively.

The MPPT system was then designed with two inputs (power and voltage) and one output (PWM), applying the Mamdani fuzzy method. Simulations were conducted on five different input scenarios to evaluate the accuracy and consistency of the PWM output, both in simulation and through manual calculations using the centroid defuzzification method.

Flowchart

The research began with the identification of problems related to the low power conversion efficiency of PLTS systems, particularly under fluctuating conditions such as variations in light intensity and ambient temperature. After formulating the problem, a comprehensive literature review was conducted to understand the output characteristics of solar panels and the fundamentals of fuzzy logic-based control systems, with a focus on the Mamdani method as the primary approach for control system design.

The next stage was data collection from experiments aimed at obtaining actual voltage and current values from a 10 WP solar panel. Data were collected under various lighting conditions (low, medium, and high irradiance) to represent natural variations commonly encountered in PV applications. These data were used to map the relationship between output power and environmental variables, and to serve as the foundation for designing the fuzzy logic system.

After the data were collected, the MPPT model based on fuzzy logic was developed using MATLAB Simulink and the Fuzzy Logic Toolbox. The model consisted of two main inputs (voltage and power) and one output (PWM signal) to control the solar panel operating point at the Maximum Power Point (MPP). The system design was constructed using a fuzzy rule base that represented the linguistic relationship between input and output conditions, and was tested through simulation.The overall research process can be illustrated in the following flowchart:

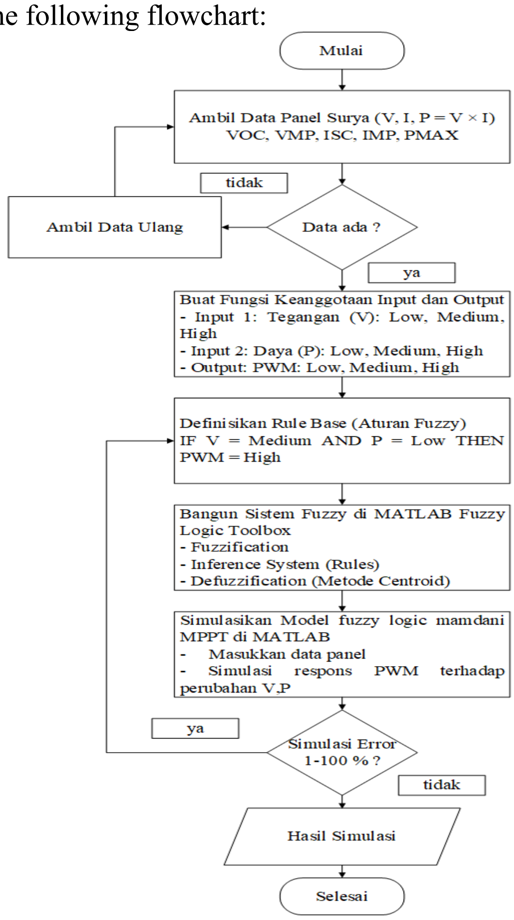

Figure 1. Research Flowchart

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

IV. DISCUSSION

Design and Simulation of Fuzzy Logic MPPT

After obtaining the voltage and power characteristics of a 10 WP solar panel under various irradiance conditions, the next step was to design and simulate an MPPT control system based on a Fuzzy Logic Controller (FLC) using MATLAB Simulink. The simulation was conducted to evaluate the effectiveness of the fuzzy algorithm in regulating the panel's operating point so that it remains near the Maximum Power Point (MPP).

The fuzzy model was developed using the Fuzzy Logic Toolbox with two main inputs: change in power (ΔP) and change in voltage (ΔV), and one output in the form of Pulse Width Modulation (PWM). The system's fuzzy structure was constructed based on a rule base that represents the relationship between ΔP and ΔV and the corresponding adjustment of the PWM signal. For example, if ΔP is positive and ΔV is negative, then the PWM value is increased.

