Jurnal Pena Sains
Jurnal Pendidikan Sains dan Sains Murni

Journal homepage: https://journal.trunojoyo.ac.id/penasains

THE INFLUENCE OF TILT ANGLE ON THE DAILY PROFILE TOTAL ENERGY OF PHOTOVOLTAIC POLYCRYSTAL

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ABSTRACT

This preliminary study aims to determine the daily profile of the power output generated from solar panels, with variations in the house's roof angles of 15º, 0º, 15º. Tilt angle investigation expects to discover the impact of placing solar panels on the slope of the tile used on the house's roof. The collecting data of this study was investigated the data of current and voltage every hour that produced by solar panel. Besides, this study also comparing the result of total energy output value for daily profile of solar panel during ten hour per day (start from 7 am to 5 pm). The results show that solar panels with an angle of -15º at 07:00 – 10:00 WIB have higher output voltage and current than other angle variations. At a tilt angle of 0º, the output voltage and current of the solar panel are higher at 11:00-14:00 WIB, while at a tilt angle of 15º in the afternoon. Based on observations, each solar panel with exposure for 10 hours obtained the total energy value for polycrystalline solar panels with a tilt angle of -15º of 258.44 Wh, solar panels with an angle of 0º obtained an energy value of 263.64 Wh, and a tilt angle of 15º obtained energy values 260.69 Wh. The photonic energy emitted for 10 hours is 2097.47 Wh. The energy efficiency value for each polycrystalline solar panel is 12.32% for the angle of -15º, the angle of 0º is 12.57%, and 12.43% for the angle of 15º. In conclusion, variations in the angle of the solar panels have significant effect on the voltage, current, and energy generated from polycrystalline solar panels in every hour. However, based on the data result the total energy exposure and the efficiency value for each variation angle has no significant different. Pyramid-shaped house roof construction has the advantage of increasing the value of the cross-sectional area of the tile, which has the opportunity to install wider-sized solar panels so that a greater value of electrical energy is obtained.

Article Info

Article history:	***Keywords:***
Received: March 28, 2023 **Accepted:** March 24, 2024 **Published:** April 28, 2024	Current-voltage; Polycrystal; Solar cell tile; Solar panels; Tilt angle

10.21107/jps.v11i1.19506 Aryaseta et al. E-ISSN: 2527-7634

Introduction

Solar energy is one of the new renewable energy sources widely used in society. The use of solar energy as an energy source is unlimited in number without causing greenhouse gas emissions or pollutant levels that are very low or even non-existent(Rehman & Siddiqui, 2015; Yousuf, Siddiqui, & Rehman, 2018) The increasing population significantly affects the amount of electricity consumption required. Conventionally, the source of electrical energy is generated from fossil fuel sources. Thus, with the continuous increase in population, fossil fuel energy sources will decrease or even run out, as well as the level of pollution and environmental damage caused by massive mining. (Duan, Ruggles, & Caldeira, 2022; Zhu, Victoria, Andresen, & Greiner, 2020). In Indonesia, reliance on fossil energy sources is still quite high at around 96%, of which 21.1% is used as a source of supply from the availability of electrical energy(Huang, Kazhamiaka, & Keshav, 2021; Setyono & Kiono, 2021). Therefore, globally, the government has been gradually innovating by using solar energy as an alternative and renewable energy source.

The Indonesian government has a target in 2025 to achieve a 23% share of renewable energy in the national energy (Nugroho & Sudiarto, 2021; Sitepu & Gunadhi, 2014). It is one way to promote clean and sustainable energy and fulfill international commitments to tackle climate change. Indonesia has benefits greatly from the high intensity of sunlight cause of the location of Indonesia on the equator. In Indonesia, the sun has passed almost the whole year, which strongly supports the use of solar cells as a new renewable energy source.

The utilization of solar cells as an energy source uses photovoltaic solar panels. The photovoltaic panels used can convert solar energy into electrical energy by utilizing the semiconductor materials used in solar panels (Sivaram, Dabiri, & Hart, 2018; Thamrin, Erlangga, & Susanty, 2018). In Indonesia, the most common use of photovoltaics is monocrystalline and polycrystalline solar panels. The two types of solar panels have different characteristics. Solar panels that have different materials have different output intensity power values (Suwarti, Wahyono, & Prasetiyo, 2018). In this research, an investigation study of the daily performance profile of polycrystalline solar panels will be carried out.

