Analysis of TiO$_2$/Water-based Photovoltaic Thermal (PV/T) Collector to Improve Solar Cell Performance

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Abstract. Indonesia is a country with a tropical climate, so it gets a large amount of solar energy. Along with technological developments, solar energy can be converted into electrical energy by using a device called a PV panel. From several research that have been carried out, it was concluded that with an increase in every 1 °C the working temperature of the PV panels will reduce efficiency by 0.5%. This article will discuss the effect of using TiO$_2$/water nanofluid with a concentration of 0.5 vol.% on a collector photovoltaic thermal (PV/T) system for PV panel cooling. The results obtained at the radiation intensity of 1100 W/m$^2$, the use of a TiO$_2$/water-based PV/T collector system can reduce the working temperature of solar panels by 11.4 °C. It also increased output power by 10.38 W and efficiency by 2.69% compared to PV panels without cooling.

Keywords: Solar cell, PV/T system, TiO$_2$/water nanofluid

1. Introduction

Energy is the main source of life in the world. The more time is developing, the greater the source of energy needed. Renewable energy is needed at this time given the growing energy needs. In order to fulfill the increasing energy needs, solar energy can be the right solution because it is a source of renewable energy. Indonesia is one of the countries that receives a large amount of sunlight because it has a tropical climate and locate on the equator. Radiant rays and heat from the sun are the main components of solar energy that can be used as a source of renewable energy. One source of energy that can be produced from solar energy conversion is electricity. Solar energy can be converted into electrical energy by using solar cells through the photovoltaic process. The photovoltaic process is the process of the flow of electrons from solar cell semiconductor material. Photon energy contained in sunlight with certain wavelengths will excite electrons [1]. PV panel will change the flow of electrons that occur into electrical energy.

At this time, many countries around the world are using photovoltaic panels as a source of renewable electricity energy. PV panels can work on the conditions of diffusion of solar radiation. The performance of the PV panel is influences on the electrical efficiency produced. Some of the heat energy absorbed by the PV panels is not used which causing the efficiency of solar cells to be low. Excessive heat energy can significantly increase the working temperature of a PV panel. Solar irradiation that can be converted into electrical energy is only 15-20%, and the others will be wasted as heat energy. At the increase of every 1°C the working temperature of the solar panel, will reduce the efficiency of the PV panel by 0.4-0.65%. [2]
The first generation of solar cells that have been developed are silicon solar cells. There are two types of silicon solar cells, that is monocrystalline and polycrystalline. Silicon solar cells are a type of solar cell with high efficiency. The efficiency of solar cells can also decrease due to the open circuit voltage and load parameters to decrease due to temperature rise. The efficiency and heat transfer of a photovoltaic will decrease when the panel heats up. By cooling the photovoltaic module, it will increase the efficiency of solar panels [3].

Solar energy is a major factor in the development of renewable energy, but the energy conversion efficiency of photovoltaic (PV) panels is too low. Most of the sun's energy is transferred to waste heat. This waste heat can cause panel temperatures to rise, and high temperatures reduce panel efficiency, with efficiencies decreasing by about 0.5% for each 1 °C temperature rise [4]. To overcome this problem, it is necessary to have a PV panel cooling process. There are several types of PV panel cooling processes, one of which is the collector thermal photovoltaic (PV/T) system. This method uses the principle of forced heat transfer from the flow of working fluid in a pipe attached to the bottom of the PV panel.[3]

Several research on the PV/T collector system have been conducted. Working fluids commonly used are air and water. Water coolers have better cooling capabilities than air-cooled ones [5]. From previous studies the results obtained in the air-based photovoltaic thermal (PV/T) collector have a maximum electrical efficiency of 12.6% [6]. Whereas the water-based photovoltaic thermal (PV/T) collector has a maximum electrical efficiency of 15% [7].

In several recent research, a photovoltaic thermal (PV/T) collector method has been developed using nanofluid working fluids. Nanofluid is a suspension of solid particles with characteristic sizes of less than 100 nm which are dispersed in a liquid base [8]. Theoretically, nanofluids can increase the thermal properties of basic fluids. On TiO$_2$/water nanofluid with a concentration of 1% can increase the convective heat transfer coefficient by 14% [9].

