

The Effect of Tilt Angle of 200 WP Polycrystal Type Solar Panels on Output Power and Electrical Energy Efficiency

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ABSTRACT

This research aims to determine the effect of the tilt angle of 200 Wp polycrystal type solar panels on output power and efficiency and to determine the optimal tilt angle in producing output power and efficiency. The data analysis techniques used are descriptive analysis techniques and regression analysis with One Way ANOVA statistics. The results of research on variations in solar panel tilt angles show that the output power and efficiency of 200 Wp polycrystal type solar panels, which have the most optimal solar panel slope angle is 30 degrees with data collection time at 12.00 WITA (Indonesian Central Time). This tilt angle produces the highest power output and efficiency values close to the specifications of the solar panels used

INTRODUCTION

Renewable Energy is an alternative energy source that is abundant in nature. Renewable energy can be used continuously and never runs out. Renewable energy can save the earth from global warming and minimize the use of fossil fuels (Sunardi et al., 2021). Potential renewable energy in Indonesia that can be developed includes geothermal energy, sunlight and bioenergy. The sun is a source of light energy that can be utilized directly or we can also convert it into other forms of energy, such as heat energy and electrical energy (Dwisari, Sudarti, and Yushardi (2023).

One potential alternative energy that needs to be prioritized is sunlight, if utilized optimally it can be used as an alternative energy to replace fossil fuels. This is because Indonesia is a country located on the equator. Solar energy that can be used for all of Indonesia's land area of 2 million km² is 4.8 kWh/m² every day, or the equivalent of 112,000 GWp (Hasrul, 2021).

Solar energy can be used as alternative energy which will be converted into electrical energy using solar cells. A solar panel is a device consisting of solar cells that convert sunlight into electrical energy. A solar cell is a semiconductor layer that has a large surface area and consists of a series of diodes. This large potential of solar energy provides many benefits, especially if it is converted into electrical energy. Some of the advantages compared to other energy are that it does not produce air pollution, is available continuously, is obtained free of charge, is free of waste, and so on (Sariman, 2021).

The way to get maximum solar radiation is by positioning the surface of the solar panel at a certain angle so that it faces the sun. The solar panels installed so far are still static, pointing in one orientation. With this condition, the solar panels cannot capture maximum sunlight throughout the day, as a result the power and efficiency released are not optimal. To increase the power output and efficiency of solar cells, the solar cells must always be directed towards the sun's rays.

The position of the sun always changes over time with the rotation of the earth's surface so that the reception of solar energy in solar cells is not optimal. The angle of inclination in the placement of solar panels greatly influences the output produced (Basuki, Rosadi, and Hadi, 2020). Therefore, this research aims to examine the influence of the tilt angle of a 200 Wp polycrystal type solar panel on output power and efficiency for producing electrical energy.

LITERATURE REVIEW

Solar Panel

Solar panels are an element semiconductors that can convert solar energy into electrical energy using the photovoltaic principle. A solar module is a collection of several solar cells, and A solar panel is a collection of several solar modules. The voltage and electric current produced by the cell The sun is influenced by two physical variables, namely intensity of solar radiation and temperature environment. The intensity of solar radiation received by the solar cell is proportional to the voltage and electric current produced by solar cells, meanwhile if the environmental temperature gets higher with fixed intensity of solar radiation, then The solar panel voltage will decrease and the electric current will decrease the resulting amount will increase (Suryana D, 2016).

The amount of energy produced by solar panels depends on available solar energy, which in particular depends on the direction of the module sun against sun. When the solar panels get input in the form of sunlight intensity then it will can generate current. The amount of current produced by solar panels is directly proportional to the size the intensity of sunlight entering the cell solar. The intensity of sunlight changes accordingly with a shift in the position of the sun (Sihite, 2021)

Types of Solar Panels

The types of solar cells are classified based on their manufacturing technology and are divided into three types, namely:

1) Mono-Crystalline

This type is made from pure silicon crystal rods that are sliced thinly, resulting in solar cell pieces that are identical to each other and have high performance. This solar cell is the most efficient type compared to other types of solar cells, the efficiency is around 15% - 20%. Monocrystalline solar panels are panels the most efficient, producing electrical power highest unit area. Disadvantages of this type of panel is that it will not work well in bright light If there is not enough sun (shade), efficiency will decrease drastically in cloudy weather (Napitupulu, et al. 2017).

