Design of solar cell using mirror, cooling, double axis, and solar tracking

Yulianta Siregar[1], Mai Kai Suan Tial[2], Yopi Fernando Soarez Purba[1], Suherman[1], Soeharwinto[1]
[1]Department of Electrical Engineering, Universitas Sumatera Utara, Medan, Indonesia
[2]Department of Electrical Power Engineering, Faculty of Engineering, Yangon Technological University, Yangon, Myanmar

Article Info

Article history:

Received Jun 14, 2022
Revised Aug 30, 2022
Accepted Sep 14, 2022

Keywords:

Cooling
Double-axis
Mirror
Solar cell
Solar tracking

ABSTRACT

Fossil energy sources are dwindling. It is necessary to develop alternative energy sources for future energy. The solar cell is an alternative energy that can be used in Indonesia. The current challenge is utilizing solar panels for the best possible power production. This research gives the solution to design an increase in solar cell output power by using mirrors, cooling, and a double-axis solar tracking control system. The results show that using a mirror, cooling, and double-axis solar tracking produces optimal output power with a current and power are 2.43 amperes and 40.3 watts, respectively. Meanwhile, several factors can affect this solar panel's efficiency. Specifically, the amount of solar radiation that the solar panel can receive depends on the climate on the day and location of the research and the solar panel's dimensions.

Corresponding Author:

Yulianta Siregar
Department of Electrical Engineering, Universitas Sumatera Utara
Dr. T. Mansur No. 9, Medan City, North Sumatera Province, Indonesia
Email: mailto:julianta_srg@usu.ac.id

1. INTRODUCTION

Fossil energy sources are dwindling. It is necessary to diversify energy sources by developing alternative energy sources for future energy needs that are cheap, flexible in use, available in abundance, and environmentally friendly [1]-[3]. The usage of non-renewable energy sources that are too expensive or environmentally damaging will be avoided. That is why renewable energy sources that do not damage the environment are important in electrical energy. Although hydroelectric power is a renewable energy source that is very cheap, it is not available everywhere in the world. On the other hand, solar power can take over all electricity generation [4]-[5]. Indonesia aims to produce 23% of its energy from renewable sources by 2025, which will be considered when undertaking additional research on the possibilities in Indonesia. Due to Indonesia's favorable environment and weather, solar photovoltaic (PV) is an alternative with significant promise for the country. Based on No. 692.Pers/04/SJI/2019, published by the Ministry of Energy and Mineral Resources on December 4, 2019 [6], the Indonesian government's initiative for renewable energy is taken seriously, as seen by the expected investment of US$36.95 billion in renewable energy power facilities [6]-[8].

The problem now is how to use solar cell panels to get optimal electrical output. Typically, solar cell panels are positioned in the same manner without changing. For instance, solar cell panels have an upward orientation. The panel will receive the most solar radiation when the sun is vertical to the solar cell plane facing up and if it is regarded as an item with a flat surface. For this reason, it is required to alter the solar cell panel's orientation to ensure that it is always perpendicular to the path the sun's beams take. Since people set solar panel direction manually, it is less effective. Thus, it is necessary to create a control system that can regulate the direction of the solar cell panels [9]-[11].

A control system requires an algorithm processing mechanism. Processing of control system algorithms can be completed with computers, microcontrollers, and other tools. The most rapidly growing algorithm processor today is the microcontroller. The microcontroller is a breakthrough in microprocessor and microcomputer technology that only requires a small space and can be mass-produced, so the price is lower than microprocessors. The small form allows the microcontroller to be installed directly on the equipment to be controlled, such as control production equipment, metalworking machines, ATM machines, photocopiers, vehicle systems, medical equipment, and others. In general, the application of microcontrollers is to optimize the work of the controlled tools or systems.

Based on the results of Kasim *et al.* [12], "Improve the performance of solar modules by reflectors," his research also said that solar cells, with the help of mirror reflectors, increase the output power even during the day it can increase up to 48%. Meanwhile, Arshad *et al.* [13], entitled "Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling," shows a considerable increase in the overall output of solar panels. With a reflector and without cooling, the efficiency increased by 32%, and efficiency increased by 52% with reflector and cooling. Further, Ismail *et al.* [14], in his research entitled " Improving the performance of solar panels by the used of dual axis solar tracking system with mirror reflection," said that solar cells with mirror reflections produce high output power and provide better and more efficient performance. Considering the above, the author tries to design a solar cell device using a mirror, cooler, and a microcontroller-based dual-axis solar tracking device that seeks to increase the solar cell's energy output.

2. PROPOSED METHOD

2.1. Sun energy

Astronomically, Indonesia is located at 6 LU–11 South Latitude and 95 OBT–145 OBB. This places Indonesia in the tropics and beyond the equator. The average daily solar irradiation level is relatively high at 4.5 kWh/m^2/day, and it has great potential for the development of solar power plants (PLTS) [15]-[17].

