ISSN 2550-1186 e-ISSN 2580-6823

Modified Perturb and Observe Approach in MPPT for a Standalone Photovoltaic System

Ramadoni Syahputra

Department of Electrical Engineering, Faculty of Engineering
Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia

*Corresponding author, e-mail: ramadoni@umy.ac.id

Abstract – *This paper proposes a modified perturb and observe algorithm approach to increase the output power of an independent photovoltaic system. Today, photovoltaic application as renewable energy power plant has been prevalent. This popularity is because photovoltaic power plants are easy to apply on-grid and off-grid schemes. In standalone power generation applications, the increased photovoltaic output power is of great help to users as it contributes to increasing overall system efficiency. The perturb and observe algorithm has been known as a reliable and inexpensive method. However, the performance still needs to be improved. Therefore, this study proposes a modified perturb and observe algorithm approach. The research results show the superiority of the proposed method.*

Keywords: *MPPT, Perturb and Observe, Solar Photovoltaic, Optimization*

I. Introduction

Penetration of renewable energy power generation has been increasingly encouraging in recent decades [1]. The main problem that causes it is the depletion of fossil energy reserves, namely oil, natural gas, and coal. Another problem the world faces is carbon emissions, or, more broadly, environmental issues [2]-[3]. Many parties have campaigned for the use of clean and environmentally friendly energy [4]. The choice is a renewable energy power plant. One type of potential renewable energy power plant worldwide, including in Indonesia, is a solar photovoltaic power plant [5]. Indonesia's solar energy potential is 207.898 GW, and the target for developing solar photovoltaic power plants in 2025 is 6.5 GW [6]. Solar power plants using solar photovoltaics are promising alternative power plants for sustainable energy development, as well as environmentally friendly and low operational and maintenance costs [7]-[9]. However, due to weather conditions and the non-linear nature of solar radiation, this power plant fluctuates significantly, requiring additional devices, such as power converters.

An essential problem with photovoltaic power plants is their low efficiency and significant energy loss during operation [10]. Therefore the main challenge of solar photovoltaic operations is extracting the maximum power generated. The technique commonly used for maximum power extraction is maximum power point tracking (MPPT) [11]-[12]. MPPT is an effort always to get the maximum power point in various solar irradiation conditions. In order to get the maximum power point of solar photovoltaic, optimization is carried out by utilizing a boost-type dc-dc converter [13]. The dc-dc converter is used in solar photovoltaic systems to regulate photovoltaic voltage by varying the duty cycle through the MPPT technique to maintain the solar photovoltaic operating point at the maximum power point. The output of this converter is controlled using a controller so that the output voltage and current will produce maximum power under various conditions of electrical load and solar irradiation that hits solar photovoltaic [14]-[15].

Researchers worldwide are competing to find a solution for maximum power extraction from solar photovoltaics using the MPPT technique [16]-[17]. However, the problem often encountered in the MPPT methods developed in these studies is the system's stability when the electrical load changes. The greater the electrical load solar photovoltaics serves, the ability to extract maximum power

Manuscript received September 2022, revised November 2022

decreases. These studies include those in Ref. [18], which describes a power monitoring method with conventional MPPT techniques designed to operate under uniform environmental conditions. In contrast, non-uniform conditions do not give the desired results.

Furthermore, in reference [19], using microcontroller-based control techniques, maximum power extraction with fewer oscillations is carried out. In references [20] and [21], mathematical modeling of solar photovoltaics must consider variations in solar illumination, voltage, and output current. This modeling is advantageous in further MPPT method development. The most widely used MPPT maximum power extraction method in the literature is the perturb and observe (P&O) method, as described in Refs [22]-[24]. The P&O method operates by periodically varying the terminal voltage of the solar photovoltaic and correlating the previous fault cycle with the generated power. Perturbed will inform the pattern of changes in solar photovoltaic voltage and current, while observing will calculate the generated power. The addition or reduction of voltage in the next step is evaluated by comparing the power generated before and after the perturbed process [25]. This procedure continues until the output power reaches the maximum level. The weakness of this method is that it could be faster and more accurate in finding the optimal duty cycle operating point due to the many steps of the procedure. In addition, this method will not work correctly when the measured data contains noise or weather conditions change rapidly. At a steady state, the resulting power output continuously oscillates around the peak point with a significant losses.

