

Maximum power control system for solar panels using the Sliding Mode Controller (SMC) method

Ksatria Nugraha¹, Muldi Yuhendri¹

¹Department of Electrical Engineering, Faculty of Engineering, Padang State University, Padang, Indonesia

Article Info

Article history:

Received August 06, 2025

Revised September 27, 2025

Accepted October 22, 2025

Keywords:

Solar Panel

MPPT

Sliding Mode Controller

Boost Converter

Arduino Mega 2560

PWM.

ABSTRACT

Solar energy is a promising renewable energy source that offers solutions to the energy crisis and carbon emission reduction, but the power output generated by solar panels is fluctuating due to changes in light intensity and ambient temperature. This study develops a Maximum Power Point Tracking (MPPT) control system using the Sliding Mode Controller (SMC) method to optimize the power output of solar panels. The system design includes the use of a boost converter as a voltage regulator and an Arduino Mega 2560 microcontroller as the control center, with the SMC algorithm developed in Simulink MATLAB to generate a PWM signal that controls the duty cycle. Test results show that the SMC algorithm can achieve a maximum power point of 30 watts in 20 seconds, faster and more efficient than the Perturb and Observe (P&O) method, which only reaches 25 watts in 30 seconds, and demonstrates lower and more stable power oscillations. The boost converter was also proven effective in increasing the output voltage of the solar panel. Thus, the SMC-based MPPT system demonstrates superior performance in efficiency and adaptability to dynamic environmental conditions, making it suitable for application in the development of more reliable solar energy systems.

Corresponding Author:

Ksatria Nugraha

Department of Electrical Engineering, Faculty of Engineering, Padang State University

Prof. Dr. Hamka Street, Padang, Indonesia

Email: ksatrianugraha27@gmail.com

1. INTRODUCTION

Renewable energy is now a key focus in addressing issues of dependence on fossil fuels and increasing greenhouse gas emissions[1],[2]. Among various renewable energy sources, solar energy is one of the most promising and widely utilized due to its abundant availability and environmentally friendly nature. Advancements in photovoltaic (PV) technology have led to improved energy conversion efficiency, including through the use of innovative materials such as tandem solar cells and perovskite[3],[4]. Additionally, integrating solar panels with smart control systems enables real-time power optimization in response to varying environmental conditions [5].

In tropical regions like Indonesia, solar panel performance is significantly influenced by environmental temperature and humidity. Based on testing, monocrystalline panels demonstrate better performance than polycrystalline panels under high temperature and humidity conditions, with output power differences of up to 40 watts under extreme conditions[6]. However, the main challenge in utilizing solar energy is its intermittent nature—fluctuating power production due to changes in light intensity and temperature, leading to instability in electrical output [7]. This requires an adaptive control system to ensure solar panels operate optimally.

To maintain solar panel performance at the maximum power point (MPP), the Maximum Power Point Tracking (MPPT) algorithm is used in combination with DC-DC converters such as boost converters[8]. One popular MPPT method is Perturb and Observe (P&O) due to its ease of implementation. However, this algorithm is less responsive to rapid changes in environmental conditions and often causes

oscillations around the MPP, resulting in power loss [9],[10]. Therefore, a more adaptive and robust algorithm is needed to maintain system stability.

This study proposes the implementation of a Sliding Mode Controller (SMC) algorithm in the MPPT system as a solution to the limitations of the P&O algorithm. SMC is known for its fast response, robustness against disturbances, and ability to significantly reduce power oscillations[11]. The system will be implemented using a boost converter on a 1 x 50 WP solar panel and controlled by an Arduino Mega 2560 microcontroller. The objective of this research is to design and test the performance of an SMC-based MPPT control system and compare it with the performance of the P&O algorithm. This research is expected to contribute to improving the efficiency and stability of solar energy systems, particularly for applications in tropical environments.

