Analysis of photovoltaic with water pump cooling by using ANSYS

Z Syafiqah1, N A M Amin2, Y M Irwan3, M Z Shobry 2 and M S A Majid2

1Centre of Excellence for Renewable Energy, School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia
2School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Malaysia
3Centre for Diploma Studies, Universiti Malaysia Perlis (UniMAP), Malaysia

Abstract: Almost all regions in the world are facing with problem of increasing electricity cost from time to time. Besides, with the mankind’s anxiety about global warming, it has infused an ideology to rapidly move towards renewable energy sources since it is believed to be more reliable and safer. One example of the best alternatives to replace the fossil fuels sourced is solar energy. Photovoltaic (PV) panel is used to convert the sunlight into electricity. Unfortunately, the performance of PV panel can be affected by its operating temperature. With the increment of ambient temperature, the PV panel operating temperature also increase and will affect the performance of PV panel (in terms of power generated). With this concern, a water cooling system was installed on top of PV panel to help reduce the PV panel’s temperature. Five different water mass flow rate is tested due to investigate their impact towards the thermal performance and heat transfer rate.

1. Introduction
The overall performance of PV panel is dependent on the PV panel’s temperature. When the ambient temperature increases, the temperature of PV panel will rise, thus affecting the performance of PV panel. With the help of water cooling method, it can ensure that PV panel can operate at high efficiency. The cooling agent, which is water, is circulated on top of the PV panel to cool down the operating temperature of PV panel. Akbarzadeh et al. [1] investigated a hybrid photovoltaic-thermal (PV/T) system and it is found out that the output power increased by 50%. With the PV/T attached to it, the PV panel’s temperature can maintain at lower than 46 °C when exposed for 4 hours. Dubey et al. [2] tested a combined system of PV panel with thermal solar water heater (PV/T) in outdoor condition of New Delhi, India. The authors studied the efficiency of PV panel under three different cases, which are absorbed of fully covered, 50% covered by a PV panel and partially covered by the PV panel. They found out that the efficiency increase from 33% to 64% when the PV panel are fully covered. Meanwhile, Kluth [3] experimented a water cooling system to increase the PV panel efficiency. The surface of the PV panel was sprayed with water by using a fan. Unfortunately, it is not an efficient method because the water was not sprayed entirely over the surface. Hence, there will be some part of PV panel that not cooled and has a high water loss.

From the literature review, it can be concluded that water a cooling mechanism is more effective than air cooling. Thus, the main goal of this paper is to build a PV panel with water cooling
system due to solve the PV panel’s operating temperature problem. In this paper, the PV panel with water cooling system was studied with 5 different water mass flow rates. These different water mass flow rate was then compared in terms of thermal performance (by using ANSYS CFX) and heat transfer rate.

2. CFD modelling

The geometry of PV panel with water cooling system has been drawn by using CATIA software. The dimension of the PV panel is 120 cm x 54 cm. This dimension and thickness of PV panel were based on the actual dimension. A thin layer of water is added to the surface of PV panel, which was embraced as the water cooling system. The water layer is assumed to flow on the entire surface of PV panel. Usually PV panel consists of 5 different layers, which are glass (covering the surface), Ethylene Vinyl Acetate (EVA1 which act as encapsulation to the silicon), silicon layer (device that convert sunlight into electricity), EVA2 and tedlar (at back surface). Each layer has different thickness with different specific heat capacity, density as well as thermal conductivity as shown in Table 1.

| Materials | Thickness (m) | Specific Heat Capacity (J/kg°C) | Density (kg/m³) | Thermal conductivity (W/m°C) |
|-----------|---------------|---------------------------------|-----------------|-----------------------------|
| Water     | 0.0045        | 4180                            | 997.0           | 0.59                        |
| Glass     | 0.003         | 500                             | 3000            | 0.98                        |
| EVA1      | 0.003         | 2090                            | 960             | 0.23                        |
| Silicon   | 0.004         | 712                             | 2.329           | 148                         |
| EVA 2     | 0.003         | 2090                            | 960             | 0.23                        |
| Tedlar    | 0.0001        | 1250                            | 1200            | 0.36                        |

ANSYS CFX is one of the computational fluid dynamic (CFD) software that has been used for this simulation study. The PV panel with water cooling that has been drawn in CATIA need to be imported into ANSYS CFX software by using .igs format as shown in Figure 1. A hexahedron meshing has been applied to the geometry drawing, with the skewness near 0, which is considered as a good meshing according to Hiren [5]. The PV panel with water cooling system is consists of 6 different domains with different properties, as clarified in Table 1. The water is flowing on top of surface of PV panel, assuming that the flow is laminar and steady flow.

