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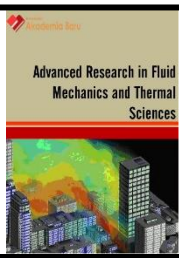

Effect of Water Cooling Temperature on Photovoltaic Panel Performance by Using Computational Fluid Dynamics (CFD)

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ABSTRACT

Photovoltaic (PV) panel is directly converted solar irradiance into electrical energy. The temperature of the PV panel increased as it absorbs solar irradiance lead to a reduction in its output power. This undesired impact can be prevented through the use of a cooling system with PV panel. In this research, a water cooling system was designed to the PV panel in order to reduce its temperature. The objective of this research is to predict the temperature distribution of the PV panels without and with water cooling system. In the water cooling system, the water flow over the front surface of the PV panel in order to reduce the temperature of the PV panel. In addition, this research also focused on the impact of inlet water temperature on the performance of water cooling effect. The result of this research shows that the average temperature distribution of the PV panel without water cooling system is higher than that with water cooling system. The average temperature of the PV panel without cooling system is 50.68 °C. For the water cooling system, the PV panel with the inlet water temperature of 20 °C can be reduced the temperature of PV panel by 15.63 °C as compared to the PV panel with inlet water temperature of 45 °C. This research could be beneficial for researchers and students to understand the effects of temperature to the PV panel.

1. Introduction

In the recent years, many researchers have focused on renewable energy. This is explained by the fact that an increasing concern of environmental pollutants produced by the combustion process of conventional energy sources (coal, natural gas and oil) [1]. In addition, conventional energy supply uncertainty led to the requirement for more dependable as well as renewable energy resources. New alternative energy sources are expected to be able to provide a sufficient number of continuing resources and have the minimum environmental impact such as reduce the carbon emissions [2-4].

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Among all the alternatives energy, solar energy offers one such a choice and illustrates all of these desirable capabilities [5-6].

In general, solar power generation can be used for two types of technology that are solar thermal and PV [7]. In solar thermal system, solar irradiance is used to heat liquids to produce steam that is used to turn a steam turbine to generate electricity. In contrast, PV technology directly converts solar irradiance into electricity. Nowadays, solar researchers and engineers have been facing various problems for each technology, especially in the PV system. This is caused by a large portion of the solar energy is converted to heat energy not converted into electricity.

In addition, the use of PV technology will face a number of challenges to local environmental and operating condition [8-9], particularly solar irradiance, high ambient temperatures, PV panel temperature and dust. It is known that PV cells are composed of silicon that is a semiconductor material. The semiconductor is sensitive to the high temperature. In the conversion process, a large amount of heat energy faced by PV cells, and it will increase the temperature of the PV panels [10]. This leads to a decrease in the electrical properties of PV panels [11]. PV cells are influenced by the temperature in an unwilling way because of the negative temperature coefficient of crystalline silicon. The negative temperature coefficient was found to be in the range of 0.3 %/°C to 0.65 %/°C according to the types and material used of the PV panel [12]. This is directed to the output power and electrical efficiency of the PV panel reduced.

Recently, there have been numerous attempts to suppress the reduction in output power and electrical efficiency of the PV panel. One of the methods is applied cooling devices to the PV panel [13-14]. These cooling devices also was used to decrease the temperature of PV panel when the PV panels faced higher solar irradiance and higher ambient temperature. This is due to ensure that the PV panel can generate higher output power as the PV panel temperature drop. Therefore, water cooling system is one such a type of cooling system to dissipate the heat away from the PV panels.

K.S. Matthew *et al.,* [15] investigated a water cooling system by using a number of ice cubes filled into the water tank to maintain the temperature of water as low as possible. Thus, water flow over the surface of the PV panels was transferred heat to the water. This result in the temperature of PV panel with water cooling system is always lower than the PV panel without water cooling system. Moreover, the electrical behavior of the PV panel can be improved 4.6 % by using water cooling system. An experimental study was carried out by Saad and Masud [16] using water cooling to enhance the electrical efficiency of the PV panel. This experiment was conducted in a long-term performance test. Based on the experimental results, the water able to transfer heat from the surface of the PV panel and improved by about 15 % of the output system for the peak sun hour. Besides that, Masayuki Fuji *et al.,* [17] suggested using water cooling device to curb the degradation in output power to the PV panel in the high temperature condition. When the temperature of cooling water is higher than 40 °C, fresh water will replace the hot water to ensure that the cooling water always in the lowest temperature. This method was enhancing the output power performance than the reference PV panel.

A research work was performed by H. Baihadarah *et al.,* [18] carried out a water pump attached to the PV panel. One unit of water pump (373 Watts) was used to pump the water flow over the surface of the PV panel from an insulated tank. According to the experimental measurement, PV panel with cooling system can be reduced 7.3 °C in temperature as compared to that without cooling system. This leads to the electrical efficiency of the PV panel with water cooling system has increased 9 %, with a reduction in temperature. Similarity, Dong-Jun Kim *et al.,* [19] applied a water-closed circulation to the PV panel to overcome the overheating issues. In the case of the cooling system, the water pump is drained water on the surface of the PV panels and hot water has flowed back into the water tank. This cycle of water flow will always continue. It can be noted that the PV panel with cooling system has increased an additional 11.6 % of the output power from the PV panel without the cooling system by reducing the temperature of the PV panel.