2. METHOD

This research was conducted by applying an MPPT control system to a 1x50 WP solar panel. The MPPT system was designed using a boost converter to control the output voltage of the solar panel. PWM pulse width adjustment was performed to control the output voltage of the boost converter used. The MPPT control system designed in this research was implemented using Arduino Mega 2560 with Simulink MATLAB for programming.

Figure 1. shows the MPPT control system schematic for the solar panel with a DC-DC converter, using an MPPT algorithm based on a Sliding Mode Controller (SMC). From this study, the data collected includes the output current and voltage of the solar panel to obtain power and power changes, which will be used as input data for the Sliding Mode Controller (SMC) algorithm. Meanwhile, the output data is the desired duty cycle change. The data will then use the Sliding Mode Controller (SMC) algorithm in the MATLAB application to determine the duty cycle value of the PWM signal to be sent to the DC-DC converter to determine the voltage value, thereby producing the maximum power point.

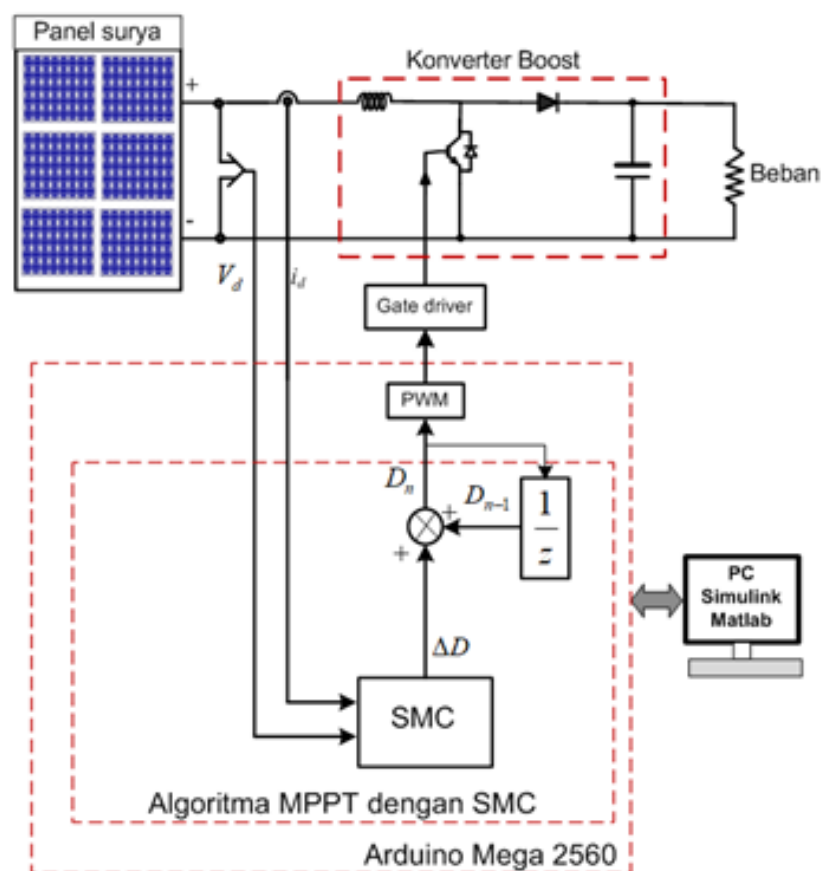


Figure 1. MPPT control scheme using SMC

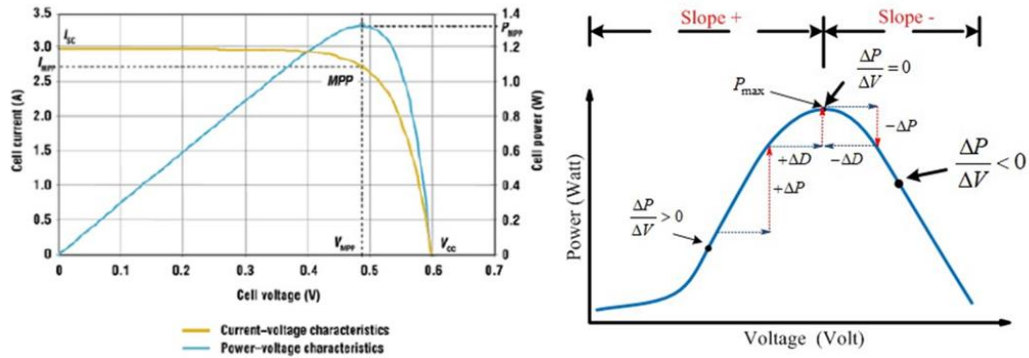


Figure 2. MPPT System (a) Maximum Power Point (MPP) (b) perturb and observe algorithm (P&O)

The Perturb and Observe (P&O) algorithm is a commonly used method for detecting the maximum power point (MPP) on the power versus voltage (P-V) curve of a solar panel. The first step in this algorithm, which involves changing the voltage (dV), is known as the perturbation step. Meanwhile, the second step, which involves observing changes in power (dP), is referred to as the observation step [12]. Figure 2(b) above illustrates the working principle of the P&O algorithm.

