Simulation study of air and water cooled photovoltaic panel using ANSYS

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Abstract. Demand for alternative energy is growing due to decrease of fossil fuels sources. One of the promising and popular renewable energy technology is a photovoltaic (PV) technology. During the actual operation of PV cells, only around 15% of solar irradiance is converted to electricity, while the rest is converted into heat. The electrical efficiency decreases with the increment in PV panel's temperature. This electrical energy is referring to the open-circuit voltage (Voc), short-circuit current (Isc) and output power generate. This paper examines and discusses the PV panel with water and air cooling system. The air cooling system was installed at the back of PV panel while water cooling system at front surface. The analyses of both cooling systems were done by using ANSYS CFX and PSPICE software. The highest temperature of PV panel without cooling system is 66.3 °C. There is a decrement of 19.2% and 53.2% in temperature with the air and water cooling system applied to PV panel.

1. Introduction
Solar PV system is one of the growing renewable energy technologies, besides wind energy and it is expected to become a major renewable energy in the future [1]. PV cells are semiconductor that convert the solar irradiance into electricity. The terms solar irradiance is referring the measure of power density of sunlight receives at any location on earth, and it is measured in watt per metre square (W/m²) [2]. When the solar irradiance rises, the open-circuit voltage (Voc) and short-circuit current (Isc) will also rise. The short-circuit current (Isc) increases with the increment of solar irradiance, hence improving the power generated by PV panel. Besides solar irradiance, temperature also plays an important role in determining the performance of PV panel. When the PV cell’s temperature increase, the rate of photon generation increases. The reverse saturation current will increase rapidly, which lead to reduce in the band gap thus affecting the PV cell’s electrical parameters. The open-circuit voltage (Voc) is the parameter that will most affect [3].

As solar irradiance acts as a positive factor in affecting the performance of PV panel, meanwhile temperature will acts as a negative factor. When the solar irradiance increase, the output power generated by PV panel will increas too. However, with the increase of PV panel’s temperature, the output power generated will decrease. With the PV panel temperature gain, its efficiency (in terms of power output) decreases because of the negative temperature coefficient (-0.5%/°C rise in temperature) [4]. It can be said that PV panels are more efficient at a lower temperature, thus a cooling system is needed due to lower the PV panel’s temperature. Numerous researchs have been conducted
to enhance the performance of PV panel [5-7]. It has been proven by Smith [8] that with a cooling
system attach to PV panel, the power generated increase by 5%. Sayran [9] and Saurabh [10] had
immersed the PV panel into water with different depth due to increase the efficiency of PV panel. It is
found out that the efficiency increases by 11% at water depth of 6 cm and 17.8% at depth of 1 cm
respectively. While, Teo [11] maintained the PV panel’s temperature by 38 °C with a blower that was
attached at the backside of PV panel. Besides, the electrical efficiency also increases from 8.6 % to
12.5% with the utilisation of cooling system. Prastish [12] evaluate the effectiveness of PV/T hybrid
water collector that generates thermal energy and electricity, hence, producing a higher energy
conversion rate of absorbed solar radiation. Authors also emphasize the effect of PV panel temperature
towards the electrical, thermal and exergy efficiency. It is concluded that the electrical, thermal and
exergy efficiency can be raise if the heat was removed from the PV panel completely.

Khelifa [13] studied solar hybrid photovoltaic thermal (PV/T) using ANSYS Fluent software.
The author had simulated the heat transfer phenomenon and fluid flow between the PV cells and the
coolant. The results show that with a lower PV cell temperature, the thermal and electrical
performance increased. Hiren et al. [4] presented an experimental study and CFD analysis for PV
panel with a heat exchanger of water, flowing on top of it. The authors also demonstrated that the
refraction of incident solar radiation while striking to PV panel through the water was favorable. The
overall electrical efficiency had increased from 6% to 40% by the water cooling system. Another
direct water cooled PV panel experimental analysis has been studied by Stefan [14]. It is found that
with the help of cooling, monthly energy saving efficiency had increased to approximately 10.3%.
Salih [7] improved the net power saving of PV panel by experimented a water spraying technique
cooling system with a constant water mass flow rate. The water cooling system has been installed at
front of PV panel due to spray the water thus removing the heat. The performance of the water cooling
system was studied by observing its electrical performance throughout the day.

This paper presents a study on the performance differences of PV panel with DC fan and
water cooling system. The performance study will based on thermal performance, which will be
evaluated by ANSYS CFX, while the electricity study will be evaluate using PSPICE software.

2. DC fan and water cooling system analysis
Figure 1 shows the water and air cooling system investigated in this study. These cooling systems
were designed to tackle the problem of the negative effect of the temperature towards PV panel. The
utilisation of these cooling systems are presumed to reduce the temperature of PV panel, hence
increasing its performance (output power generated).

