**Proceeding of International**
Conference on Science and Technology
Lembaga Penelitian Pengabdian kepada Masyarakat dan Dakwah Islamiyah, Universitas Islam Kuantan Singingi, Indonesia, September 19th 2024
DOI : https://doi.org/10.36378/internationalconferenceuniks.v2i1
ISSN 2985-8739
**Page: 156-163**

# Analysis and Simulation of Perturb and Observe MPPT Algorithm Based on Fuzzy-PI Controller Combination for Photovoltaic Systems

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***Abstract***

*In this paper, a P&O-based maximum power point tracking (MPPT) system that combines a Fuzzy-PI controller on a proposed PV system is analyzed to achieve the highest power production of a photovoltaic (PV) system and improve system performance and fast response. The proposed PV system consists of a Photovoltaic array, a voltage riser, a DC to DC type converter, and an MPPT algorithm using a combined P&O method of Fuzzy-PI controller. All elements of the PV system are simulated using MATLAB/Simulink. The simulation results show that the maximum power point tracking approach using P&O combined with Fuzzy-PI provides a high efficiency of 97.39% with a speed of 0.025 seconds reaching the optimum point and a steady ripple of 0.06 volts. Meanwhile, the optimum point tracking system without the Fuzzy-PI combination to reach the maximum power point takes 0.14 seconds and the steady state ripples are 30 volts. However, when a P&O-based MPPT system is combined with a PI controller, the response time reaches a maximum power point of 0.11 seconds with a steady state ripple of 17 volts. The results of the proposed analysis and simulation produce high performance, both in terms of response speed time, low ripple and high efficiency.*

*Keywords: MPPT, P&O, Fuzzy-PI Combination, Solar Panel.*

## 1. Introduction

In modern times, electricity is a primary necessity for humanity. Without electricity, human activities, whether in households, government, business, or industry, would come to a halt. The demand for electricity increases each year, and in 2023, electricity consumption reached 288.44 terawatt-hours (TWh), marking a 5.32% increase compared to 273.76 TWh in 2022 [1].

According to data released by the Ministry of Energy and Mineral Resources (ESDM) in May 2023, the total installed capacity of power plants in Indonesia in 2023 reached 83,842.83 MW or 83,842 MW. Of this total, fossil energy accounts for 71,197.38 MW or 71,197 MW (15%), while renewable energy sources (EBT) account for 12,645.45 MW or 12,645 MW (85%)[2].

Power plants that supply energy for human needs generally rely on fossil fuels such as coal, oil, and natural gas. Based on their life cycle, oil produces 970 grams of $CO_2$ per kilowatt-hour ($gCO_2/kWh$), coal 820 grams of $CO_2$ per kWh, and natural gas 490 grams of $CO_2$ per kWh. Thus, while these three types of fossil fuels are effective in generating electricity, they also have negative impacts in the form of $CO_2$ emissions per kWh. Fossil fuels directly contribute to climate change, cause various negative effects on the environment, and are considered dirty energy sources [3].

Indonesia has a vast potential of natural resources that can be developed as renewable energy sources. However, the development of renewable energy for daily use has not yet become a top priority. In fact, Indonesia's renewable energy potential reaches 3,687 GW, which includes 3,294 GW from solar energy, 95 GW from hydro, 57 GW from bioenergy, 155 GW from wind, 23 GW from geothermal, and 63 GW from ocean energy. Indonesia needs to urgently accelerate the transition to renewable energy [4].

The low-carbon development strategy is a key element in the transition to a green economy and sustainable development, supported by various policies outlined in Law No. 71 of 2021 and Presidential Regulation No. 98 of 2021. Achieving Indonesia's vision for 2045 and the net zero emissions target by 2060 will require significant challenges and strong collaboration from all parties. Indonesia has set an ambitious target to reduce greenhouse gas emissions by 31.89% by 2030, in line with Law No. 4 of 2023 concerning the Development and Strengthening of the Financial Sector. The government also aims to develop rooftop solar power plants (PLTS) with a total capacity of 2,145 megawatts during the 2021-2030 period [5].

Currently, there are various options for using solar panels, tailored to the needs and environmental conditions where the panels are installed. Some of the types of solar panels available on the market include: Monocrystalline, which has a solar cell efficiency of about 15% to 20%, and Poly-Crystalline, with an efficiency of around 13% to 16%. However, solar panels have nonlinear output characteristics, influenced by factors such as irradiation, temperature, and load impedance, resulting in energy production ranging from 13% to 20%. [6-8].