2) Poly-Crystalline

This type is made from several rods of silicon crystals which are melted and then poured into a square mold. The purity of the silicon crystals is not as pure as monocrystalline solar cells, therefore the resulting solar cells are not identical to each other and their efficiency is around 13% - 16% lower.

3) Thin Film Photovoltaic

Thin Film Photovoltaic is a solar panel (two layers) with a microcrystal-silicon and amorphous thin layer structure with a module efficiency of up to 8.5% so that the surface area required per watt of power produced is greater than monocrystals and polycrystals. "The latest innovation is Thin Film Triple Junction Photovoltaic (with three layers) can function very efficiently in very cloudy air and can produce up to 45% more electrical power than other types of panels with equivalent power."

These three types of solar panels are made from silicon crystal bars pure thinly sliced into crystal pieces thin silicone. With technology like this, it will the resulting pieces of solar cells are identical to each other others and high performance. So it becomes a solar cell the most efficient compared to other types of solar cells others, around 15% - 20% (Fitryah, 2015).

Working Principle of Solar Panels

The working principle of photovoltaics is energy Photons in sunlight produce energy kinetic capable of releasing electrons to conduction band to create an electric current. Kinetic energy will get bigger along with increasing light intensity from the sun. The highest intensity of sunlight is absorbed by the earth during the day to produce solar power absorbed by the earth is around 120,000 Terra Watts. Type The metal used will also determine performance rather than solar cells (Arrasyid A. H, 2017).

Temperature and Solar Panel Temperature

Solar cell temperature (T_c) is the temperature measured on the surface of the solar panel. Solar panels will work optimally at a standard temperature of 25°C. The greater the temperature of the solar panels will have an impact on the power produced by the solar panels. Solar panels will be more optimal when they face the sun directly, in the sense that the surface of the solar panel is directly facing the incoming radiant or perpendicular to the sun.

Determining the Tilt Angle of Solar Panels

The sun always changes its path in one year in the direction of latitude (south north direction). The range of movement of the sun's path is from 23° 0.26' north latitude to 23° 0.26' south latitude. The tilt angle of a solar panel is an angle solar panels in the direction of latitude relative to the line horizontal, and the azimuth angle is the angle deviation of solar panels with respect to latitude. Tilt angle and azimuth angle of solar panels fixed installation greatly affects the total power that solar panels can produce (Yassir, 2019).

The solar panel array must be installed with proper tilt angle and azimuth angle, that is compass direction from the direction of the sun's rays. Direction The facing of the solar panels greatly determines the amount of output enough from the power plant. Ideally, direction The facing of the solar panels must be arranged perpendicular to the sunlight to receive radiation directly directly (Shalih & Suratno, 2019).

The angle of inclination is an important factor which affects the amount of radiation received the sun on the surface of the solar panel. Solar panels installed still cannot receive the amount maximum solar radiation. How to get Maximum solar radiation by positioning the surface of the solar panel at a certain slope so that directly facing the sun. To get maximum output energy, can be done with optimize the reception of solar radiation by solar panels. For this reason it is necessary to position the panel solar at a certain tilt angle and azimuth in order can receive maximum solar radiation (Pandria et al, 2021).

Solar Radiation Intensity

Radiation is a process of propagating energy (heat) in the form of electromagnetic waves without the need for intermediaries. Solar energy can reach the earth's surface by means of radiation (radiation), because between the earth and the sun there is a vacuum (no intermediary substances), while electromagnetic waves are a form of wave that is propagated in the form of electric and magnetic field components, so that it can propagate at very high speeds and without the need for intermediate substances or media.

Power

Solar panel power refers to the amount of electrical energy that a solar panel can produce from the sunlight it receives. Solar panels consist of photovoltaic cells that convert sunlight energy into electrical energy. The power produced by a solar panel depends on the size and efficiency of the panel, the intensity of sunlight received, and the environmental temperature around the panel. The International or SI unit for power is Joule/Second (J/s) = Watt (W).

