Optimal cleaning robot on solar panels with time-sequence input based on internet of things

Dwi Nur Fitriyanah[1,2], Rivaldi Dwi Pramana Saputra[1], Imam Abadi[2], Ali Musyafa[2]
[1]Department of Instrumentation Engineering, Faculty of Vocational Studies, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2]Department of Engineering Physics, Faculty of Industrial Technology and System Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Article Info

Article history:

Received May 14, 2024
Revised Sep 9, 2024
Accepted Oct 1, 2024

Keywords:

Cleaning system
Electrical energy
Internet of things
Solar energy
Solar panel

ABSTRACT

Solar panels are the main component of solar power generation systems, and they function by converting solar energy into electrical energy. Indonesia has great potential for solar energy. Solar panels will work optimally at temperatures of 25 °C to 28 °C. The greater the temperature of the solar panel, the more power generated by the panel. The influence of solar radiation intensity can be caused by dust and animal droppings attached to the surface of the solar panel module. If the surface of a solar panel is covered with dust or dirt, which can block the entry of solar radiation, the resulting power output is not optimal. The aim of this research is to design and implement an automatic cleaning system for solar power plants. The system used is using ESP32 based on the Blynk application and adding internet of things (IoT) devices with a cleaning method using pumped water spraying, then assisted with wipers which have silicon rubber material to clean dust and dirt. Based on the cleaning optimization simulation calculations, we found that the optimal or efficient cleaning condition was once a month, with an efficiency of 75.17%.

Corresponding Author:

Imam Abadi
Department of Engineering Physics, Faculty of Industrial Technology and System Engineering, Institut Teknologi Sepuluh Nopember
Building A of ITS Keputih Campus, Sukolilo, Surabaya, Indonesia
Email: imamabadi02@gmail.com

1. INTRODUCTION

Energy has become an essential need in society as a life support component to support daily activities. The general electrical energy in Indonesia comes from fossils; the burning of these can cause global warming. Indonesia has a renewable energy potential of more than 400,000 MW, 50% of which is solar energy. However, the Ministry of Energy and Mineral Resources (ESDM) stated that the use of this energy source is only 0.08% or 150 MW of the existing potential [1], [2]. The use of solar energy from the sun via solar panels is an alternative to the use of electrical energy sourced from fossil fuels. Electrical energy from the sun has low operational costs of 1 USD per watt and guarantees the availability of energy sources. The use of solar energy for electricity generation is estimated to increase by 18% from 2013 to 2050 [3].

Solar panels are the primary equipment in solar power generation systems, and they function by converting solar energy into electrical energy [4]. Indonesia has great potential for solar energy due to its equator position and tropical climate, resulting in a significant solar energy potential of approximately 4.8 kWh/day [5], [6]. However, the output power generated from this conversion process is influenced by various environmental conditions, such as solar radiation intensity and temperature [7], [8].

High temperatures can limit the energy production of solar panels because the intensity of solar radiation increases from morning until noon. Solar panels work optimally at temperatures between 25 °C and 28 °C [9], [10]. The larger the temperature of the solar panel, the more impact will be on the power generated by the panel. The influence of solar radiation intensity can be affected by dust and animal dirt adhering to the surface of the solar panel module [11], [12]. For example, if the surface of a solar panel is covered with dust or dirt, it can obstruct the entry of solar radiation intensity, thereby affecting the optimal output power. One way to minimize high temperatures and remove dust and animal dirt from solar panels is to clean and spray water onto the surface of the solar panel module [13].

Solar panels, as a technology for using solar energy, require proper maintenance to maintain their performance. Solar panel cleaners are a solution for efficiently and sustainably maintaining panel cleanliness, thus contributing to environmental conservation. The use of solar energy as a clean and sustainable alternative energy source is increasing [14], [15]. However, the efficiency of solar panels is affected by environmental factors, such as the accumulation of dirt and dust. This leads to a decrease in the electrical energy production. Therefore, research into panel cleaners is important for maintaining optimal solar panel performance and maximizing solar energy utilization. Solar panel cleaners can be a solution to increase panel efficiency and extend their lifespan, thus providing better return on investment [16].

In a previous study [17] titled "Automated design for boosting offshore photovoltaic (PV) performance," a solar panel cleaning robot was designed for offshore locations using brushes or dust brushes to clean substances like sand, dirt, and bird droppings from the surface of the solar panel module, which can significantly decrease the performance of the solar panel module. The PV performance decrease is due to the formation of a layer of dust particles on the front surface of the solar panel, which causes shading effects [15]. One drawback of this tool is the lack of water to clean the solar panel surface. Additionally, it uses a programmable logic controller (PLC) controller, which makes the system less efficient because the PLC needs to connect to a controlled computer to activate the system, so it cannot be remotely controlled.

Based on several objectives, this research aims to design and implement an automatic solar panel cleaning system for solar power plants. The system uses water spraying, which is pumped through a wiper equipped with silicon rubber to remove dust and dirt. The system is activated at predetermined intervals. Additionally, to ensure thorough cleaning of the solar panels, a direct current (DC) motor is employed as the cleaning device's drive. A limit switch is used as a work limiter in the cleaning system. This solar panel cleaning system uses an ESP32 microcontroller based on the Blynk application, allowing remote control through the internet. There are two control modes: manual and automatic. In the automatic mode, the system runs according to a predetermined schedule, namely once a month; in the manual mode, there is a manual button to activate the system.