Based on the literature review described above becomes the basis for carrying out this research. In this research, a control strategy is carried out in optimizing the power of the converters used in solar photovoltaic systems using perturb and observe (PO) algorithms.

II. MPPT of Solar Photovoltaic

II.1. Maximum Power Point Tracking

The photovoltaic's maximum power point changes in the photovoltaic radiation and temperature. Photovoltaic reach its maximum working point is not done automatically but needs to be controlled. MPPT is a method of finding the optimum photovoltaic working point and maintaining the photovoltaic work at that point.

Many methods have fundamentally different characteristics. Each of the methods used has different characteristics. The use of MPPT increases the value of the output power to determine the difference factor from using MPPT.

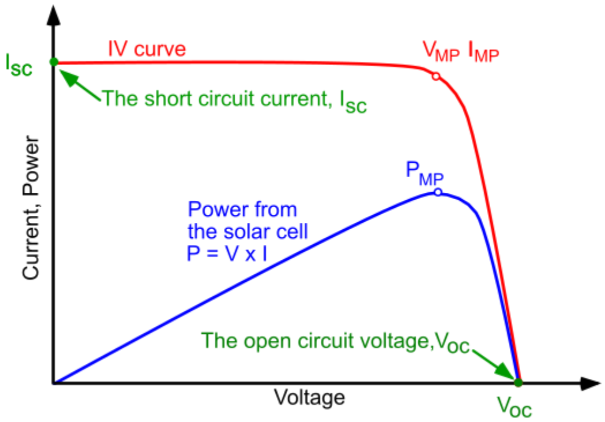

Fig. 1. Current voltage (IV) curve of a solar cell [26]. Operation at the point of maximum power is required to get the maximum power output of the solar cell.

II.2. Solar Photovoltaic Specification

The type of solar photovoltaic module used in this study is 1Soltech 1STH-215-P which has a maximum output power of each solar photovoltaic module of 213.15 watts peak. This type of solar photovoltaic module is polycrystalline. The module's open circuit voltage is 36.3 volts, while the voltage at the maximum power point is 29 volts. The temperature coefficient of the open circuit voltage set is -0.36099 %/°C, where the number of sets for each module is 60 pieces. The short circuit current of the solar photovoltaic module is 7.84 amperes, with the current at the maximum power point being 7.35 amperes. The specified short circuit current temperature coefficient is -0.102 %/°C.

Figure 2 shows the characteristics of the 1Soltech 1STH-215-P solar photovoltaic type at 25°C used in the simulation in this study. The graph above shows the relationship between the solar photovoltaic output current and the output voltage at various solar irradiations. The current versus voltage characteristics in the graph are shown for solar irradiation of 0.2 kW/m^2, 0.4 kW/m^2, 0.6 kW/m^2, 0.8 kW/m^2, and 1.0 kW/m^2. In the figure, it can be seen that solar irradiation significantly affects the current generated by solar photovoltaics. Solar irradiation of 0.2 kW/m^2 can produce an electric current of 3.5 amperes.

In comparison, solar irradiation of 0.4 kW/m^2, 0.6 kW/m^2, and 0.8 kW/m^2 can produce a current of 3.8 amperes, 4.6 amperes, and 6.8 amperes. Maximum solar irradiation of 1.0 kW/m^2 can produce a current of 8 amperes. The higher the solar irradiation that hits the solar photovoltaic, the greater the current that can be generated. From these characteristics, it can also be seen that the applied working voltage has a wide range, which can be used at 1 volt to 35 volts to get the same current at the same solar irradiation. A working voltage of more than 40 volts will cause the current to decrease, and the lowest point is in the range of 37 volts.