In the present work, a simulation analysis of the PV panel without and with water cooling system is conducted. The water cooling system was used to act as a heat exchanger and applied to a commercially available PV panel. The objective of this present paper is to investigate the thermal behavior of a PV panel integrated with a water cooling system. Therefore, three-dimensional models of the PV panels without and with water cooling system are developed by using ANSYS CFX. The thermal performances of the PV panels without and with water cooling system has been compared in this paper. Moreover, the effect of the inlet water temperature in the cooling case has also been studied detail in the next section.

2. Methodology

A model CATIA V5 software was used to build a three-dimensional geometry model of the PV panel. The dimensional of this geometry model is established according to the commercially available PV panel that is monocrystalline SNM-100P with the maximum peak power of 100 Watts. The length of this PV panel is 120 cm, the width of 54 cm and the height of the PV panel is 3 cm. This PV panel consists of six layers that are glass covering, Ethylene Vinyl Acetate (EVA) layer 1, monocrystalline silicon PV cells, EVA layer 2, Tedlar and aluminum frame as showed in Figure 1. In the case of water cooling system, a number of water nozzles were located at the upper side of the PV panel in order to spray water for cooling the PV panel as displayed in Figure 2. Moreover, Table 1 shows the material properties of each layer within PV panel geometry model.

In addition, the completed geometry model of the PV panel was then imported into the ANSYS CFX software. This software was used to study the thermal model of the PV panels with a reduction in the time taken and costs of the new-product prototype. In addition, it is possible to observe the temperature distribution through the PV panels without and with water cooling system.

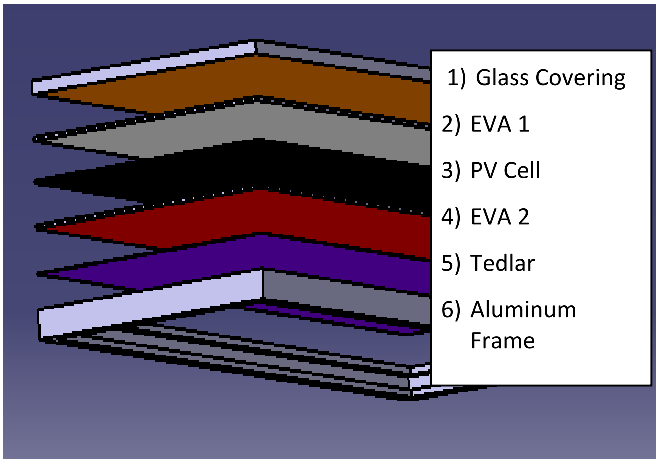

Fig. 1. Sketch of the geometry model of PV panel without cooling system

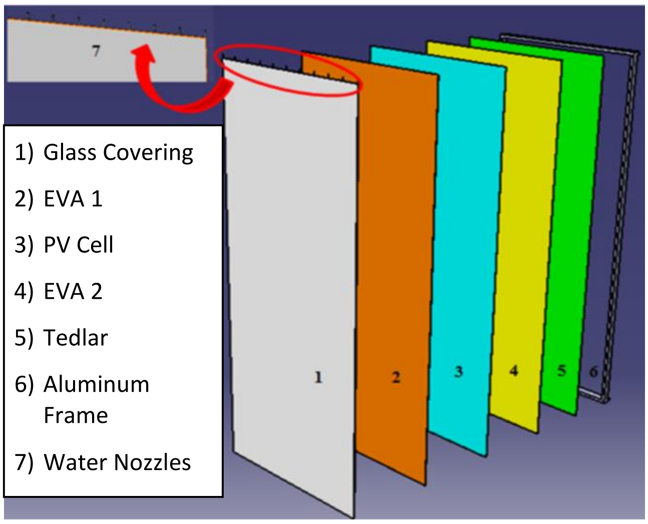

Fig. 2. Sketch of the geometry model of PV panel with water cooling system

Table 1
Material properties and sizes of each layer in PV panel [20]

No.	Material (Layer)	Thick (cm)	Thermal Conductivity (W/m°C)	Specific Heat Capacity (J/kg°C)	Density (kg/m^3)
1.	Glass Covering	0.3	1.8	500	3000
2.	EVA Layer 1 & 2	0.05	0.35	2090	960
3.	PV Cell	0.04	148	677	2330
4.	Tedlar	0.01	0.2	1250	1200
5.	Aluminum Frame	2	204	996	2707

In the simulation procedure, the first step is to define material properties of each layer within the PV panel in the Engineering Data. After that, each layer of the PV panel was named in the geometry section. ANSYS Mechanical was utilized to break the geometry model into elements that is called as the meshing process, as displayed in Figure 3. Following this, ANSYS Mechanical was also added the boundary condition to the geometry model. Besides that, convection boundary conditions were applied to the front and back surface for PV panel without water cooling system. However, the convection boundary condition just applied to the back surface of the PV panel with water cooling system. For the water cooling system, the inlet boundary condition was defined by a uniform velocity that applied on the front surface of the PV panel and the outlet boundary condition was set to zero pressure.

The developed geometry model was utilized to measure the transient thermal response of PV panel for the local environmental conditions. These environmental and operating conditions were applied to the outer layer of the geometry model that is glass covering and Tedlar. The data of environmental condition was obtained from the site location (Perlis, Malaysia) by using DAVIS Vantage Pro2 Weather Station. The day of weather condition chosen for the detail research was 14 March 2018 due to its highest solar irradiance. This selected date is appropriate for investigating the effect of cooling on PV panel performance since it has the highest average solar irradiance throughout the year. The selected time step for the transient analysis of these PV panels without and with water cooling system is set to 10 minutes. The input conditions utilized in the models were replaced by 10-minute data and then applied to the model. Simulations of these PV panel models were started at 9:00 a.m. until to 5:00 p.m.