2. METHOD

The first stage begins with a literature review that identifies references to the research to be conducted. Thus, a system consisting of hardware and software design components was created. After designing the tool, a tool consisting of hardware and software. After implementing the tool, the Blynk software was integrated into ESP32. After implementing the tool, the Blynk software was run on the ESP32. The proposed tool was tested for performance after integration. If the system works properly, data collection and analysis are performed. If a disturbance remains, an evaluation can be made of the tool manufacture. The last step is the preparation of the report.

Figure 1 shows the design of a robot cleaning a solar panel. The solar panel used in this cleaning medium is of the on grid type with a capacity of 500 Wp. The solar panels with a monocrystalline capacity of 100 Wp are 5 pcs. There are 2 types of solar panels used in this solar panel: 8 pcs of polycrystalline and 2 pcs of monocrystalline. The solar system wiring was configured in series and parallel according to the input voltage range of the selected grid tie inverter 22-50 volts direct current (VDC). The connection to a series of solar panel modules uses an MC4 connector, which can be used in outdoor locations. The solar panel module is mounted on a rail frame made of stainless steel, 4 rails are used with a length of 3,500 mm each, and the rails are supported by permanent rear and front legs on a concrete base with a total of 6 each. To lock the solar panel module to the rail, end clamps were used on the ends and mid clamps on the middle side, 8 end clamps and 16 mid clamps.

This tool has dimensions of 120×12×7 cm. This body cleaning system in Figure 2 consists of several components such as a nozzle that functions to provide water pressure to be sprayed on the solar panel, a motor that drives the body cleaning system horizontally, a hose that functions as a water flow, drive wheels attached to the motor and the bottom of the body cleaning system, and a support wheel to support the body cleaning system. At the bottom of the body cleaning system, there is a rubber or plastic wiper to remove any remaining water from the surface of the solar panel. Water remaining on the surface of the solar panel can cause mold or water spots, which are called hotspots, to remain.

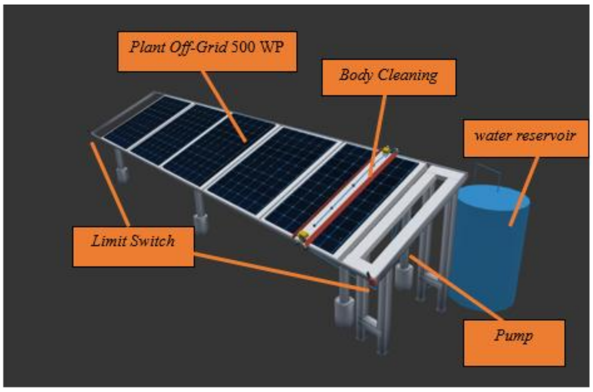


Figure 1. 3D design automatic cleaning system

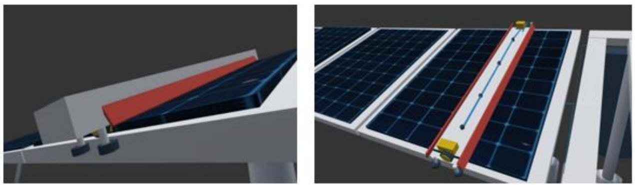


Figure 2. Design of body cleaning systems

Figure 3 shows the workflow of the automatic cleaning system begins by selecting either automatic or manual mode. If the automatic mode is selected, the main input is a predefined time schedule to activate the system. If the manual mode is selected, the user can activate the cleaning system using the button provided in the Blynk application. If the system is active, the controller commands the relay to activate the pump for 5 s. Then, the DC motor moves forward until it reaches limit switch A. The motor then stopped for 5 s before moving backward until it reached limit switch B. Once the cleaning process is complete, the system performs drying using the same cleaning sequence, but the pump is not activated.

Based on the system design in Figure 4, there are several inputs such as selector switches, push buttons, and limit switches. This input instructs the ESP32 controller to drive the actuator in the form of a molar pump and a GW4632-370 motor. Selector switch B provides manual and automatic functions to determine whether the system runs automatically or manually. When selecting manual conditions, the system can be started or stopped on demand by selecting buttons B or C. The pump provides pressure that causes water to produce the optimal spray diameter. The spray cleans the attached dust and bird droppings and can lower the PV temperature. A motor is used to run body cleaning horizontally so that the cleaning process runs evenly. A limit switch is used to rotate the direction of the motor when it reaches the end of the off-grid solar panel.

