Analysis the effect of reflector (flat mirror, convex mirror, and concave mirror) on solar panel

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ABSTRACT

At the time of the sun a straight line with solar cells may not necessarily produce the maximum output. Various ways continue to be done in order to get the maximum output. The maximum utilization of output from solar cells will accelerate the function of the solar cell. The use of reflectors is an excellent way to maximum output with effective time. The author will analyze solar cells with flat mirror, convex mirror, concave mirror, and without reflector. Each reflector is given varying treatment by calibrating the angle of the reflector to the solar cell by 60°, 90°, and 120°. After testing and data retrieval turns reflector very influential on the output of solar cells. The solar cell output power increases with each different reflector. Maximum output is obtained in a concave mirror with an angle is 90°.

Keywords:
Effeciency, Mirror, Polycrystalline, Reflector, Solar cells.

1. INTRODUCTION

Making life more simple has become the lifestyle of today's society. People are increasingly innovating in search of renewable technology. The development of technology with the utilization of natural resources is needed nowadays. One of the countries that have very prosperous natural resources is Indonesia, but Indonesia is still lacking in the utilization and facilities of natural resources. From Sabang to Merauke all are illuminated by sunlight, this is a very valuable natural asset. The solar irradiation in Indonesia is reaching 4.5 kWh/m²/day. The need for electricity is the most important thing, for it is needed a renewable technology such as solar panels. Solar energy can be utilized with solar panel technology [1]. The working principle of solar panels is when the light of the silicon cell and light will be absorbed by the silicon cell. The absorbed light energy will be transferred to silicon semiconductor properties. The energy stored inside the semiconductor will cause the electrons to loose and flow in the semiconductor. All these photovoltaic cells also have an electric field that forces the electrons loose because of the absorption of that light to flow in a particular direction.

Currently many methods have been done to get a maximum solar panel output, but it doesn't get a significant effect. One of the ways to get maximum output voltage is by adding a reflector. The addition of the reflector is very helpful and efficient for the sun exposure focused on solar panels but many reflectors do not function properly with solar cells [2]. Many types of reflectors can be used for further research but for this analysis the authors use mirrors. The mirror is an excellent reflector. The types of mirrors are flat mirror, convex mirror, and concave mirror. Each type of mirror has different reflections. The difference in angle for reflection of light on the Solar Panel determines the amount of light absorbed. The author will compare and see the effects of the three types of mirrors to get a mirror that is recommended to reflect light on solar cells with the same treatment.
2. RESEARCH METHOD

The addition of reflector in the form of flat mirror, convex and concave is expected to increase efficiency of solar panel output [3]. This research will test every mirror characteristic to the change of solar cell output. Each mirror will be compared before and after being given a reflector. As for the three types of mirrors there are several experimental circuits that we will test and compare with solar cells without reflector:

1. Solar cells circuit without using reflector.
2. Solar cells with reflector angle flat mirror value are 120°, 90°, and 60°.
3. Solar cells with reflector angle convex mirror value are 120°, 90°, and 60°.
4. Solar cells with reflector angle concave mirror value are 120°, 90°, and 60°.

Indonesia is a very good area functioned as the utilization of renewable technology that is solar panel, the more radiation received an area hence greatly affect the performance of solar panel. The sampling of this data is done at Jalan Kapuk Margonda Depok located at position 6° 22'06.9" S 106° 50'06.7" E. For one type of mirror reflector, a sample is needed for 3 hours in one day at 11:00-14:00 because we know that at that time the sun is very much received by radiation collectors on earth [4].

![Figure 1. Flowchart](image)

2.1. Equipment and materials for testing

a. Solar cells

This research focuses on solar cells that use the sun as an energy source. Solar cell used in this analysis is polycrystalline type [5]. Below are the pictures and specifications of the solar cell to be tested, solar cells as shown in Figure 2.
In accordance with the data we get from the solar cell specifications that we use, and then we can determine the Fill factor [6]:

$$\text{FF} = \frac{V_{\text{MPP}} \times I_{\text{MPP}}}{V_{\text{OC}} \times I_{\text{SC}}}$$

$$\text{FF} = \frac{18.5 \times 1.08}{22.14 \times 1.16}$$

$$\text{FF} = 0.77$$

With the equation below we can calculate the output power of solar cell that is:

$$P_{\text{out}} = V_{\text{OC}} \times I_{\text{SC}} \times \text{FF}$$

$$P_{\text{out}} = 22.14 \times 1.16 \times 0.77$$

$$P_{\text{out}} = 19.77 \text{ W}$$

The next step we determine the maximum output efficiency is defined as the percentage of optimum output power to light energy [7], [8]. Because of the dimensions of solar cells that we use measuring 48.5x36 then we can determine $P_{\text{in}}$ to 174.6W.