Furthermore, the thermal behavior of the PV panel will be affected by the operating parameters of the water cooling system. Therefore, the effect on the inlet water temperature was focused to study in this present paper. The range of inlet water temperature was from 20 °C to 45 °C with an interval of 5 °C and the velocity of inlet water was fixed in 350 L/h. In the ANSYS CFX, "Probe" device used to act as a temperature sensor to measure the temperature distribution of the PV panel. Four units of temperature sensors placed at the backside of each PV panel as displayed in Figure 4. In addition, Figure 5 shows a temperature sensor was installed in the inlet and outlet of the water cooling system to measure the temperature of water in and water out, respectively.

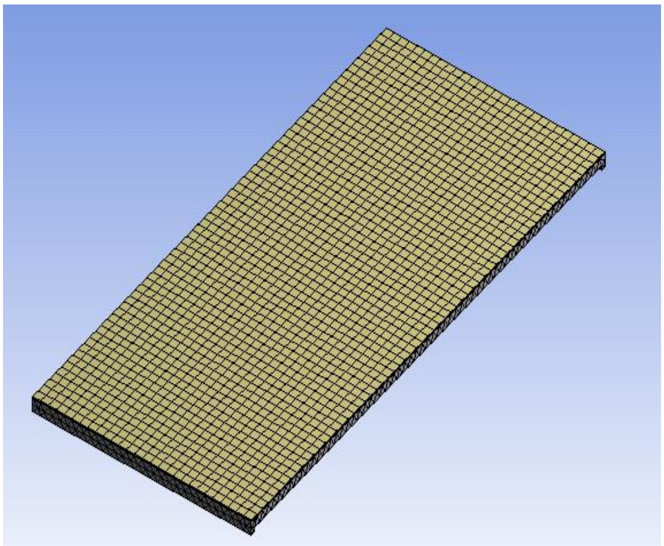

Fig. 3. PV panel was meshing using ANSYS

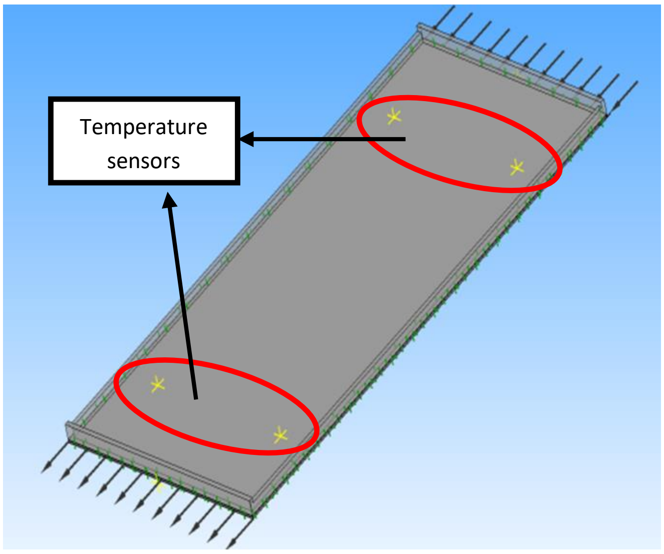

Fig. 4. Temperature sensors placed at backside of geometry model

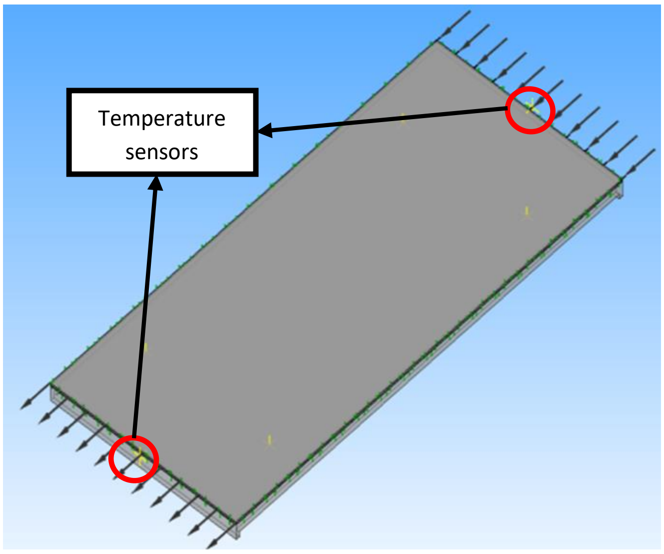

Fig. 5. Temperature sensors installed at inlet and outlet of water cooling

The maximum output power of these PV panels was calculated from the obtained operating temperatures. Therefore, the maximum output power of the PV panels was corrected by following equation [21]:

$$Pmax_{corrected} = Pmax_{stc} \times \{ 1 + \left[\left(\frac{\Upsilon}{100}\right) \times \left(T_{panel} - T_{stc}\right)\right]\} \quad (1)$$

where, $P_{max_{corrected}}$ is the corrected output power of the PV panels according to the temperature coefficient, $P_{max_{stc}}$ is the maximum output power under standard test condition (STC), Υ is the maximum output power temperature coefficient according to the manufacturer data, T_{panel} is the measured temperature of PV panel, and T_{stc} is temperature of the PV panel under STC.

3. Results

The simulation results of the PV panel without and with water cooling system are displayed and analysed in this section. Apart from this, this simulation also focused upon the effect of the inlet water temperature on the performance of the water cooling system.