The following equations and calculations were used to determine [18] the time required for a wheel to move from one end of the solar panel to the other at a motor speed of 40 revolutions per minute (RPM).

$$\begin{aligned} T &= RPM \times 1/60 \\ T &= 40 \times 1/60 \\ T &= 0.66\ RPS \end{aligned} \tag{1}$$

From (1), the frequency was found to be 0.66 rotations per second (RPS). From this value, we can find the angular velocity (ω) using the equation below [19].

$$\begin{aligned} \omega &= 2\pi \times T \\ \omega &= 2(3.14) \times 0.66 \\ \omega &= 4.14\ rad/s \end{aligned} \tag{2}$$

From (2), the angular velocity was found to be 4.14 rad/s. Since the angular velocity is known, the next step is to find the linear velocity using the known angular velocity [20].

$$v = r \times \omega$$
$$v = 0.035 \times 4.14 \quad (3)$$
$$v = 0.144\ m/s$$

Based on (3), the linear velocity was calculated as 0.144 m/s. Next, the total time taken by the technology to cover the distance was calculated. The distance covered was 3.78 m × 2 (due to the back-and-forth motion). The following equation was used [21]:

$$t = s/v$$
$$t = (7.56\ m)/(0.144\ m/s) \quad (4)$$
$$t = 52.5\ s$$

Based on (4), the wheel required 52.5 s to clean from one end of the solar panel to the other at a motor speed of 40 RPM. If this process is repeated 4 times, the total duration is 210 s (approximately 3.5 min).