![Figure 1. PV panel with (a) DC Fan cooling system (b) water cooling system](image)
A Sharp Solar panel with peak power of 100 W, $I_{sc}$ of 5.78 A and $V_{oc}$ of 22.2 V has been employed for both simulation. The PV panel dimension was based on actual dimension, which is 1200 mm x 540 mm. A thin layer of air and water were added at the back and top of PV panel respectively. The geometry model has been drawn by using Solidwork before imported into ANSYS CFX for further analysis. Normally, PV panel consists of 5 different layers, which are glass surface, Ethylene-Vinyl Acetate 1 (EVA1), silicon, EVA 2 and tedlar. Each layer is differed in thickness, density, thermal conductivity and specific heat capacity.

The heat transfer from the air and water flowing at the back and top of PV panel respectively were modelled by using a computational fluid dynamic (CFD) software. Several assumptions have been made, such as, both working fluids were considered as incompressible fluid. The governing differential equations used to describe the heat transfer and fluid flow of the both PV panel cooling system are given as follow:

Conservation of mass (continuity)
\[
\nabla (p \vec{V}) = 0
\]

Conservation of momentum
\[
\vec{V} \cdot \nabla (p \vec{V}) = -\nabla \cdot \left( \mu \nabla \vec{V} \right)
\]

Conservation energy for fluid
\[
\vec{V} \cdot \nabla (pc_p T_f) = \nabla \cdot (k_f \nabla T_f)
\]

Conservation of energy for solid
\[
\nabla \cdot (k_w \nabla T_w) = 0
\]

The computations were performed by using the commercial package ANSYS CFX software. The PV panel with air cooling system was acknowledged standard k-Omega model because the flow is turbulent ($Re > 2200$). Whereas, the PV panel with water cooling was considered as laminar model since the flow is laminar ($Re < 2000$). The energy equations and flow momentum were solved with a first-order upwind scheme. Both simulations were performed using a convergence criterion of $10^{-4}$. A fine hexa mesh grid scheme was used to mesh both cooling system. The PV panel with air cooling system consists of 29208 nodes and 30109 element, while, the nodes and element for PV panel with water cooling are 22272 and 10584 respectively. The meshed model does satisfy the 0.85 of maximum skewness and have a low aspect ratio.

Boundary condition needs to be applied at all PV panel’s surface. Under the sun, not all surfaces of PV panel will directly expose to it. Hence, only the outer layer of PV panel will be considered receiving the solar irradiance and wind. The ambient temperature and solar irradiance are varying with time, whereby it started at 8.00 a.m. until 7.00 p.m. The temperature of PV panel is assumed dependent on the ambient temperature. Meanwhile, the initial temperature for air and water were 25 °C. Since both of the cooling system are an active cooling system, a similar power input is chosen which is 2.16 W. For air cooling system, 2 units of DC fan were installed at the back of PV panel with wind speed of 3.07 m/s. As for water cooling system, a water mass flow rate of 0.0556 kg/s was selected. Both PV panels cooling systems will be analysed with the same weather conditions. The comparative performance of it will be analysed in terms of thermal performance using ANSYS CFX as well as electricity performance by using PSPICE software.

Besides PSPICE software, the electricity performance of PV panel with cooling panel will be evaluated by studying its parameter. The parameters involved are $I_{sc}$, $V_{oc}$, I-V curve, fill-factor (FF) and efficiency. The maximum power output generate by PV panel can be calculated as follow:
\[
P_{mp} = V_{mp} \cdot I_{mp}
\]
Imp is the maximum current generated by PV panel, while, Vmp is the maximum voltage generated by PV panel. FF represent the ratio of Pmax from the PV panel to the product of Isc and Voc, by which determines the maximum power from PV panel.

\[
FF = \frac{P_{mp}}{I_{sc} \cdot V_{oc}}
\]  

(6)

The performance of PV panel with cooling system also can be compared by using the efficiency parameters. Efficiency is the ratio of power output generated by PV panel (Pout) to the input power (Pin) from the sun. It defines how much solar irradiance is converted into electrical energy, indicating how efficient the PV cells functions. P in is the product of input solar irradiance (G, in W/m²) with surface area of PV cell (A in m²). The conversion efficiency (\(\eta\)) is determined by:

\[
\text{Efficiency}(\eta) = \frac{I_{mp} \times V_{mp}}{G \times A}
\]  

(7)

3. Results

This section presents and discussed both PV panels with cooling systems impact towards thermal performance and output power generated. Figure 2 displays the temperature of PV panel without and with cooling system. The highest ambient temperature recorded was 36.5 °C with solar irradiance of 1175 W/m² at 1.30 p.m. The highest temperature of PV panel with air cooling system is 53.6 °C while for PV panel with water cooling system is 31.3 °C. In the meantime, the highest temperature for PV panel without cooling system is 66.3 °C. There are almost 12.7 °C differences in temperature for PV panel without cooling system and PV panel with air cooling system. It can be said that with the aid of cooling system, the PV panel’s temperature can be lowered. PV panel with water cooling system shows the largest decrement in temperature compared to air cooling system, which is almost 35.0 °C differences in temperature when compared to PV panel without cooling system.