Membership functions for the input and output variables were represented using triangular and trapezoidal shapes, selected to ensure smooth and stable system responses. The PWM output generated by the fuzzy system was used to adjust the duty cycle of the DC-DC converter in the simulation so that the panel operates close to the maximum power point in real-time. Figure 2 shows the Mamdani fuzzy system design developed using MATLAB Simulink:

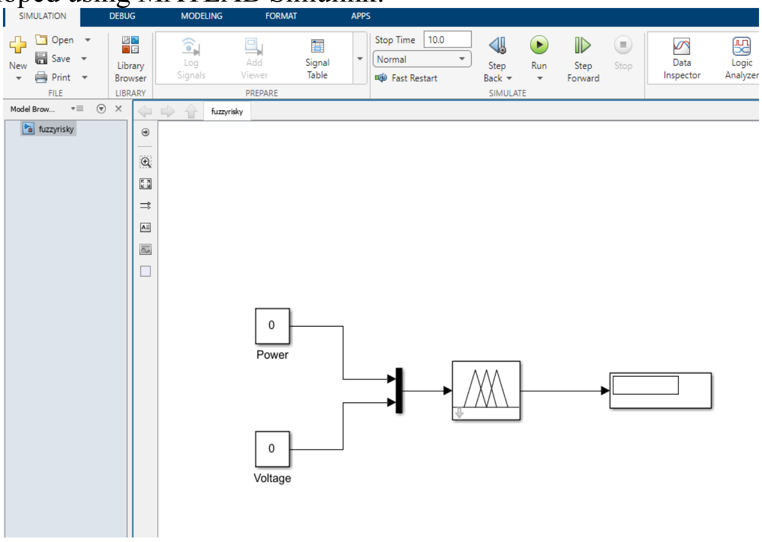

Figure 2 Fuzzy Logic Design in Simulink

After the Simulink design was prepared, the simulation process was executed by integrating the fuzzy Mamdani file into the model. Figure 3 shows the block parameters of the fuzzy system in Simulink:

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

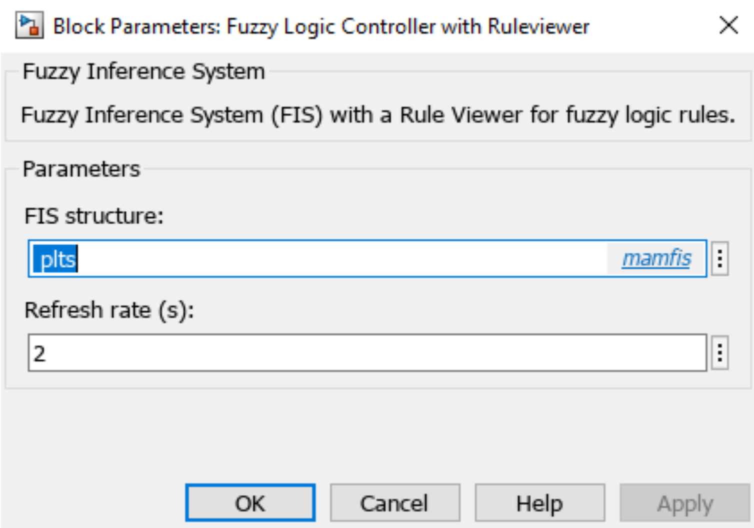

Figure 3. Block Parameters of Fuzzy Logic in Simulink

Simulation Test 1

In the first simulation, the system was tested with an initial input of 1 W of power and 5 V of voltage, representing the operating condition of a 10 WP solar panel under low irradiance. This initial condition was selected to evaluate the controller's response from a minimum operating point and to assess its ability to effectively track the maximum power point. The simulation results are shown in Figure 4 :