Solar energy is one of the rapidly developing renewable energy sources and offers a highly promising solution. Since the efficiency of solar cells available on the market is still low, methods are needed to enhance the efficiency of the electricity generated by solar panels by maximizing the power at a specific operating point known as the Maximum Power Point (MPP). Therefore, MPPT is required to find the MPP when temperature and/or irradiance changes. Changes in irradiance directly affect the MPP of the solar panels, so MPP tracking techniques are needed to adjust to the speed and direction of irradiance changes [9-11].

Energy optimization of solar panels is achieved using the Maximum Power Point Tracking (MPPT) technique, which ensures that the solar panels operate at the Maximum Power Point (MPP). MPP is the point on the voltage-current (V-I) or voltage-power (V-P) curve of the solar panel where the panel operates at maximum efficiency and delivers maximum power [12].

The low efficiency of PV systems serves as a major impetus for seeking the maximum power output from these systems. In recent years, there has been significant research focused on developing PV systems using MPPT methods. Direct MPPT methods for finding the Maximum Power Point (MPP), such as the Perturb and Observe (P&O) method, have been extensively studied [13-17]. Another method to enhance the power output of solar panels by finding the maximum power point in the system is the Fuzzy Logic Controller, which can improve the efficiency of the solar panel's power output [18-21]. Next, many researchers employ methods that combine proportional and integral controllers with Fuzzy, fractional order, and P&O to quickly achieve maximum power and ensure high precision stability [22-25]. In this paper, a combined fuzzy-PI control algorithm is proposed for maximum power point tracking (MPPT) in photovoltaic (PV) systems. This algorithm is designed to address the shortcomings of using PI or fuzzy control algorithms individually in MPPT applications. By integrating traditional PI control with fuzzy control, the fuzzy-PI algorithm is developed. In this approach, when tracking errors are large, the fuzzy controller is activated to adjust quickly and enhance control robustness. Conversely, when tracking errors are small, the control switches to the PI algorithm to minimize errors in stable conditions. Simulation results demonstrate that the fuzzy-PI algorithm achieves high speed and precision in MPPT. Moreover, this combined algorithm can effectively adjust to new maximum power points even with changes in environmental conditions, offering improved performance and tracking stability.

This paper aims to develop a maximum power point tracking (MPPT) system that can continuously identify and maintain the maximum energy output from solar panels. This chapter focuses on modeling MPPT using a perturb and observe algorithm combined with Fuzzy-PI to enhance the power output of photovoltaic solar systems with high efficiency and accuracy. Simulations will be carried out on PV systems equipped with MPPT as well as on PV systems without MPPT using MATLAB/Simulink software. An analytical comparison will be performed between the two systems under various temperature and solar irradiance conditions.

## 2. Research Methodology

In this study, the components used include a Fux meter, a laptop, and Simulink Matlab software. The steps taken to analyze and simulate the maximization of solar panel energy using the Perturb and Observe algorithm combined with a Fuzzy-PI controller are as follows: first, analyzing and designing the boost converter model parameters; second, analyzing the P&O algorithm; third, designing proportional and integral controller parameters using Simulink Matlab software; and fourth, analyzing Fuzzy membership and designing and analyzing the combination of P&O and Fuzzy-PI control. The optimization scheme for the solar panel system using MPPT based on P&O combined with the Fuzzy-PI controller is shown in Figure 1.

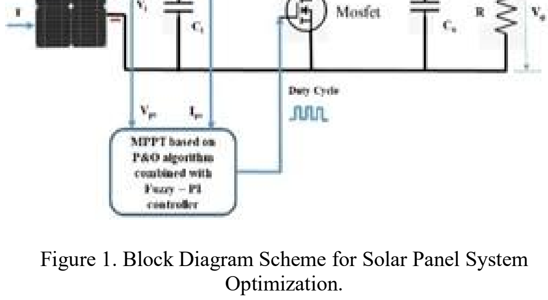



Figure 1. Block Diagram Scheme for Solar Panel System Optimization.

## 2.1. Characteristics of Photovoltaic (PV) Solar Panels.

The conversion of sunlight into electrical energy, which results in voltage, current, and power through a photovoltaic system, is influenced by changes in irradiance and temperature produced by the photovoltaic panels. To analyze the I-V and V-P characteristics, refer to Figure 2, which shows temperature variations at 25°C, 35°C, and 45°C with a constant irradiance of 1000 W/m². The photovoltaic power data using the TSM-250PA05.08 module with a capacity of 250 WP is also listed in Table 1.