2. Methods

In this research a PV panel was cooled using a photovoltaic thermal (PV/T) collector system using a TiO$_2$/water nanofluid working fluid. The working fluid is flowed through a pipe with a rectangular cross section attached to the bottom of the PV panel. The use of TiO$_2$/water nanofluid working fluids can increase the heat absorption ability of PV panels. It also can increase the electrical efficiency of PV panels compared to PV/T collector systems with pure water working fluids and PV panels without cooling.

| Table 1. Properties of working fluid |
|-------------------------------------|
| Water                              |
| $\rho$ (kg/m$^3$) | $C_p$ (kJ/kg.K) | $K$ (W/m.K) |
| 1000                               | 4.18            | 0.614        |
| TiO$_2$/water nanofluid            |
| 1006.5                             | 4.15            | 0.626        |

This study aims to determine the effect of the use of TiO$_2$/water-based photovoltaic thermal (PV/T) collector in an effort to reduce work temperature and increase the performance of photovoltaic solar panels. The experiment was conducted by comparing the performance of photovoltaic solar panels without cooling, with a PV/T collector system for pure working fluid, and PV/T collector for working fluid TiO$_2$/water nanofluid concentrations 0.5%. The PV panel used has dimensions of 655 x 670 x 25 mm with a maximum power of 50 Wp. Full specifications of solar panels are shown in the following table.
Table 2. Len 50 Wp solar module specifications

| Specifications                     | Value                           |
|-----------------------------------|---------------------------------|
| Solar cell                        | Polycrystalline 62.4 x 156 mm   |
| Open-circuit voltage (VOC)        | 21.2 V                          |
| Short-circuit current (ISC)       | 3.35 A                          |
| Maximum power (PMPP)              | 50 Wp                           |
| Efficiency                        | 14%                             |
| Operating module temperature      | -40 °C until 85 °C              |
| Dimension                         | 655 x 670 x 25 mm               |
| Temperature coefficient of power  | -0.44% per °C                   |

The pipe used in this system has a direct-flow configuration and has a rectangular section with a size of 3 x 1.5 mm and a thickness of 1 mm. The material of this pipe uses stainless steel which has strong characteristics, weldability, and good thermal conductivity. Selected pipes with rectangular sections with the aim of increasing the area of surface contact. The design of the pipe can be seen in Figure 2.
The research scheme can be seen in Figure 3. The magnitude of the current and voltage is measured using an ammeter and a voltmeter. Then also add a variable resistor to adjust the amount of electrical resistance. This variable resistor has 17 resistance values that have been adapted to solar panel specifications. The purpose of this variable resistor is to produce an I-V curve in each data collection. Measurement of solar radiation intensity shook the Lutron SPM-1116SD Solar Power Meter. Working fluid is flowed using a DC pump with 5 l/min flow rate. Temperature measurement using K-type thermocouple.

Figure 3. Schematic of a series of experiments

This research was conducted at Rooftop Building 6 Faculty of Engineering, Sebelas Maret University (Latitude -7.56234 °S, Longitude 110.8538 °E), Surakarta, Central Java, Indonesia. The study was conducted in April 2020. Data collection began at 07:30 until 16:00 GMT+7.

3. Data and analysis
Data analysis was carried out based on the variation of the cooling system with the photovoltaic thermal (PV/T) collector used in this study. The data collection method uses quantitative methods. Quantitative data obtained in this study are temperature (T), short circuit current (Isc), open circuit voltage (Voc), maximum power (PMPP), and efficiency (η).

3.1. Temperature
When a solar panel works continuously, the temperature will increase and affect the performance of the solar panel [2,4]. By providing cooling using the PV/T collector system, it can reduce the working temperature of photovoltaic solar panels.
Figure 4. The relationship between radiation intensity and temperature

Figure 4 shows the effect of radiation intensity on the PV panel temperature. On the graph it can be seen that with increasing radiation intensity, temperature will also increase in each variation of this experiment. From each variation, the maximum temperature in the solar panel occurs when the radiation intensity is 1100 W/m². The maximum temperature obtained on ground panels, panels with a water-based PV/T system, and TiO₂/water-based PV/T systems are respectively 65.2 °C, 56.5 °C, and 53.8 °C. Solar panels with cooling systems have an average temperature of 8.7 °C to 11.4 °C lower than solar panels without a cooling system.

The results of previous research conducted by Rahman showed that increasing the intensity of solar radiation will increase the temperature of the solar panels [4]. This is because the greater the intensity of solar radiation received, the greater the photon energy received by the solar panel. The effect of the magnitude of the photon energy causes the electron excitation process to increase so that the temperature of the solar panel will also increase [10].

The use of a PV/T collector cooling system has an influence on the heat transfer process in solar panels. Working fluid flowing in the pipe will carry heat from solar panels with the principle of forced convection. The use of TiO₂/water nanofluid as a working fluid has a better performance in lowering the temperature of solar panels. This is because TiO₂/water nanofluid has a better convective heat transfer coefficient compared to pure water [9].

TiO₂ nanoparticles dispersed in pure water will have an effect on increasing the value of density, specific heat, and thermal conductivity [11]. All of these parameters will increase the convective heat transfer coefficient of the working fluid which can have an effect on the temperature drop and the improved performance of the solar panel.