The energy produced by the sun can reach the Earth's surface utilizing radiation. This energy is in the form of heat that propagates to the Earth's surface or light that falls to the Earth's surface. Both forms of energy can be converted or utilized into electrical energy, but the light is the focus of the energy source converted by solar panels. Solar radiation that solar panels can receive is divided into three types, namely:

- Direct radiation: the amount of solar energy that directly gets to the surface of the Earth is known as direct radiation (also known as beam radiation).
- Solar radiation: solar radiation that get the Earth's surface diffusely because it is reflected by clouds and other airborne particles.
- Reflected radiation: reflected radiation, namely radiation reflected by adjacent surfaces, the magnitude of which is affected by the reflectance of adjacent surfaces

2.2. Efficiency of solar panel

Solar cells have good efficiency, which has maximum power and small losses. With high efficiency and small losses, this solar cell can be a suitable one. Several parameters need to get the efficiency value from solar panels, namely [18]:

- Output voltage of solar cell (V)
- Output current of the solar cell(I)
- Sunlight intensity (G)
- Surface area of the solar cell (Apv)
- Fill factor value (FF): the fill factor value ranges from 0.7 to 0.85. Solar panels will work better if the FF value of a solar panel is greater and has higher efficiency. The calculation of the FF value can be seen in (1).

$$FF = \frac{I_{mp}\ x\ V_{mp}}{I_{sc}\ x\ V_{oc}} \tag{1}$$

- Power output of the solar cell (Pout); diffuse the calculation of the output power can be seen in (2).

$$P_{out} = V\ x\ I\ x\ FF \tag{2}$$

- Power input from the solar cell (Pin); equation (3) describes the power input due to light source irradiation can be calculated.

$$P_{in} = G \ x \ A_{pv} \quad (3)$$

- Efficiency of solar panels; calculation of solar panel efficiency can be seen in (4).

$$\eta = \frac{P_{out}}{P_{in}} x \ 100\% \quad (4)$$

The maximum efficiency of solar panel energy conversion depends on temperature, solar radiation, wind speed, the location of the solar cell to the sun (tilt angle), and the state of the earth's atmosphere [19]. The intensity of solar radiation will have a lot of effect on the current generated and little effect on the voltage. In the laboratory, the maximum efficiency of ordinary solar cells is currently about 24-25%. For commercial use, monocrystalline solar cells' efficiency ranges from 13-19%. Commercial cells with efficiencies above 20% are expected to be achieved in the coming years [19], [20]. Some ways that can be done to increase efficiency are by increasing the intensity of sunlight, such as using a light-gathering lens or a light reflector such as a mirror.

2.3. Solar cell parameters

Several parameters influence the maximum operation of solar cells, such as [21], [22]: Temperature: Photovoltaics can work optimally if the temperature is still within normal limits of 25 ℃. However, if the temperature is greater than the normal temperature, the voltage value will be reduced. Because every 1 ℃ increase in temperature from 25 ℃ will reduce the voltage value by around 0.5% of the sum of the energy generated or two times the rate at which the temperature was previously raised every 10 ℃ [23]. The following formula is used to calculate the amount of power that decreases when the temperature increases.

$$P_{\text{temperature rise ℃}} = 0{,}5\%℃ \ x \ P_{MPP} \ x \ \text{temperature rise (℃)} \quad (5)$$

$$P_{MPP \text{ temperature rise ℃}} == P_{MPP} - P_{\text{temperature rise ℃}} \quad (6)$$

$$TCF = \frac{PMPP_{MPP \text{ temperature rise ℃}}}{PMPP} \quad (7)$$

- Solar radiation: solar radiation is very dependent on the conditions of the spectrum of sunlight caught on earth. The current is highly influenced by how potent the sun's radiation shines. If the value of the intensity of solar radiation absorbed by the photovoltaic is lower, the current will also be lower.
- Wind rapidity: the wind rapidity that blows circa the area can weaken the heat from the glass surface temperature on the solar panel.
- Tilt angle and Azimuth: the sun's location can be determined by using the angle of the sun (azimuth, and tilt angle). The inclination angle significantly influences the effectiveness of solar (photovoltaic) panels. The angle of inclination is time and location dependent. Each location will have a different inclination angle for different times of the year. Thus, it is very important to orient the solar panels at an inclination angle for any given location to get maximum power output. The best position for solar panels is perpendicular to the sun.
- Earth's Atmosphere: the maximum electric current of PV has been determined by Earth's atmospheric conditions, including cloudiness, airborne dust particles, smoke, fog, and pollution.

2.4. System of solar tracking

The system of solar tracking is a system that controls the orientation of the solar cell to the position of the sun so that the intensity of the sunlight can be absorbed more optimally. There are two kinds of sun tracking systems: single-axis trackers and dual-axis trackers. The single-axis tracker is divided into two parts: a vertical rotating axis and an inclined rotating axis. A tracking mechanism called the vertical rotating axis controls the azimuth angle from east to west. At the same time, the inclined rotating axis is a tracking system used to control the tilt angle. The dual-axis solar tracking system combines a vertical rotating axis and an inclined rotating axis [23]-[25].

3. METHOD

3.1. Solar cell

This research uses a 50 watt monocrystalline solar cell, three mirrors, a light depending resistor (LDR) sensor, an Arduino UnoR3, and an active cooler. The following proposed approach to increase experimental data from four distinct directions is used to determine the efficiency of solar panels. The first only uses a solar cell, the second uses a solar cell with double-axis solar tracking, and the third uses a solar cell, double-axis solar tracking, and mirrors. Then the fourth uses a solar cell, double-axis solar tracking, mirrors, and coolers. Figure 1 depicts the design of the solar panel utilized in this investigation, and the panel's specifications, as shown in Table 1.

Figure 1. Solar panel 50 Wp

Table 1. Specifications of solar panel

Specification	Measure
Peak power of solar cell (WP)	50 WP
Power tolerance (%)	0-3
Voltage of solar cell (V)	17.5
Current of solar cell (A)	2.85
Voltage in an open circuit (V)	19.5
Current short circuit (A)	3.05
System voltage maximum (V)	1000

3.2. Light sensor

The LDR resistance value will rise to 200 kΩ in low light and fall to 500 in high light. Figure 2 is the light sensor (LDR) used in this study. Before being put into the microcontroller, the LDR is included in a voltage divider circuit. To change the resistance of the LDR into a voltage according to the needs of the microcontroller input.