Table 1: Specifications Data for the TSM-250PA05.08 Photovoltaic Panel

| | |
|---|---|
| Power Rating (Vmp) | 250 W |
| Voltage at Maximum Power (Vmp) | 31 V |
| Current at Maximum Power (Imp) | 8,06A |
| Open-Circuit Voltage (Voc) | 37,6V |
| Short-Circuit Current (Isc) | 8,55A |
| Total Number of Cells in Series (Ns) | 60 |
| Total Number of Cells in Parallel (Np) | 1 |
| Series Resistance Rs | 0,247 |
| Parallel Resistance Rsh | 301,814 |

Based on the data in Table 1, the characteristic graph of the solar panel at an irradiance of 1000 W/m² with varying temperature values is presented in Figure 2.

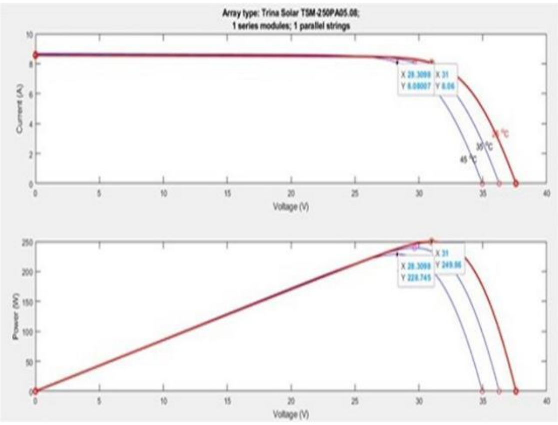


Figure 2. I-V and V-P Characteristics of the Solar Panel with Temperature Variation.

Figure 2 shows that the maximum power occurs at point Pm, which is the result of the multiplication between maximum voltage and maximum current on the photovoltaic panel. At an irradiation of 1000 W/m² and a temperature of 25°C, the maximum voltage is 31V, the maximum current is 8.06 A, and the maximum power is 249.86 W. At a temperature of 35°C, the maximum voltage decreases to 29.67V, the maximum current remains 8.06 A, and the maximum power is 239.18 W. At a temperature of 45°C, the maximum voltage further drops to 28.31 V, the maximum current is 8.44 A, and the maximum power is 228.75 W. This indicates that, at the same irradiation level, the maximum power decreases with increasing temperature, so as the temperature rises, the energy produced by the photovoltaic panel decreases. Additionally, the characteristics of the photovoltaic panel at a temperature of 25°C with varying irradiance of 500 W/m², 800 W/m², and 1000 W/m² are shown in Figure 3.

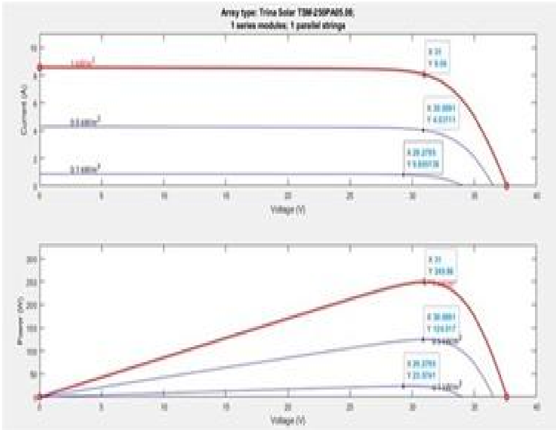


Figure 3. shows the characteristics of the I-V and V-P

Figure 3 shows the characteristics of the I-V and V-P curves for photovoltaic systems with varying irradiation levels. It demonstrates that maximum power occurs at point Pm, which is the product of maximum voltage and maximum current for the photovoltaic panel at a temperature of 25°C. At an irradiation of 1000 W/m², the maximum voltage is 31V, maximum current is 8.06 A, and maximum power is 249.86 W. At 500 W/m², the maximum voltage is 30.89V, maximum current is 4.03 A, and maximum power is 124.52 W. At 100 W/m², the maximum voltage is 29.28 V, maximum current is 0.81 A, and maximum power is 23.57 W. This indicates that, at the same temperature, as irradiation increases, the maximum power also increases. Therefore, higher irradiation levels result in greater photovoltaic energy output.

### *2.2. Boost Converter*

This type of converter is a direct current (DC) converter designed to produce an output voltage higher than its input voltage, commonly known as a boost converter. As shown in Figure 4, the main components of this converter include a Mosfet, diode, inductor, and capacitor.

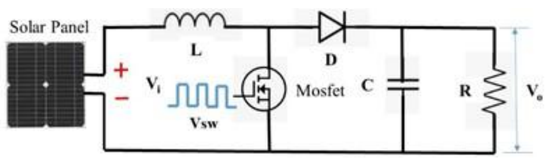



Figure 4: Boost Converter Circuit (Rashid, 1993)

The inductor is designed to maintain voltage stability per second in the converter and to reduce output current fluctuations. It is expected that the inductor will operate in continuous conduction mode with a current ripple ranging from 20% to 40% of the output current (Hauke, 2010). Thus, the inductor value is 2 mH, and the desired output voltage ripple is 0.1%, which determines the capacitor capacitance to be 2 mF, and the output resistance is 3.85 ohms.