The day of weather condition was highlighted at the simulation analysis is 14 March among the year 2018. This selected date is well suited for investigating the effect of water cooling on PV panel performance since it has the highest average solar irradiance throughout the year. Figure 6 shows the highest solar irradiance is 1012 W/m^2, while the lowest solar irradiance is 329 W/m^2. The average solar irradiance for this day is 724.82 W/m^2. Meanwhile, the maximum ambient temperature is 36 °C and the minimum ambient temperature on this day is 30.7 °C. The average ambient temperature for this particular day is 33.57 °C. At the same time, the maximum and minimum wind speed is 6.4 m/s and 2 m/s, respectively. The average wind speed on this day is 4.51 m/s as displayed in Figure 7.

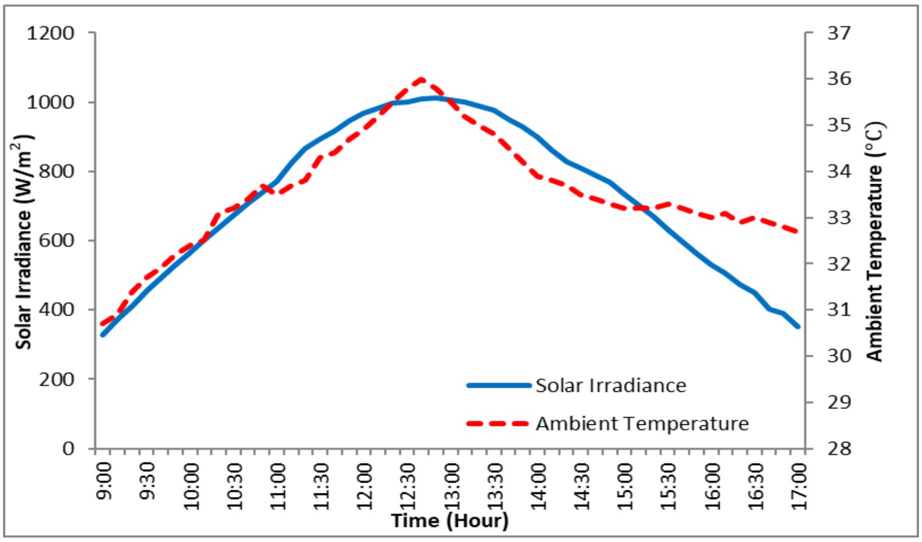

Fig. 6. Weather conditions versus time throughout 14 March 2018

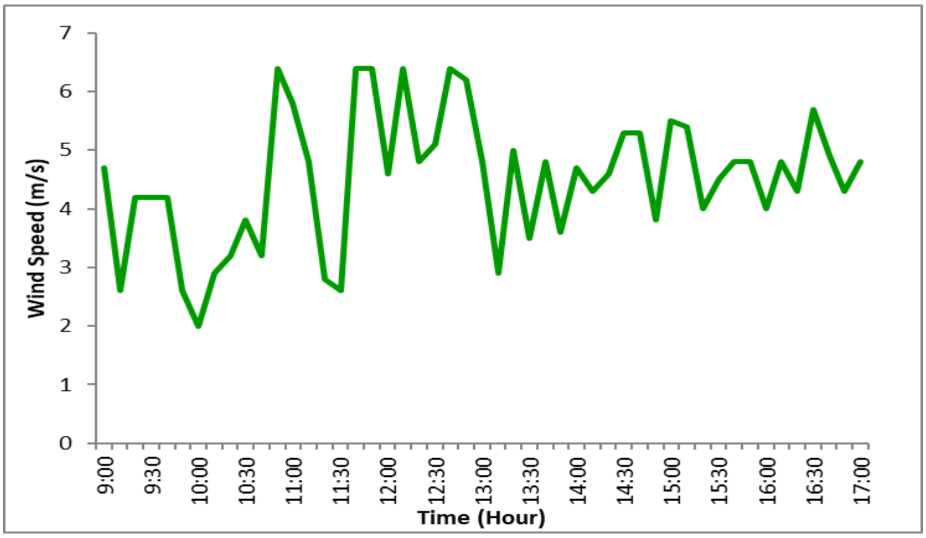

Fig. 7. Hourly wind speed

Figure 8 presents the temperature of the PV panel without cooling system during the test day. The maximum and minimum temperature of the PV panel without cooling system is 58.43 °C and 36.3 °C, respectively. Besides that, the average temperature of the PV panel without cooling system is 50.68 °C. Moreover, Figure 9 displays a contour plot of the temperature distribution of a PV panel without cooling system that captured at the highest solar irradiance. In this figure, a range of colour contour plots represented the different temperature values. The bright-red colour represents the hottest areas in the geometry model that consist of the highest temperature. In contrast, dark-blue is the coldest areas of the geometry model, and it is the lowest temperature generated by the PV panel. It can be noted that the surface of the PV panel without cooling system is most covered with bright-red colour. This implies that this PV panel is facing the hottest temperature.