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

$$\eta = \frac{19.77}{174.6} \times 100\%$$

$$\eta = 11.32\%$$

b. Reflector

There are three types of reflectors selected by the writer to analyze the output voltage of solar cell that is flat, convex, and concave mirror. Reflector is made of glass and aluminum. For a flat mirror the size used is 40cm x 40cm while for convex and concave mirror using a mirror with a diameter of 20cm. each reflector will be placed in contact with the solar cell with different angles for reflection that occurs between the suns against the mirror of the solar cell.
2.2. Measuring instrument

This study uses several measurements as references to get accurate results. The following are the measuring tools used by the author for data collection:

a. Protractor

Protractor is a measuring instrument to determine a degree. The degree usually denoted by $\circ$, is the angular measure that can be formed on a flat plane. This tool is very important to determine the variation of the angle of the benchmark in the study.

b. Thermometer

Thermometer is used as a temperature gauge. Temperature is a very important and influential parameter for the output of solar cells.

c. Lux Meter

The intensity of light is very influential in the measurement, for the authors use this tool as a parameter of how much the internality received by solar cells at the time of measurement [9]. Lux meter has a range between 0.1~20.000 Fc with resolution 0.1 Lux/0.1 Fc. Accuracy of 4% with speed 2 times / second and Operating Environment is 14 to 122F (-10 to 50C), 10% ~ 90% RH. Here's a figure of the lux meter. Lux meter as shown in Figure 3.

![Lux meter](image)

Figure 3. Lux meter

2.3. Schematic of research tool

Solar Sell is a major component of this research. After we get all that we need in this research, then we set the location of solar cell testing. Solar cells will be tested without a reflector and use three reflectors. Arrangements between solar cells and reflectors should also be considered. Here's a schematic of a solar cell tool without a reflector and using a reflector.

a. Schematic of the Solar Cells that Stand

The first circuit is composed of solar cells that will convert solar energy into electrical energy. The circuit of solar cells we measure using a digital multimeter that can simultaneously measure the current (I) and voltage (V). Any changes whether the current or voltage that occurs during the experiment will be recorded by taking into account some parameters of temperature and light internality received by solar cells. The circuit below shows solar cells without reflector as shown in Figure 4.

![Solar cells circuit without reflector](image)

Figure 4. Solar cells circuit without reflector
b. Schematic of a solar cell with the addition of reflectors

The next series is the same as the first but that distinguishes it only by adding three different types of reflectors at different times. Its main components are solar cells and reflectors in the form of flat mirrors, convex mirrors, and concave mirrors. Each reflector will be tried differently with different test times as well so at the time of measurement will also have different light intensity and temperature. Here is a picture of the three types of reflectors and solar cells.

![Schematic of solar cell with reflectors](image)

Figure 5. a) Solar cells with flat mirror reflectors, b) solar cells with convex mirror, and c) solar cell with mirror concave.

2.4. Testing variation

Each earthly region has different radiation values received depending on the location and position of the area. The slope angle of the solar cell module with the reflector greatly affects the output of the solar cells. At the time of our tests conducted at JalanMargonda, Depok, West Java then the position of solar modules directed to the north. The variation of slope angle testing between the solar cell and the reflector we arrange for the reflector to work optimally by increasing the number of solar cell outputs.

3. RESULTS AND ANALYSIS

3.1. Input radiation calculation due to reflector addition

The following calculations are useful for some parameters for solar cells with the use of reflectors with reflector angle 60°, 90°, and 120°.

a. Determining the Angle of Declination

\[
\delta = 23.45 \sin \left( \frac{360 \times 284.63}{365} \right)
\]

\(n = 04\) March 2018 = 63

\[
\delta = 23.45 \sin \left( \frac{360 \times 284.63}{365} \right)
\]

\(\delta = 17.703^\circ\)

b. Determining the Equation of Time

\[
E = 9.87 \sin 2B - 7 \cos B - 1.5 \sin B
\]

\[
B = \frac{360(63 - 1)}{365}
\]

\(B = 61.151^\circ\)

So,
\[ E = 8.342 - 3.377 - 1.314 \]
\[ E = 3.651 \text{ minutes} \]

c. Determining the Solar Time

\[ t_s = \text{standard time} + E + 4(L_{st} - L_{loc}) \]