The Sliding Mode Control-based MPPT algorithm is an improvement over the P&O algorithm to address the limitations of the P&O algorithm. The main limitation of this method is that the power generated oscillates around the maximum power point (MPP) when operating conditions are stable, meaning the method may track in the wrong direction during rapid changes in environmental conditions. Additionally, it affects the magnitude of oscillations around the MPP during stable conditions, as well as the system's speed in reaching the maximum power point [13].

Therefore, in this study, the MPPT algorithm based on the Sliding Mode Controller (SMC) is used to provide a faster response to changes in environmental conditions, minimize power oscillations around the MPP, and maintain system stability more effectively due to its robustness against disturbances and system uncertainties. Figure 3 shows the curve of the Sliding Mode Control (SMC).

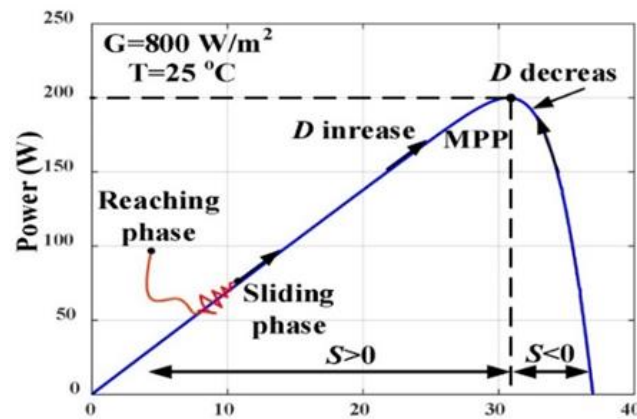


Figure 3. Sliding Mode Control (SMC) curve

The sliding mode control (SMC) process is a nonlinear control method designed to reliably (robustly) regulate high-order nonlinear dynamic systems, even under conditions of uncertainty. SMC works by providing high-speed switching feedback and can be applied to both linear and nonlinear systems. The main advantage of SMC is its ability to maintain control performance despite external disturbances or changes in environmental parameters [14]. In solar panel systems, SMC is used to optimize power output through the Maximum Power Point Tracking (MPPT) method, by adjusting the duty cycle based on the difference between the actual voltage and the reference voltage so that the panel always operates at the maximum power point. For partial shading conditions, the Partial Shading-SMC (PS-SMC) algorithm was developed to detect power reduction and automatically adjust the MPP voltage (V_{MPP}) [15]. Sliding Mode Control is used to determine changes in the duty cycle that will regulate the voltage from the boost converter.