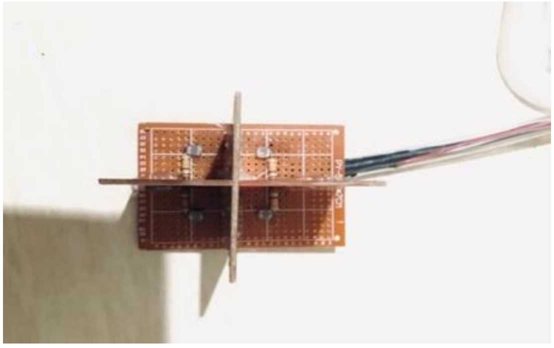

Figure 2. Light sensor of solar panel

3.2. Servo motor

A Servo motor is a DC motor equipped with a control circuit with a closed feedback system integrated with the motor. The position of the rotating axis is informed back to the control circuit in the servo motor. Figure 3 shows the servo motor used in this study and the panel specifications, as seen in Table 2.

Figure 3. Servo motor of solar panel

Table 2. Specifications of servo motor

Specification	Measure
Modulation	Analog
Motor Type	Coreless
Operation Voltage	4.8 - 7.2 Volts
Torque	13.0kg/cm (4.8V)
Speed	0.20 sec/60 (4.8V)

3.4. Arduino

Arduino is a system or physical device using software and hardware that can receive stimuli and provide feedback. In practice, this concept is applied to using sensors in tool design and project projects using sensors or microcontrollers to translate analog inputs into software systems to control equipment, such as lights, and motors. Figure 4 shows the Atmega328 in the Arduino module is used as a control device for all sensors used in this study and then sends the measurement results to a laptop for storage and analysis. Meanwhile, the controller's specifications as shown in Table 3.

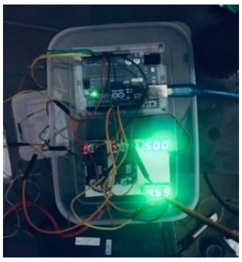

Figure 4. Arduino connected to a measuring instrument

Table 3. Specifications of arduino

Specification	Measure
Operating Voltage (Volt)	5
Voltage Input (Volt)	7-12
Digital I/O pin	14
Analog pin	6
DC current per I/O pin (mA)	50
Memory Flash (KB)	32
SRAM (KB)	2

3.5. Cooling

The performance of the solar module is very sensitive to temperature, so the temperature of the solar module to stay below the permissible limit is necessary to achieve maximum output power. In this research, the cooling method is carried out using an aluminum block fed with water and mounted on the back of the solar cell. Both ends of the aluminum block filled with water are closed using a good and strong cover so that not a single drop of water leaks out that it can last for a long time. Furthermore, this water block will absorb heat from the solar panel, and then the heat can be transferred or released quickly to the surrounding air through the heatsink, as seen in Figure 5.

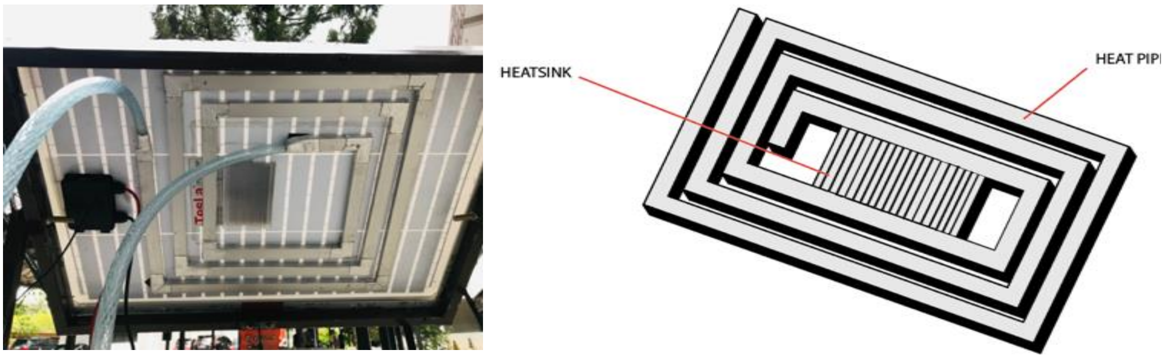

Figure 5. Frame design cooling method

3.6. Design sistem

The design of this research is seen in Figure 6. The design of the two-axis solar tracking system is made with lightweight materials so that the performance of the motor is not too heavy. In this study, we are using aluminum. In addition to solar panels, the main devices attached to the frame are two motors. The electrical circuit design is seen in Figure 7. This electrical circuit uses an ATMega 328 Microcontroller. The sensors used are four LDR sensors to detect sunlight and two potentiometers to detect the angular position of the motor. The motor driver uses the l293n type to control two servo motors. Plus two servo motors that are embedded in a gearbox. A voltage source of 12 V obtained from either the battery or power supply becomes a voltage source for the ATMega 328 Microcontroller and servo motor, connected to the l298n motor driver.

