The Effect of Copper-Aluminium Perforated Heat Sink to Improve Solar Cell Performance

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Abstract. Fossil-based energy is diminishing due to the increasing global energy demand. The sun as a renewable energy source can be converted into electrical energy using solar cells. The performance of solar cells is influenced by the operational temperature produced. This article discusses the use of copper heat sink with aluminum fins as passive cooling to reduce operating temperatures to improve the performance of solar cells. The performance of solar cells using a heat sink with a copper base variation of 5 and 10 aluminium fins compared to solar cells without cooling. The results show that at the same intensity of 1100 W/m², the solar cell without cooling gets an operating temperature of 64.6 °C, an efficiency of 9.50% and an output power of 36.63 W. Solar cells with a 5-fin heat sink, can reduce the operating temperature is 57.7 °C, an efficiency of 11.42% and an output power of 44.02 W. Whereas the cooling panel with 10 fins obtains a temperature of 55.6 °C, maximum efficiency and power are 12.03% and 46.37 W respectively. The addition of 10-fin heat sinks to solar cells produces the best performance which can reduce operating temperatures by 9 °C, increasing efficiency and output power are 2.53% and 9.74 W respectively compared to solar cells without cooling.

Keywords: Solar Cells; Copper-Aluminium Heat sink; Fins Number;

1. Introduction

Energy is a necessity for human life. Energy supply has so far been very dependent on fossil-based energy. The energy consists of coal, oil, and natural gas which will progressively run out if used continuously [1]. This can cause a crisis for energy needs in the future. Therefore, it needs efforts to overcome this problem by using renewable energy.

Renewable energy is a source of energy that is produced naturally and sustainably without requiring a long time. The energy sources come from geothermal, water, wind, biomass, and solar energy. Solar energy has a very abundant amount, one of which is in Indonesia. Indonesia has a tropical climate since its location on the equator, causing a very large amount of sunlight. Indonesia produces an average daily solar radiation intensity of around 4.8 kWh/m² [2].

Many researchers began to use this energy to be converted into other forms of energy. Solar energy can be converted into electrical energy by using solar collectors. Solar cells work through the photovoltaic process by utilizing photons in sunlight to flow electrons in semiconductor materials. The flow of electrons will be converted into electric current [3].
Silicon solar cells are the oldest and most commonly used type of technology in everyday life. This solar cell produces the highest level of efficiency compared to other types of solar cells. The efficiency of solar cells can also decrease when operational temperatures rise at a constant intensity of sunlight. The amount of solar irradiation that can be converted into electrical energy by solar cells ranges from 15% to 20%, the rest will turn into heat. This heat can increase the operating temperature of solar cells [4].

At the intensity of solar radiation 1000 W/m², the operating temperature of solar cells can reach 58 °C to 88 °C. Every 1 °C rise in temperature can reduce output power by 0.65% and efficiency by 0.08% [5,6]. High operational temperatures can also cause damage to solar cells until they burn. Therefore, it needs efforts to reduce operating temperatures to optimize the performance of solar cells [7]. Decreasing the operating temperature of solar cells can be done by active or passive cooling methods [4,8].

Passive cooling is chosen because it works without outside power. This cooling utilizes natural convection to transfer heat from solar cells to the environment. Some passive cooling methods that are often used are: adding Phase Change Material (PCM), cooling solar cells with floating systems, and adding heat sinks to solar cells [6]. The use of heat sinks has the advantages of ease in manufacturing, installation, and flexibility in the placement of solar cells. Gotmare (2015) experimented by adding a heat sink to the lower surface of the solar cell. The results of the Gotmare experiment (2015) were able to reduce the working temperature up to 4.2% and increase the output power up to 5.5% [9].

Heat sinks are usually made of copper and aluminum because they have excellent thermal conductivity values [10]. Choosing copper as the material for base plates of heat sinks is quite proper because the thermal conductivity of copper has a higher value than aluminum [11]. Riupassa (2019) conducted heat transfer analysis on material variations. The results revealed that the conduction heat transfer of copper is faster than aluminum [12]. To speed up heat transfer, heat sinks are created by adding hollow fin geometry. Fins that have been given several holes aim to flow wind through the fins to release heat into the environment [13].

Chen (2015) cooled solar cells using heat sinks with and without fins. The experimental results showed that the addition of fins can increase efficiency by 0.17-0.19% and output power by 45-55 W [14]. The heat transfer by convection on the heat sink fin is influenced by several parameters such as the area of the system (A), fluid velocity (v), density (g), viscosity (h), and specific heat (Cp) produced. The thermal conductivity of material has little effect on heat transfer by convection. Aluminum has a conductor and lightweight properties so it is suitable for use in heat sink fin applications [15].

Besides add a few holes to the fins, the number of fins on the heat sink affects the performance in transferring heat because it can expand the area of the heat sink. Therefore, in this study using the passive cooling method of solar cells by adding heat sinks with a copper base that is given variations of the number of aluminum-perforated fins. This passive cooling method using a heat sink increase the rate of heat transfer and the efficiency of solar cell modules effectively and efficiently.