Input Power

The input power from a solar panel is the intensity of sunlight (W/m²) and the cross-sectional area of the solar panel (m²) (Darwin and Suwarno, 2020). To determine the input power, the formula from the following equation can be used:

$$P_{in} = I_{rad} \cdot A \dots\dots\dots (1)$$

Where:

- P_{in} = Solar panel Input Power (W)
- I_{rad} = Solar Radiation Intensity (W/m²)
- A = Cross-sectional Area of Solar Panels (m²)

Where is the way to get the conversion value for the intensity of sunlight (I_{rad}) from Lux Meters to (W/m²) as follows:

$$1 \text{ Lux} = 0,0079 \text{ W/m}^2,$$

so that:

$$I_{rad} = \text{Lux} \cdot 0,0079 \text{ W/m}^2 \dots\dots\dots(2)$$

Where:

- I_{rad} = Solar Radiation Intensity (W/m²)
- 0,0079 W/m² = Per-Lux Unit Conversion

Output Power

The output power from solar panels is current and voltage. Solar panel output power is a measure of how much electrical energy a solar panel can produce under certain conditions.

$$P_{out} = V_{pv} \cdot I_{pv} \dots\dots\dots(3)$$

Where:

- P_{out} = Solar panel output power (W)
- V_{pv} = Solar panel voltage (V)
- I_{pv} = Solar panel output current (A)

Calculation of Solar Panel Efficiency

Solar panel efficiency is a measure of the power of a solar panel divided by its cross-sectional area and the intensity of sunlight. In general, the higher the efficiency of a solar panel, the more electricity the solar panel produces. The equation to determine the efficiency of solar panels is:

$$\text{Efficiency } (\eta) = P_{\text{out}} / P_{\text{in}} \times 100\% \dots\dots\dots(4)$$

Keterangan:

P_{out} = Solar panel output power (W)

P_{in} = Solar panel Input Power (W)

η = Efficiency (%)

Hypothesis Testing

This hypothesis test is used to determine the effect of the angle of the solar panel tilt on the output power and efficiency of the electricity generation by using variations in the angle of the panel tilt of 0°, 30°, 60° and 90° degrees. The analysis used to determine the effect of the angle of the tilt on the output power and efficiency of the solar panel, namely statistics One Way ANOVA using the IBM SPSS statistics 27 application.

Hypothesis:

H_1 = There is an influence of the tilt angle on the solar panel output power

H_2 = There is an influence of the tilt angle on the efficiency of solar panels

The conceptual design of the research can be described as follows:

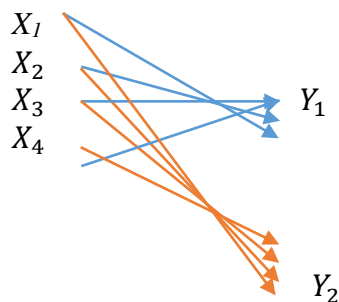


Figure 1. Conceptual Framework

Where:

X_1 = 0° tilt angle

X_2 = 30° tilt angle

X_3 = 60° tilt angle

X_4 = 90° tilt angle

Y_1 = output power (Wp)

Y_2 = efficiency (%)

METHODOLOGY

Research Flow

This research is an experimental research with the following flow:

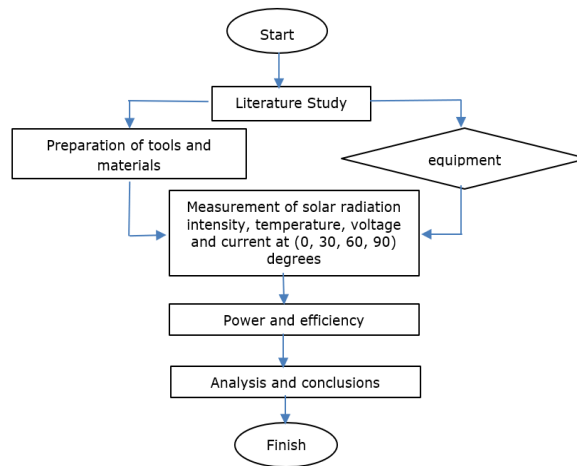


Figure 2. Research Flow

Research Instrument

To carry out this research requires tools and materials. The tools and materials we use are as follows:

Research Materials

The materials used in carrying out this research were one unit of 200 Wp 12 V Polycrystal Type Solar Panel.