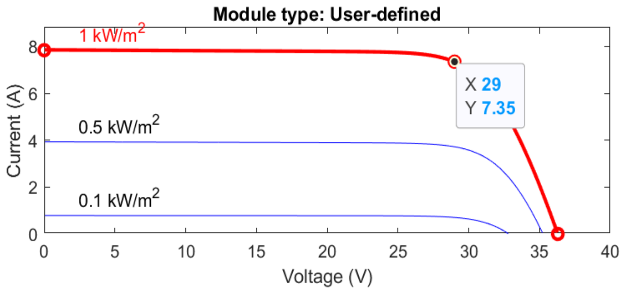

Fig. 2. Characteristics of the solar photovoltaic

III. Modified Perturb and Observe Algorithm

Figure 3 shows the flowchart of the modified Perturb and Observe (PO) algorithm. The PO algorithm works in 2 stages, and perturbation is the disturbance of the Vref value. At the same time, the observation process observes the power value that has changed due to the previous perturb. When the algorithm works, it is positive if there is a change in the observed power. The following perturbation process will continue in the same direction. If the observed process occurs, the power value changes negatively, and the perturbation process goes the opposite. An algorithm (P&O) with the Hill Climbing method can be used to control maximum power point tracking. The method in this algorithm is based on Figure, there are three types of section points, and their positions are located in three different parts. On the left peak section $\Delta P/\Delta V > 0$, the peak of the $\Delta P/\Delta V = 0$, and on the right peak $\Delta P/\Delta V < 0$.

This method works based on the perturbing (increasing or decreasing) duty cycle. When there is a change in the duty cycle value, the power changes will be seen. If the current power is greater than the previous power, the duty cycle value will increase. The duty cycle value will be reduced if the current power is less than the previous power. Therefore, this method requires an input value of the output power to determine the power that falls on the load.

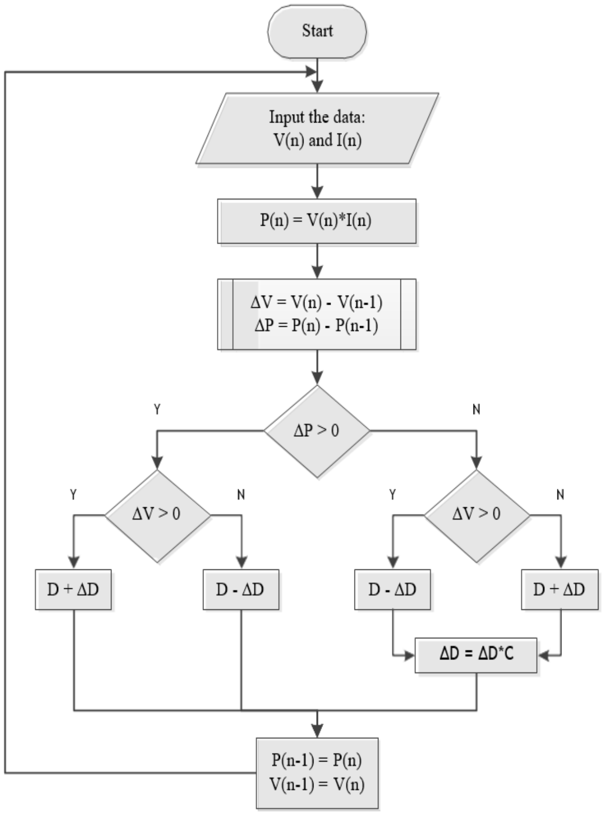

Fig. 3. Flowchart of the modified Perturb and Observe (PO) algorithm [6]

IV. Results and Discussion

The modified PO algorithm in this research tests its sensitivity value based on parameter changes to the optimization results. In the experiments tested, radiation values were used between 0.6 kW/m^2 to 1 kW/m^2 with a fixed temperature value of 25 °C and a resistance value of 20 Ω.