### 2.3. Perturb and Observe algorithm

```
function duty=MPPT_Pand0(Vpv,Ipv)
duty_init=0;
duty_min=0;
duty_max=0.95;
delta=125e-6;
persistent Vold Pold duty_old
if isempty(Vold)
% Initial value of the variable is set to 3, and 3
variables are initialized to zero.Vold=0;
Pold=0;
duty_old=duty_init;
end
% Calculate measured arry power
P=Vpv*Ipv;
 % Increase or decrease duty cycle base
if (P-Pold)~=0
% Comparing the current power with the power
before
if (P-Pold)>0
if (Vpv-Vold)>0
duty=duty_old-delta;
else
duty=duty_old-delta;
end
else
if(Vpv-Vold)>0
duty=duty_old+delta;
else
duty=duty_old-delta;
end
end
else
duty= duty_old;
end
% Limit the duty cycle, as during operation it can
be greater than one or less than zero.
if duty>=duty_max
duty=duty_max;
elseif duty<=duty_min
duty=duty_min;
end
% Then update the internal values
duty_old=duty;
Vold=Vpv;
Pold=P;
```

### 2.4. Fuzzzy Logic System

Fuzzy logic is a method of logic that mimics human thinking by dealing with uncertainty through the use of values between 0 and 1 and logical operations. A fuzzy controller is an advanced technology that enables the creation of nonlinear controllers based on the knowledge and experience of experts. Generally, fuzzy logic involves several process stages: fuzzification, inference, rule base, and defuzzification. This process takes numeric data as input and, through fuzzification, inference, rule base, and defuzzification, produces numeric data as output. Fuzzy processes can be applied in both numerical and linguistic domains. The block diagram of a fuzzy controller can be found in Figure 5.

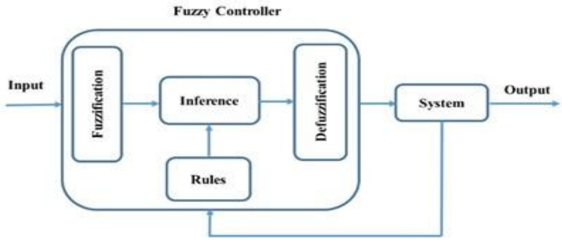



Figure 5. Block diagram of the fuzzy logic controller.

### 2.5. Proportional Integral (PI) Control.

The use of Proportional Integral (PI) control aims to achieve optimal performance in terms of settling time and maximum overshoot, while ensuring system stability [28-29]. The block diagram of PI control is shown in Figure 6 below.

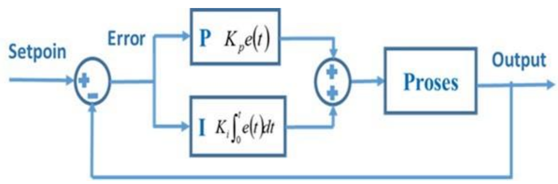



Figure 6: Block diagram of PI control action.

A PI controller (Proportional-Integral Controller) is a special case of a PID controller that does not use the derivative (D) of the error.

### 2.6. Fuzzy-PI Design

Figure 7: Shows the design of the fuzzy-PI logic system

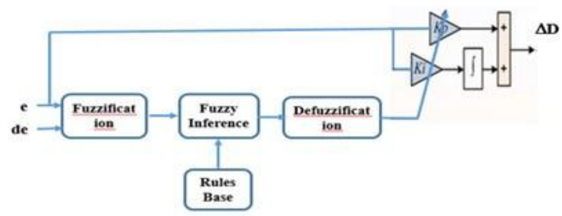



Figure 7. Design of the fuzzy-PI logic system

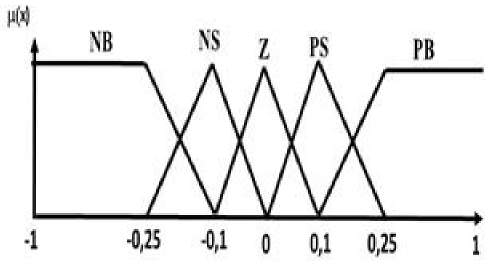
The Fuzzy control applied in this system uses the Mandani inference method. In this Fuzzy Mandani inference system, both the input and output membership functions are presented through Fuzzy membership functions. The system has two inputs:

1. The first input is the error of the power-to-voltage change ratio (e), represented by five Fuzzy membership functions: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB).
2. The second input is the change in error of the power-to-voltage change ratio (de), represented by three membership functions in the form of trapezoidal and triangular functions with categories of Negative, Zero, and Positive.