![Figure 1. Geometry model of PV panel layer with water cooling system](image-url)
The initial water temperature is assumed as 25 °C, while the temperature of PV panel follows the ambient temperature. The weather data, such solar irradiance (W/m²), wind speed (m/s) and ambient temperature (°C) were based on actual data that was taken at Ulu Pauh, Perlis. The data was taken from 8.00 a.m. until 7.00 p.m. The highest ambient temperature and solar irradiance that has been recorded are 36.6 °C and 1037 W/m² respectively. The simulation is repeated with 6 different mass flow rates, due to compare its thermal performance and the heat transfer rate. The thermal performance will be the temperature output obtained from ANSYS CFX simulation. While, the heat transfer rate will focused on the convection heat transfer which occurs at the backside of PV panel (tedlar layer). The convection heat transfer is described as the energy transfer between a solid surface and a fluid surrounding of that surfaces [8]. If the surface (tedlar) is at a temperature \( T_s \), and the fluid (surrounding air) has a temperature \( T_\infty \) that is lower than the surface temperature, then the equation used to describe such heat transfer is as follow:

\[
Q_{conv} = hA_s(T_s - T_\infty)
\]

This equation is known as Newton’s Law of Cooling because the surface is being cooled by the fluid. If the fluid were hot and heated a cooler surface, then equation is as follow:

\[
Q_{conv} = hA_s(T_s - T_\infty)
\]

Equation (2) is known as Newton’s Law of Heating. In a general form, Newton’s Law of Convection can be written as follow:

\[
Q_{conv} = hA_s(\Delta T)
\]

where \( \Delta T \) is the temperature difference between solid (tedlar) and the average surrounding temperature of the fluid. The area, \( A \) (m²) is the area of the tedlar and \( h \) indicates the convective heat transfer coefficient of air (W/m²·°C). The convection heat transfer coefficient is not a property of fluid. It is an experimentally determined parameter whose value depends on the variables that influence the convection, such as surface of geometry, nature of fluid motion and properties of fluid. The heat transfer coefficient can be obtained by using correlation below, where \( V \) is referred to the wind speed (m/s).

\[
h = 2.8 + 3.8V
\]

3. Results

The temperature of PV panel with a different mass flow rate is shown in Figure 2. It can be seen that, without a cooling system, the highest PV panel temperature is 70.2 °C at 1.20 p.m. But, with a 0.01 kg/s water mass flow rate being applied, the temperature can be reduced until 48.5 °C. There is almost 20 °C in temperature difference when the water mass flow rate is 0.01 kg/s and 0.05 kg/s. The PV panel temperature started to increase at 8.10 a.m. and slowly drop at 2.00 p.m., following the ambient temperature. It can be concluded that with increasing water mass flow rate, it helps to lower the PV panel’s operating temperature.
Figure 2. Temperature of PV panel with 5 different mass flow rate of water.

Meanwhile, Table 2 shows the differences in PV panel contour at a water mass flow rate of 0.01 kg/s, 0.02 kg/s, 0.03 kg/s, 0.04 kg/s and 0.05 kg/s. The PV panel contour was taken at 1.20 p.m., whereby the ambient temperature is the highest, which is 36.6 °C. PV panel surface with 0.00 kg/s (without cooling) covered with red spot the most, which indicated that it suffers from a high operating temperature. With a cooling system applied to it, the red spot slowly disappeared. The blue spot on the PV panel surface with 0.05 kg/s indicated that a lower temperature, compared with 0.01 kg/s. It is proven that, with the increase mass flow rate, it helps to reduce the PV panel’s temperature slightly.
Table 2. The differences of PV panel contour at different water mass flow rate.

| Mass flow rate (kg/s) | PV panel contour at 1.20 p.m. |
|-----------------------|------------------------------|
| 0.00                  | ![Image](image1.png)         |
| 0.01                  | ![Image](image2.png)         |
| 0.02                  | ![Image](image3.png)         |
| 0.03                  | ![Image](image4.png)         |
| 0.04                  | ![Image](image5.png)         |
| 0.05                  | ![Image](image6.png)         |

The convection heat transfer rate between tedlar and surrounding air is illustrated as in Figure 3. The heat transfer rate are varied with the increment of water mass flow rate. The heat transfer rate decreases with the increase of water mass flow rate. PV panel without cooling system recorded the highest heat transfer rate of 30 869 W. The average heat transfer rate for PV panel with 0.00 kg/s, 0.01 kg/s, 0.02 kg/s, 0.03 kg/s, 0.04 kg/s and 0.05 kg/s water mass flow rate are 18 804 W, 6 063 W, 3 236 W, 2 918 W, 2 798 W and 235 W respectively. A positive heat transfer rate indicates that the heat transfer is from a high temperature to a lower temperature, which is from surrounding air to tedlar. Meanwhile, a negative heat transfer indicates that the heat is transferred from tedlar to surrounding air,
since tedlar has the low temperature. PV panel with water mass flow rate of 0.05 kg/s reach a negative heat transfer rate at 2.35 p.m., since it is the fastest in achieving a lower temperature, compared with others. With both agreement result from thermal analysis and heat transfer rate, PV panel with 0.05 kg/s is considered as the suited mass flow rate in reducing PV panel’s temperature.

![Figure 3. Convection heat transfer rate between tedlar and surrounding air.](image)

**4. Conclusion**

As the conclusion, PV panel with water cooling system gives a difference in terms of thermal performance and heat transfer rate, compared with PV panel without cooling system. With the help of water cooling system, the PV panel’s temperature slightly drops. The impact of water mass flow rate towards thermal performance and heat transfer rate also has been discussed. When the water mass flow rate increase, the PV panel’s temperature also decreases. The convection heat transfer rate reduced greatly with the increase of water mass flow rates. PV panel with 0.05 kg/s mass flow rates eventually has the lowest average heat transfer rate of 235 W.

**5. Acknowledgement**

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