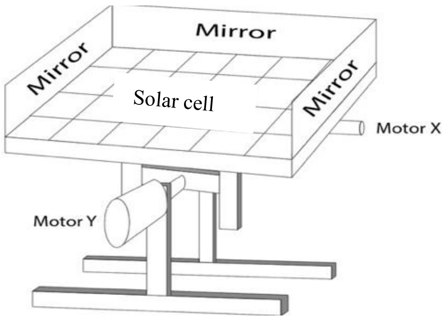

Figure 6. Design system of solar cell

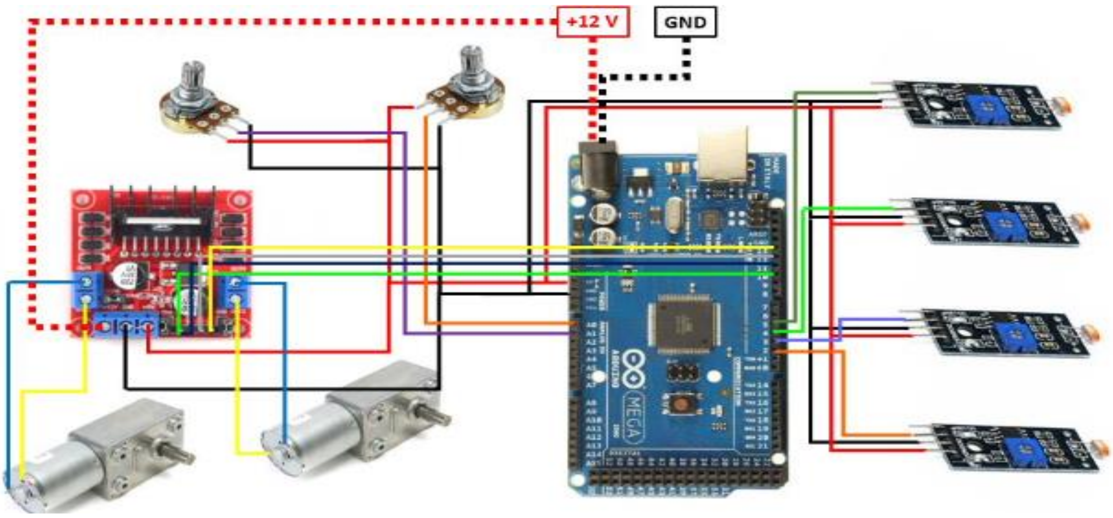

Figure 7. Design of electrical circuit

4. RESULT AND DISCUSSION
4.1. Electric output of the solar cell
Data collection on solar panels is carried out every hour from 10:00 WIB to 15:00 WIB with different weather conditions and intensity of sunlight. Measurements use a multimeter to measure the current and voltage generated in the solar panel. Meanwhile, to measure temperature or temperature using a temperature sensor. The results of the average measurement of the electrical power output of the solar cell as shown in Table 4.

Table 4. Measurement data of output current, voltage, and temperature

Time	Solar cell			Solar cell with double-axis solar tracking			Solar cell, double-axis sola tracking, and mirrors.			Solar cell, double-axis sol tracking, mirrors, and cool			Angle Tracker
	Temp-erature (°C)	V	I	Temp-erature °C)	V	I	Temp-erature (°C)	V	I	Temp-erature (°C)	V	I	
10:00	41.4	19.1	1.11	43.5	20.4	1.53	45.8	20.4	1.96	44.4	20.4	2.18	30^0
11:00	46.3	20.3	1.35	47.4	20.4	1.71	51.5	20.4	2.20	49.7	20.4	2.34	15^0
12:00	48.2	20.0	1.43	48.8	20.4	1.80	49.3	20.1	2.26	47.0	20.1	2.29	0^0
13:00	52.9	20.3	1.30	54.1	20.4	1.77	56.5	20.4	2.13	54.6	20.4	2.17	-15^0
14:00	50.3	20.2	1.22	51.6	20.4	1.65	53.6	20.4	2.05	50.9	20.4	2.14	-30^0
15:00	46.4	20.2	1.07	42.2	20.4	1.54	49.3	20.4	2.10	47.7	20.4	2.15	-45^0

4.2. Solar panel power calculation
The maximum efficiency of solar panel energy conversion depends on temperature, solar radiation, wind speed, the position of the solar panel to the sun (tilt angle), and the state of the earth's atmosphere. The intensity of solar radiation will have a lot of effect on the current (I) generated and little on the voltage. Meanwhile, the power received by solar panels from solar radiation is calculated based on actual data from measuring instruments for solar radiation installed on solar panels. To calculate the amount of power that reaches the solar panels can be calculated using (3).

$$P_{in} = G\ x\ A_{pv}$$

$$P_{in} = 358.4\ x\ (0.780\ x\ 0.510)$$
$$P_{in} = 142.5\ watt$$

4.3. Fill factor calculation
The fill factor (FF) equation uses the open-circuit voltage (Voc) parameter from the direct measurement results on the solar panel. The Fill Factor value usually lies between values ranging from 0.7 to 0.85. The greater the FF value of a panel, the better the performance of a solar panel, and it will also have a high-efficiency value. To calculate the fill factor can be calculated using (1), as seen in Table 5.

Table 5. Calculation results of fill factor

Solar cell	Solar cell, double-axis solar tracking, and mirrors.	Solar cell, double-axis solar tracking, mirrors, and coolers
$FF = \frac{V_{oc} - ln\ (V_{oc} + 0,72)}{V_{oc} + 1}$	$FF = \frac{V_{oc} - ln\ (V_{oc} + 0,72)}{V_{oc} + 1}$	$FF = \frac{V_{oc} - ln\ (V_{oc} + 0,72)}{V_{oc} + 1}$
$= \frac{20,1 - ln\ (20,1 + 0,72)}{20,1 + 1}$	$= \frac{20,4 - ln\ (20,4 + 0,72)}{20,4 + 1}$	$= \frac{20,4 - ln\ (20,4 + 0,72)}{20,4 + 1}$
$FF = 0,804$	$FF = 0,810$	$FF = 0,810$