Using photovoltaics or solar panels as an alternative energy source using the sun, the performance of the solar panels depends on the intensity of the sun, the direction of the sun, the wind direction and other meteorological parameters (Besharat, Dehghan, & Faghih, 2013). To save money, time, and the necessary storage space, proper and optimum electrical energy storage is crucial. Three polycrystalline solar panels were used in this investigation, and their output voltage and current values were measured while they were connected directly to the accumulator or battery. Concerning the battery durability, operating costs, and available storage space, the choice of load storage capacity is crucial to considerusage of it (Wardhani et al., 2022). When the amount of sunshine is insufficient, the surplus load produced by the solar panels can be stored by choosing the appropriate storage capacity from the accumulator or battery, which also acts as a source of power or charge (Wardhani et al., 2022).

One of the parameters that influence the performance of solar panels is the intensity of sunlight and the amount of solar power that affects the surface area of the solar panel (Napitupulu, 2017). Efforts that can be made to improve the performance of solar panels are by adjusting the position and tilt angle to place solar panels on the roof of the house so that they are perpendicular to the direction of sunlight. The optimal tilt angle of the solar panel can affect the value of the intensity of sunlight (Pangestuningtyas D & Hermawan, n.d.; Qomaria & Sudarti, 2021). Sunlight hitting the surface of the solar panel perpendicularly can obtain a maximum energy of 1 kW/m^2 (Yuliananda, Sarya, & Retno Hastijanti, 2015). Previous research has shown that self-contained photovoltaic (PV) systems using polycrystalline arrays can be successfully installed in embedded environments, typically powered from the mains grid, without customer annoyance. can improve service reliability for critical loads. Complimentary onsite performance (Chowdhury, Taylor, Chowdhury, Saha, & Song, 2007).

Previous study stated that polycrystalline solar panels have a larger and wider cross-sectional area than monocrystalline solar panels to produce an output power of the same value. (Septiady & Musyahar, 2018) However, the output voltage produced by the polycrystal is more stable in extending the accumulator's lifetime and solar panel conditions. In addition, polycrystalline solar panels have a relatively lower price compared to monocrystalline photovoltaic (Kurniawan, Hadi, &

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Sarwono, 2016). The focus of the research is a comparative test of variations in the angle of inclination of solar panels to the daily profile of polycrystalline solar panel performance on the roof of a house located in *Rungkut* District, Surabaya. This study was conducted to determine the daily performance profile of the output voltage and current value of a 50wp solar panel installed on the roof of a house with variations in the angle of the solar panel as the first step in the study to install a solar cell tile to create an energy-independent home. Power generation utilizing photovoltaic (PV) panels on urban rooftops require increasingly precise measurements to predict solar radiation levels due to the rapid expansion of urban solar energy applications (Yousuf et al., 2018).

By investigating the power output levels produced by the solar panel as the tilt angle changes, the daily profile of the performance of the solar panels in a day can be seen. The amount of voltage generated by the solar panel is influenced by the elevation angle of exposure to sunlight hitting the surface of the solar panel. By investigating the tilt angle, it is expected that the impact of placing solar panels on the slope of the tile used on the roof of the house will be known. The surface area of solar panels that can absorb solar heat energy at different angles affects changes in the power output output values generated by the solar panels.

The purpose of this research is to determine the correlation between the tilt angle of the solar panels and the energy produced each hour and the total daily energy of the solar panels installed on the roof tiles for 10 hours. The innovation of this study is the use of variations in the angle of inclination of the solar panels installed with a different construction of the angle of inclination of the solar panels compared to research that has been carried out previously. The variation of solar panel construction angles of -15 degrees and 15 degrees chosen in this study refers to the slope angle construction of roof tiles which is widely used in houses in Indonesia. The angle of roof 15 degrees and -15 degrees connected, it will be shaped to the pyramid shape that represented to be pyramid-roof shaped. Most of roof tiles used on houses in Indonesia use pyramid construction.