2. Methods

This research is conducted to determine the effect of the number of aluminum-perforated fins on the heat sink with a copper base to enhance the performance of solar cells. Variation of experiments is carried out by comparing the performance of solar cells without cooling, heat sink amounted to 5 fins and heat sink amounted to 10 fins. Polycrystalline solar cells have dimensions of 655 x 670 x 25 mm with a maximum power of 50 Wp.

The experiment took place in the rooftop of building 6 of the Faculty of Engineering, Universitas Sebelas Maret (Latitude -7.56234 ° S, Longitude 110.8538 ° E), Surakarta, Indonesia in April. The experiment began at 07.30 until 16.00 GMT+7. Figure 1. shows the schematic of the series of experiments.
Current and voltage produced by solar cells are measured using the Heles UX838-TR Multimeter. Also, the researchers add a variable resistor to adjust the size of the electrical resistance. This resistor variable has 17 resistance, where the resistance value is 0; 2.5; 3.5; 4.7; 5.4; 5.8; 6; 6.4; 6.6; 6.9; 7.4; 8.5; 13.8; 19.6; 42.5; 111 and 330 ohms. I-V curves are obtained from the use of variable resistors in the experimental circuit. The measurement of the intensity of solar radiation uses the Lutron SPM-1116SD Solar Power Meter. The framework for laying solar cells is closed on several sides, so the effects of changing winds can be ignored. The flow of wind is regulated only through one side perpendicular to the fins on the heat sink. The research area wind speed is set to be constant at 1.5 m/s. Temperature is measured using a K-type thermocouple that will be read by the reader.

The heat sink in this study has a thickness of 2 mm with a base made of copper. The bottom of the heat sink are fins arranged in parallel from aluminum with a thickness of 3 mm. Figure 2 shows the dimensions and heat sink geometry. This study uses a heat sink with a variation in the number of perforated fins shown in Figure 2. The heat sink is affixed to the bottom of the solar cell by coating the thermal grease on the contacting parts.

Figure 1. The schematic of a series of experiments.
3. Results and Discussion

The experiment is carried out with a variety of solar cells with no cooler, solar cells with 5-fin heat sinks, and solar cells with 10-fin heat sinks. Quantitative data collection methods produce current values (I), voltage (V), and temperature (T). Furthermore, the data is processed to produce parameters of open-circuit voltage (Voc), short-circuit current (Isc), maximum power (PMPP), and efficiency (η).

3.1. Operational Temperature of Solar Cell

The increase in operating temperature affects the performance of solar cells [4,5,16]. The increase in operating temperature was due to increased radiation intensity received by solar cells [9]. The addition of a heat sink can reduce the operational temperature of solar cells due to the process of heat transfer from the heat sink to the environment.

Figure 2. Dimensions and geometry a) 10-fin heat sink and b) 5-fin heat sink and c) perforated fins
Figure 3. The effect of intensity on temperature

Figure 3 shows an increase in the intensity of solar radiation causing the operating temperature of solar cell also increase. At the intensity of solar radiation at 1100 W/m², the operating temperature shows the highest value in each variation of the experiment. In the solar cell experiment without cooling, solar cell with 5-fin heat sinks and solar cell with 10-fin heat sinks obtained maximum temperatures of 64.6 °C, 57.7 °C, and 55.6 °C respectively. The addition of 5 fin heat sinks on solar cells can reduce operating temperatures 6.9 °C lower than solar cells without cooling. Whereas solar cells with 10-fin heat sinks can reduce operating temperatures 9 °C lower than without cooling.

Rahman’s experiment also stated that the increase in the temperature of solar cell was due to the large intensity of the solar radiation captured [5]. The higher the increase in the intensity of solar radiation, the more photons will be captured. Photon energy consisting of visible light, ultraviolet light, and infrared light will excite the electrons in the solar cell to produce electrical energy. If the photon energy absorbed exceeds the bandgap energy limit (1.11 eV), the operational temperature of the solar cell rises [17].

3.2. Short Circuit Current (Isc)
Short circuit current (Isc) is the maximum current condition obtained when the resistance value in the circuit approaches zero. The increase in the intensity of solar radiation affects the value of Isc [6].
Figure 4. The effect of intensity on Isc

Figure 4 shows the Isc increases due to the greater intensity of the received solar radiation. At a maximum radiation intensity of 1100 W/m², the Isc value obtained by the solar cell without cooling is 2.81 A. Whereas the solar cell with 5-fin and 10-fin heat sinks yields the Isc value of 3 A and 3.12 A. The value of Isc will increase with the increasing intensity of solar radiation. The magnitude of the intensity of solar radiation affects the energy of photons captured by solar cell. The more electrons that are excited by photon energy, the greater the electric current produced [18].