Sliding Surface SMC :

$$S = \frac{\Delta P_{pv}}{\Delta V_{pv}} \quad (1)$$

$$\Delta P_{pv} = P_n - P_{n-1} \quad (2)$$

$$P_n = I_{pv} \times V_{pv} \quad (3)$$

$$\Delta V_{pv} = V_n - V_{n-1} \quad (4)$$

The output value of Sliding Mode Control in the form of duty cycle changes is formulated as follows :

$$U_{smc} = \Delta D = k \times Sgn(S) \quad (5)$$

$$Sgn(s) = \begin{cases} 1 & \text{if } S > 0 \\ 0 & \text{if } s = 0 \\ -1 & \text{if } s < 0 \end{cases} \quad (6)$$

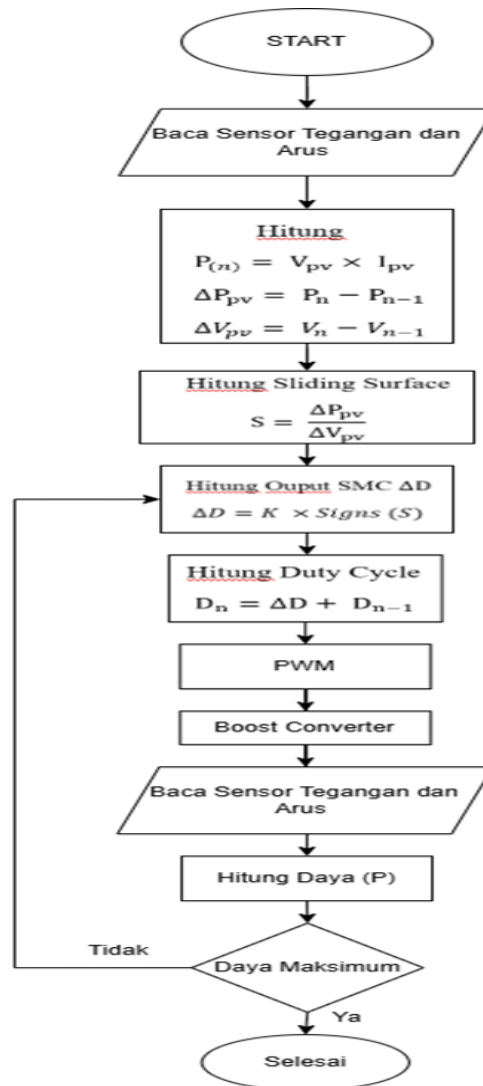


Figure 4. Overall System Flowchart

Figure 4. illustrates the flowchart of the Sliding Mode Controller (SMC) algorithm used in the Maximum Power Point Tracking (MPPT) control system. The process begins by calculating the output power of the solar panel using the equation $P_n = V_{pv} \times I_{pv}$. This power value is then used by the microcontroller to determine changes in power and voltage, calculated using $\Delta P_{pv} = P_n - P_{n-1}$ and $\Delta V_{pv} = V_n - V_{n-1}$, respectively. Based on these two parameters, the sliding surface is calculated using the equation $S = (\Delta P_{pv}) / (\Delta V_{pv})$. The S value is then used to generate the SMC control signal in the form of a duty cycle change using the equation $\Delta D = K \times \text{Sgn}(S)$. Finally, the duty cycle is updated using $D_n = \Delta D + D_{n-1}$. This duty cycle value is then used to control the PWM signal that regulates the operation of the boost converter to optimize the output voltage from the solar panel.

3. RESULTS AND DISCUSSION

In this study, the system was implemented on a 1x50 WP solar panel installed on the roof of the laboratory, as shown in Figure 5. The solar panel terminals on the laboratory roof were connected to the panels inside the laboratory. Then, the panels in the laboratory were arranged in parallel to test the equipment.



Figure 5. solar panel (a) The solar panels are installed on the laboratory roof. (b) solar panel in the laboratory

When the solar panels receive changes in temperature and light intensity from sunlight, it will be reflected in the changes in current and voltage on the panels in the laboratory. The panels that have been assembled in parallel are then connected to a device to test the validation of the boost converter as well as the current and voltage on the device.



Figure 6. Hardware Boost Converter with Measuring Instrument

After validating the boost converter, the current sensor and voltage sensor were successfully implemented, then connected to a computer to run the program and load was applied.