Table 1. Polycrystalline Solar Panel Specifications

Model	VGH-200-18-P
Type	Polycrystalline
Maximum Power (P_{max})	200 Wp
Cell Efficiency	17.34%
Maximum Rated Voltage (V_{mp})	18.4 V
Maximum Power Current (I_{mp})	10.87A
Short Circuit	11.56 A
Voltage On Open Circuit	22.3 V
Tolerance	± 3
Maximum Voltage System	1000 V
Dimensions	1230x990x35 (mm)
Weight (Kg)	13.2Kg

Research Tools

Tools used to measure panel tilt angles, light intensity, temperature, current and voltage include the following: Avometer, Lux Meter and Protractor

Place and Time of Research

This research was conducted in January 2024 in Padang Savana, Laikang Village, Manggarabombang District, Takalar Regency, South Sulawesi. Takalar Regency is located between 5°031' to 5°0381' South Latitude and between 199°0221' to 199°0391' East Longitude. The air temperature in the Takalar area is 21°-33 °C with a relative humidity level of ±81%.

Research Stages

1. Preparation Before Research

- Collect various references related to research on the effect of solar panel tilt angle on output power and efficiency from book sources, journals, electronic reading media and other media.
- Gather theoretical foundations derived from previous relevant research.

2. Test Preparation

- Prepare research materials in the form of one unit of 200 Wp polycrystal type solar panels and solar panel test equipment.
- Adjusting test equipment, namely Avometer, Lux Meter and protractor.
- Adjust the tilt angle of the solar panel to angle positions 0°, 30°, 60°, and 90° using a protractor.
- Carry out functional checks on solar panels to measure temperature, solar radiation intensity, current and voltage.
- Carry out functional checks on solar panels to measure temperature, solar radiation intensity, current and voltage.

3. Measurement and Data Collection of Solar Panels

- Measure the intensity of solar radiation using a lux meter.
- Installing an Avometer to measure current and voltage on solar panels produced at different angles (0°, 30°, 60°, dan 90°).
- Data collection every hour, starting at 08.00 - 16.00 WITA for 3 days at each angles (0°, 30°, 60°, dan 90°).
- Print test results in the form of voltage, current and output power data as well as efficiency on 200 Wp polycrystal type solar panels.
- The data produced is in the form of tables, pictures and graphs based on hourly measurements and based on changes in the position of the solar panel tilt angle.

RESULTS

Determining the position of the solar panels in this research is adjusted to the location or place of research based on Indonesia's geographic location, which is to the south of the earth, so the solar panels must face the true north. Then rotate slightly towards the northeast with an azimuth angle of 10° degrees at the research location. The Azimuth angle can be determined using the Global Solar Atlas website by entering the coordinates of the research location. Apart from being able to display azimuth angle data, Global Solar Atlas provides information regarding air temperature, terrain elevation and direct normal irradiation.

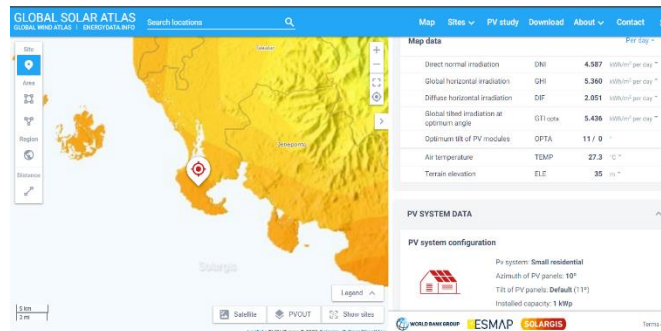


Figure 3. Location of Research Points

Output Power Measurement and Calculation Results

Table 2. Solar Panel Output Power

Time (WITA)	Output Power (Wp)			
	0°	30°	60°	90°
08.00	47.27	74.77	66.87	41.66
09.00	67.6	100.43	82.88	63.20
10.00	111.46	143.79	102.14	94.38
11.00	124.34	178.7	121.95	111.99
12.00	140.49	188.99	175.35	119.55
13.00	120.67	150.63	129.49	102.34
14.00	86.88	119.10	117.63	66.96
15.00	58.67	82.58	88.82	50.37
16.00	47.48	58.09	61.18	41.76
Mean (Wp)	89.42	121.89	105.14	76.91

Note: (WITA: Central Indonesian Time)

Table 2 above shows the results of the output power calculation with each variation of tilt angle (0°,30°,60° and 90°) as well as the data collection time starting at 08.00-16.00 Wita with a 1 hour data collection interval. At angle 0° the average value of output power produced is 89.42 Wp. The average output power value obtained for a 30° angle is 121.89 Wp. Then at an angle of 60° the average output power value was 105.14 Wp and finally the 90° angle test had an output power value of 76.91 Wp.