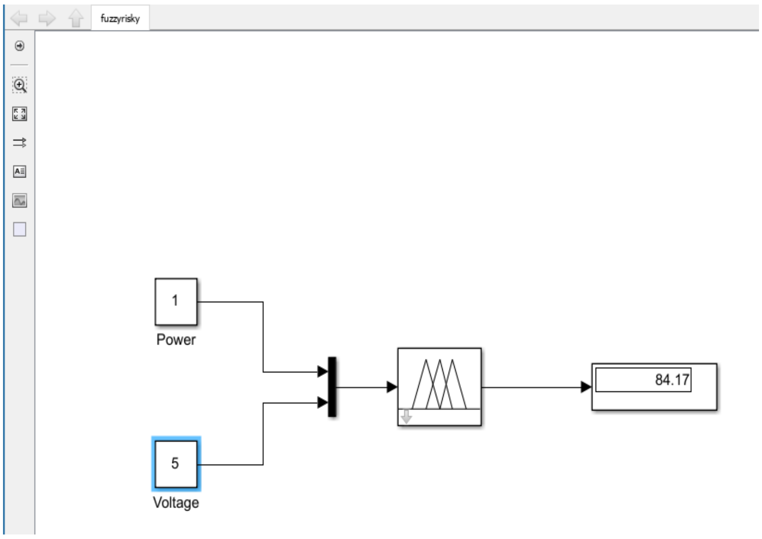

Figure 4. Simulation Result 1 in Simulink

Figure 5. Fuzzy Mamdani Rule Base Result 1

From the simulation, the PWM output value obtained was 84.2. To validate this result, a manual calculation using the Mamdani fuzzy method with the same input (Power = 1 W, Voltage = 5 V) was performed. The fuzzification, rule evaluation, and defuzzification (centroid method) stages confirmed that the manual result was consistent with the simulation :

1. Fuzzifikasi
a. Power = 1 W → Low = 0,8; Medium = 0,2; High = 0
b. Voltage = 5 V → Low = 0,6; Medium = 0,4; High = 0

2. Rule Base
a. Aturan: If Power is Low and Voltage is Low, then PWM is Medium
b. Derajat kebenaran rule: Min(0,8, 0,6) = 0,6
c. PWM untuk rule ini = 80 (contoh skala 0–100)
d. Rule lain aktif: Power Low & Voltage Medium → PWM High, Min(0,8, 0,4) = 0,4, PWM = 100
3. Defuzzifikasi (Metode Centroid)

a. Calculating PWM output:

$$PWM = \frac{0{,}6\ x\ 80) + 0{,}4\ x\ 100)}{0{,}6 + 0{,}4} = \frac{48 + 40}{1{,}0} = 88$$

Simulation Test 2

In the second simulation, the system was tested with an input of 5 W of power and 10 V of voltage using the designed fuzzy Mamdani model in MATLAB Simulink:

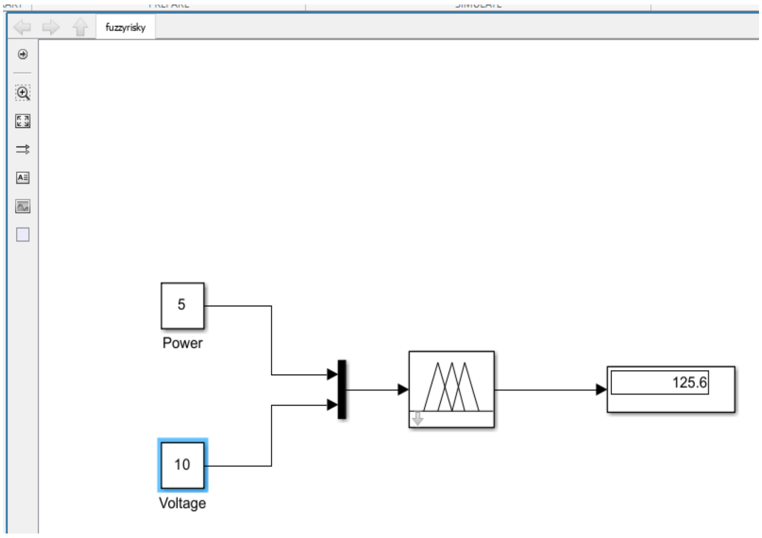

Figure 6. Simulation Result 2 in Simulink

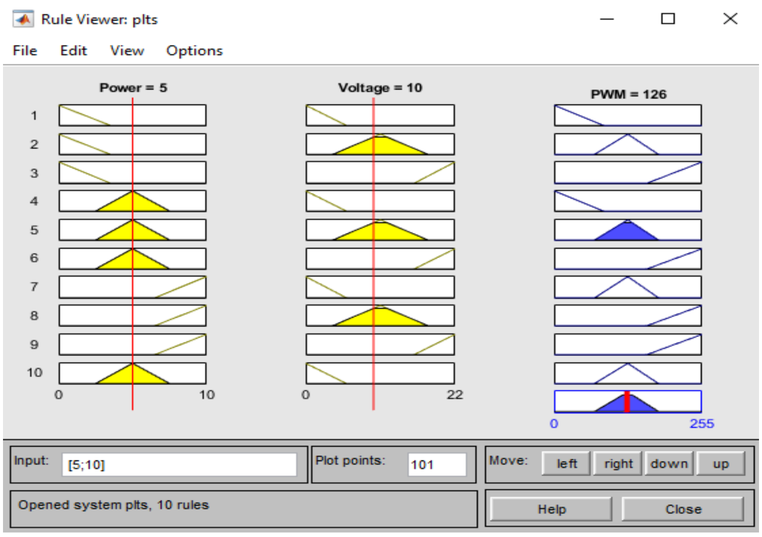

Figure 7. Fuzzy Mamdani Rule Base Result 2

Based on the results of the second simulation, a PWM output value of 126 was obtained. To validate these results, manual calculations were performed using the Mamdani fuzzy method with the same inputs, namely Power = 5 watts and Voltage = 10 volts. This process included the stages of fuzzification, application of the rule base, and defuzzification using the centroid method.

Simulation Test 3

In the next simulation stage, testing was conducted by providing input in the form of power of 10 watts and voltage of 22 volts into the Mamdani fuzzy system that had been designed in MATLAB Simulink:

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

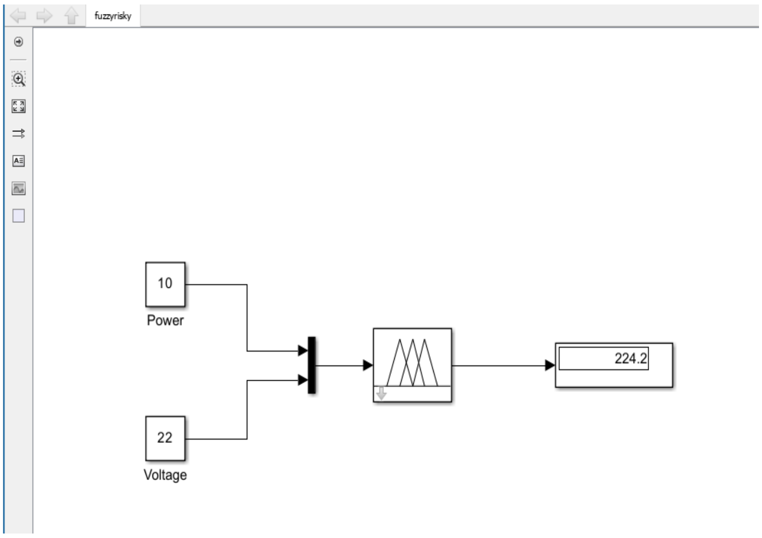

Figure 8. Result in Simulink

Figure 8 shows the simulation results of the Mamdani-based Fuzzy Logic Controller (FLC) system in MATLAB Simulink. The system inputs consist of Power = 10 W and Voltage = 22 V, which represent the conditions of the solar panel at a specific operating point. This input is forwarded to the Fuzzy Inference System (FIS) that has been designed to optimally regulate the PWM output. The FIS block processes the input through the stages of fuzzification, rule base application, and defuzzification, resulting in a PWM output value of 224.2. This value indicates the control signal that will be used to regulate the MPPT system so that the solar panel can operate close to its maximum power point.

Figure 9. Fuzzy Mamdani Rule Base result 3

Figure 9 shows the processing of the Mamdani-based Fuzzy Logic Controller (FLC) system using a rule base. The system inputs are Power = 10 W and Voltage = 22 V, which represent the conditions of the solar panel at a specific operating point. These input values are applied directly to the rule base, where predetermined fuzzy rules determine the appropriate output. After going through the fuzzification, rule base evaluation, and defuzzification stages, the system produces an output of PWM = 224.2. This value indicates the optimal control signal for regulating the MPPT system so that the solar panel operates close to the maximum power point.

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

After conducting a simulation using MATLAB with an input power of 10 watts and a voltage of 22 volts, a PWM output value of 224 was obtained. To ensure the validity of the simulation results, manual calculations were performed using the Mamdani fuzzy method. This process consisted of the stages of fuzzification, rule base application, and defuzzification using the centroid (weighted average) method.