The simulation results from the sensitivity test show that the irradiance value increases in direct proportion to the power generated. 600 W/m^2 irradiation produces a solar PV output power of 125.9 W. Furthermore, for 800 600 W/m^2, radiation produces an output power of 166.3 W. The final test is 1 kW/m^2 irradiation, which produces a solar PV output power of 206 W.

The next step is to simulate to analyze the solar cell system for the output power under different solar radiation conditions and cell temperatures. For starters, the simulation is carried out under conditions at a fixed temperature according to environmental conditions. In this condition, the solar radiation is 1 kW/m^2, and the cell temperature is 25 °C. The simulation results for the P-V curve are shown in Figure 4, Figure 5, and Figure 6.

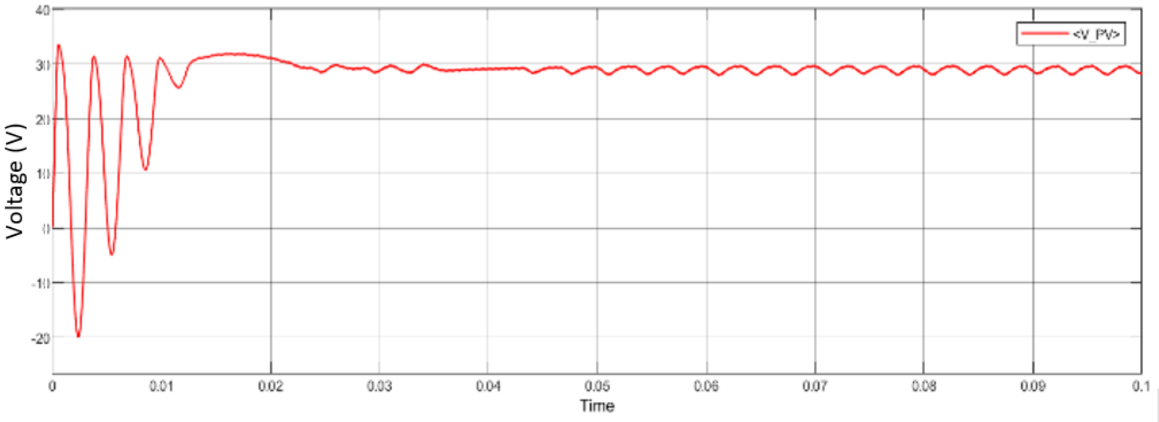

Fig. 4. Voltage of solar photovoltaic at 25 °C

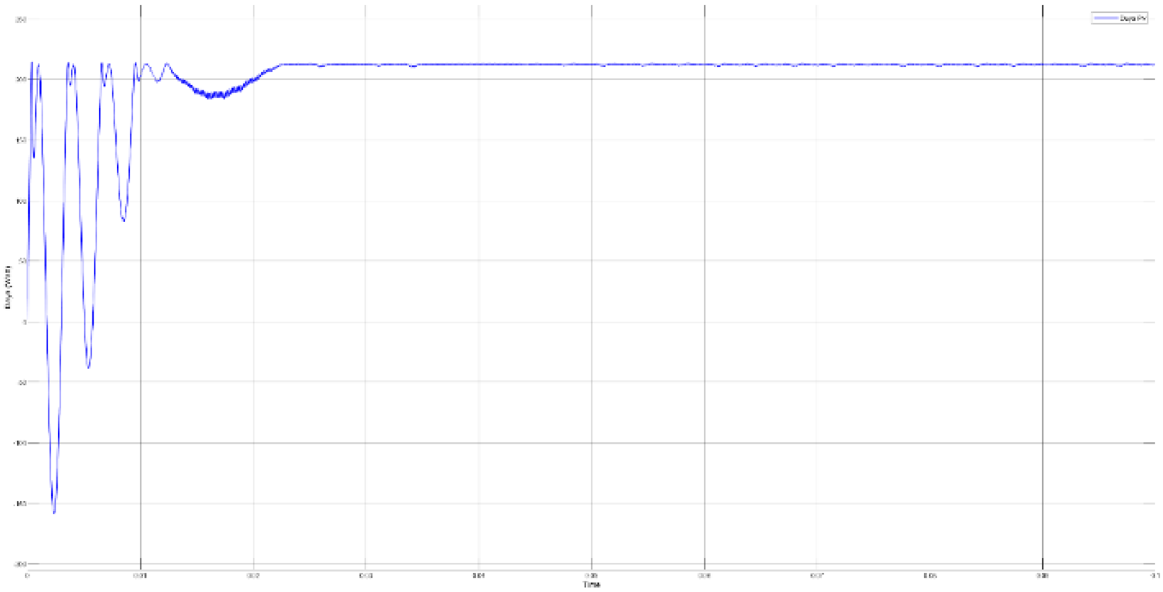

Fig. 5. Power of solar photovoltaic at 25 °C

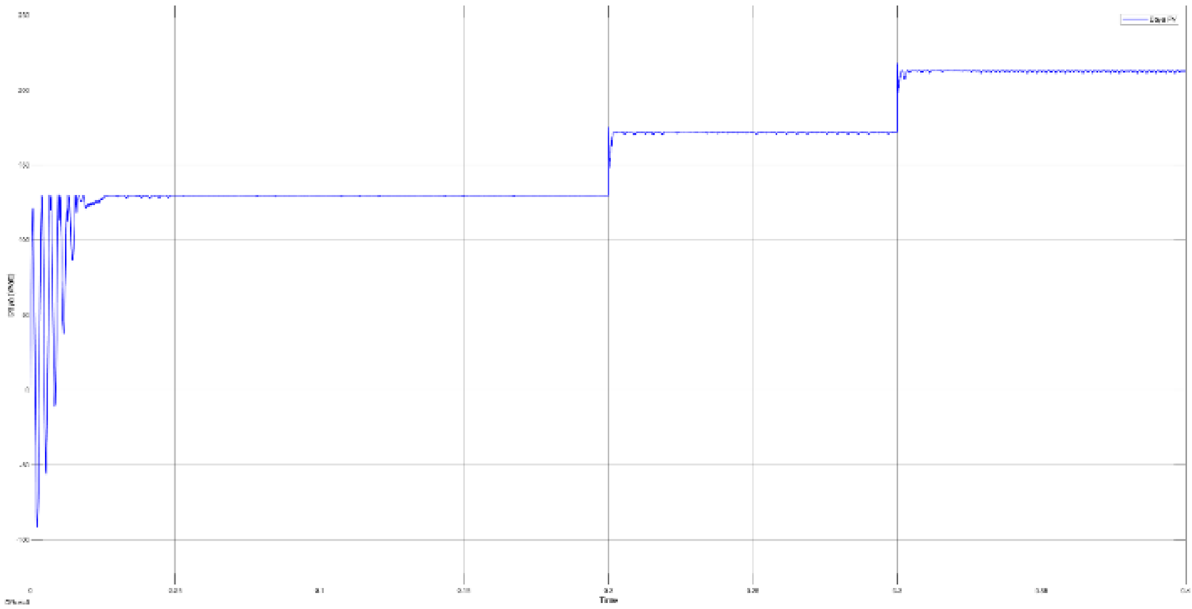

Fig. 6. Power change of solar photovoltaic with change of solar irradiance at 25 °C

Figure 4 shows the voltage of solar PV at 25 ◦C. The figure shows the change in solar photovoltaic voltage in a period of 0.1 seconds. In this brief span of time, it can be seen that the dynamics of changes in solar photovoltaic voltage occur. Violent fluctuations occurred during the first 0.013 seconds. The photovoltaic solar voltage oscillates from 0 to a maximum of 34 volts in 0.002 seconds, then drops to -19 volts in 0.002 seconds. This fluctuation occurs for the first 0.013 seconds, and then there is no significant oscillation. This condition without significant oscillation is achieved by outputting a solar photovoltaic voltage in the range of 30 volts. This system achieved a 30-volt voltage that lasted a long time. There are ripples in achieving this 30-volt voltage, but the ripples are small. Thus, the modified PO algorithm applied to the MPPT solar photovoltaic has succeeded in making a great control. This reasonable control also produces a maximum output voltage in the range of 30 volts, according to the solar photovoltaic rating of 29 volts.