4.4. Calculation of solar cell output power
The output power can be expressed as electrical power generated by the solar cell using (2), as seen in Table 6. As in Table 4, solar panels using a solar tracker, mirror, and cooler produce the highest power. On the other hand, solar cells without using solar trackers, mirrors, and coolers produce the smallest output power.

$$P_{out} = V_{oc}\ x\ FF\ x\ I_{sc}$$

Table 6. Calculation results of solar cell output power

Solar cell	Solar cell, double-axis solar tracking, and mirrors.	Solar cell, double-axis solar tracking, mirrors, and coolers
$P_{out} = 20{,}1\ x\ 0{,}804\ x\ 1{,}53$ $P_{out} = 25\ W$	$P_{out} = 20{,}4\ x\ 0{,}810\ x\ 1{,}96$ $P_{out} = 32\ W$	$P_{out} = 20{,}4\ x\ 0{,}810\ x\ 2{,}28$ $P_{out} = 37W$

4.5. The efficiency of solar cell

This efficiency value has something to do with the fill factor because both are related to the ability to absorb sunlight energy in every state of data collection. The following is a table for calculating solar panel efficiency during measurements, as shown in Table 7. As presented in Table 7, the greatest efficiency occurred at 10.00 by using a solar tracker, mirror, and cooler of 24.4%.

$$\eta = \frac{P_{out}}{P_{in}} x\ 100\%$$

Table 7. Result of solar panel efficiency

Time	Radiation (W/m²)	Solar cell	Solar cell, double-axis solar tracking, and mirrors	Solar cell, double-axis solar tracking, mirrors, and coolers
10:00 WIB	388.4	$\eta = \frac{25.3}{154.4} x\ 100\%$ =16.4%	$\eta = \frac{32.4}{154.4} x\ 100\%$ = 21%	$\eta = \frac{37.7}{154.4} x\ 100\%$ = 24.4%
11:00 WIB	517.1	$\eta = \frac{28.3}{205.7} x\ 100\%$ =13.7%	$\eta = \frac{35.0}{205.7} x\ 100\%$ =17%	$\eta = \frac{40.3}{142.5} x\ 100\%$ = 19.6%
12:00 WIB	611.6	$\eta = \frac{29.7}{243.3} x\ 100\%$ =12.2%	$\eta = \frac{36.3}{243.3} x\ 100\%$ =14.9%	$\eta = \frac{39.5}{243.3} x\ 100\%$ =16.2%
13:00 WIB	709.6	$\eta = \frac{29.2}{282.3} x\ 100\%$ =10.4%	$\eta = \frac{34.9}{282.3} x\ 100\%$ =12.4%	$\eta = \frac{37.5}{282.3} x\ 100\%$ =13.3%
14:00 WIB	541.9	$\eta = \frac{27.3}{215.6} x\ 100\%$ =10.52%	$\eta = \frac{33.5}{215.6} x\ 100\%$ =15.6%	$\eta = \frac{36.4}{215.6} x\ 100\%$ =16.9%
15:00 WIB	434.1	$\eta = \frac{25.4}{172.2} x\ 100\%$ =14.7%	$\eta = \frac{34.2}{172.2} x\ 100\%$ = 19.6%	$\eta = \frac{37.2}{172.2} x\ 100\%$ = 21.5%

4.6. Power analysis with temperature

Table 4. shows that the highest air temperature on the flat panel at 13:00 WIB is 51.7 ℃. There is an increase of 1.9 ℃ from the standard working temperature of the solar panel (25 ℃). The solar panel used as a reference is a panel that has a power specification (PMPP) of 50 Wp. Then the amount of power that decreases when the temperature increases by 1.9 ℃ is calculated by (2):

P (t rises) °C=0.5% /°C x PMPP x temperature rise (°C)
=0.5 % x 50 x 26.7 °C
=6.67 Watt

PMPP (t rises) °C=PMPP – P (t rises) °C
=50 W – 6.67 W
=43.32 Watt

The cooling system used shows a decrease in temperature at all hours. Meanwhile, the decrease in surface temperature is much faster in the afternoon. The maximum temperature occurs at 13:00 WIB at 56.5 ℃ with a solar cell, double-axis solar tracking, and a mirror. All these values as shown in Figure 8.

As seen in Figure 9, in the solar cell, the largest current at 12:00 WIB is 1.43 Ampere, and the minimum current occurs at 10:00 WIB is 1.07 Ampere. On the other hand, in a solar cell with double-axis solar tracking, mirrors, and coolers, the largest current was obtained at 11:00 WIB at 2.34 Ampere, and the minimum current occurs at 15:00 WIB is 2.15 Ampere.

Based on Figure 10, the power output of solar panels using a solar tracker, mirror, and cooler is greater than that of flat solar panels. At 11:00 WIB shows the maximum power output that the solar panels can generate. Meanwhile, at 12:00 WIB, the power produced from the solar cell decreased. The temperature of the solar panel has an impact on this, which has exceeded the maximum working temperature limit of the solar cell. As a result, the power that comes out of the solar panel has decreased. And at 15:00 WIB, the power produced by the solar cell using a solar tracker, mirrors, and coolers began to increase again in line with the normal temperature of the solar panels.