To strengthen the validation analysis of the Mamdani fuzzy system, a comparison was made between the simulation results using MATLAB Simulink and the manual calculation results using the centroid method. The following table summarizes the PWM output values from both methods based on variations in power and voltage inputs.

Table .1 Comparison of Simulation and Manual Calculation Results

No	Input		Output PWM		Difference (%)
	Power (W)	Voltage (V)	Calculation	MATLAB	
1	1	5	81.5	84.2	3.31
2	5	10	127	126	-0.79
3	10	22	212.5	224	5.41
4	0	5	81.5	84.2	3.31
5	10	5	166.4	162	-2.64

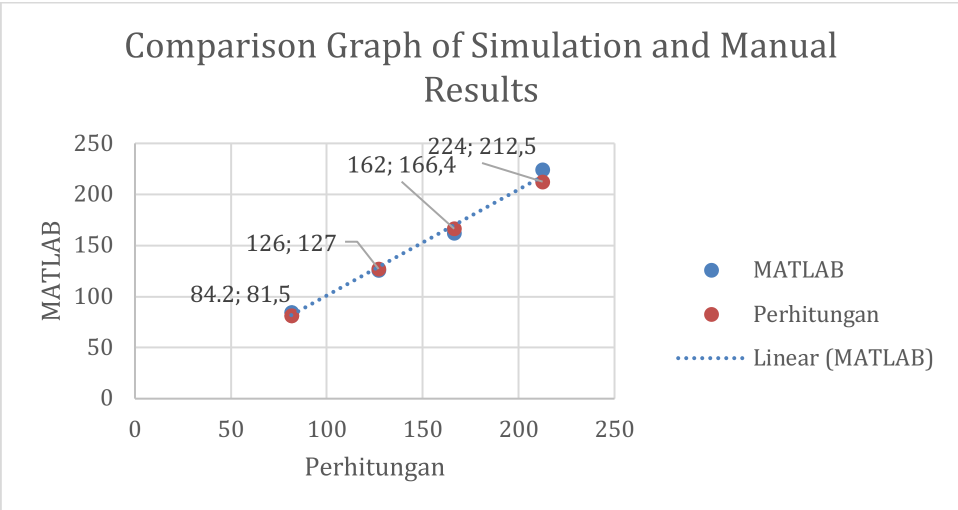

Figure 10. Comparison Graph of Simulation and Manual Results

The Mamdani fuzzy MPPT system showed consistent and accurate results between simulation and manual calculations. Across the five test scenarios with variations in power and voltage, the difference between simulation and manual PWM outputs ranged from 1 to 11 units, with an average error of less than 5%. These results demonstrate that the manual centroid defuzzification method successfully captured the system's fuzzy behavior.

In the first to third test scenarios, the system responded well, with PWM values falling within the medium range for low power and High range for higher power, indicating proper adaptation to input conditions. Even in extreme conditions (zero power or low voltage), the system maintained stable and efficient responses. Overall, the Mamdani fuzzy system proved to be effective in managing MPPT, with strong adaptability to varying input conditions and reliable performance for maintaining energy conversion efficiency in small-scale PV systems.

Volume 8, No. 2 September 2025
e-ISSN 2621-5276 (online)

V. CONCLUSION

Based on the results of simulations and analysis, it can be concluded that the MPPT system based on a Fuzzy Logic Controller (FLC) using the Mamdani method has been successfully designed and effectively simulated with MATLAB Simulink for a 10 WP PV system. This system utilizes two inputs, namely power and voltage, and one output in the form of a PWM signal to regulate the operating point of the solar panel so that it consistently operates near the Maximum Power Point (MPP).

The triangular membership functions used in the system effectively represented linguistic logic in a simple yet reliable manner. The test results demonstrated that the differences between simulation and manual calculations were very small, indicating high accuracy and consistent responses.

The Mamdani fuzzy system proved to be adaptive to various input conditions without requiring complex mathematical models and can be effectively implemented in small to medium-scale PV systems. With its flexibility and reliability, this method has strong potential to be adopted in real applications based on microcontrollers such as the ESP32 and extended into Internet of Things (IoT)-based systems.