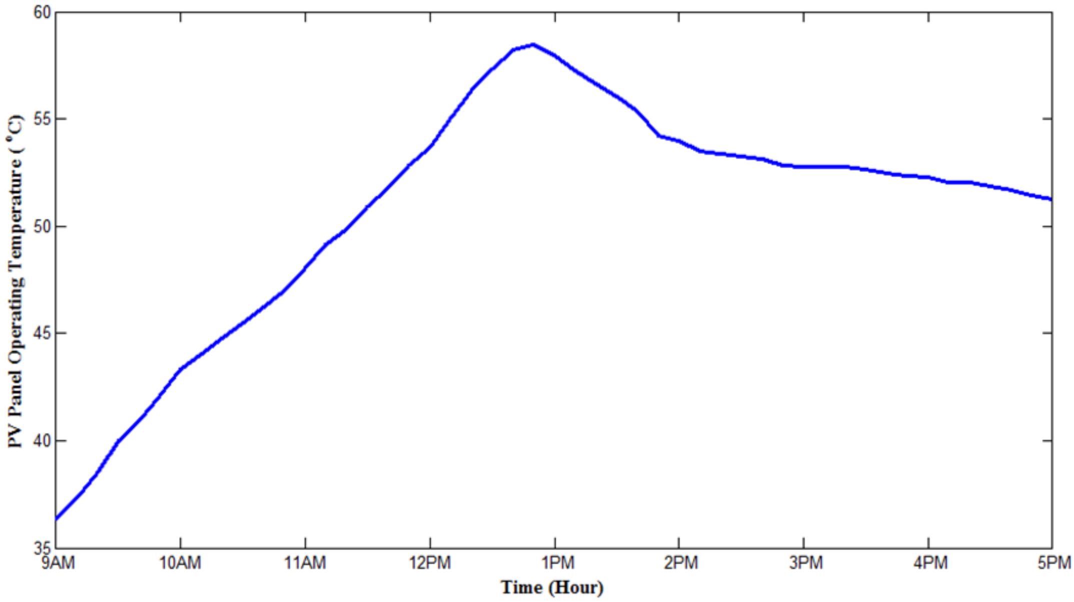

Fig. 8. Temperature of PV panel without cooling system

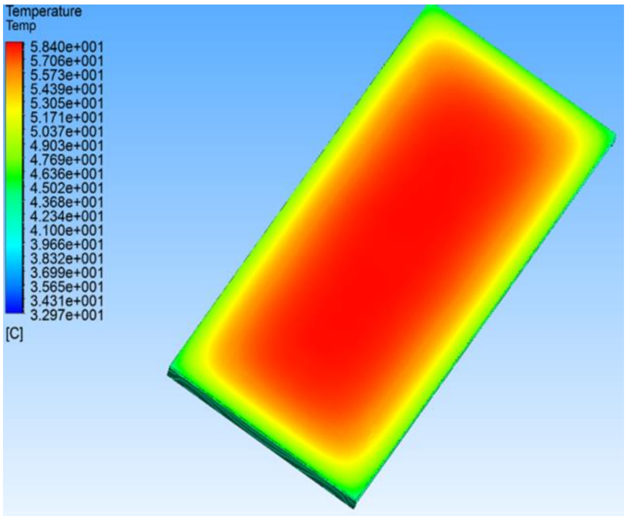

Fig. 9. Temperature distribution of PV panel without cooling system

In this simulation analysis, the effect of inlet water temperature on the performance of water cooling system has been investigated. Figure 10 displays the average temperature variation of the PV panels affected by the different inlet water temperatures. It is obvious that the highest average temperature of the PV panel is 45.34 °C that is operated at an inlet water temperature of 45 °C. On the other hand, the lowest average temperature of the PV panel is 29.71 °C, which is operated at an inlet water temperature of 20 °C. This indicates that an average increment in the temperature of the PV panel is observed to be 15.63 °C when the temperature of inlet water is increased from 20 °C to 45 °C. It can be concluded that the inlet water temperature is linearly proportional to the temperature of the PV panel. When the temperature of inlet water increases, the less heat is dissipated from the PV panel through the water. This results in an increment in the temperature of the PV panel. Besides that, this signifies that the water cooling system dissipated the heat away from the PV panel to surroundings. Therefore, the temperature of the PV panel with water cooling system is lower than the PV panel without water cooling system.