![Figure 2. Temperature of PV panel without and with cooling system.](image-url)

With the highest temperatures that were recorded at 1.30 p.m., a P-V curve is formed by using PSPICE software as illustrated in Figure 3. This is due to evaluate the power generated for each PV panel cooling. Pradhan [2] stated that, when PV panel’s temperature increases, it will cause only marginal changes in current, but major changes in voltage. This is proven with the graph shown in Figure 3. As the PV panel without cooling system has the highest temperature, hence its Voc is only
19.0 V. But, with water cooling system attach to it, the $V_{oc}$ is enhanced up to 21.5 V. The $V_{oc}$ for PV panel with air cooling system recorded is 20.0 V. Besides, the output power generated by PV panel is the highest with water cooling system, which is 78.5 W, compared with air cooling system, only 71.1 W. Overall, it has an increment in output power generated by PV panel compared to without a cooling system.

![Figure 3. The P-V curve for PV panel without and with cooling system.](image1)

Table 1 presents the net output power saving for PV panel without and with cooling system. The power generated is by using the highest temperature at 1.30 p.m. Both PV panel cooling systems are active cooling system, by which it consumes external energy to operate it. In the other words, it used the power generated by PV panel to operate the cooling system. Therefore, it is important to select a cooling system that does not consume much power in operating it. Even though both cooling systems have the same input power, but water cooling system eventually has the highest output power saving compared to air cooling system, which is 9.38 W. This is because water has the higher specific heat capacity compared to air. The greater the heat capacity, more heat per unit mass is needed in raising the temperature of PV panel [15].

| Without cooling system | Air cooling system | Water cooling system |
|-----------------------|-------------------|---------------------|
| PV panel output power generated (W) | 66.96 | 71.13 | 78.5 |
| Power consumption (W) | 0.0 | 2.16 | 2.16 |
| Net output power (W) | 66.96 | 68.97 | 76.34 |
| Net output power saving (W) | - | 2.01 | 9.38 |
| Percentage of net output power saving (%) | - | 3.00 | 14.00 |

Table 1. Net output power saving for PV panel without and with cooling system.

The efficiency of the system is illustrated as in Table 2. The net output power is referred to the output power generated from PV panel after considering the power consumption of each cooling system. There is only slightly difference of net output power of PV panel without cooling system and with air cooling system. The output power from PV panel was obtained from PSPICE simulation. From that, the efficiency of each cooling system can be calculated. It is found out that, the PV panel with water cooling system actually has the highest efficiency.
compared to others. Since there is only slightly differences in net output power for PV panel without cooling system and with air cooling system, hence its efficiency only differs for about 0.66 %. The efficiency of PV panel with water cooling system increase 3.11 %. These efficiency were calculated based on net output power generated at 1.30 p.m., with a solar irradiance of 1175 W/m² and ambient temperature of 36.5 °C. The efficiency of the water cooling system then was compared with the existing research by Bahaidarah et. al [16]. Author developed a numerical model of solar thermal collector by using Engineering Equation Solver (EES). The heat exchanger (cooling panel) was attached at the backside of PV panel, and it is found out that the energy efficiency has increased 9 %. The simulation was based on Dhahran, Saudi Arabia weather data location, with highest ambient temperature of 21 °C and solar irradiance of 979 W/m².

Table 2. Efficiency of the system.

|                      | Without cooling system | Air cooling system | Water cooling system |
|----------------------|------------------------|-------------------|---------------------|
| Net output power (W) | 66.96                  | 68.97             | 76.34               |
| Fill factor, FF      | 0.522                  | 0.538             | 0.595               |
| Efficiency, $\eta$ (%) | 21.99                  | 22.65             | 25.07               |

4. Conclusion
This paper presents the comparison between PV panel with air cooling system and PV panel with water cooling system. Both cooling system is compared with the temperature criteria, as well as output power generated by PV panel. The input power for both cooling is the same which is 2.16 W with DC fan speed of 3.07 m/s and water mass flow rate of 0.0556 kg/s. As a conclusion, PV panel with cooling systems show a decrement in temperature compared to PV panel without cooling system. By using the highest temperature, the P-V curve is formed due to evaluate the output power generated by PV panel at that particular time. The water cooling system is chosen as the best cooling compared to air cooling system, since it has the highest output power saving, compared to it.

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