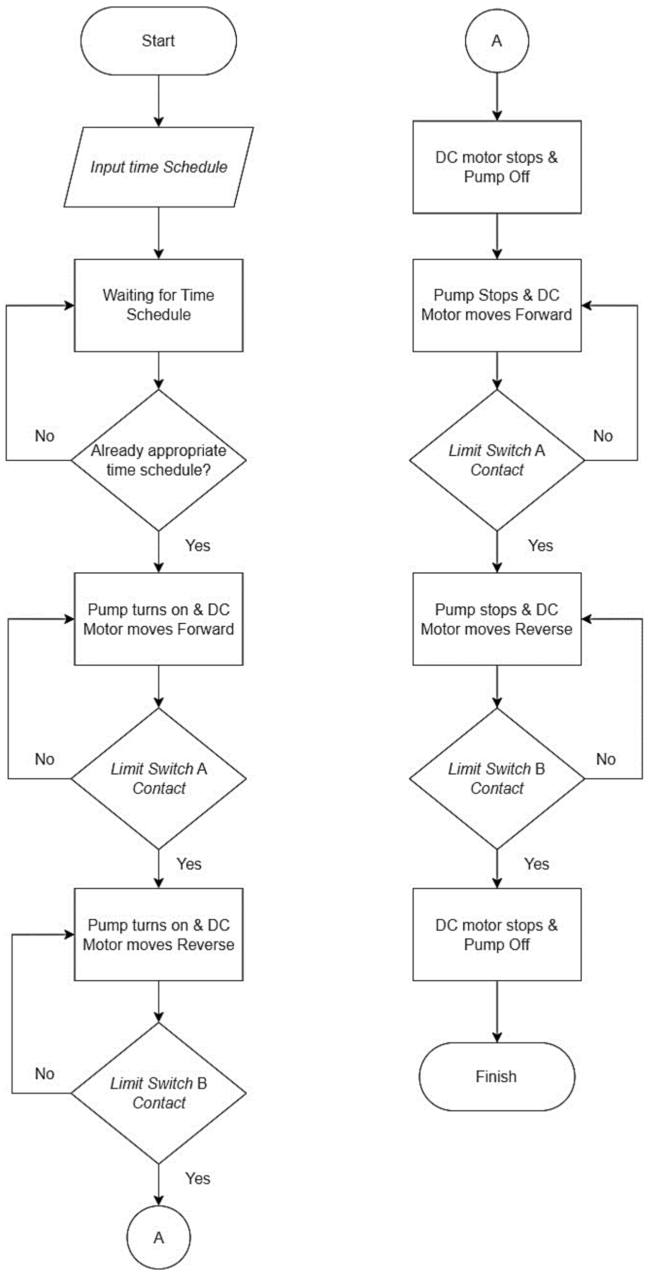


Figure 3. Flowchart automatic cleaning system

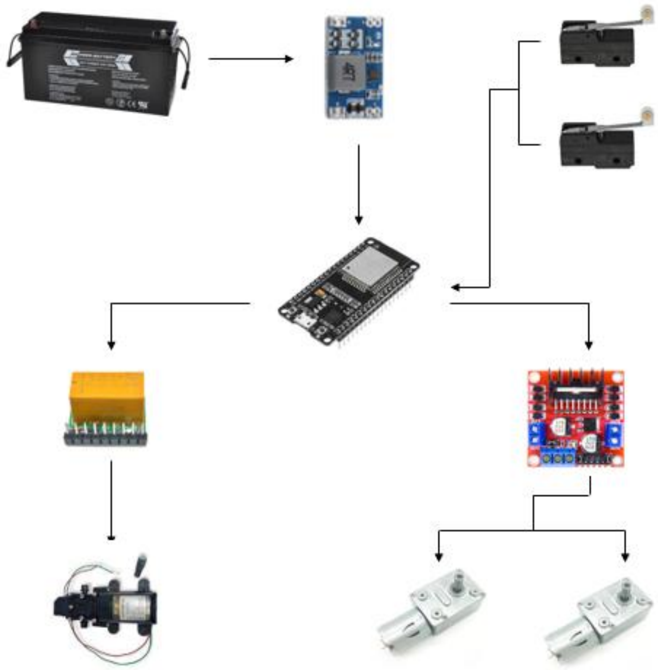


Figure 4. Control system design of the cleaning technology on solar panels

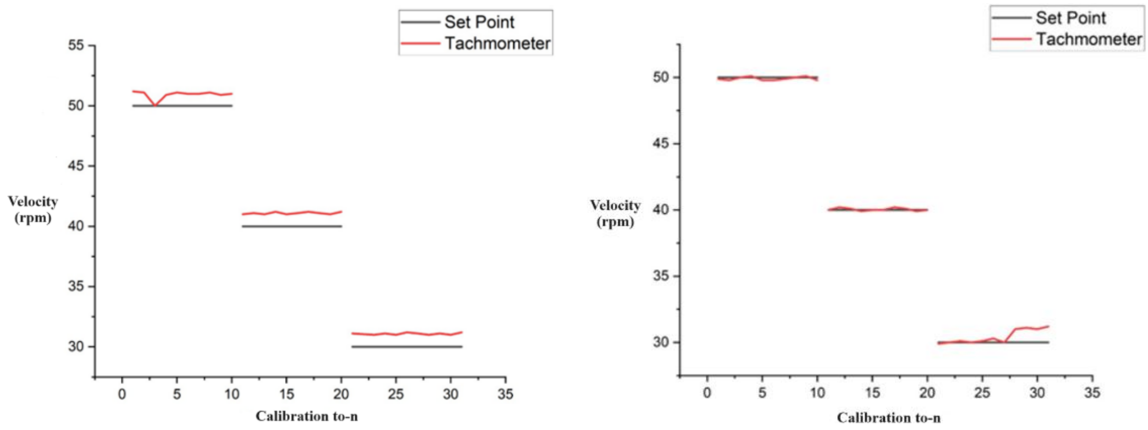
3. RESULTS AND DISCUSSION

3.1. Motor transmission calibration

Motor testing was carried out in Figure 5 to determine the value of rotation per minute when given a load or not given a load. The results of calculations based on motor specifications compared with a standard measuring instrument, namely a tachometer. By knowing the rpm, you can calculate the time required for the system to clean. The RPM measurements were performed using a noncontact tachometer that was fired at the motor. Based on several experiments conducted with variations in voltage, the obtained voltage data and rpm values were compared to the tachometer.

Based on the no-load motor test graphic, the highest obtained power was 2.52 W. The input voltage to the motor affects the resulting speed. The greater the value of the input voltage , the faster the motor speed will also be faster. Conversely, if the input voltage is low, the motor speed will also be low. Figure 6(a) and Figure 6(b) shows RPM testing on motor 1 and motor 2. This test was carried out to determine whether the rpm of the motor was in accordance with the calculation by knowing how long the system was running from start to stop.

Figure 5. Motor RPM testing



(a) (b)

Figure 1. Graph RPM testing: (a) motor 1 and (b) motor 2

3.2. Testing the ESP32 Wi-Fi module range

The overall testing of the components in this study was conducted in an open space to avoid disrupting Wi-Fi signal propagation. Testing was carried out in the Instrumentation Engineering Department, as shown in Figure 7. In this trial, the internet was used as a connection between the automatic cleaning device and the smartphone. The purpose of this test was to determine the range of the automatic cleaning device's control with the smartphone. Here, we present thether results of the Wi-Fi module range test.

The data in Table 1 show the distance between the access point and the Wi-Fi module on the ESP32 microcontroller for the automatic cleaning device. The access point to the Wi-Fi module of the cleaning device can be controlled from a distance of 1 to 11 m. At distances of 16–25 m, the connection between the access point and the Wi-Fi module began to weaken, resulting in significant delays in controlling the cleaning device. At distances of at least 31 m, the connection between the access point and the Wi-Fi module is lost, and the automatic cleaning device cannot be controlled. This indicates that the Wi-Fi module on the ESP32 microcontroller can be wellcontrolled at a distance of up to 25 m between access points. However, the application’s connection to the ESP32 microcontroller through Blynk can be accessed and controlled remotely from a different location [22]–[26] as long as the Wi-Fi module on the microcontroller is connected to the internet. This allows users to remotely input their cleaning time schedule and control their devices via the Blynk application on their smartphone.

Figure 7. Range area ESP32 Wi-Fi module

Table 1. Testing the ESP32 Wi-Fi Module Range

No	Distance (Meters)	Status	Delay (s)	Description
1	1-5	Connected	1.05	An automatic cleaning tool can operate well.
2	6-10	Connected	1.23	An automatic cleaning tool can operate well.
3	11-15	Connected	1.11	An automatic cleaning tool can operate well.
4	16-20	Weak connection	09.38	An automatic cleaning tool can operate with a delay.
5	21-25	Weak connection	10.01	An automatic cleaning tool can operate with a delay
6	26-30	Weak connection	Can’t	An automatic cleaning tool can operate with a delay.
7	31-35	Unconnected	Can’t	An automatic cleaning tool cannot operate

3.3. Qualitative and quantitative testing results of the cleaning technology

In this testing, two main aspects were independently evaluated to assess the cleaning device's performance: the quality of the cleaning technology and the solar panel output. The cleaning technology was assessed for its effectiveness in removing debris without damaging the panels, while the solar panel output was measured before and after cleaning to determine how much the process improved energy efficiency. Together, these evaluations provided a comprehensive view of the device's impact on solar panel performance.