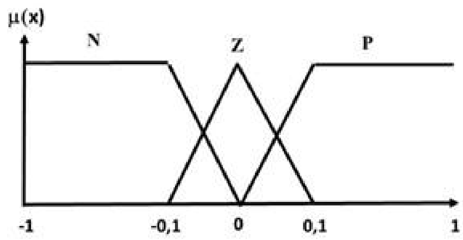
For the outputs, there are two types of Fuzzy membership functions:

1. The first output relates to KP (proportional gain constant), represented by three Fuzzy membership functions: Small (S), Medium (M), and Big (B).
2. The second output relates to Ki (integral gain constant), represented by five membership functions: Very Small (VS), Small (S), Medium (M), Big (B), and Very Big (VB).

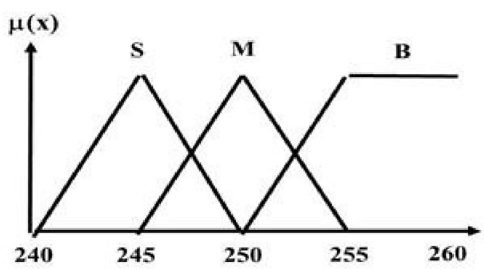
The proportional values for KP range from 240 to 260, while the values for Ki range from 400 to 430. The structure of the Fuzzy Mandani inference system with input and output membership functions is detailed in Figure 8 [9].



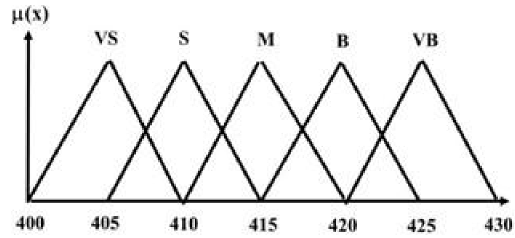

Membership Function of Input Error (e)




Membership Function of Input Change in Error (Δe)




Membership Function of Proportional Gain (Kp) Output




Membership Function of Integral Gain (Ki) Output

The rule base in fuzzy logic control represents a form of "If-Then" or "If-Then" implication rules. The fuzzy logic system design has 25 rule bases as shown in Table 2.

Table 2. Fuzzy Rule Base Design

| e / Δe | NB | NS | Z | PS | PB |
|---|---|---|---|---|---|
| N | M | M | M | B | B |
| Z | M | M | M | B | B |
| P | M | M | M | B | B |

Rule Base for KP Output

| e / Δe | NB | NS | Z | PS | PB |
|---|---|---|---|---|---|
| N | S | M | B | VB | VB |
| Z | VS | M | M | B | VB |
| P | VS | S | M | M | VB |

Rule Base for Ki Output

The Fuzzy Mamdani results from the rule base in Table 3 show that if the input error is set to 0.1 and the change in error is also set to 0.1, then the proportional gain (Kp) is 256.2 and the integral gain (Ki) is 415, as presented in Figure 9.

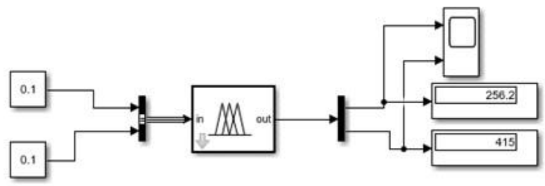



Figure 9. Fuzzy Mamdani Results from Simulink Matlab

## 3. Results and Discussions

The performance of the MPPT-based P&O method combined with a Fuzzy-PI controller is evaluated and compared with the MPPT-based P&O method without the Fuzzy-PI controller, as well as the MPPT-based P&O method alone. This evaluation is carried out through theoretical analysis and digital simulation under three different conditions using MATLAB/Simulink. The PV module is connected to the load via a DC-DC boost converter. The simulation circuit schematic for the MPPT-based P&O method combined with the Fuzzy-PI controller is shown in Figure 10.

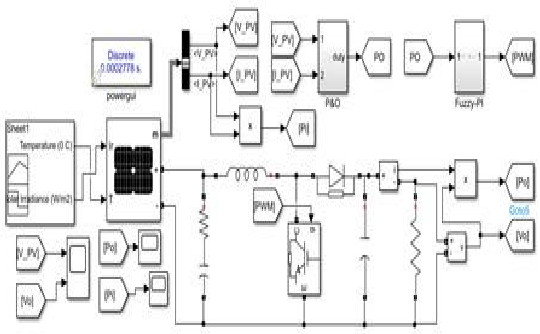


Figure 10. Simulation circuit schematic of the MPPT-based P&O method combined with a Fuzzy-PI controller

When the performance of the MPPT-based P&O method combined with a Fuzzy-PI controller was evaluated under radiation conditions of 1000 W/m² and a temperature of 25°C, the simulation results are shown in Figure 11.