Research Methods

In this study, two stages were carried out, namely the installation of solar panels with different tilt angle variations and observing the resulting output values. This study was conducted to determine the effect of the angle of the solar panel on the output value of the voltage and current of polycrystalline solar panels mounted on the roof of the house. The result data of voltage and current was collected every hour using the voltmeter, start from 7 am to 5 pm for three variations of tilt angle of solar panel. Then, in this study also calculate the total energy produced by the solar panels for a day (10 hours) and compare the data result of energy per hour that produced by solar panel.

Installation of Polycrystalline Solar Panel Tilt Variations on the Roof of the House

At this research stage, polycrystalline solar panels were installed on the roof with various tilt angles of -15, 0, and 15. For this purpose, lightweight steel support construction is required. Angle adjustment is made by installing a hinge at one end and a support rod at the other. Angle adjustment is based on the support lengths at both ends of the support board. The profile of the support arm of solar panel is illustrated in Figure 1. In previous studies, it was stated that the tilt angle of the solar panel with an angle of 15° is the optimal tilt angle that can produce energy of 3407 kWh (Kristiawan, Kumara, & Giriantari, 2019). The appearance of the variations in the solar panels' tilt angle is shown in Figure 1. The solar panels used are polycrystalline solar panels. The method of this research is connected the solar panel to an accumulator that has been discharged and connected to a multimeter digital measuring instrument. Multimeter digital functioned as an ammeter and voltmeter. The variation in the solar panels angle used in this study was directed to follow the contours of the slope of the roof in general. The polycrystalline solar panels used in this study have factory specifications, as shown in Table 1.

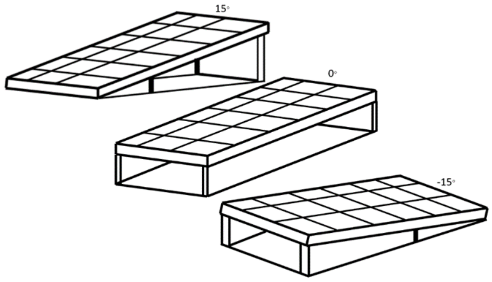

Figure 1. The profile of the support arm of solar panel

Table 1. Manufacturer Specifications of Polycrystalline Solar Panel

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Manufacturer Specifications of Polycrystalline Solar Panel	
Maximum Power	50 W
Maximum Power Voltage	17.6 V
Maximum Power Current	2.85 A
Weight	4.5 kg
Dimension	700*510*30 mm
Standard test condition	
Temperature	25^{0}C
AM=1.5 Irradiance= 1000W/m^2	