3.3.1. Qualitative testing of the cleaning technology

The qualitative testing in Figure 8, the focus was on assessing the overall cleaning performance of the proposed technology. Dry tissues were used as tools to simulate the cleaning process on the solar panel surfaces. Observations were made to evaluate how well the technology removed dirt, dust, and other contaminants from the panels.

Based on the results of qualitative testing in Table 2, the most effective cleaning method for different types of contaminants on solar panels was identified. A pump with a voltage of 12 is recommended when dealing with stubborn bird droppings. This higher voltage provides sufficient water pressure and force to effectively remove tough bird droppings from solar panels. On the other hand, when solar panels are combined with dust and bird droppings, a pump with a voltage of 10 is found to be the optimal choice [27]. This voltage level provides adequate cleaning power for both types of contaminants. For regular cleaning tasks, where the solar panels mainly have dust and lighter contaminants, a pump with a voltage of 8 can be used. This low voltage still provides efficient cleaning while saving power by using a voltage lower than the pump's specifications.

Figure 8. Testing cleaning technology on solar panels

Table 2. Testing the quality of the cleaning technology

Pump voltage (Volt)	Solar panel condition before cleaning	Solar panel condition after cleaning
12	There are mosquito repellent powder and porridge	Clean the the solar panel without leaving any water behind
10	There are mosquito repellent powder and porridge	Clean the solar panel without leaving any water behind
8	There are mosquito repellent powder and porridge	Clean the solar panel without leaving any water behind
6	There are mosquito repellent powder and porridge	Unclean and without leaving any water
4	There are mosquito repellent powder and porridge	Unclean and without leaving any water

3.3.2. Quantitative testing of solar panel output

This testing evaluated the difference in solar panel output power when an automatic cleaner was used and when it was not. The focus was on analyzing how cleaning impacts the performance of solar panels by measuring key parameters such as the output voltage, current, and temperature. By comparing these parameters before and after the cleaning process, this study quantifies the improvements in panel efficiency and the effectiveness of the automatic cleaner in maintaining optimal solar panel performance.

Figure 9 is a quantitative test of solar panel output, which measures the output of the solar panel before and after cleaning. Based on the test data obtained in Tables 3 and 4, the irradiation value was almost the same but had a different output power. When tested, the solar panels that have not been cleaned can produce a power of 334.2 Watthour (Wh), and when tested after cleaning using an automatic solar panel cleaner, it can generate a power of 605.6 W. It can be seen that the difference is very significant, which is equal to 271.4 W.

Figure 9. Quantitative testing of the solar panel ouput

Table 3. Quanttitave test of solar panel ouput without automatic cleaner and dirt

Time	(Voltage)	(Ampere)	Power (Watt)	Temperature (°C)	Irradiation (W/m^2)
09:00	13.66	0.06	0.819	28.8	750.3
10:00	19.97	3.4	67.8	51.7	859.1
11:00	18.86	3.9	73.5	52.5	946.1
12:00	17.77	3.8	67.5	56.5	865.5
13:00	19.75	3.7	73.0	53.5	789.5
14:00	14.46	3.4	49.1	34.5	76.3
15:00	14.03	0.06	0.84	34.5	74.4
16:00	13.83	0.06	0.83	29.1	65.6
17:00	13.76	0.06	0.82	27.5	52.4
Total			**334.2 Wh**		

Table 4. Quanttitave test of solar panel ouput after automatic cleaning and dirt cleaning

Time	(Voltage)	(Ampere)	Power (Watt)	Temperature (°C)	Irradiationn (W/m^2)
09:00	30.02	0.06	1.80	28.6	758.4
10:00	17.97	7.43	133.5	47.5	872.0
11:00	16.96	7.60	128.8	48.3	972.4
12:00	17.36	7.38	128.1	51.0	983.6
13:00	17.66	7.04	124.3	50.0	903.3
14:00	17.29	5.02	86.7	40.3	616.5
15:00	13.78	0.06	0.82	29.8	101.6
16:00	13.54	0.06	0.81	27.4	51.7
17:00	13.35	0.06	0.80	25.5	16.9
Total			**605.6 Wh**		

Based as the graph in Figure 10, the results obtained on the panel before being cleaned and treated with dirt are shown as a black graph indicating that the graph has the lowest graph. The highest power was obtained at 11:00 has an output power of 73.5 watts. Then, on the red graph is a solar panel, which after cleaning with a cleaning tool shows that the graph has the highest graph with the highest power obtained at 10:00 having an output power of 133.5 watts. Therefore, the graph of the solar panel after cleaning shows a significant difference in output power.