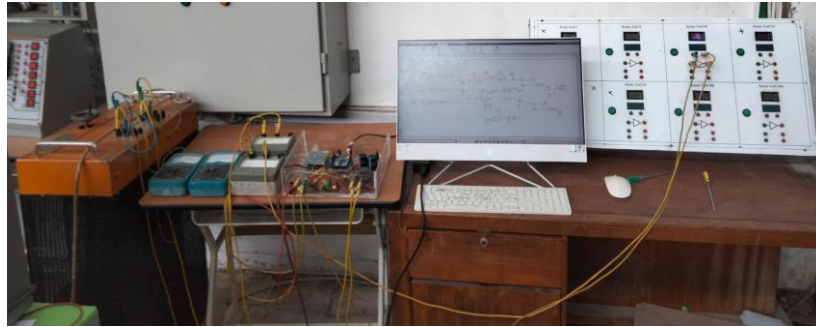


Figure 7. Overall Hardware System

Figure 7 shows the complete hardware setup that will be tested using the MPPT system program with the Sliding Mode Controller (SMC) algorithm in Simulink Matlab. The testing was conducted at 10:00 AM local time under slightly cloudy and sunny weather conditions. As a result, several tests were conducted that affected the temperature of the solar panels and variations in light intensity. The results of testing the MPPT control system with the SMC algorithm are shown in Figure 8, where the data is displayed as current versus voltage after the system was tested with the Sliding Mode Controller (SMC) algorithm.