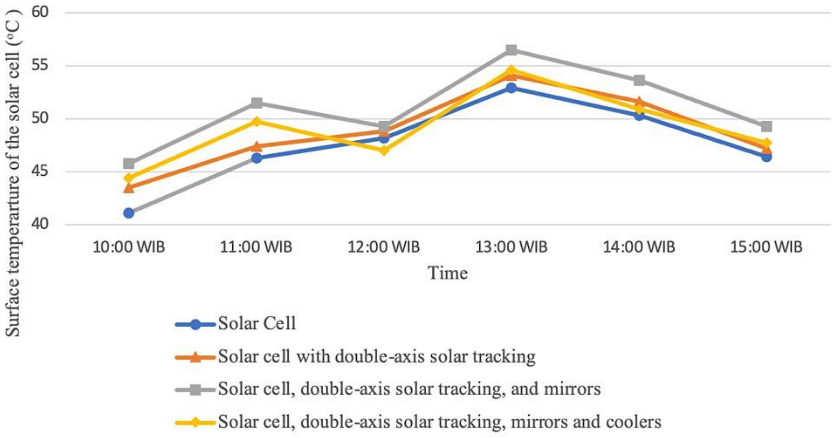

Figure 8. Temperature comparison of solar panels

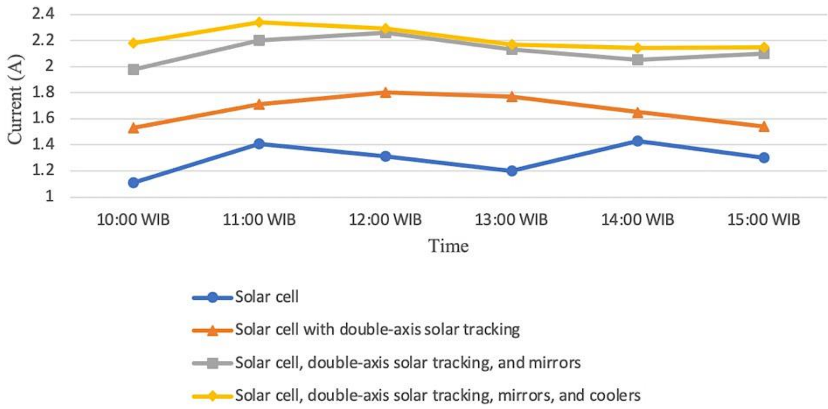

Figure 9. Comparison of the output current on the solar panel

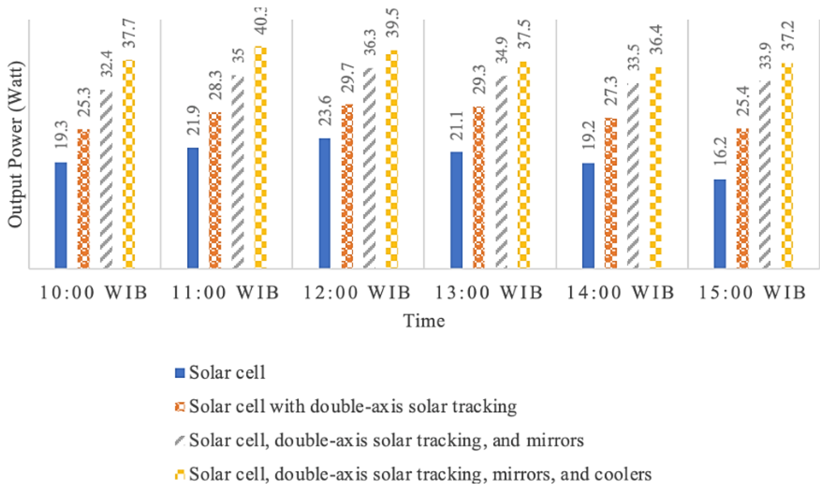

Figure 10. Solar electricity output produced by solar panels

As shown in Figure 11, it can be explained that the efficiency produced by solar panels using water cooling is better than solar panels without using cooling. The highest efficiency of solar panels is produced at 10:00 WIB using the research method (a) solar panel efficiency is 5%, with (b) solar panel efficiency produces 17.7%, (c) panel efficiency solar by 22.7%, and (d) solar panel efficiency by 26.4%, The efficiency of this solar panel can be influenced by several things, namely climatic conditions on the day and place of research and the dimensions of the solar cell that affect the amount of solar radiation that the solar panel itself can receive.