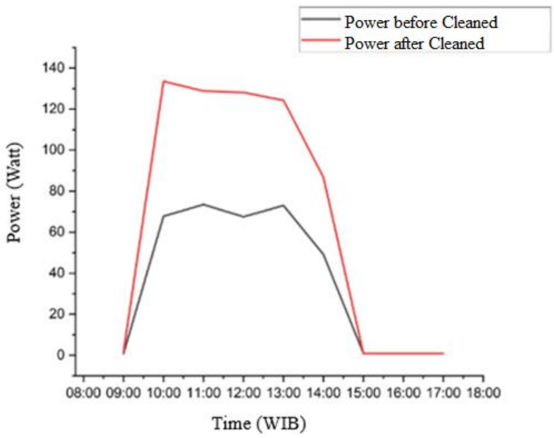


Figure 10. Graph of the power output comparison results

Based on the graph in Figure 11, the panel before exposure to spray water is represented by a black curve, indicating that the graph obtained the highest temperature. The highest temperature recorded at 14:00 UT was 56.5 °C. Then, on the red graph Then, on the red graph is a solar panel which after being cleaned with a cleaning tool containing spray water shows that the graph has the lowest graph with the highest temperature obtained at 12:00 with a temperature of 51.0 °C. Therefore, after cleaning the solar panel, the temperature difference is very significant.

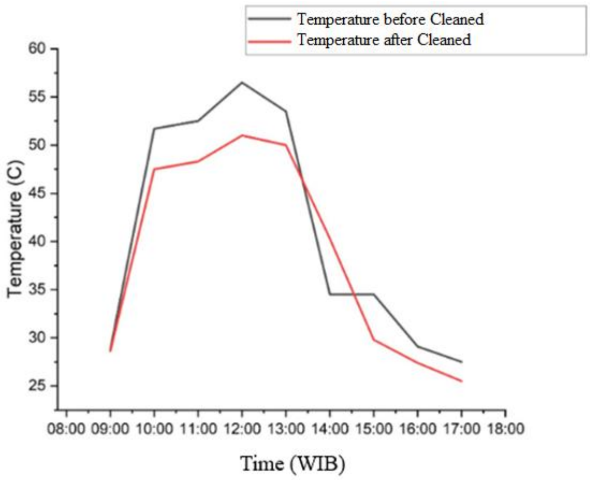


Figure 11. Temperature comparison results

3.3.3. Optimal cleaning calculation results

The results of this calculation were used to determine the optimal time for cleaning the solar panels. This calculation is based on the results of the solar panel output power test data shown in Table 3, in which the solar panels were under dust conditions, and the test data results shown in Table 4. For dust conditions, solar panels can produce an output power of 334.2 Wh. When solar panels are dust-free or cleaned with an automatic cleaning tool, they can produce an output power of 605.6 Wh. This calculation simulates calculations for time periods of 1 week, 2 weeks, 3 weeks, 4 weeks, or 1 month. The optimal cleaning calculation formula is as (5).

$$Efficiency = \frac{Energy\ after\ Cleansing - Energize\ before\ Cleansing}{Energize\ before\ Cleansing} \times 100\% \tag{5}$$

Calculation of optimal cleaning efficiency within 1 week. Solar panels under dust conditions produce an output power of 334.2 Wh, multiplied by 7 days or a week, producing a power of 2,339.4 Wh. Then, the solar panels after cleaning produce an output power of 605.6 Wh multiplied by 6 days because 1 day the automatic cleaning device is turned on, producing 3,633.6 Wh. The equation (6) is the optimal efficiency calculation for 7 days or once a week.

$$Efficiency = \frac{3633.6-2339.4}{2339.4} \times 100\% = 55.32\% \tag{6}$$

Calculation of optimal cleaning efficiency within 2 weeks. Solar panels under dust conditions produce an output power of 334.2 Wh, multiplied by 14 days or a week, producing a power of 4,678.8 Wh. Then, the solar panels after cleaning produce an output power of 605.6 Wh multiplied by 13 days because 1 day the automatic cleaning device is turned on, producing 7,872.8 Wh. The equation (7) is the optimal efficiency calculation for 14 days or twice a week.

$$Efficiency = \frac{7872.8-4678.8}{4678.8} \times 100\% = 68.27\% \tag{7}$$

Calculation of optimal cleaning efficiency within 3 weeks. Solar panels under dust conditions produce an output power of 334.2 Wh, multiplied by 21 days or a week, producing a power of 7,018.2 Wh. Then, after cleaning, the solar panels produce an output power of 605.6 Wh multiplied by 20 days because 1 day the automatic cleaning device is turned on, producing 12,112 Wh. The equation (8) is the optimal efficiency calculation for 21 days or thrice a week.

$$Efficiency = \frac{12112-7018.2}{7018.2} \times 100\% = 72.58\% \quad (8)$$

Calculation of the optimal cleaning efficiency within 4 weeks or 1 month. Solar panels under dust conditions produce an output power of 334.2 Wh, multiplied by 30 days or a week, producing a power of 10,026 Wh. Then, after being cleaned, the solar panels produce an output power of 605.6 Wh multiplied by 29 days because 1 day the automatic cleaning device is turned on, producing 17,562.4 Wh. The equation (9) is the optimal efficiency calculation for 30 days or 1 month.

$$Efficiency = \frac{17562.4-10026}{10026} \times 100\% = 75.17\% \quad (9)$$

Therefore, based on optimal cleaning calculations at time intervals of once a week, once 2 weeks, once 3 weeks, and once a month, it shows that the optimal conditions that are the highest or most efficient for cleaning are once a month with an efficiency value of 75.17%.