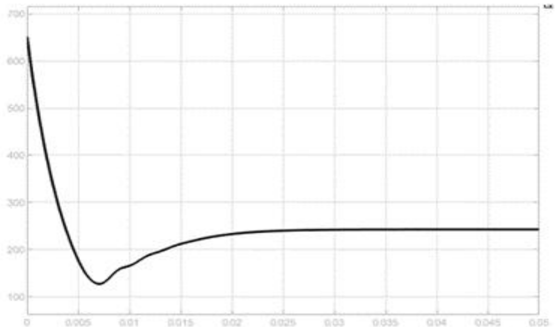


Figure 11. Output power response time to reach steady-state for the MPPT-based P&O method combined with the Fuzzy-PI controller

Figure 11 shows that the output power signal of the solar panel reaches its maximum value within 0.025 seconds, with a steady-state ripple of 0.06 V, as illustrated in Figure 12.

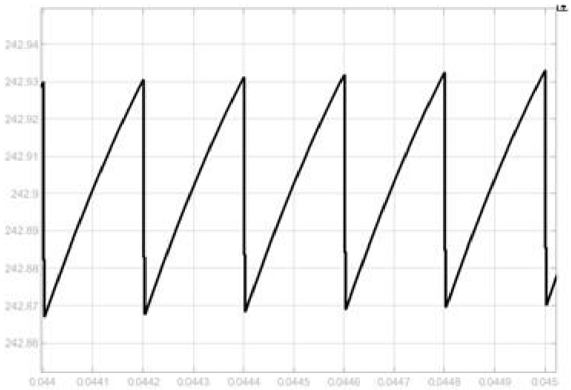


Figure 12. Steady-state ripple response of the MPPT-based P&O method combined with the Fuzzy-PI controller.

Meanwhile, the response of the MPPT-based P&O method without the Fuzzy-PI controller under radiation conditions of 1000 W/m² and a temperature of 25°C is shown in Figure 13.

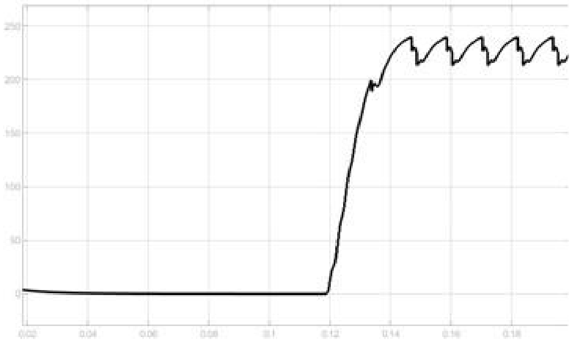


Figure 13. Output power response time to reach steady-state for the MPPT-based P&O method without a Fuzzy-PI controller.

Figure 13 shows that the output power signal of the solar panel reaches a steady or stable state within 0.14 seconds, with a steady-state ripple of 30 volts. Meanwhile, the response of the MPPT-based P&O method without a PI controller under radiation conditions of 1000 W/m² and a temperature of 25°C is shown in Figure 14.

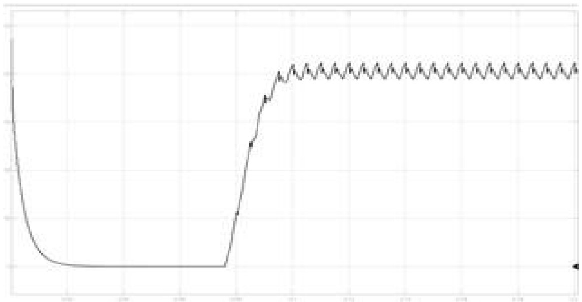


Figure 14. Response of the MPPT-based P&O method with a PI controller

Figure 14 shows that the output power signal of the solar panel reaches a steady or stable state within 0.11 seconds, with a steady-state ripple of 17 volts.

## 4. Conclusion

Based on the performance of the three methods analyzed and simulated, when the solar panel is controlled using only the P&O algorithm, the response time for the output power signal to reach the optimum point is 0.14 seconds, with a steady-state ripple of 30 volts. After the solar panel utilizes the MPPT-based P&O method with a PI controller, the output power signal reaches the maximum power point in 0.11 seconds, but the steady-state ripple decreases to 17 volts. Meanwhile, with the MPPT-based P&O method combined with the Fuzzy-PI controller, the response time to reach the maximum power point is only 0.025 seconds, and the steady-state ripple is just 0.06 volts.