Figure 5 shows the power output of solar PV at 25 ◦C. Similar to the change in voltage in Figure 4, Figure 5 also shows the change in solar photovoltaic power in a period of 0.1 seconds. In this brief period, it can be seen that there is a dynamic change in the output power of solar photovoltaics. Violent fluctuations also occurred during the first 0.013 seconds. The oscillating solar photovoltaic output power starts from 0 to reach a maximum of 215 watts in 0.002 seconds, then drops to -155 watts in 0.002 seconds. This fluctuation occurs for the first 0.013 seconds, with no significant oscillation. This condition without significant oscillation is achieved with a solar photovoltaic power output in the range of 213 watts. This achieved an output power of 213 watts lasts a long time. There are ripples in the achievement of this 213-watt power, but the ripples are small. Thus, the modified PO algorithm applied to the MPPT solar photovoltaic has succeeded in making a great control. This reasonable control also produces a maximum output power in the range of 213 watts, according to the solar photovoltaic rating, which is 213.15 watts.

The performance of the built MPPT system will also be seen in the changing exposure to solar radiation. Therefore, a simulation assumes the cell temperature remains at 25 ◦C, and the solar radiation varies. At $0<t\leq 0.2$, the solar radiation is set to 600 W/m^2; when $0.2<t\leq 0.3$, the solar irradiance value is increased until it reaches 800 W/m^2; when $0.3<t\leq 0.4$, the value of solar radiation is increased again to 1000 W/m^2.

Figure 6 shows the Power change of solar photovoltaic with a change of solar irradiance at ◦25 ◦C. Solar irradiance of 600 W/m^2 produces a solar photovoltaic output power of 129.5 watts. Furthermore, under 800 W/m^2 solar irradiances, it produces a solar photovoltaic output power of 171.9 watts. The last simulation of changes in solar irradiance was carried out when the maximum conditions were 1000 W/m^2. At this peak condition, a maximum power of 213 watts is generated, according to the specifications of the solar photovoltaic used.

In Figure 6, it can also be seen that at the beginning of solar photovoltaic generating electricity with a solar irradiance of 600 W/m^2, there was a significant oscillation. However, these oscillations only occur within a narrow time span of 0.013 seconds. The oscillating solar photovoltaic output power starts from 0 to reach a maximum of 215 watts in 0.002 seconds, then drops to -155 watts in 0.002 seconds. This fluctuation occurs for the first 0.013 seconds, with no significant oscillation. This condition without significant oscillation is achieved with a solar photovoltaic power output in the range of 213 watts. This system achieved an output power of 213 watts and lasted a long. There are ripples in the achievement of this 213-watt power, but the ripples are small. MPPT control using this modified PO algorithm produces a maximum output power in the range of 213 watts, according to the solar photovoltaic rating, which is 213.15 watts. Thus, the modified PO algorithm applied to MPPT solar photovoltaics has successfully optimized the output power.

In Figure 6, it can also be seen the performance of the modified PO algorithm in controlling MPPT at changes in solar irradiance to 800 W/m^2 and 1000 W/m^2. Changes in solar irradiance can be appropriately controlled by the system built. In Figure 6, it can be seen that the power oscillations that occur are tiny in amplitude and very short in time. These excellent results demonstrate the superiority of the proposed modified PO algorithm.

V. Conclusion

This research was conducted on the performance of solar photovoltaic systems using an MPPT controller based on a modified PO algorithm. This algorithm has the advantage of being able to calibrate without oscillation to determine the maximum power output.

The modified PO algorithm can produce a photovoltaic output power at a load of 206 watts.

Based on the simulation, solar radiation conditions are directly proportional to the output power of the solar cell system. In contrast, the cell temperature conditions are inversely proportional to the output power of the solar cell. The modified PO algorithm in the MPPT system can optimize the power generated by solar cell modules.