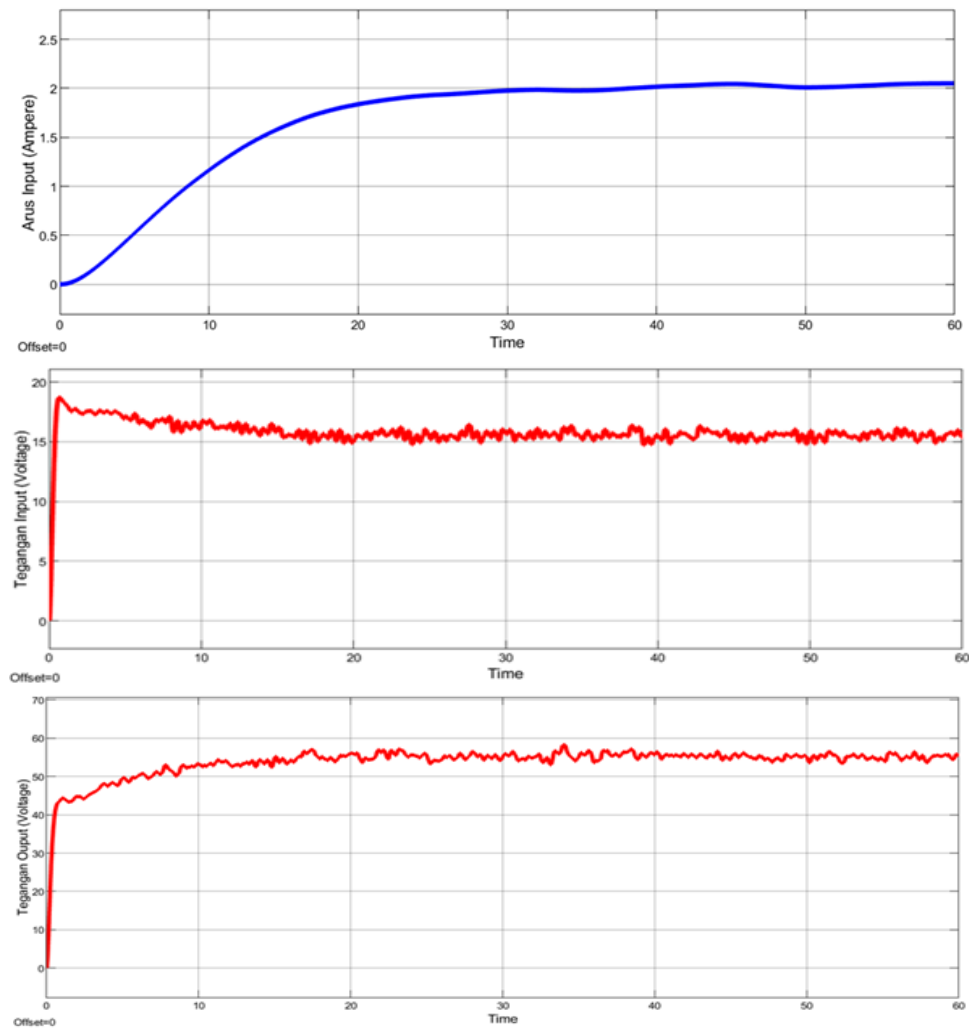


Figure 8. Relationship between current, input voltage, and output voltage of the solar panel after installing the boost converter.

Figure 9 shows the maximum power value after the installation of the MPPT control system using the Sliding Mode Controller (SMC) algorithm. From the results obtained, the maximum power point can be reached at 30 watts in 20 seconds. This means that the Artificial Neural Network algorithm is able to quickly reach the maximum power point of the solar panel, so that the maximum power generated by the solar panel can be used under load.

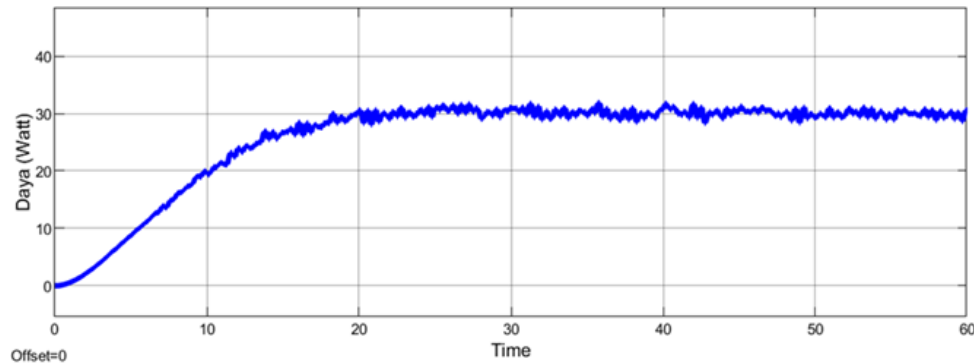


Figure 9. Maximum power of the MPPT system with the Sliding Mode Controller algorithm

4. CONCLUSION

Based on the results of the research conducted, it can be concluded that the Maximum Power Point Tracking (MPPT) control system based on the Sliding Mode Controller (SMC) algorithm shows good performance in optimizing the output power of solar panels against variations in temperature and solar radiation intensity. This system was designed and implemented using Arduino Mega 2560 to control the power from a 1x50 WP solar panel. The primary objective of using the SMC algorithm is to accelerate the process of finding the maximum power point and reduce power oscillations that occur when the system operates at that point. Test results show that the SMC algorithm can achieve a maximum power of 30 watts in 20 seconds with smooth and stable power oscillation characteristics around the maximum point. This achievement demonstrates that the SMC-based control approach not only improves the efficiency of maximum power point search but also provides system stability in the face of external disturbances, such as changes in temperature and light intensity. Therefore, the SMC algorithm is worthy of consideration as an adaptive and reliable control method for MPPT applications in small-scale and medium-scale solar power generation systems