## Reference


[1]. Statistik PLN 2023

[2]. Handbook of Energy & Economic Statistics of Indonesia 2022.

[3]. *World Nuclear Association*. 2024

[4] *https://ebtke.esdm.go.id/post/2023/07/24/3536/kapasitas.terpasang.ebt.capai.127.gw.ini.gerak.cepat.pemerintah.serap.potensi.ebt*

[5]. https://www.ekon.go.id/publikasi/detail/3917/ekonomi-hijau-dan-pembangunan-rendah-karbon-mendorong-pertumbuhan-ekonomi-dan-meningkatkan-kesejahteraan-sosial.

[6]. Tomi Alamsyah, Ayong Hiendro, Zainal Abidin. 2021. Analisis Potensi Energi Matahari Sebagai Pembangkit Listrik Tenaga Surya Menggunakan Panel Mono-Crystalline dan Poly-Crystalline Di Kota Pontianak dan Sekitarnya, Journal of Electrical Engineering, Energy, and Information Technology (J3EIT), 9(2) https://jurnal.untan.ac.id/index.php/j3eituntan/article/view/48425/75676590121

[7]. Agus Noor Sidiq, Suwardi, 2022. Calculation Of Carbon Emissions And Cap And Trade/Tax Schemes At Co-firing Coal Power Plants. Traksi: Majalah Ilmiah Teknik Mesin : 22(2), Tahun Hal. 273-293. DOI: https://dx.doi.org/10.26714/traksi.22.2.2022. 273-293.

[8]. Suwarti, 2022, Optimasi Pembangkit Listrik Tenaga Surya Tipe Solar home System dengan Kapasitas 800 WP, Jurnal ISAINTEK.Volume 5, (2): 101-119. https://isaintek.polinef.ac.id/index.php/isaintek/article/download/80/93.

[9]. Dimas Juniyanto, Tatyantoro Andrasto, dan Suryono, 2018. Optimalisasi Stand-Alone Photovoltaic System dengan Implementasi Algoritma P&O-Fuzzy MPPT, Jurnal Teknik Elektro,10(1). https://journal.unnes.ac.id/nju/jte/article/viewFile/14108/7871

[10]. M. Kermadi, Z. Salam, J. Ahmed and E. M. Berkouk,2019. An Effective Hybrid Maximum Power Point Tracker of Photovoltaic Arrays for Complex Partial Shading Conditions. in IEEE Transactions on Industrial Electronics, vol. 66, no. 9, pp. 6990-7000, doi: 10.1109/TIE.2018.2877202.

[11]. Arsalan Muhammad Soomar, Abdul Hakeem, Mustapha Messaoudi, Piotr Musznicki, Amjad Iqbal, Stanislaw Czapp.2022. Solar Photovoltaic Energy Optimization and Challenges. *Solar Energy.Volume 10 - 2022* https://doi.org/10.3389/fenrg.2022.879985.

[12]. Puji Setiyawan, Sukarno Budi Utomo, dan Agus Adhi Nugroho.2021. Analisa Optimasi Photovoltaic(PV) 100 W Menggunakan MPPT dengan Alogaritma Perturb dan Observe . Elektrika, 13(1). Hal 1-6 https://journals.usm.ac.id/index.php/elektrika/article/view/2984.

[13]. Mohammad Haziq Ibrahim, Swee Peng Ang, Muhammad Norfauzi Dani, Mohammad Ishlah Rahman, Rafidah Petra , and Sheik Mohammed Sulthan. 2023. Optimizing Step-Size of Perturb & Observe and Incremental Conductance MPPT Techniques Using PSO for Grid-Tied PV System. VOLUME 11, pp. 13079- 13090, 2023 https://ieeexplore.ieee.org/stamp/stamp.jsp? ar number=10038703

[14]. Ke Yan; Yang Du; Zixiao Ren., "MPPT Perturbation Optimization of Photovoltaic Power Systems Based on Solar Irradiance Data Classification", IEEE Transactions on Sustainable Energy, Volume : 10, Issue: 2, April 2019). pp. 514 – 521. DOI: 10.1109/TSTE.2018.2834415 Publisher: IEEE. https://ieeexplore.ieee.org/abstract/document/8356136

[15]. M. Kavya & S. Jayalalitha, "Developments in Perturb and Observe Algorithm for Maximum Power Point Tracking in Photo Voltaic Panel ", A Review. Volume 28, pp. 2447–2457, 2021. https://doi.org/10.1007/s11831-020-09461-x.

[16]. Abubakari Sadick.2023. Maximum Power Point Tracking Simulation for Photovoltaic Systems Using Perturb and Observe Algorithm. DOI: 10.5772/intechopen.111632, https://www.intechopen.com/online-first/87083.