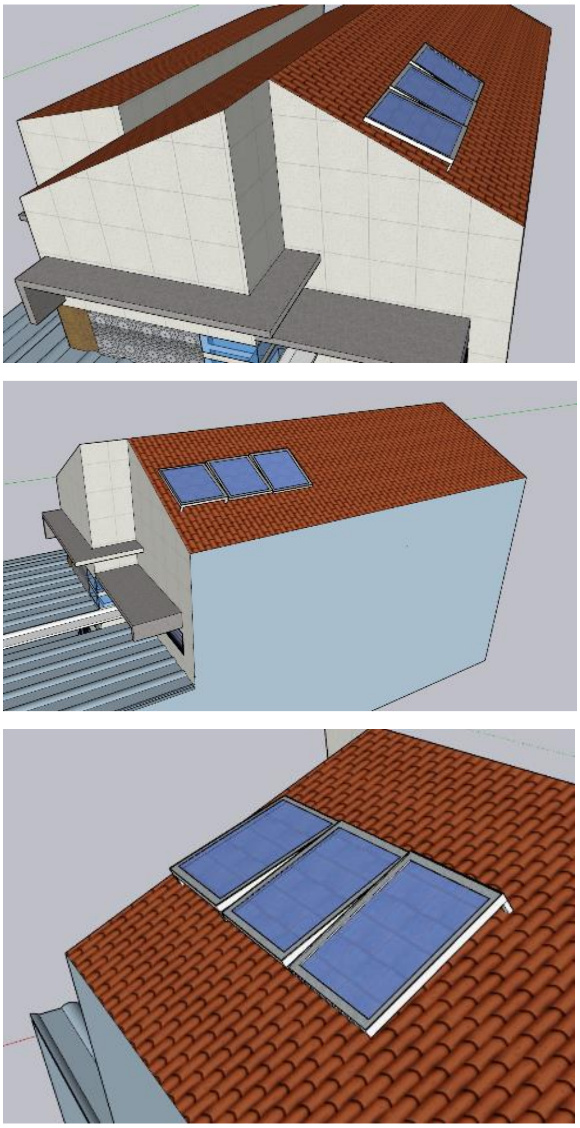

Figure 2. Installation of the Tilt Angle of the Solar Panel on the tile on the roof of the house (source: research design using sketch up)

The polycrystalline solar panels used in this study were assembled into a single roof area with parallel positions. Three polycrystalline solar panels were used to observe the resulting power output values. In the iron frame of the three solar panels, hinges were given to adjust the angle according to the variation in the angle of the solar panel. In this study, each solar panel was conditioned in a static state or did not experience a shift in position.

The Influence of the Inclination of the Solar Panel on the Value of the Polycrystalline Photovoltaic Output Electric Current-Voltage

Data collection from solar panels, namely current, voltage, and power, was carried out by observing every hour at 07:00 - 17:00 WIB in a day for this type of polycrystalline solar panel. Data collection of output values generated by solar panels was carried out by observing from a multimeter digital. In data collection, observations were also made of the the value of the resulting output voltage from the solar panels directly Measurement of the power output of the solar panel using two digital multimeter type GDM-391 brand GW, each of which functions as an ammeter and voltmeter. In addition, the smallest scale value for the ammeter is 0.01 A, and the voltmeter is 0.01 V. A scheme for measuring the solar panel current and output voltage is shown in Figure 3. In this study, output power output data collection were carried out every hour with ten repetitions of data collection for each variable. The calculated value of electric charge (Q) and solar panel energy (E) can be determined based on the output voltage and current value. Data collection of current (I) and voltage (V) on the solar panel for each variation of the angle of the solar panel was carried out continuously.

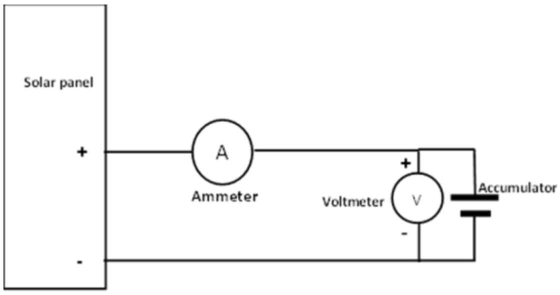

Figure 3. The Scheme of Solar panel output power output measurement

Result and Discussion

Solar Panel Installation with Variation of Tilt Angle of Polycrystalline Solar Panels on the Roof of the House

In this study, a solar panel installation was obtained with three variations of the angle of inclination to the solar panel frame on the roof or tile of the house. In this study, three variations of angles for polycrystalline solar panels were used,

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namely -15°, 0°, and 15° to the ground surface. The image of the solar panel installation on the roof of the house is depicted in Figure 2. In Figure 2, it is shown that the angle variation made on the polycrystalline solar panel aims to vary the application of roof tile installation. The position of the house as the research site determines how the solar panel's angle varies depending on the direction of the sun's rays.

Figure 4. The installation of the tilt angle of the solar panel on the tile on the house's roof

The Influence of the Tilt Angle of the Solar Panel on the Power output Value of Polycrystalline Photovoltaic Output

Based on the results of the study, it can also be represented that the output voltage value from with type of solar panels is polycrystalline with an angle variation of -15° experienced a trend where the voltage value in the morning at 07:00 – 10:00 WIB was higher than the output voltage from solar panels with variations in the angle 0° and 15°. Meanwhile, during the day, at 11:00 – 15:00 WIB, the output voltage generated by solar panels with a variation of the angle of 0° has a higher value than the variation of the angle of -15° and 15°. After 15:00 WIB, the result of the output voltage on the solar panel with a tilt angle of 15° is higher. This is due to the movement of sunlight as an energy source so that the output value of the voltage produced by solar panel with type is polycrystalline with variations in the tilt angle experiences differences at certain times. The intensity of sunlight is the main factor that effects of the resulting voltage value. The output voltage from the solar panel is the greatest when the intensity of sunlight hits the surface with a perpendicular elevation angle to get the optimal value.