REFERENCES

- [1] A. I. Osman *et al.*, "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review," *Environ. Chem. Lett.*, vol. 21, no. 2, pp. 741–764, 2023, doi: 10.1007/s10311-022-01532-8.
- [2] R. Ridlo and A. Hakim, "ANDASIH Jurnal Pengabdian kepada Masyarakat Model Energi Indonesia, Tinjauan Potensi Energy Terbarukan Untuk Ketahanan," *ANDASIHJurnal Pengabd. Kpd. Masy.*, vol. 1, no. 1, p. 1, 2020.
- [3] U. Arachchige and S. R. . Weliwaththage, "(PDF) Solar Energy Technology," *J. Res. Technol. Eng.*, vol. 1, no. 3, pp. 67–75, 2020.
- [4] A. Lindo and M. Yuhendri, "Sistem Kendali Daya Maksimum Panel Surya Berbasis Fuzzy Logic Controller," *JTEIN J. Tek. Elektro Indones.*, vol. 3, no. 1, pp. 102–110, 2022, doi: 10.24036/jtein.v3i1.207.
- [5] D. S. Vijayan *et al.*, "Advancements in Solar Panel Technology in Civil Engineering for Revolutionizing Renewable Energy Solutions—A Review," *Energies*, vol. 16, no. 18, pp. 1–33, 2023, doi: 10.3390/en16186579.
- [6] I. Kurniawan, M. Yuhendri, A. Hendra, and R. Hidayat, "Implementation of Maximum power control of Solar Panels using Modified Perturb and Observe Algorithm based on Adaptive Neuro Fuzzy Inference System," *J. Ind. Autom. Electr. Eng.*, vol. 01, no. 01, pp. 200–208, 2024.
- [7] N. S. M. N. Izam, Z. Itam, W. L. Sing, and A. Syamsir, "Sustainable Development Perspectives of Solar Energy Technologies with Focus on Solar Photovoltaic—A Review," *Energies*, vol. 15, no. 8, pp. 1–15, 2022, doi: 10.3390/en15082790.
- [8] G. Dileep and S. N. Singh, "Application of soft computing techniques for maximum power point tracking of SPV system," *Sol. Energy*, vol. 141, pp. 182–202, 2017, doi: 10.1016/j.solener.2016.11.034.
- [9] H. Masrepol and M. Yuhendri, "Implementasi MPPT Panel Surya Berbasis Algoritma Perturbasi & Observasi (PO) Menggunakan Arduino," *JTEIN J. Tek. Elektro Indones.*, vol. 2, no. 2, pp. 162–167, 2021, doi: 10.24036/jtein.v2i2.155.
- [10] R. I. Jabbar, S. Mekhilef, M. Mubin, and K. K. Mohammed, "A Modified Perturb and Observe MPPT for a Fast and Accurate Tracking of MPP Under Varying Weather Conditions," *IEEE Access*, vol. 11, no. July, pp. 76166–76176, 2023, doi: 10.1109/ACCESS.2023.3297445.
- [11] P. Fernández-Bustamante, I. Calvo, E. Villar, and O. Barambones, "Centralized MPPT based on Sliding Mode Control and XBee 900 MHz for PV systems," *Int. J. Electr. Power Energy Syst.*, vol. 153, no. July, p. 109350, 2023, doi: 10.1016/j.jepes.2023.109350.

- [12] I. Winarno and L. Natasari, "Maximum Power Point Tracker (MPPT) Berdasarkan Metode Perturb and Observe Dengan Sistem Tracking Panel Surya Single Axis," *Umj*, no. November, pp. 1–9, 2017.
- [13] M. R. Mostafa, N. H. Saad, and A. A. El-sattar, "Tracking the maximum power point of PV array by sliding mode control method," *Ain Shams Eng. J.*, vol. 11, no. 1, pp. 119–131, Mar. 2020, doi: 10.1016/j.asej.2019.09.003.
- [14] A. Faizal and B. Setyaji, "Desain Maximum Power Point Tracking (MPPT) pada Panel Surya Menggunakan Metode Sliding Mode Control," *J. Sains, Teknol. dan Ind.*, vol. 14, no. 1, pp. 22–31, 2019.
- [15] M. Farhat, O. Barambones, and L. Sbita, "A new maximum power point method based on a sliding mode approach for solar energy harvesting," *Appl. Energy*, vol. 185, pp. 1185–1198, Jan. 2017, doi: 10.1016/j.apenergy.2016.03.055.