Efficiency Measurement and Calculation Results

Table 3. Solar Panel Efficiency

Time (WITA)	Efficiency (%)			
	0°	30°	60°	90°
08.00	7.5	8.95	8.35	7.28
09.00	8.39	9.92	9.22	8.14
10.00	10.04	10.64	10.00	9.72
11.00	10.16	11.65	10.11	9.93
12.00	10.68	12.12	11.69	10.27
13.00	10.17	11.03	10.18	9.98
14.00	9.34	10.31	10.09	8.27
15.00	7.83	9.49	9.48	7.51
16.00	7.44	7.69	8.60	7.23
Rata-Rata (%)	9.96	10.2	9.74	8.70

Note: (WITA: Central Indonesian time)

Table 3 above shows the results of calculating efficiency values with each variation of tilt angle (0°, 30°, 60° and 90°) as well as the data collection time starting at 08.00-16.00 WITA with a 1 hour data collection interval. At angle 0° the average efficiency value is 9.96%. The average efficiency value obtained in testing with an angle of 30° degrees was 10.2%. Then, in the tilt angle test of 60° degrees, the average efficiency value was 9.72% and the final angle test was an angle of 90°, an efficiency value of 8.7% was obtained.

Statistical Analysis Results

The results of statistical analysis to determine the effect of variations in solar panel tilt angle on output power and efficiency are shown in the following Table 4 and Table 5.

Table 4. Results of One Way Anova Test Analysis of Solar Panel Output Power
ANOVA

Output Power (OP)

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3413.234	3	1137.745	36.344	.000
Within Groups	250.441	8	31.305		
Total	3663.674	11			

Multiple Comparisons

Dependent Variable: Output Power (OP)

Tukey HSD

(I) Tilt Angle	(J) Tilt Angle	Mean Difference (I-J)	Std. Error	Sig.	% Confidence Interval Lower Bound
0°	30° OP	-32.290*	4.568	.000	-46.92
	60° OP	-15.497*	4.568	.038	-30.13
	90° OP	12.733	4.568	.090	-1.90
30°	0° OP	32.290*	4.568	.000	17.66
	60° OP	16.793*	4.568	.026	2.16
	90° OP	45.023*	4.568	.000	30.39
60°	0° OP	15.497*	4.568	.038	.87
	30° OP	-16.793*	4.568	.026	-31.42
	90° OP	28.230*	4.568	.001	13.60
90°	0° OP	-12.733*	4.568	.090	-27.36
	30° OP	-45.023*	4.568	.000	-59.65
	60° OP	-28.230*	4.568	.001	-42.86

*. The Mean Difference is Significant at the 0.05 Level

From the results of hypothesis testing carried out using One Way ANOVA statistics, it is known that there is an influence of the tilt angle of the solar panels on the output power. The obtained Sig value (0.000) < (0.05) So, H0 is rejected. So the four angles have different average influences.

Table 5. Results of One Way Anova Test Analysis of Solar Panel Efficiency
ANOVA

Efficiency	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4.045	3	1.348	26.500	.000
Within Groups	.407	8	.051		
Total	4.452	11			

Multiple Comparisons

Dependent Variable: Efficiency

Tukey HSD

(I) Tilt Angle	(J) Tilt Angle	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound
0°	30° Efficiency	-1.133*	.184	.001	-1.72
	60° Efficiency	-.680*	.184	.025	-1.27
	90° Efficiency	.360	.184	.280	-.23
30°	0° Efficiency	1.133*	.184	.001	.54
	60° Efficiency	.453	.184	.142	-.14
	90° Efficiency	1.493*	.184	.000	.90
60°	0° Efficiency	.680*	.184	.025	.09
	30° Efficiency	-.453	.184	.142	-1.04
	90° Efficiency	1.040*	.184	.002	.45
90°	0° Efficiency	-.360	.184	.280	-.95
	30° Efficiency	-1.493*	.184	.000	-2.08
	60° Efficiency	-1.040*	.184	.002	-1.63

*. The Mean Difference is Significant at the 0.05 Level

From the results of the hypothesis test carried out using One Way ANOVA statistics, it is known that there is an influence of the tilt angle of the solar panel on the efficiency value. The obtained Sig value (0.000) < (0.05) So, H₀ is rejected. So the four of tilt angle have different average influences