3.3. Open Circuit Voltage (Voc)

Open circuit voltage (Voc) is the maximum voltage condition obtained when the resistance value is high so that no current flows in the circuit. Voc value is influenced by the magnitude of the intensity of solar radiation and temperature on solar cell [5].

Figure 5. The effect of intensity on Voc

Figure 5 shows a decrease in the value of Voc due to the increased intensity of solar radiation in each variation of the experiment. At a maximum radiation intensity of 1100 W/m², the lowest Voc
value is produced on a solar cell without cooling that is 19.2 V. Panels with a 5-fin heat sink obtain a Voc value of 19.5 V. While the highest value is produced by panels with a 10-fin heat sink of 19.6 V.

Voc value will decrease along with the increasing intensity of solar radiation. The increase in the intensity of solar radiation causes the temperature of the solar cell to rise, thus creating a reverse saturation current (Irs) effect [17]. The effect of reverse saturation current is very much influenced by the temperature of the solar cell. The greater the effect of reverse saturation current causes the value of Voc decreases [19].

3.4. Maximum Power (PMPP)

Maximum power (PMPP) is the product of the maximum current and voltage multiplication. Maximum power is affected by the intensity of solar radiation received by the solar cell.

![Figure 6. The effect of intensity on maximum power](image)

Figure 6 shows the effect of the intensity of solar radiation on the maximum power of solar cell. In each variation of the experiment, the output power increases with increasing intensity of solar radiation. The addition of 10-fin heat sinks on solar cells produces the greatest output power compared to other variations. The highest value of the output power is obtained when the intensity of solar radiation reaches 1100 W/m². The output power of the solar cell without cooling is 36.63 W. While the solar cell with the heat sink of 5 fins and 10 fins produces an output power of 44.02 W and 46.37 W. The use of the heat sink of 5 fins and 10 fins on the panel solar power can increase the output power by 7.39 W and 9.74 W is greater than without cooling.

3.5. I-V and P-V Curves

The purpose of this experiment is to produce I-V and P-V curves in solar cells. Figure 7 shows the relationship of solar cell performance parameters at an intensity of 1100 W/m². The temperature of the solar cell without cooling, 5 fins heat sink, and 10 fins heat sink were 64.6 °C, 57.7 °C, and 55.6 °C, respectively. The lower the temperature, the value of the voltage, and the current generated is increasing. Besides, the lower the temperature, the maximum power value (PMPP) produced will increase.
3.6. Efficiency ($\eta$)

Efficiency is the ratio between the maximum power (PMPP) to the power of solar radiation (Plight) received by solar cells. The plight is obtained from the multiplication of sunlight intensity (IRAD) with the area of the solar cell (A). Equation 1 is used to find the value of solar cell efficiency.

$$\eta = \frac{P_{MPP}}{I_{light}} = \frac{P_{MPP}}{I_{rad} \times A} = \frac{I_{SC} \times V_{OC} \times FF}{I_{rad} \times A}$$

Figure 8 shows the effect of temperature on efficiency. Each variation of the experiment results in different levels of efficiency. The increased operating temperature can result in decreased solar cell efficiency. At an intensity of 1100 W/m², panels with of 10-fin heat sinks provide the highest level of efficiency compared to other variations of 1.203% when the temperature is 55.6 °C. Panels with 5-fin heat sinks provide efficiency of 11.42% when the temperature is 57.7 °C. Whereas the solar cell without cooling produces the lowest efficiency which is 9.50% when the temperature is 64.6 °C. The use of 10-fin and 5-fin heat sinks can improve the efficiency value respectively 2.53% and 1.92% higher than solar cells without cooling. Table 1 shows the parameters for the results of all experiment variations.
Table 1. The Performance of Solar Cell at 1100 W/m²

| Variation                | $V_{oc}$ (V) | $I_{sc}$ (A) | Power (W) | FF (%) | $T$ (°C) | $\eta$ (%) |
|--------------------------|--------------|--------------|-----------|--------|---------|------------|
| Without Cooling          | 19.2         | 2.81         | 36.63     | 0.68   | 64.6    | 9.50       |
| Heat sink with 5 fins    | 19.5         | 3.00         | 44.02     | 0.76   | 57.7    | 11.42      |
| Heat sink with 10 fins   | 19.6         | 3.12         | 46.37     | 0.76   | 55.6    | 12.03      |

The addition of heat sinks with perforated fins on solar panels aims to expand the heat sink area so as to increase the heat transfer process. The effect of giving fins causes power output to increase and temperature to decrease [4]. Therefore, increasing the number and distance of fins used will increase efficiency and decrease the temperature of solar cells.

4. Conclusion

The conclusion drawn from this study is that the use of heat sinks with 5 fins can reduce operating temperatures around 6.9 °C, increase the output power by 7.39 W and increase the efficiency of 1.92% of solar cells without cooling. Whereas the heat sink with 10 fins can reduce the operating temperature by 9 °C, increase the output power by 9.74 W and increase the efficiency by 2.53% of solar cells without cooling.

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