Standard Time = 12:11:12 PM (Taken from the middle hour between the initial hours of data retrieval and the final hours of data retrieval is at 10:18:03 AM – 14:05:20 PM)

\[ t_s = 12:11:12 + 3.651 + 4(106 - 105) \]
\[ t_s = 12:18:58 \text{ AM} \]

d. Determining the Clock Angle

\[ \omega = 15^\circ (12:18:58 - 12:00:00) \]
\[ \omega = 15^\circ (12:18:58 - 12:00:00) \]
\[ \omega = 2.835^\circ \]

e. Determining the Zenith Angle

\[ \cos \Theta_z = (\cos \delta \cos \phi \cos \omega + \sin \delta \sin \omega) \]
\[ \cos \Theta_z = (\cos 17.703^\circ \cos 6^\circ \cos 2.835^\circ + \sin 17.703^\circ \sin 6^\circ) \]
\[ \cos \Theta_z = 0.974 \]
\[ \Theta_z = 13.093^\circ \]

f. Determine the angle of the Sun’s Altitude

\[ \alpha_s = 90^\circ - \Theta_z \]
\[ \alpha_s = 90^\circ - 13.093^\circ \]
\[ \alpha_s = 76.907^\circ \]

g. Determining the Angle of the Sun Azimuth

\[ \sin \gamma_s' = \frac{\sin \omega \cos \delta}{\sin \Theta_z} \]
\[ \gamma_s = 12.004^\circ \]

h. Determining the Intensity of solar radiation outside the Earth’s atmosphere

\[ G_{on} = G_{sc} \left(1 + 0.033 \cos \frac{360.63}{365}\right) \]
\[ G_{on} = G_{sc} \left(1 + 0.033 \cos \frac{360.63}{365}\right) \]
\[ G_{on} = 1373.867 \]
3.2. Solar module output calculations using the sun as a source of energy

We will test the magnitude of Voltage ($V_{oc}$), Current ($I_{sc}$) and Power ($P_{out}$) at each angle of the reflector. Tests are conducted within the time range 10:00 WIB-14:00 WIB.

a. Output results from solar cells without using reflector

By doing the experiment several times then obtained the results of experiments from solar cells without reflector. From this result we will be able to see the comparison of outputs produced by solar cells using and without reflector.

| Hour (WIB) | Light Intensity (Lux) | Input Radiation (W/m²) | Temperature (°C) | Open Circuit Voltage / $V_{oc}$ (V) | Short Circuit Flow / $I_{sc}$ (A) | Output Power / $P_{out}$ (W) | Input Power / $P_{in}$ (W) | Efficiency (%) |
|------------|----------------------|------------------------|------------------|--------------------------------------|----------------------------------|----------------------------|-----------------|----------------|
| 10:18:03   | 197400               | 1559.46                | 35.7             | 19.60                                | 0.467                            | 19.153                     | 272.90          | 7.018          |
| 10:21:24   | 195600               | 1545.24                | 39.2             | 19.75                                | 0.482                            | 19.519                     | 270.41          | 7.218          |
| 10:51:43   | 184600               | 1458.34                | 41.9             | 19.38                                | 0.499                            | 19.670                     | 255.20          | 7.707          |
| 11:30:56   | 191700               | 1514.43                | 38.7             | 19.91                                | 0.991                            | 19.730                     | 265.02          | 7.444          |
| 11:53:20   | 185100               | 1462.29                | 40.4             | 20.49                                | 0.625                            | 18.806                     | 255.90          | 5.004          |
| 11:56:09   | 171200               | 1352.48                | 43.0             | 19.53                                | 0.970                            | 18.944                     | 236.68          | 8.004          |
| 12:01:10   | 192500               | 1520.75                | 41.7             | 19.90                                | 0.904                            | 17.989                     | 266.13          | 6.759          |
| 12:13:23   | 186700               | 1474.93                | 40.1             | 19.22                                | 0.830                            | 15.952                     | 258.11          | 6.180          |

We will test the magnitude of Voltage ($V_{oc}$), Current ($I_{sc}$) and Power ($P_{out}$) at each angle of the reflector. Tests are conducted within the time range 10:00 WIB-14:00 WIB.

b. Output results from solar cells with flat mirror reflector with angle 60°, 90°, and 120°

From the data can be seen generally: at an angle of 60° the voltage and current do not have a significant difference, an angle of 90° for the output voltage almost the same is only slightly different, and an angle of 120° the output current produced changes over time due to the temperature received by solar cells.