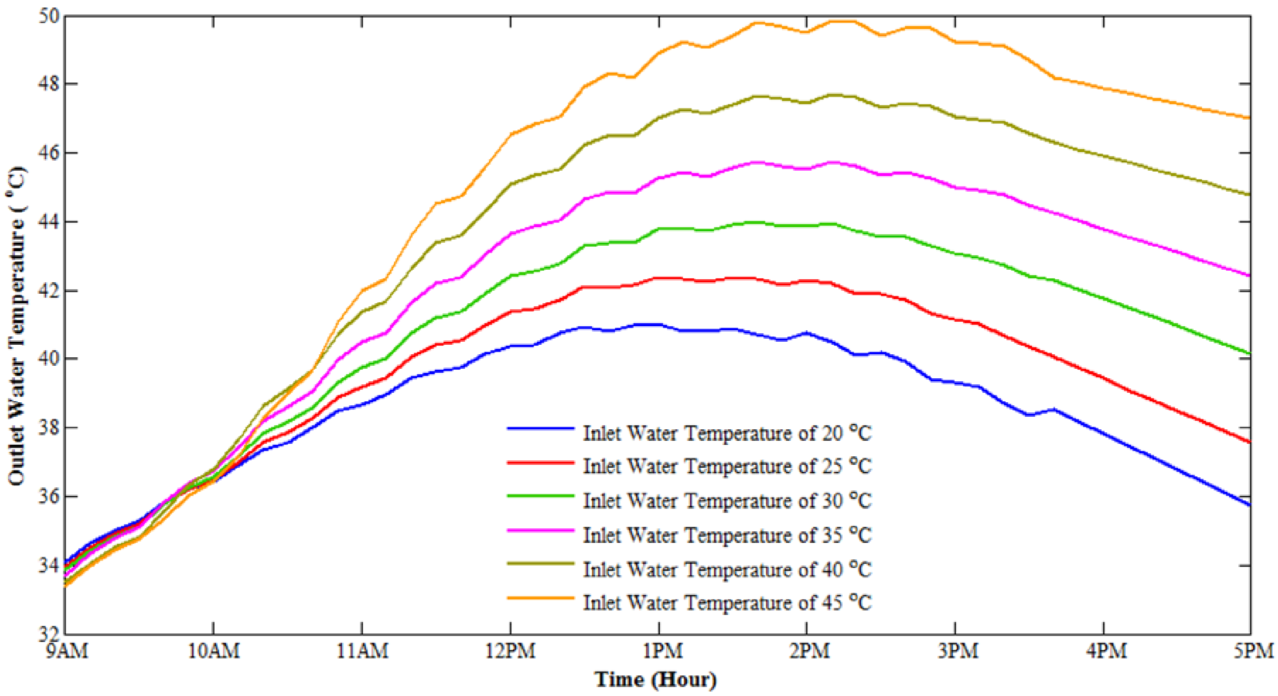

Fig. 10. Temperature of PV panel under different inlet water temperature

Figures 11 - 16 present the contour plot of the temperature distribution on the surface of the PV panels at different inlet water temperature. It is clearly displayed that the coldest surface of the PV panel is covered with most blue at an inlet water temperature of 20 °C, as indicated in Figure 11. While the PV panel operated at the inlet water temperature of 45 °C is the hottest, with the surface of the PV panel being covered with the most yellowish orange, as displayed in Figure 16. This is due to the fact that a higher inlet water temperature transfers less heat from the PV panel than a lower inlet water temperature. This is lead to a higher temperature of the PV panel. In the other word, the lower the inlet water temperature, the better the cooling effect for the PV panel.

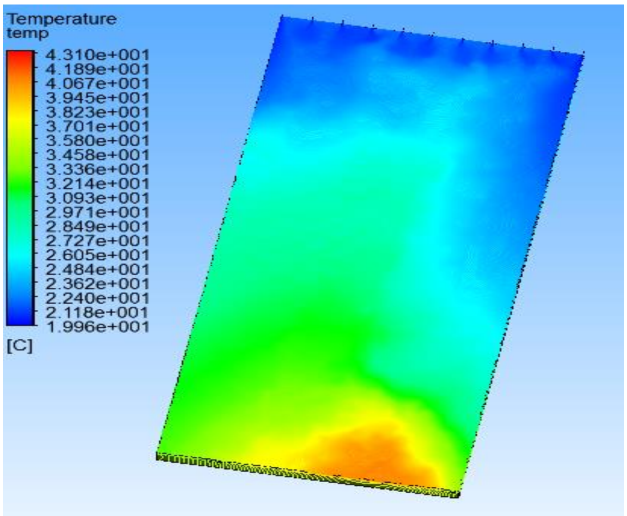

Fig. 11. Temperature distribution of PV panel at inlet water temperature of 20 °C

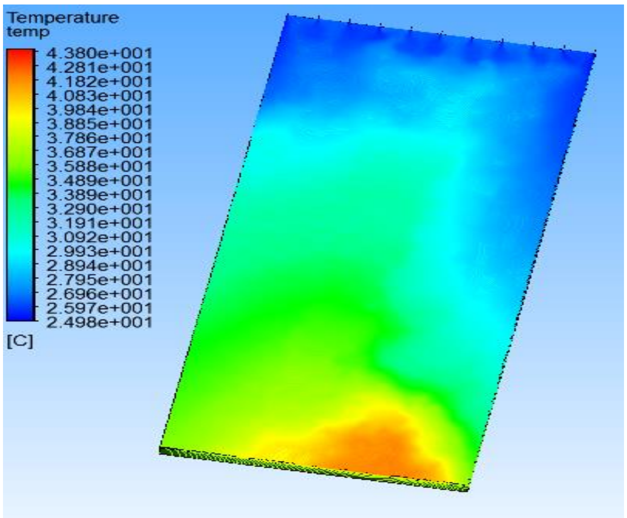

Fig. 12. Temperature distribution of PV panel at inlet water temperature of 25 °C

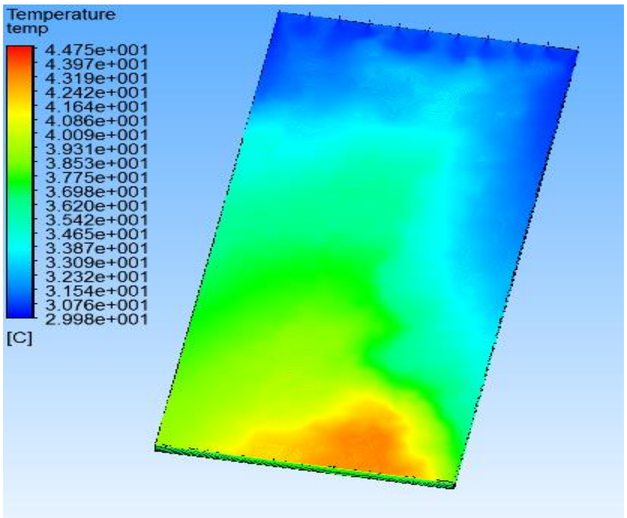

Fig. 13. Temperature distribution of PV panel at inlet water temperature of 30 °C