4. CONCLUSION

This technology is effective for cleaning dust and animal waste that adheres to solar panels. The distance between the access point and the Wi-Fi module on the ESP32 microcontroller for the automatic cleaning device indicates that the Wi-Fi module on the ESP32 microcontroller can be well controlled at a distance of up to 25 meters between the access point. based on the results of qualitative testing in carrying out the best cleaning, that is, if the condition of the solar panel has stubborn bird droppings, a pump with a voltage of 12 can be used. Then, if the condition of the solar panels has dust and bird droppings, you can use a pump with a voltage of 10 and a pump with a voltage of 8 because it can clean dirt and leave little water, and it can also save power because it uses a lower voltage than the pump specifications. The results of the power output in testing solar panels that have not been cleaned can produce a power of 334.2 Wh, and in testing after cleaning using an automatic solar panel cleaner, it can generate a power of 605.6 W. It can be seen that the difference is very significant, which is equal to 271.4 W. The highest power was obtained at 11:00, and the output power was 73.5 watts. Then, on the red graph is a solar panel, which, after cleaning with a cleaning tool, shows that the graph has the highest power at 10:00 with an output power of 133.5 watts. Based on the optimal solar panel cleaning calculation, the optimal cleaning conditions are once a month, with an efficiency of 75.17%.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge financial support from the Institut Teknologi Sepuluh Nopember under the project scheme of scientific research and the Publication Writing and IPR Incentive Program (PPHKI).

REFERENCES

[1] N. A. Shoffiana *et al.*, “PV maximum power-point tracking by using artificial neural network,” in *2023 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation, ICAMIMIA 2023 - Proceedings*, Nov. 2023, pp. 859–863, doi: 10.1109/ICAMIMIA60881.2023.10427794.

[2] E. H. Setyawan, I. Abadi, and S. A. Kusumawarni, “Estimation of hourly solar radiation on horizontal surface using GAMF (genetic algorithm modified fuzzy) (Case study in Surabaya),” *IOP Conference Series: Materials Science and Engineering*, vol. 588, no. 1, Aug. 2019, doi: 10.1088/1757-899X/588/1/012024.

[3] I. Abadi, E. H. Setyawan, and M. Ardiansyah, “Design of automatic switching system and data acquisition on mobile hybrid solar tracking system for standalone small PV with reflector,” *IOP Conference Series: Earth and Environmental Science*, vol. 520, no. 1, Jun. 2020, doi: 10.1088/1755-1315/520/1/012001.

[4] R. A. Messenger, *Photovoltaic fundamentals*. Washington: National Renewable Energy Laboratory, 2012.

[5] I. Abadi, A. Musyafa’, W. Z. Putra, and D. N. Fitriyanah, “Performance analysis of dual axis solar tracker based on fuzzy PID controller on street lighting,” in *CENIM 2020 - Proceeding: International Conference on Computer Engineering, Network, and Intelligent Multimedia 2020*, Nov. 2020, pp. 257–263, doi: 10.1109/CENIM51130.2020.9297938.

[6] C. Imron, I. Abadi, I. Amirul Akbar, J. Maknunah, Y. Ahmad Nor, and A. Saepul Uyun, “Performance comparison of the single axis and two-axis solar system using adaptive neuro-fuzzy inference system controls,” *E3S Web of Conferences*, vol. 190, Sep. 2020, doi: 10.1051/e3sconf/202019000005.

[7] A. . Smirnov, A. G. Vozmilov, and P. A. Romanov, “Comparison of discrete sun tracking methods for photovoltaic panels,” in *2019 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, Mar. 2019, pp. 1–5, doi: 10.1109/ICIEAM.2019.8742775.

[8] S. Hong, Z. Fu, and R. E. Stamper, “Discrete-position solar tracking for photovoltaic system,” in *Rose-Hulman Undergraduate*