This algorithm optimizes power through the difference factor of the average output power using the maximum power point tracking system, which increases by 16.4% and can optimize the photovoltaic output power even though the value of radiation and ambient temperature changes.

Acknowledgements

The author would like to thank the Research and Innovation Boards (LRI) of Universitas Muhammadiyah Yogyakarta for supporting this research.

References

[1] K. Pal, S. Kumar, B. Singh, and T.C. Kandpal, "Implementation of frequency integrated multi-order generalized integrator for solar energy sourced grid," *International Journal of Electrical Power & Energy Systems*, vol. 131, October 2021, p. 106918.

[2] A. Raj, S. R. Arya, and J. Gupta, "Solar PV array-based DC–DC converter with MPPT for low power applications," *Renew. Energy Focus*, vol. 34, September 2020, pp. 109–119.

[3] R.B. Ballipo, S. Mikkili, and P.K. Bonthagorla, "Hybrid, Optimal, Intelligent and Classical PV MPPT Techniques: A Review," *CSEE Journal of Power and Energy Systems*, vol. 7, no. 1, January 2021.

[4] A. Jouda, F. Elyes, A. Rabhi, and M. Abdelkader, "Optimization of Scaling Factors of Fuzzy-MPPT Controller for Stand-alone Photovoltaic System by Particle Swarm Optimization," *Energy Procedia*, vol. 111, September 2016, pp. 954–963.

[5] R.A. Alhasibi, S.P. Hadi, and Sarjiya, "The Integration of Renewable-Distributed Energy Resources into Electrical Power System Expansion with Intermittency Consideration," *IREMOS*, vol. 14, no. 2, 2021, pp. 89-100.

[6] R. Syahputra and I. Soesanti, "Performance Improvement for Small-Scale Wind Turbine System Based on Maximum Power Point Tracking Control," Energies, 12 (20), 2019, p. 3938.

[7] R. Singh, S.M. Amrr, and M.S.J. Asghar, "Supervisory control strategy for the effective solar energy utilization in a residential microgrid system using a cost-effective controller," *International Journal of Electrical Power & Energy Systems, vol.* 132, November 2021, p. 107170.

[8] A. Arther Jain, B. J. Rabi, and S. S. Darly, "Application of QOCGWO-RFA for maximum power point tracking (MPPT) and power flow management of solar PV generation system," *Int. J. Hydrogen Energy*, vol. 45, no. 7, pp. 4122–4136, 2020,

[9] H. Tao, M. Ghahremani, F. W. Ahmed, W. Jing, M. S. Nazir, and K. Ohshima, "A novel MPPT controller in PV systems with hybrid whale optimization-PS algorithm based ANFIS under different conditions," *Control Eng. Pract.*, vol. 112, February 2021, doi: 10.1016/j.conengprac.2021.104809.

[10] A.F.C. Borray, A. Garces, J. Merino, E. Torres, and J. Mazon, "New energy bound-based model for optimal charging of electric vehicles with solar photovoltaic considering low-voltage network's constraints," *International Journal of Electrical Power & Energy Systems, vol.* 129, July 2021, p. 106862.

[11] S.D. Al-Majidiab, M.F. Abboda, and H.S. Al-Raweshidya, "A novel maximum power point tracking technique based on fuzzy logic for photovoltaic systems," *International Journal of Hydrogen Energy*, vol. 43, no. 31, 2018, pp. 14158-14171.

[12] B. Laxman, A. Annamraju, and N. V. Srikanth, "A grey wolf optimized fuzzy logic based MPPT for shaded solar photovoltaic systems in microgrids," *Int. J. Hydrogen Energy*, vol. 46, no. 18, pp. 10653–10665, 2021.

[13] Q. Zhao and C. Li, "Two-Stage Multi-Swarm Particle Swarm Optimizer for Unconstrained and Constrained Global Optimization", *IEEE Access*, vol. 8, 2020, pp. 124905 - 124927.