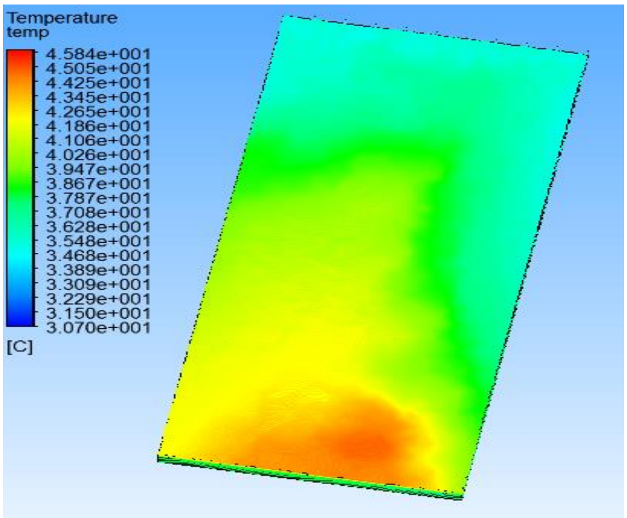

Fig. 14. Temperature distribution of PV panel at inlet water temperature of 35 °C

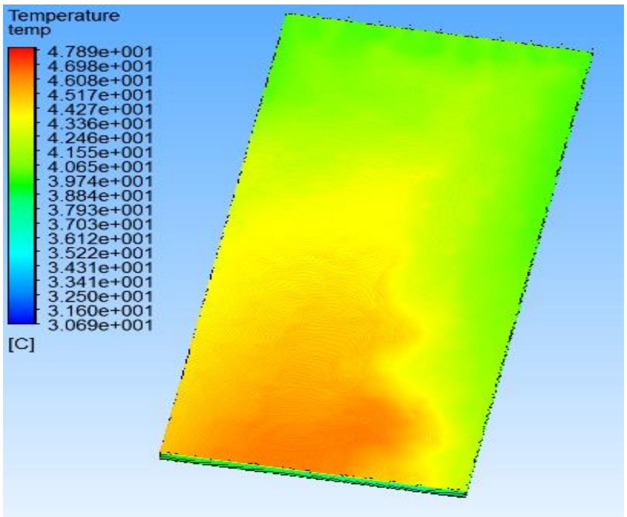

Fig. 15. Temperature distribution of PV panel at inlet water temperature of 40 °C

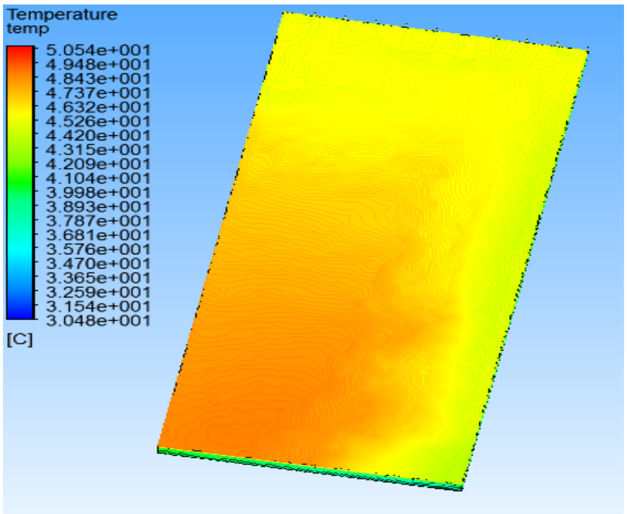

Fig. 16. Temperature distribution of PV panel at inlet water temperature of 45 °C

Figure 17 displays the outlet water temperature at the different inlet water temperature. It is clearly show that the highest average temperature of the outlet water flow is 45.01 °C, which happened at an inlet water temperature of 45 °C. In contrast, the lowest average temperature of the outlet water flow is 38.61 °C at an inlet water temperature of 20 °C. It can be seen the outlet water temperature at the range of inlet water temperature between 20 °C and 45 °C is increased by about 6.4 °C. This implies that when the temperature of inlet water increases, the temperature of outlet water rises as well.