According to the study's findings, the solar panel angle's tilt impacts the amount of output voltage that the solar panel produces. However, the output voltage value does not have a significant difference, so later, the installation of solar panels with variations in the tilt angle can be applied to the house's tile roof. In installing solar panels on a tile roof, it is necessary to consider the direction of the sun's rays and the condition of the house or building. This is so that the intensity of sunlight that hits the surface area of the solar panel is of optimal value.

Table 2 Observation Result of Tilt Angle Correlation of Polycrystalline Solar Panel to Output Current-Voltage

TIME	T (°C)	P sensor (mW)	I_{Sun} (W/m²)	Polycrystalline					
				Angle -15°		Angle 0°		Angle 15°	
				I (A)	V (V)	I (A)	V (V)	I (A)	V (V)
07.00	28.6	60	476.37	0	20.89	0	20.5	0.52	20.32
08.00	31.9	78	596.82	1.44	20.52	1.42	20.44	1.03	20.37
09.00	32.2	90	728.19	2	20.35	2.04	20.32	1.65	20.26
10.00	39.8	98	841.42	1.72	20.27	1.93	20.43	1.9	20.29
11.00	40.9	119	927.30	1.77	20.08	2	20.22	2.02	20.14
12.00	44.2	121	983.40	2.08	20.16	2.13	20.18	2.05	20.11
13.00	39.3	115	829.12	1.94	20.25	2.03	20.23	1.98	20.17
14.00	38.2	117	482.73	1.61	20.33	1.24	20.39	1.79	20.35
15.00	33.1	34	132.13	0.1	18.51	0.11	18.63	0.12	18.57
16.00	31.9	23	108.11	0.07	18.31	0.08	18.43	0.09	18.47
17.00	31.8	10	84.65	0.01	15.7	0.01	16.12	0.01	16.5
Notes: T = Solar Panel temperature (°C) I_{sun} = Sunlight Intensity (W/m²)									

The polycrystalline solar panel used in this study has a surface area of 3.5 m^2. Polycrystalline solar panels with three tilt angle variations are not significantly different. The three variations of the tilt angle of the polycrystalline solar panel show that the tilt angle of 0° has the highest voltage and current value among other angle variations at 12:00-13:00 WIB, with the average value of 2.13A. Based on the study's results, it can also be seen that the value of the voltage spike stored in the accumulator has a significant difference from 7 am to 08:00 WIB. This is because the intensity of the sun hitting the surface of the solar panel is starting to get high so that the voltage generated by the solar panel has increased drastically. The results on Graph. 3, show that the graph is in accordance with the graph when charging the accumulator, where the current when charging the accumulator has a significant increase and is followed by a decrease in the current value until it reaches a stable

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condition. The highest output current on the three solar panels with different tilt angle variations has a value range between 2 A - 2.5 A. This study does not provide another load when observing the value of the charge stored in the accumulator. Therefore, the value of the voltage and current recorded on the accumulator is the result of the solar panel.

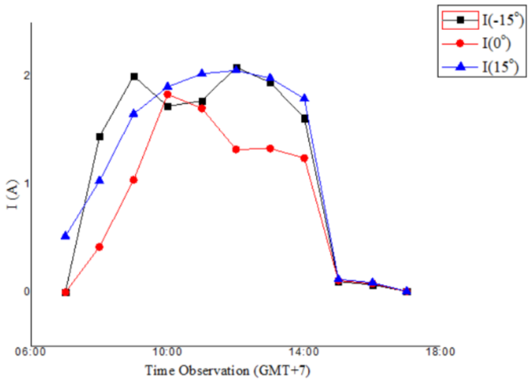

Figure 3. Result of Output Current of Three Different Variations of Angle Solar Panel on Time Observations

This study shows that the output power output generated on the polycrystalline solar panel for the three angle variations have the highest value at 12:00 WIB. This is because the intensity of sunlight is highest at the time of observation during the day. Moreover, the elevation angle given to the three variations of solar panels is not too large. In solar panels or photovoltaic (PV), the power value will be maximum when the sunlight intensity is at 90º or perpendicular to the area of the PV module (Heo, Jung, Kim, & Han, 2020; Tseng, Wang, & Lin, 2019).