[14] X. Ge, F. W. Ahmed, A. Rezvani, N. Aljojo, S. Samad, and L. K. Foong, "Implementation of a novel hybrid BAT-Fuzzy controller based MPPT for grid-connected PV-battery system," *Control Eng. Pract.*, vol. 98, March 2020.

[15] M. O. Okwu and L. K. Tartibu, "Particle Swarm Optimisation," *Stud. Comput. Intell.*, vol. 927, pp. 5–13, 2021.

[16] M. Jiang, M. Ghahremani, S. Dadfar, H. Chi, and Y.N. Abdallah, "A novel combinatorial hybrid SFL–PS algorithm based neural network with perturb and observe for the MPPT controller of a hybrid PV-storage system," *Control Engineering Practice*, vol. 114, 2021, p. 104880.

[17] Y. Singh and N. Pal, "Reinforcement learning with fuzzified reward approach for MPPT control of PV systems," *Sustainable Energy Technologies and Assessments*, vol. 48, October 2021, p. 101665.

[18] A. Ali, K. Almutairi, S. Padmanaban, V. Tirth, S. Algarni, K. Irshad, S. Islam, M.H. Zahir, M. Shafiullah, and M.Z. Malik, "Investigation of MPPT Techniques Under Uniform and Non-Uniform Solar Irradiation Condition–A Retrospection," *IEEE Access*, vol. 8, 2020.

[19] N. Shankar and N. SaravanaKumar, "Reduced Partial shading effect in Multiple PV Array configuration model using MPPT based Enhanced Particle Swarm Optimization Technique," *Microprocess and Microsystem*, vol. 2020, p. 103287.

[20] Y. Soufi, M. Bechouat, and S. Kahla, "Fuzzy-PSO controller design for maximum power point tracking in photovoltaic system," *Int. J. Hydrogen Energy*, vol. 42, no. 13, pp. 8680–8688, 2017.

[21] Y. Shi, Y. Sun, J. Liu, and X. Du, "Model and stability analysis of grid-connected PV system considering the variation of solar irradiance and cell temperature," *International Journal of Electrical Power & Energy Systems, vol.* 132, November 2021, p. 107155.

[22] V. Q. B. Ngo, M. Latifi, R. Abbassi, H. Jerbi, K. Ohshima, and M. khaksar, "Improved krill herd algorithm based sliding mode MPPT controller for variable step size P&O method in PV system under simultaneous change of irradiance and temperature," *J. Franklin Inst.*, vol. 358, pp. 3491–3511, 2021.

[23] M. Rastogi, A. Ahmad, and A. H. Bhat, "Performance

investigation of two-level reduced-switch D-STATCOM in grid-tied solar-PV array with stepped P&O MPPT algorithm and modified SRF strategy," *Journal of King Saud University - Engineering Sciences.*, vol. 2021.

[24] M. Jiang, M. Ghahremani, S. Dadfar, H. Chi, Y. N. Abdallah, and N. Furukawa, "A novel combinatorial hybrid SFL–PS algorithm based neural network with perturb and observe for the MPPT controller of a hybrid PV-storage system," *Control Eng. Pract.*, vol. 114, June 2021.

[25] M. Mohammadinodoushan, R. Abbassi, H. Jerbi, F.W. Ahmed, H.A.K. Ahmed, and A. Rezvani, "A new MPPT design using variable step size perturb and observe method for PV system under partially shaded conditions by modified shuffled frog leaping algorithm- SMC controller," *Sustainable Energy Technologies and Assessments,* vol. 45, 2021, p. 101056.

[26] https://www.pveducation.org/pvcdrom/solar-cell-operation/iv-curve.

Authors' information

Ramadoni Syahputra received Ph.D degree at the Department of Electrical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember in 2015.
Dr. Ramadoni Syahputra is an Associate Professor in Department of Electrical Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia.
His research interests are in artificial intelligence in power system, computational of power system, power system control, fuzzy logic in power system, optimization, and renewable energy.