| Hour (WIB) | Light Intensity (Lux) | Input Radiation (W/m²) | Temperature (°C) | Open Circuit Voltage / $V_{oc}$ (V) | Short Circuit Flow / $I_{sc}$ (A) | Output Power / $P_{out}$ (W) | Input Power / $P_{in}$ (W) | Efficiency (%) |
|------------|----------------------|------------------------|------------------|--------------------------------------|----------------------------------|----------------------------|-----------------|----------------|
| 10:31:09   | 184700               | 1459.13                | 34.3             | 20.03                                | 0.596                            | 19.937                     | 255.34          | 4.674          |
| 10:45:23   | 195800               | 1546.82                | 37.7             | 20.23                                | 0.706                            | 14.282                     | 270.69          | 5.276          |
| 10:57:58   | 191900               | 1516.01                | 38.7             | 19.80                                | 0.964                            | 19.087                     | 265.30          | 7.194          |
| 11:31:18   | 195900               | 1547.61                | 38.8             | 20.35                                | 0.943                            | 19.190                     | 270.83          | 7.085          |
| 11:57:10   | 196600               | 1553.14                | 36.0             | 19.97                                | 0.922                            | 18.412                     | 271.79          | 6.774          |
| 11:58:20   | 198700               | 1569.73                | 39.4             | 20.90                                | 0.912                            | 19.060                     | 274.70          | 6.938          |
| 12:04:34   | 189700               | 1498.63                | 41.1             | 20.10                                | 0.945                            | 18.994                     | 262.26          | 7.242          |
| 12:31:44   | 192100               | 1517.59                | 39.3             | 20.32                                | 0.890                            | 18.084                     | 265.57          | 6.809          |

Table 3. The amount of solar cell output with a flat mirror at an angle of 60°, 90°, and 120°

At this measurement with convex mirror reflector we found that the efficiency was quite good which reached 9% even though it was unstable.
The radiation received by solar cells at this angle is not too far away from the temperature of the area which is not too different from each measurement data. An angle of 90° has experienced a change in current and voltage that is quite good than the others but the measurement with an angle of 120° has a high
d. Output results from solar cells with concave mirror reflector with Angle 60°, 90°, and 120°

The radiation received by solar cells at this angle is not too far away from the temperature of the area which is not too different from each measurement data. An angle of 90° has experienced a change in current and voltage that is quite good than the others but the measurement with an angle of 120° has a high temperature compared to the others.

| Table 4. The amount of solar cell output with a convex mirror at an angle of 60°, 90°, and 120° |
|---|---|---|---|---|---|---|---|
| Angle (°) | Hour (WIB) | Light Intensity (Lux) | Input Radiation (W/m²) | Temperature (°C) | Open Circuit Voltage / Voc (V) | Short Circuit Flow / Isc (A) | Output Power / Pout (W) |
| 60 | 10:42:20 | 191400 | 1512.06 | 37.8 | 20.01 | 0.612 | 12.246 |
| 11:07:38 | 185300 | 1463.87 | 38.6 | 20.28 | 0.642 | 13.019 |
| 11:46:34 | 175600 | 1387.24 | 36.1 | 20.00 | 0.896 | 17.920 |
| 90 | 12:11:12 | 190500 | 1527.07 | 38.1 | 20.11 | 0.921 | 18.521 |
| 12:27:52 | 191300 | 1534.97 | 39.4 | 20.23 | 0.910 | 19.142 |
| 13:18:07 | 184300 | 1478.88 | 39.5 | 20.24 | 0.928 | 18.689 |
| 13:32:14 | 182000 | 1495.47 | 39.2 | 20.13 | 0.894 | 17.978 |
| 13:58:18 | 189300 | 1553.93 | 37.8 | 19.93 | 0.624 | 15.473 |
| 11:03:13 | 196700 | 1568.94 | 36.1 | 20.13 | 0.751 | 15.297 |
| 11:48:22 | 187800 | 1411.73 | 36.6 | 19.91 | 1.227 | 24.838 |
| 120 | 12:13:04 | 180200 | 1519.79 | 37.4 | 20.18 | 0.809 | 18.489 |
| 12:29:48 | 189100 | 1527.07 | 38.4 | 20.11 | 0.950 | 19.127 |
| 13:21:18 | 192200 | 1518.38 | 39.4 | 20.78 | 0.940 | 21.407 |
| 13:36:17 | 192300 | 1519.17 | 39.1 | 20.11 | 0.894 | 17.978 |
| 13:56:32 | 192300 | 1574.47 | 38.7 | 20.01 | 0.958 | 19.169 |