Theoretically, the amount of electric charge produced (Q) can mathematically be written as the equation (1).

$$Q = \int I(t)dt \qquad (1)$$

While the value of energy produced by polycrystalline solar panels (E) can be determined based on the formula as follow:

$$E = Q\,V \qquad (2)$$

The relationship between voltage, current, electric charge, and energy produced, according to the equation (2) by polycrystalline solar panels with variations in the angle of inclination with exposure to sunlight for 10 hours are shown in table 3, table 4, and table 5.

Table 3. Calculation Results of Solar Panel Electrical Energy Value with an Angle of -15º

TIME	I(A)	Q (Ah)	V(V)	E (Wh)
07.00	0	0.72	20.89	15.04
08.00	1.44	1.72	20.52	35.29
09.00	2.00	1.86	20.35	37.85
10.00	1.72	1.74	20.27	35.37
11.00	1.77	1.92	20.08	38.65
12.00	2.08	2.01	20.16	40.52
13.00	1.94	1.77	20.25	35.94
14.00	1.61	0.85	20.33	17.38
15.00	0.1	0.08	18.51	1.57
16.00	0.07	0.04	18.31	0.73
17.00	0.01	0.005	15.70	0.07

Table 4. Calculation Results of Solar Panel Electrical Energy Values with an Angle of 0º

TIME	I (A)	Q (Ah)	V(V)	E (Wh)
07.00	0	0.71	20.50	14.55
08.00	1.42	1.73	20.44	35.36
09.00	2.04	1.98	20.32	40.33
10.00	1.93	1.96	20.43	40.14
11.00	2.00	2.06	20.22	41.75
12.00	2.13	2.08	20.18	41.97
13.00	2.03	1.63	20.23	33.07
14.00	1.24	0.67	20.39	13.76
15.00	0.11	0.09	18.63	1.77
16.00	0.08	0.04	18.43	0.83
17.00	0.01	0.005	16.12	0.08

Table 5. Calculation Results of Solar Panel Electrical Energy Value with an Angle of 15º

TIME	I(A)	Q (Ah)	V(V)	E (Wh)
07.00	0.52	0.77	20.32	15.74
08.00	1.03	1.34	20.37	27.29
09.00	1.65	1.77	20.26	35.96
10.00	1.90	1.96	20.29	39.77
11.00	2.02	2.03	20.14	40.98
12.00	2.05	2.01	20.11	40.52
13.00	1.98	1.88	20.17	38.02
14.00	1.79	0.95	20.35	19.43
15.00	0.12	0.10	18.57	1.95
16.00	0.09	0.05	18.47	0.92
17.00	0.01	0.005	16.50	0.08

From the observed results of the correlation between output current and observation time shown in Fig. 3, the value of charge generated by each solar panel with 10 hours of exposure time is as follows. A solar module with a tilt angle of -15° generates a charge of 12.74 Ah. Then a solar panel with a tilt angle of 0° will generate 12.99 Ah of charge. At the same time, a solar panel with a tilt angle of 15° generates 12.9 Ah of charge.

The total energy of polycrystalline solar panels can be determined by calculating the product of the electric charge and the electric voltage generated by each of these panels. Based on the observations for each solar panel with 10 hours of exposure, the total energy value for polycrystalline solar panels with an angle of -15º is 258.44 Wh, and 0º is 263.64 Wh, while a tilt angle of 15º obtained an energy value of 260.69 Wh. In a previous study, the performance profile of solar panels for one year was observed in Bali using a solar panel tilt angle of 15° (Gunawan et al., 2019). This angle can produce electrical energy with a value of 3407 kWh, greater than the solar panel tilt angle of 30,96° (3214.6 kWh) (Kristiawan et al., 2019).