Research Publications, 2018, pp. 1–12.
[9] V. Dabra, K. K. Paliwal, P. Sharma, and N. Kumar, "Optimization of photovoltaic power system: a comparative study," *Protection and Control of Modern Power Systems*, vol. 2, no. 1, Dec. 2017, doi: 10.1186/s41601-017-0036-2.
[10] I. Abadi, T. Oktavia Hardiana, C. Imron, D. Nur Fitriyanah, Y. Jani, and K. Abdullah, "Design of adaptive neuro-fuzzy inference control based one-axis solar tracker on battery charging system," *E3S Web of Conferences*, vol. 190, Sep. 2020, doi: 10.1051/e3sconf/202019000015.
[11] M. U. Khan *et al.*, "Modeling and design of low-cost automatic self cleaning mechanism for standalone micro PV systems," *Sustainable Energy Technologies and Assessments*, vol. 43, 2021, doi: 10.1016/j.seta.2020.100922.
[12] B. B. ÖLMEZ, Ö. ERGEZER, and G. N. GÜĞÜL, "Autonomous solar panel cleaning robot with rubber wheeled and air-absorbing motor," *International Journal of Energy Applications and Technologies*, vol. 8, no. 4, pp. 182–187, Dec. 2021, doi: 10.31593/ijeat.938629.
[13] M. R. Habib *et al.*, "Automatic solar panel cleaning system based on Arduino for dust removal," in *2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS)*, Mar. 2021, pp. 1555–1558, doi: 10.1109/ICAIS50930.2021.9395937.
[14] Y. Zatsarinnaya, D. Amirov, and M. Elaev, "Solar panel cleaning system based on the Arduino microcontroller," in *Proceedings of the 2020 Ural Smart Energy Conference, USEC 2020*, Nov. 2020, pp. 17–20, doi: 10.1109/USEC50097.2020.9281239.
[15] K. Jaiganesh, K. Bharath Simha Reddy, B. K. D. Shobhitha, and B. Dhanush Goud, "Enhancing the efficiency of rooftop solar photovoltaic panel with simple cleaning mechanism," *Materials Today: Proceedings*, vol. 51, pp. 411–415, 2021, doi: 10.1016/j.matpr.2021.05.565.
[16] M. A. Baballe and N. D. Academy, "Review of the literature on robotic solar panel cleaning," *Global Journal of Research in Engineering and Computer Sciences*, vol. 3, pp. 21–25, 2023, doi: 10.5281/zenodo.8197565.
[17] S. M. Al-Dhaheri, L. A. Lamont, L. El-Chaar, and O. A. Al-Ameri, "Automated design for boosting offshore photovoltaic (PV) performance," in *IEEE PES T&D 2010*, 2010, pp. 1–6, doi: 10.1109/TDC.2010.5484258.
[18] D. Ewen, N. Schurter, and P. E. Gunderson, *Applied physics 10th edition*. 2008.
[19] P. A. Tipler and G. Mosca, *Physics for scientists and engineers*, 6th ed. W.H. Freeman and Company, 2003.
[20] D. Halliday, R. Resnick, and G. H. Bowen, "Fundamentals of physics," *Physics Today*, vol. 25, no. 4, pp. 53–54, Apr. 1972, doi: 10.1063/1.3070817.
[21] G. B. Thomas, M. D. Weir, J. R. Hass, and F. R. Giordano, *Thomas' calculus early transcendentals Thomas series*. Reading, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 2005.
[22] M. Aqib, R. Mehmood, A. Alzahrani, I. Katib, A. Albeshri, and S. M. Altowaijri, "Smarter traffic prediction using big data, in-memory computing, deep learning and GPUs," *Sensors*, vol. 19, no. 9, May 2019, doi: 10.3390/s19092206.
[23] N. Stylos and J. Zwiegelaar, *Big data as a game changer: How does it shape business intelligence within a tourism and hospitality industry context?* 2019.
[24] K. Sivaraman, R. M. V. Krishnan, B. Sundarraj, and S. Sri Gowthem, "Network failure detection and diagnosis by analyzing syslog and SNS data: Applying big data analysis to network operations," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, pp. 883–887, 2019, doi: 10.35940/ijitee.I3187.0789S319.
[25] A. D. Dwivedi, G. Srivastava, S. Dhar, and R. Singh, "A decentralized privacy-preserving healthcare blockchain for IoT," *Sensors*, vol. 19, no. 2, Jan. 2019, doi: 10.3390/s19020326.
[26] S. Schulz, M. Becker, M. R. Groseclose, S. Schadt, and C. Hopf, "Advanced MALDI mass spectrometry imaging in pharmaceutical research and drug development," *Current Opinion in Biotechnology*, vol. 55, pp. 51–59, 2019, doi: 10.1016/j.copbio.2018.08.003.
[27] F. H. M. Noh *et al.*, "Development of solar panel cleaning robot using arduino," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 3, pp. 1245–1250, Sep. 2020, doi: 10.11591/ijeecs.v19.i3.pp1245-1250.

BIOGRAPHIES OF AUTHORS

Dwi Nur Fitriyanah received an M.T. degree (Master of Engineering) in engineering physics from the Institut Teknologi Sepuluh Nopember, Indonesia, in the research "Type-2 fuzzy logic control design based on BFO on hybrid PV solar Tracker Ocean wave energy converter (OWEC)". She is currently a lecturer in instrumentation engineering at the Institut Teknologi Sepuluh Nopember, Indonesia. Her research interests include control, renewable energy, and its application. She can be contacted at email: fitriyanah@its.ac.id.

Rivaldi Dwi Pramana Saputra final-year student at the Instrumentation Engineering Department, Vocational Faculty, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia. Currently, he is working on his final project in this research. He can be contacted at email: aldypramana3010@gmail.com.

Imam Abadi is currently a lecturer at the Sepuluh Nopember Institute of Technology (ITS). He received his Ph.D. in electrical engineering from the ITS and M.Sc. in instrumentation and control engineering from the Bandung Institute of Technology in 2016 and 2005. His Ph.D. research is in the field of power systems. His research interests include grid-connected photovoltaic systems, PV systems, power control systems, instrumentation systems, and renewable energy. He can be contacted at email: abadi@ep.its.ac.id.

Ali Musyafa was born in Indonesia in 1960. He received his B.Sc., M.Sc., and Ph.D. degrees in 1985, 2000, and 2012. He is currently a senior lecturer and the head of the Department Representative Commission of Engineering Physics, Sepuluh Nopember Institute of Technology (ITS). He has been involved in major projects for ITS and the national company. He has published in international journals and conferences on power systems and renewable energy. His research interests include renewable energy systems, instrumentation, and automation. He can be contacted at email: musyafa@ep.its.ac.id.