[17]. Muhammad Kamran, Muhammad Mudassar, Muhammad Rayyan Fazal, Muhammad Usman Asghar, Muhammad Bilal, Rohail Asghar.(2020). Implementation of improved Perturb & Observe MPPT technique with confined search space for standalone photovoltaic system. Journal of King Saud University - Engineering Sciences. Volume 32, Issue 7, November 2020, Pages 432-441. https://doi.org/10.1016/j.jksues.2018.04.006

[18]. Bima Romadhon Parada Dian Palevi," Irrine Budi Sulistiawati, Penerapan Algoritma Fuzzy Logic Pada Solar MPPT Controller", ALINIER JURNAL VOL 2 NO 2 NOVEMBER 2021. Pp.56-67 https://ejournal.itn.ac.id/index.php/alinier/article/download/4303/3029.

[19]. Rahmatiana Dewi, Yahya Chusna Arif, Lucky Pradigta Setiya Raharja, " Maximum Power Point Tracking Berbasis Fuzzy Logic Control Pada Heater Mini Sauna di Masa Pandemi", JURNAL TEKNOLOGI TERPADU VOL. 11 NO. 1. April 2023 pp.15-24.

[20]. Soedibyo; Avian Lukman Setya Budi; Mochamad Ashari; Moch Siswan Afandi, Feby Agung Pamuji, A Design of Automatic Photovoltaic Pollutant Mitigation Device Based on Fuzzy Logic Controller. Published in: 2021 International Seminar on Application for Technology of Information and Communication (iSemantic). Publisher in : 2021 IEEE DOI: 10.1109/iSemantic52711.2021.9573230. https://ieeexplore.ieee.org/abstract/document/9573230

[21]. Mohamadreza Samadi & Seyed Mehdi Rakhtala. 2019. Reducing Cost and Size in Photovoltaic Systems Using Three-Level Boost Converter Based on Fuzzy Logic Controller. Iranian Journal of Science and Technology, Transactions of Electrical Engineering, Volume 43, pp. 313–323, (2019). https://doi.org/10.1007/s40998-018-0145-6 https://link.springer.com/article/10.1007/s40998-018-0145-6

[22]. Ahlam Mohamad Shakoor, Hersh Hasan Taha. 2022. Modelling and Simulation of Perturb and Observe MPPT Algorithm Based on The PI Controller for Photovoltaic System. Kurdistan Journal of Applied Research | Volume 7 – Issue 2 – December 2022.pp. 71-83 https://doi.org/10.24017/Science.2022.2.6

[23]. Marcel Nicola, Claudiu-Ionel Nicola. 2021. Improved Performance of Grid-Connected Photovoltaic System Based on Fractional-Order PI Controller and Particle Swarm optimization . Published in: 2021 9th International Conference on Modern Power Systems (MPS). DOI: 10.1109/MPS52805.2021.9492707. https://ieeexplore.ieee.org/abstract/document/9492707.

[24]. Yin Jin; Honghua Wang; Chengliang Wang. 2017. Maximum power point tracking of photovoltaic system based on fuzzy-PI combined controller. Published in: 2017 Chinese Automation Congress (CAC) DOI: 10.1109/CAC.2017.8244018. https://ieeexplore.ieee.org/abstract/document/8244018

[25]. Ibrahim Altawil, Mohammad Awad Momani , Mahamood A. Al-Tahat , Raed Al Athamneh , Mohammed Adnan Al-Saadi , Zaid Albataineh.2023. Optimization of fractional order PI controller to regulate grid voltage connected photovoltaic system based on slap swarm algorithm. International Journal of Power Electronics and Drive Systems (IJPEDS) Vol. 14, No. 2, June 2023, pp. 1184~1200 ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i2.pp1184-1200

[26]. Muhammad M. Rashid, 1993. Power electronics Circuits, Devides,and applications, scond edition, Prentice-Hall International, Inc.

[27]. Brigitte Hauke, Basic Calculation of a Boost Converter's Power Stage, Aplication Report SLVA3728 November 2009-Revised July 2010, Texas Instruments. Low Power

DC/DC Application.
[28]. Hussian, O. S. S., H. M. Elsayed, and M. A. M. Hassan, 2019. "Fuzzy Logic Control for a Stand-Alone PV System with PI Controller for Battery Charging Based on Evolutionary Technique", 2019 10th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS),2 : IEEE, pp. 889-894, https://ieeexplore.ieee.org/document/8924269.
[29]. C. Susila and B. Rajasekhar, 2016. A Control Strategy to Stabilize PWM DC-DC Buck Converter With input Filter Using Fuzzy-PI, International Journal Of Electrical, Electronics And Data Communication, 4, ISSN: 2320-2084.