The result of data on the Table 3 to Table 4 showed that the result on energy per hour has

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different value. However, the total energy that produce by each solar panel with 3 variations of tilt angle during 10 hours has not showed difference significantly. So that, this result can be opened the prospect about the utilization of solar panel on the house-roof with the pyramid design. The pyramid design has a total area wider than the roof construction with square flat surface. Then, the total energy output for daily result profile will be greater. Considering about the surface area between the surface with This can be seen from the area of the horizontal side with the slanted side of the triangle, the projected area on the sloping side will be larger than the horizontal side (flat surface area).

To determine the efficiency of the electrical energy produced by each polycrystalline solar panel with variations in the angle of inclination, the first calculation of the value of photonic energy emitted by the sun with an exposure time of 10 hours. Based on the observation results of the solar panel's intensity, photonic power, and cross-sectional area, it can be determined that the photonic energy emitted for 10 hours is 2097.47 Wh. Furthermore, it can be determined that the energy efficiency value for each polycrystalline solar panel is 12.32% for a tilt angle of -15º, 12.57% for a tilt angle of 0º, and 12.43% for a tilt angle of 15º.

The results showed that each solar panel's output voltage and current values experienced different trends for each variation in the angle of the solar panel in three-time conditions, namely in the morning, afternoon, and evening. This difference is due to the tilt of the angle placed on the roof of a flat model house influenced by the shadow of another building's roof that blocks exposure to sunlight hitting the solar panels. Thus, in installing solar panels, several initial planning stages must be carried out, including looking at the sun rays' direction, the location of the building, and the condition of the surrounding buildings, such as the presence of tower buildings or other tall buildings. Suppose other buildings block the position of the solar panel. In that case, the intensity of sunlight hitting the solar panel will decrease, and the performance of the solar panel will not be optimal. The research that has been done mentions several things that can also reduce the performance of solar panels to be not optimal, namely, the shadows of other buildings, the wrong position of lying on the roof of the house, and the shadow of the solar panels themselves (USAID, 2020).

The results of this preliminary study show that variations in the angle of the solar panels of 15º, 0º, and -15º can be used as an alternative for flat or sloping roofs. Pyramid-shaped house roof construction has the advantage of increasing the value of the cross-sectional area of the tile, which could install wider-sized solar panels so that a greater value of electrical energy is obtained. Variations in the angle of the solar panel must pay attention to the direction of the building and the direction of sunlight so that it can receive sunlight from any direction throughout the day. By doing this research, it can be noted that the placement of solar panels is in accordance with the direction of the arrival of sunlight so that the intensity of sunlight on the solar panels is optimal.

Conclusion

In conclusion, variations in the angle of the solar panels have significant effect on the voltage, current, and energy generated from polycrystalline solar panels in every hour. This study's highest output current value was 2.13 A at 12:00 - 13:00 WIB. In the variation of the tilt angle of -15º, the highest output voltage value is obtained in the morning at 07:00 – 10:00 WIB compared to the tilt angle of 0º and 15º. During the day, the highest output voltage value of the solar panel is obtained with a tilt angle of 0º. The total energy of polycrystalline solar panels can be determined by calculating the product of the electric charge and the electrical voltage generated by each of these panels.

Based on observations for each solar panel with exposure for 10 hours, the total energy value for polycrystalline solar panels with a tilt angle of -15º is 258.44 Wh. For polycrystalline solar panels with an angle of 0º, the energy value is 263.64 Wh, while polycrystalline solar panels with a tilt angle of 15 obtained an energy value of 260.69 Wh. The photonic energy emitted for 10 hours is 2097.47 Wh. The energy efficiency value for each polycrystalline solar panel is 12.32% for a tilt angle of -15º, 12.57% for a tilt angle of 0º, and 12.43% for a tilt angle of 15º. However, based on the data result the total energy exposure and the efficiency value for each variation angle has no significant different. Pyramid-shaped house roof construction has the advantage of increasing the value of the cross-sectional area of the tile, which has the opportunity to install wider-sized solar panels so that a greater value of electrical energy is obtained.

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