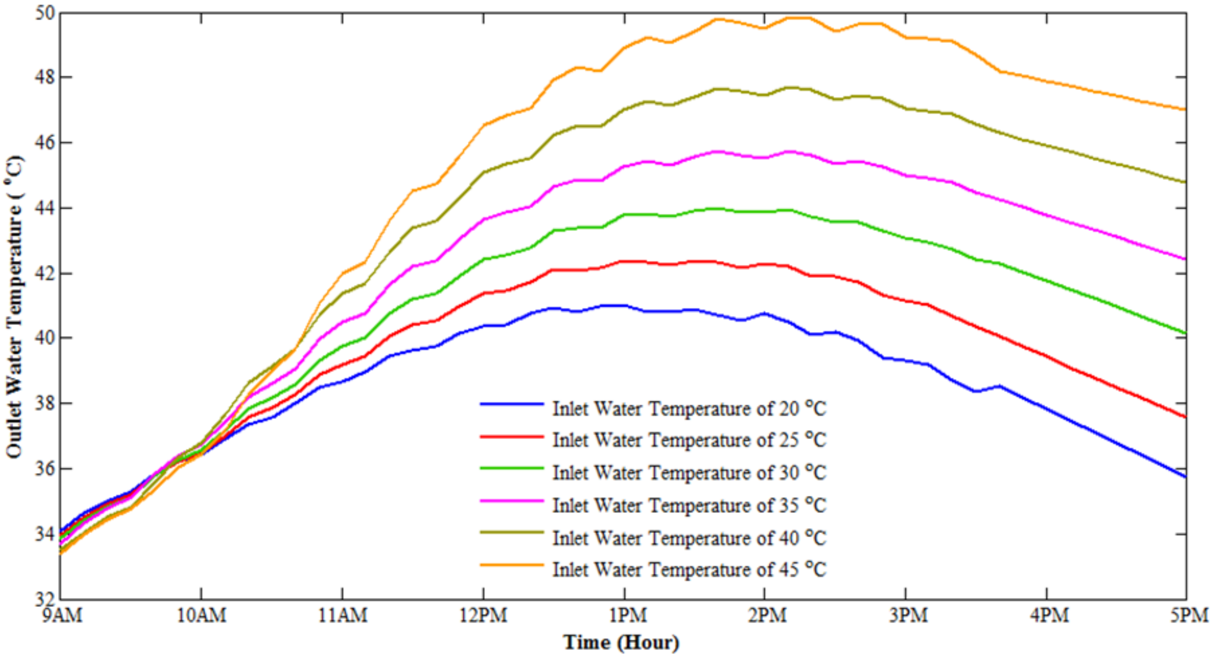

Fig. 17. Temperature of outlet water flow for each of the PV panel with water cooling system

Figure 18 presents the output power generated by the PV panel without and with water cooling system. It is shown that the PV panel without cooling system generated the lowest output power than the PV panels with water cooling system. The PV panel without cooling system produced output power of 87.1 W. For the water cooling system, the PV panel with an inlet water temperature of 20 °C generated the highest output power of 97.6 W. On the other hand, the PV panel with an inlet water temperature of 45 °C produced the lowest output power of 89.0 W. It can be concluded that the PV panel can produce higher output power as the inlet water temperature decreases. This is explained by the fact that the lower inlet water temperature can dissipate more heat from the PV panel. It can be seen that the PV panels with inlet water temperature of 20 °C and 45 °C are approximately 12.06 % and 2.18 % higher than the PV panel without cooling system, respectively.

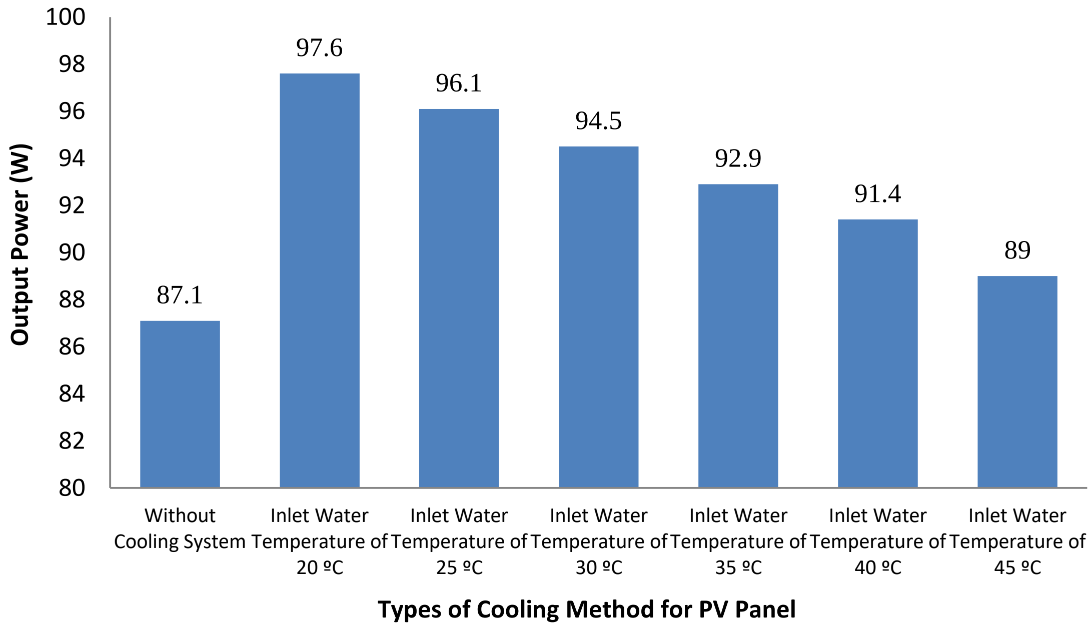

Fig. 18. Output power generated by the PV panels without and with water cooling system

4. Conclusions

Three-dimensional thermal model of the PV panels without and with water cooling system has been analysed by using ANSYS CFX software. The main purpose of this simulation analysis is to predict the temperature distribution of the PV panel on the impact of water cooling effect. This simulation analysis has made a significant contribution in the cooling system of the PV panel application. To be given to environmental and operational conditions, the temperature distribution of PV panel without cooling system is higher than the PV panel with water cooling system. Besides that, the water cooling system has also been analysed in effect of inlet water temperature to the performance of cooling effect. The selected range of inlet water temperature is from 20 °C to 45 °C with an interval of 5 °C. It can be seen that the inlet water temperature of 20 °C flow over surface of the PV panel, the average temperature of PV panel is 29.71 °C. While the inlet water temperature of 45 °C applied to the water cooling system, the average temperature of the PV panel is 45.34 °C. It can be concluded that an increase in the temperature of inlet water, the water flow was transferred less heat away from the PV panel into water. Therefore, it cannot reduce much temperature of the PV panel. In addition, the lower temperature of the PV panel produces a higher output power. Therefore, through this research paper, the solar developers and customer solar installers can refer to them in order to install the water cooling system into their solar system.

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