3.2. Short circuit current

Short circuit current (Isc) is a condition when the resistance value on the panel is 0, so that the maximum current occurs. The amount of intensity of solar radiation received will affect the value of the short circuit current (Isc) [4].
Figure 5. The relation between radiation intensity and Isc

Figure 5 shows that with the increase in the intensity of solar radiation, Isc will increase. The maximum Isc value occurs at 1100 W/m² solar intensity in all variations of the experiment. Maximum Isc values obtained on ground panels, panels with a water-based PV/T system, and TiO₂/water-based PV/T systems are 2.51 A, 2.75 A, and 3.1A, respectively.

The increase in the intensity of solar radiation causes an increase in the value of Isc because the greater intensity of the sun causes the photon energy received by the solar panel to increase. The process of electron excitation is greatly influenced by photon energy. The greater the photon energy received, the greater the process of electron excitation that occurs. When the photon received has an energy level above the energy bandgap (1.11 eV), the electron will be excited. The more electrons are excited, the greater the electric current produced [12].

3.3. Open circuit voltage

Open circuit voltage (Voc) is the maximum voltage capacity that is obtained when there is no current flowing in the open circuit. Voc is influenced by the intensity of solar radiation that received and the temperature of the solar panel. When the solar intensity and the temperature of the solar panels increase, the open circuit voltage will decrease [13].

Figure 6. The relation between radiation intensity and Voc
Figure 6 shows the effect of sun intensity on open circuit voltage (Voc). At the maximum radiation intensity 1100 W/m², the value of Voc obtained on ground panels, panels with a water-based PV/T system, and TiO₂/water-based PV/T systems is 19.2 V, 19.5 V, and 19.7 V respectively.

3.4. Maximum power

Maximum power (PMPP) is the amount of energy per unit of time. Maximum power is obtained from the I-V curve. The I-V curve for maximum power is obtained from the maximum multiplication between current and voltage in the circuit, as in Equation 1. To obtain the I-V curve, a variable resistor is needed to obtain the data. I-V curve can be seen in Figure 7.

\[ P_{MPP} = I_{MPP} \times V_{MPP} \]  

Figure 7. I-V curve at 1100 W/m² in each variation

Figure 8. The relation between intensity and maximum power
Figure 7 shows the results of the I-V curve obtained at 1100 W/m$^2$ intensity in each variation. Data is collected by using a variable resistor as a load. The resistor circuit is adjusted to the solar panel specifications so that I can form an I-V graph according to the specifications as a load. Figure 8 shows the effect of the sun’s intensity on maximum power. Any increase in radiation intensity will cause an increase in maximum power. The largest PMPP value for each variation was obtained at an intensity of 1100 W/m$^2$. At this intensity, the maximum power value (PMPP) increases from 36.12 W to 46.5 W when the working temperature of the PV panel decreases from 65.2 °C to 53.8 °C. Cooling with a water-based PV/T collector system and TiO$_2$/water-based PV/T collector increases the average PMPP value of 7.38 W and 10.38 W, greater than solar panels without cooling.

3.5. Efficiency

Energy efficiency ($\eta$) is the ratio between maximum power ($P_{\text{MPP}}$) and solar radiation power received by solar cells ($P_{\text{light}}$). Solar radiation power ($P_{\text{light}}$) is obtained from the multiplication of solar intensity ($I_{\text{RAD}}$) with the active solar cell area (A). Efficiency values are based on Equation 2.

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

(2)

![Graph showing efficiency vs. temperature](chart.png)

Figure 9. The relation between temperature and efficiency

Figure 9 shows the effect of increasing temperature on the efficiency of solar panels in each solar intensity value and each variation. When the sun's intensity is at a maximum point of 1100 W/m$^2$, by doing a solar panel cooling system can increase the efficiency of solar panels. In cooling with a water-based PV/T collector system and TiO$_2$/water-based PV/T collector, the efficiency values are 1.28% and 1.06%, respectively. From this value it can be seen that an increase in efficiency of 1.91% and 2.69% compared to solar panels without cooling has an efficiency value of 9.37%.

4. Conclusion

In each test, data collection has been carried out with variations of solar panels without cooling, with cooling water-based PV/T collector, and TiO$_2$/water-based PV/T collector. The conclusions obtained from this study are the use of a water-based PV/T collector cooling system, and the TiO$_2$/water-based PV/T collector can reduce the average temperature by 8.7 °C to 11.4 °C, increasing the average output power by 7.38 W and 10.38 W and increase efficiency by 1.91% and 2.69% compared to solar panels without cooling.
Acknowledgements
This work partially supported by the grant of HGR-PNBP from Rector of Sebelas Maret University with contract number 452/UN27.11/PN/2020 for FY 2020.

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