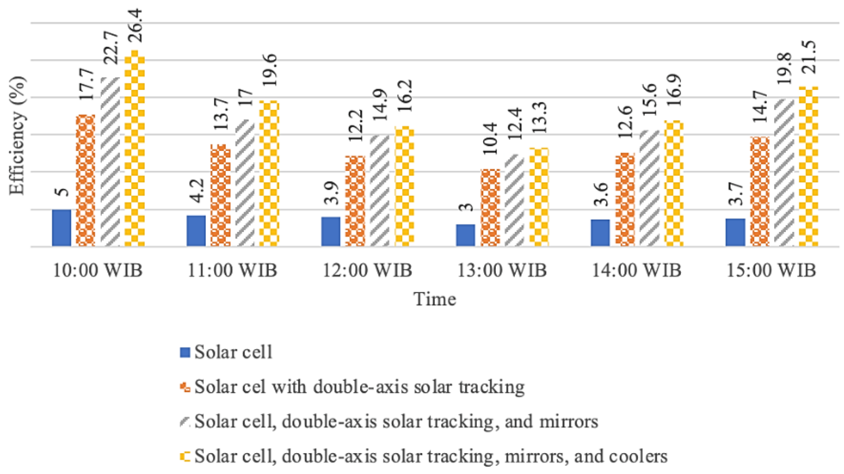

Figure 11. The efficiency of solar panel

5. CONCLUSION

As the research results, the highest intensity of sunlight is 709.6 W/m^2, with power reaching the solar panels of 282.3 Watts occurring at 13:00 WIT and the lowest solar intensity being 610 W/m^2, with power reaching the solar panels of 138.6 Watt occurring at 10:00 WIB. Following this result, the highest panel temperature in this study was at 13:00 WIB with the method (c) Solar panels using a solar tracker, using a mirror but without cooling, which was 51.7 ^{0}C. There was an increase of 26.7 ^{0}C from the standard working temperature of solar panels (25 ^{0}C). The total of power that decreases when the temperature increases are 6.675 Watt. However, the lowest solar panel efficiency of 16.2% occurred at 15:00 WIB with the research method (a) flat solar panels. Meanwhile, the highest efficiency was produced at 10:00 WIB using method (d): a mirror, a double-axis solar tracking system, and a cooler to produce a solar panel efficiency of 26.4%. The last conclusion, the highest temperature is at 13.00 using a solar cell, double-axis solar tracking, and a mirror (without cooling) of around 56 ^{0}C. High temperatures do not produce large currents and power. On the other hand, the largest current and power are 2.43 amperes and 40.3 watts using a solar cell, double-axis solar tracking, mirrors, and coolers.

REFERENCES

[1] B. S. Pali and S. Vadhera, "Renewable energy systems for generating electric power: a review," in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Jul. 2016, pp. 1–6, doi: 10.1109/ICPEICES.2016.7853703.
[2] A. Qazi *et al.*, "Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions," *IEEE Access*, vol. 7, pp. 63837–63851, 2019, doi: 10.1109/ACCESS.2019.2906402.
[3] V. Suresh, M. Muralidhar, and R. Kiranmayi, "Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas," *Energy Reports*, vol. 6, pp. 594–604, Nov. 2020, doi: 10.1016/j.egyr.2020.01.013.
[4] R. A. Diantari and I. Pujotomo, "Calculation of electrical energy with solar power plant design," in *2016 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Jul. 2016, pp. 443–446, doi: 10.1109/ISITIA.2016.7828701.
[5] S. A. M. Maleki, H. Hizam, and C. Gomes, "Estimation of hourly, daily and monthly global solar radiation on inclined surfaces: Models re-visited," *Energies*, vol. 10, no. 1, p. 134, Jan. 2017, doi: 10.3390/en10010134.
[6] Y. Siregar, Y. Hutahuruk, and Suherman, "Optimization design and simulating solar PV system using PVSyst software," in *2020 4th International Conference on Electrical, Telecommunication and Computer Engineering, ELTICOM 2020 - Proceedings*, Sep. 2020, pp. 219–223, doi: 10.1109/ELTICOM50775.2020.9230474.
[7] B. D. Siregar, B. Sudiarto, and R. Setiabudy, "Economic analysis of renewable energy power plant in Sumatra, Indonesia," in *2nd IEEE International Conference on Innovative Research and Development, ICIRD 2019*, Jun. 2019, pp. 1–4, doi: 10.1109/ICIRD47319.2019.9074768.