DISCUSSION

Optimal tilt angle of solar panels is one of the determining factors receipt of total amounts of solar radiation maximum, so it will have an impact on power solar panel output (Emes et al., 2022). The voltage and electric current produced by Solar cells are influenced by two physical variables, namely intensity of solar radiation and temperature environment. The intensity of solar radiation received by the solar cell is proportional to the voltage and electric current produced by solar cells, meanwhile if the environmental temperature gets higher with fixed intensity of solar radiation, then the solar panel voltage will decrease and the electric current will decrease the resulting amount will increase (Suryana D, 2016).

If seen in terms of exposure time the sun, the later the sun's intensity will be The further it goes down, the more it will affect the output solar panel voltage. Arrasyid (2017) believes that the intensity of sunlight The highest amount is absorbed by the earth during the day. The sun has an influence on light intensity the sun, the smaller the panel tilt angle value solar energy, the greater the intensity of the sun generated which affects the panel tension solar. Bahari, Laka & Rosmiati (2017) argue that the greater the direction of the vertical angle then the voltage will also decrease and vice versa The smaller the direction angle, the greater the magnitude voltage is also reduced.

The amount of energy produced by solar panels depends on available solar energy, which in particular depends on the direction of the module sun against sun. When the solar panels get input in the form of sunlight intensity then it will can generate current. The amount of current produced by solar panels is directly proportional to the size the intensity of sunlight entering the cell solar. The intensity of sunlight changes accordingly with a shift in the position of the sun (Sihite, 2021).

The results of this research are also in line with Magrissa's (2015) study which states that there is the effect of light intensity on solar cell efficiency on mono-crystalline silicon solar cells. Change Light intensity affects the efficiency of the cell diesel. If the light intensity is increased, then efficiency will increase. But if the intensity the light is too small or too large causes efficiency decreases or is small. Due to light energy What is produced is too little electrical energy The output is also small, and the light energy is too much large causes the internal energy of the electron to change becomes hot and the electrical energy becomes constant. This is caused by electrons in solar cells has a threshold limit for absorbing photons at certain energy level.

Changes in sunlight intensity effect on the output power of solar panels, namely the greater the intensity of sunlight generated, the greater the output power that can be produced by solar panels. Apart from that, position Installation of solar panels affects power and the intensity of sunlight produced (Shalih & Suratno, 2019).

For the correct tilt position of the solar panels will greatly determine the maximization of solar energy reception. Based on research results shows that the panel tilts has an influence on intensity sunlight. Tilt angle and azimuth angle of the panel Fixed solar installation greatly affects the total power that solar panels can produce (Yassir Y, 2019). The output power of a photovoltaic module depending on the amount of solar radiation received by module. By directing the photovoltaic module at a certain slope, solar radiation is received can be optimized. What's next is this enlarge the output of the photovoltaic module. By general, the tilt of the module is adjusted to the position latitude of placement location.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of research, analysis and discussions that have been carried out regarding the influence of the tilt angle of solar panels on output power and efficiency of electrical energy generation, it can be concluded as follows:

Calculation results of solar panel output power at each tilt angle of 0°, 30°, 60° and 90°, with a testing time of 12 days. At angle 0° the average value of output power produced is 89.42 Wp. The average output power value obtained for a 30° angle is 121.89 Wp. Then at an angle of 60° the average output power value is 105.14 Wp and at an angle of 90° with an output power value of 76.91 Wp. Meanwhile, corner 0° has an average efficiency value of 9.96%. The average efficiency value obtained in testing with an angle of 30° degrees was 10.2%. Then, in the tilt angle test of 60°, the average efficiency value was 9.72% and the final angle test was an angle of 90°, an efficiency value of 8.7% was obtained.

From the results of calculating the output power and efficiency of a 200 Wp polycrystal type solar panel, the most ideal solar panel tilt angle is 30°, producing an average output power of 121.89 Wp and an average efficiency obtained of 10.2%.

FURTHER STUDY

Future research could relate to other climate variables such as humidity levels, temperature, and wind speed, which can affect the efficiency and power output of solar panels. By expanding the scope of the study and taking these factors into account, further research can provide deeper insights and more applicable results for optimizing the use of solar energy, especially in increasing the energy efficiency of solar panels through more precise tilt settings.

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