REFERENCE

[1] F. Hasan, S. Arifin, and V. Verdiansah, "Fish Feeder Otomatis Bersumber Energi Pembangkit Listrik Tenaga Surya (PLTS)," *Jurnal Ilmiah Telsinas Elektro, Sipil dan Teknik Informasi*, vol. 7, no. 2, pp. 199–206, Sep. 2024, doi: 10.38043/telsinas.v7i2.5614.

[2] S. Hariyanto, "Rancang Bangun REFLECTOR Untuk Mengoptimalkan Daya Serap Matahari Pada Panel Surya Dengan Variasi Sudut Guna Menghasilkan Daya Optimal," *Jurnal Ilmiah Telsinas Elektro, Sipil dan Teknik Informasi*, vol. 4, no. 1, pp. 41–45, Mar. 2022, doi: 10.38043/telsinas.v4i1.2896.

[3] N. Hemalatha and R. Seyezhai, "Implementation of fuzzy MPPT controller for PV-based three-phase modified capacitor-assisted extended boost q-ZSI," *Appl Nanosci*, vol. 13, no. 3, pp. 1971–1979, 2023.

[4] A. Y. B. Dawe, "Electricity monitoring system based on fuzzy logic and Internet of things," *IOTA Journal*, vol. 1, no. 2, pp. 63–80, 2021.

[5] P. Gunuto, M. Algusri, M. Saefullah, J. P. Saragih, and E. Susanti, *PERANCANGAN MODUL PRAKTIKUM PLTS (PEMBANGKIT LISTRIK TENAGA SURYA)*. PT. Penerbit Qriset Indonesia, 2025. [Online]. Available: https://books.google.co.id/books?id=vCtNEQAAQBAJ

[6] A. A. Musyafiq *et al.*, *Teknologi Energi Baru Terbarukan: Sistem PLTS dan Penerapannya untuk Kesejahteraan Masyarakat*. RUBEQ ID, 2023.

[7] S. Karim, M. Musrawati, and A. Haslinah, "Solar Tracker Berbasis Mikrokontroler Arduino-Uno Dengan Auto Switch PLN Dan PLTS Berbasis ATS/AMF," *Jurnal Minfo Polgan*, vol. 13, no. 1, pp. 73–81, 2024.

[8] G. Ujwala, *MPPT BASED PERFORMANCE ENHANCEMENT OFINTEGRATED HYBRID WIND - SOLAR ENERGY SYSTEM*. Archers & Elevators Publishing House. [Online]. Available: https://books.google.co.id/books?id=Q2foEAAAQBAJ

[9] A.-M. Badea, D. Manaila-Maximean, L. Fara, and D. Craciunescu, "Maximizing solar photovoltaic energy efficiency: MPPT techniques investigation based on shading effects," *Solar Energy*, vol. 285, p. 113082, 2025.

[10] U. Athiyah, A. P. Handayani, M. Y. Aldean, N. P. Putra, and R. Ramadhani, "Sistem Inferensi Fuzzy: Pengertian, Penerapan, dan Manfaatnya," *Journal of Dinda: Data Science, Information Technology, and Data Analytics*, vol. 1, no. 2, pp. 73–76, 2021.

[11] S. N. Sivanandam, S. Sumathi, and S. N. Deepa, *Introduction to Fuzzy Logic using MATLAB*. Springer Berlin Heidelberg, 2006. [Online]. Available: https://books.google.co.id/books?id=a_J2P3FT9sgC

[12] O. Castillo and L. T. Aguilar, *Type-2 Fuzzy Logic in Control of Nonsmooth Systems: Theoretical Concepts and Applications*. in Studies in Fuzziness and Soft Computing. Springer International Publishing, 2018. [Online]. Available: https://books.google.co.id/books?id=uQJ2DwAAQBAJ

[13] R. V Dukkipati, *MATLAB: An Introduction with Applications*. New Age International (P) Limited, 2010. [Online]. Available: https://books.google.co.id/books?id=ZOALqysjNBwC

[14] L. A. Zadeh, “Fuzzy logic,” in *Granular, fuzzy, and soft computing*, Springer, 2023, pp. 19–49.

[15] M. F. Akkas, I. A. Rahardjo, and A. Sunawar, “Perancangan instalasi listrik menggunakan solar cell di cikaracak adventure camp,” *Journal of Electrical Vocational Education and Technology*, vol. 6, no. 2, pp. 1–5, 2022.