[8] D. F. Hakam, L. Arif, and T. Fahrudin, "Sustainable energy production in Sumatra power system," in *2012 International Conference on Power Engineering and Renewable Energy, ICPERE 2012*, Jul. 2012, pp. 1–4, doi: 10.1109/ICPERE.2012.6287246.
[9] D. Mitra, D. Das, D. Brahma, D. Maiti, and T. Mondal, "Sun tracking solar panel without microcontroller," in *2019 International Conference on Opto-Electronics and Applied Optics, Optronix 2019*, Mar. 2019, pp. 1–3, doi: 10.1109/OPTRONIX.2019.8862385.
[10] A. Singh, S. Adhav, A. Dalvi, A. Chippa, and M. Rane, "Arduino based dual axis solar tracker," in *Proceedings of the 2nd International Conference on Artificial Intelligence and Smart Energy, ICAIS 2022*, Feb. 2022, pp. 1789–1793, doi: 10.1109/ICAIS53314.2022.9742876.
[11] K. Charafeddine and S. Tsyruk, "Automatic sun-tracking system," in *Proceedings - 2020 International Russian Automation Conference, RusAutoCon 2020*, Sep. 2020, pp. 191–195, doi: 10.1109/RusAutoCon49822.2020.9208086.
[12] N. K. Kasim, A. F. Atwan, and F. M. Eliewi, "Improve the performance of solar modules by reflectors," *Journal of Physics: Conference Series*, vol. 1032, no. 1, p. 012031, May 2018, doi: 10.1088/1742-6596/1032/1/012031.
[13] R. Arshad, S. Tariq, M. U. Niaz, and M. Jamil, "Improvement in solar panel efficiency using solar concentration by simple mirrors and by cooling," in *2014 International Conference on Robotics and Emerging Allied Technologies in Engineering, iCREATE 2014 - Proceedings*, Apr. 2014, pp. 292–295, doi: 10.1109/iCREATE.2014.6828382.
[14] M. A. Ismail, K. A. Ramanathan, M. H. Idris, K. Ananda-Rao, M. Mazlan, and N. Fairuz, "Improving the performance of solar panels by the used of dual axis solar tracking system with mirror reflection," *Journal of Physics: Conference Series*, vol. 1432, no. 1, p. 012060, Jan. 2020, doi: 10.1088/1742-6596/1432/1/012060.
[15] J. Langer, J. Quist, and K. Blok, "Review of renewable energy potentials in indonesia and their contribution to a 100% renewable electricity system," *Energies*, vol. 14, no. 21, p. 7033, Oct. 2021, doi: 10.3390/en14217033.
[16] J. P. S. Briar and L. He, "A High Efficiency Solar Cell and System," in *Conference Record of the IEEE Photovoltaic Specialists Conference*, Jun. 2021, pp. 74–79, doi: 10.1109/PVSC43889.2021.9518701.
[17] S. Husein, R. Saive, and R. Saive, "1500% efficient solar power plants," in *Conference Record of the IEEE Photovoltaic Specialists Conference*, Jun. 2020, vol. 2020-June, pp. 1127–1130, doi: 10.1109/PVSC45281.2020.9300396.
[18] M. Ejgar and B. Momin, "Solar plant monitoring system: a review," in *Proceedings of the International Conference on Computing Methodologies and Communication, ICCMC 2017*, Jul. 2018, vol. 2018-January, pp. 1142–1144, doi: 10.1109/ICCMC.2017.8282652.
[19] A. Pradhan, S. K. S. Parashar, S. M. Ali, and P. Paikray, "Water cooling method to improve efficiency of photovoltaic module," in *International Conference on Signal Processing, Communication, Power and Embedded System, SCOPES 2016 - Proceedings*, Oct. 2017, pp. 1044–1047, doi: 10.1109/SCOPES.2016.7955600.
[20] A. M. Ahmed and S. H. Danook, "Efficiency improvement for solar cells panels by cooling," in *2nd International Conference for Engineering, Technology and Sciences of Al-Kitab, ICETS 2018*, Dec. 2018, pp. 39–42, doi: 10.1109/ICETS.2018.8724625.
[21] M. U. N. Khursheed, M. F. N. Khan, G. Ali, and A. K. Khan, "A review of estimating solar photovoltaic cell parameters," in *2019 2nd International Conference on Computing, Mathematics and Engineering Technologies, iCoMET 2019*, Jan. 2019, pp. 1–6, doi: 10.1109/ICOMET.2019.8673500.
[22] R. Y. Abdelghany, S. Kamel, A. Ramadan, H. M. Sultan, and C. Rahmann, "Solar cell parameter estimation using school-based optimization algorithm," in *2021 IEEE International Conference on Automation/24th Congress of the Chilean Association of Automatic Control, ICA-ACCA 2021*, Mar. 2021, pp. 1–6, doi: 10.1109/ICAACCA51523.2021.9465188.
[23] J. N. Juang and R. Radharamanan, "Design of a solar tracking system for renewable energy," in *Proceedings of the 2014 Zone 1 Conference of the American Society for Engineering Education - "Engineering Education: Industry Involvement and Interdisciplinary Trends", ASEE Zone 1 2014*, Apr. 2014, pp. 1–8, doi: 10.1109/ASEEZone1.2014.6820643.
[24] H. A. Sohag, M. Hasan, M. Khatun, and M. Ahmad, "An accurate and efficient solar tracking system using image processing and LDR sensor," in *2nd International Conference on Electrical Information and Communication Technologies, EICT 2015*, Dec. 2016, pp. 522–527, doi: 10.1109/EICT.2015.7392008.
[25] P. Sharma and N. Malhotra, "Solar tracking system using microcontroller," in *Proceedings of 2014 1st International Conference on Non Conventional Energy: Search for Clean and Safe Energy, ICONCE 2014*, Jan. 2014, pp. 77–79, doi: 10.1109/ICONCE.2014.6808687.

BIOGRAPHIES OF AUTHORS

Yulianta Siregar was born July 09, 1978 in Medan, North Sumatera Utara, Indonesia. He did his undergraduate work at University of Sumatera Utara in Medan, North Sumatera Utara, Indonesia. He received a Bachelor of Electrical Engineering in 2004. After a while, he worked for a private company. He continued taking a master's program in Electrical Engineering at the Institute of Sepuluh Nopember, Surabaya, West Java, Indonesia, from 2007-2009. He was in a Ph.D. program at Kanazawa University, Japan, from 2016-2019. Until now, he lectured at Universitas Sumatera Utara. He can be contacted at email: julianta_srg@usu.ac.id.

Mai Kai Suan Tial received the B.Sc. degrees in electrical power engineering from Technological University (Keng Tong) Myanmar (2000-2006), M.E degree in electrical power engineering, Technological University (Meikhtila) Myanmar (2007~2009), and the Ph.D. degree in electrical engineering, Kanazawa University, Japan (2014~2017). She has been a professor of electrical power engineering with Ain Shams University, since 2007. Her research interests include the high voltage engineering, plasma applications (plasma agriculture, environmental applications), plasma science & engineering. Until now, she lectured at electrical power engineering department, Yangon Technological University, Yangon, Myanmar. She can be contacted at email: maikaisuantial21@gmail.com.

Yopi Fernando Soarez Purba received a Bachelor of Eelctrical Engineering Education from Universitas Negeri Medan, Indonesia (2015-2019). He continued taking a master's program in Electrical Engineering at Universitas Sumatera Utara, Indonesia (2020–2022). He can be contacted at email: yopifernandopurba@gmail.com.

Suherman his Doctor of Philosophy in Electrical Engineering, De Montfort University, Leicester, UK (2013). Master in Networked and Distributed Systems (Computing), RMIT, Australia (2009). Bachelor degree in Electrical Engineering, University of Sumatera Utara, Indonesia (2000). Lecturer in University of Sumatera Utara, Indonesia, since 2004. He can be contacted at email: suherman.usu@gmail.com.

Soeharwinto his PhD Student in Electrical Engineering, Universitas Sumatera Utara, Indonesia (Now). Master in computer networks, Institut Teknologi Bandung, (2001). Bachelor degree in Electrical Engineering, University of Sumatera Utara, Indonesia (1996). Lecturer in University of Sumatera Utara, Indonesia, since 2000. He can be contacted at email: soeharwinto@usu.ac.id.