| Table 5. The amount of solar cell output with a convex mirror at an angle of 60°, 90°, and 120° |
|---|---|---|---|---|---|---|---|
| Angle (°) | Hour (WIB) | Light Intensity (Lux) | Input Radiation (W/m²) | Temperature (°C) | Open Circuit Voltage / Voc (V) | Short Circuit Flow / Isc (A) | Output Power / Pout (W) |
| 60 | 10:47:04 | 200200 | 1565.78 | 39.3 | 19.78 | 0.701 | 13.865 |
| 11:26:59 | 190500 | 1504.16 | 37.1 | 20.37 | 0.751 | 15.297 |
| 11:50:35 | 192500 | 1520.75 | 38.9 | 20.33 | 1.053 | 21.407 |
| 90 | 12:15:40 | 190100 | 1501.79 | 39.9 | 20.39 | 0.682 | 13.905 |
| 12:30:53 | 190400 | 1504.16 | 40.2 | 20.12 | 0.744 | 14.969 |
| 13:22:42 | 198900 | 1571.31 | 38.5 | 20.39 | 0.839 | 17.107 |
| 13:39:30 | 193800 | 1531.02 | 39.0 | 20.45 | 0.899 | 18.384 |
| 13:52:33 | 194400 | 1535.76 | 38.2 | 20.39 | 0.922 | 18.799 |
| 10:48:39 | 191600 | 1513.64 | 40.2 | 20.25 | 0.706 | 14.296 |
| 11:28:51 | 198500 | 1568.15 | 38.4 | 20.33 | 0.997 | 20.269 |
| 11:54:41 | 198700 | 1569.73 | 40.2 | 20.85 | 1.180 | 24.603 |
| 120 | 12:16:50 | 192800 | 1523.12 | 40.2 | 21.02 | 1.020 | 21.440 |
| 12:32:40 | 180200 | 1494.68 | 38.5 | 20.43 | 0.944 | 19.285 |
| 13:23:58 | 192000 | 1516.8 | 39.9 | 20.44 | 0.987 | 20.174 |
| 13:40:41 | 192200 | 1518.38 | 39.2 | 20.67 | 0.973 | 20.111 |
| 13:49:27 | 192000 | 1516.8 | 39.5 | 20.44 | 0.911 | 18.620 |

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3.3. Research Discussion

3.3.1. Analysis of solar cell output on addition of reflector

From the data obtained during the measurement, the amount of radiation received by the Solar cell will affect the output current and voltage generated by solar cells. The greater the radiation intensity received by the solar cell then the resulting voltage and current are also weakened. Generally the voltage drop is smaller than the current. Testing has been done that the uses of concave mirror reflectors get the best input radiation rays. This can be shown in the picture below.

![Figure 6. Relation of output power to radiation input](image)

With the addition of Reflector, a solar cell will get the maximum output. In the data obtained the addition of mirror reflector concave with a 90° inclination angle to get the maximum output of such as Current, Voltage, Output Power and Efficiency.

3.3.2. Analysis of the influence of reflector on the temperature of solar cells

Temperature of solar cells also affects the performance of the solar cell. The voltage and current of the Solar cells are affected by the temperature. The greater the temperature received the voltage slightly reduced and inversely proportional to the electric current. Temperatures value of the solar cell is influenced by the radiation received by the solar cell itself. So the greater the radiation received is the greater the temperature of a solar cell. Here is a picture of the effect of radiation on temperature.

![Figure 7. Tendency of solar cell temperature to radiation](image)
4. CONCLUSIONS

The data obtained in the form of solar radiation and temperature received by solar cells depends on the condition of data collection where each time is different. The greater the radiation received by solar cells is the effect on the large temperature solar cells so that will get different outputs. The most widely accepted experiment of radiation is on a concave mirror reflector. For the solar cell output, the maximum average maximum voltage produced is 20.553 V and the average of the maximum electric current generated is 0.964 A which is produced by the addition of a concave mirror reflector with inclination angle is 90°. The maximum voltage generated by the solar cell is 21.02 V which is produced by the addition of a concave mirror reflector with a 90° inclination angle and for the maximum electric current generated is 1.180 A ie by the addition of a concave mirror also with an angle of 90°. Solar Cells that have been tested can produce maximum output when added reflector with angle is 90°

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