Comparison Analysis on the Performance of the Filtered Photovoltaic (PV) Module

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Abstract. The photovoltaic system is the most significant conversion device for solar energy compared to other available systems. It converts solar radiation into electricity, but the performance of the PV module degrades as the PV temperature increases. This is because only selected bands of wavelength, 0.35 to 0.82 µm, are converted into electricity while the remaining solar radiation will generate heat in the PV system. In order to maintain PV performance, the operating PV temperature can be maintained by applying various cooling methods, which are either passive or active. Some wavelengths, such as UV and Infrared, need to be eliminated. Therefore, this research aims to investigate the effects related to the presence of water in the filtered PV module. At the end of this study, the performance of the PV with and without the water filter was compared, and the results show that the PV module with the water filter achieved a higher efficiency of 9.96% compared to the filtered PV module without water, which had an efficiency of 9.61%.

1. Introduction
Great concerns on the depletion of natural resources has increased efforts in finding alternative sources of energy. One such renewable source, solar energy, gained its popularity in industry and research due to its availability throughout the year. [1]. The composition of solar energy includes ultraviolet, visible, and infrared radiation of 5%, 46%, and 49%, respectively [2]. The photovoltaic (PV) is one of the devices that is able to convert solar radiation and visible light into electricity. However, the components of solar energy are not perfectly converted into electricity. Unconverted solar radiation is converted into heat instead; this increase in temperature affects the performance and efficiency of the PV panel [3], [4]. It is important to maintain the operating temperature to achieve a maximum output parameter, open circuit voltage or output voltage, and a short circuit current [5]. The reasonable maximum operating temperature for the PV under 1000 W/m² of solar radiation without the existence of wind is 66°C, whereas given wind, the maximum operating PV temperature is less than 40°C [6]. Therefore, various approaches of active and passive cooling methods are applied for the PV module such as air cooling, water cooling, heat exchanger, and fins cooling.

The attachment of a standalone cotton wick at behind the PV panel is one of the passive cooling methods able to increase PV efficiency, improving performance from anywhere between 10.8% to 12.3%, accompanied with a 20°C drop in temperature [7]. On the other hand, the
Implementation of air cooling as one of the active cooling methods for the PV module has been proven by its capability in increasing PV efficiency to 12% to 14% [8] when compared to its performance without an active cooling method. An array of air ducts was installed underneath the PV panel to allow air to pass through while heat is transferred to the moving fluid with an attachment of the fins. As for the water-cooling method, one of the approaches uses a photovoltaic water pumping system (PVPS). The main condition in operating this system is that the nominal array power produced should always be more than the actual power output. In order to adhere to this condition, the water spray system is applied. The system operates every five minutes and is able to reduce the temperature by 10°C [9]. Furthermore, another study on simulating water cooling was carried out by L. W. Zhe et al. [10], where sets of water nozzles were attached on top of the PV and the system operated frequently in the time span of 10 minutes. The results obtained showed that the PV module temperature is affected by the temperature of the inlet water. At an inlet water temperature of 20°C, the PV achieved a better efficiency of 12.06%. At higher temperatures of the PV panel (45°C), PV efficiency drops by 2.18%. With supported data on the improvement of PV performance, this study proposes the idea of filtering solar radiation with and without water. The main purpose of the water filter is to eliminate the components of solar radiation such as UV and Infrared, since the PV module converts only selected bands of wavelength, specifically 0.35 to 0.82 µm [2], [11].

2. Experiments
A setup was designed to investigate how the operating temperature of the PV affects its efficiency. A schematic diagram of the filtered experimental setup is shown in Figure 1. Different measurements, such as the top and bottom temperature of the PV, output voltage, short circuit current, and also solar radiation in this case, were recorded by using a thermocouple, multimeter, and pyranometer to analyse the relationship between PV temperature and the output voltage. In this study, two conditions were applied, whereby the filter is filled with and without water. All experiments were conducted in the span of twenty-two to thirty minutes each time.

Fig.1: A Schematic Diagram of the Filtered Experimental Setup

Average measurements for the top PV temperature, bottom PV temperature, short circuit current generated, and output voltage will then be calculated [12] in order to identify which of the said conditions will provide a higher PV efficiency.
3. The Experimental Results

3.1 Results of 5mm Filtered PV Panel without Water
The water filter was placed at the top of the PV panel during the experiment. In this case, the experiment was conducted without water inside the filter, and it was carried out for twenty-two minutes. The highest level of irradiation during this experiment was recorded to be 874 W/m$^2$, while the lowest level was found to be 264 W/m$^2$. The temperature of the PV at the top and bottom sides of the PV ranged from 51.9°C to 52.7°C, and 45.1°C to 45.3°C, respectively. Subsequently, the effect of solar irradiation towards the output voltage and current generated by the PV module is shown in Figure 2 and 3. The highest voltage measured was 19.49 V, whereas the lowest was 18.60 V. Meanwhile, the maximum current generated was 3.99 A, and the minimum was 1.64 A. Based on the data gathered as shown in Figure 4, the average efficiency of the filtered PV without water is 9.61%.

3.2 Results of 5mm Filtered PV Panel with Water
The same experimental setup was applied at this instance, with the exception of having the filter container filled up with water. The experiment lasted twenty-four minutes. The highest transmitted irradiation measured during this experiment was 869 W/m$^2$, while the lowest transmitted irradiation was 385.8 W/m$^2$. Based on Figure 5 and Figure 6, the highest voltage was 19.88 V, while the lowest voltage was 18.87 V; the generated current recorded a maximum of 3.58 A and a minimum of 2.33 A.

![Fig.2: Transmitted Irradiation and Voltage vs Time (5mm Filtered PV without water)](image1)

![Fig.3: Transmitted Irradiation and Current vs Time (5mm Filtered PV without water)](image2)
The top PV temperature was found to be slightly higher than temperature of the bottom PV. The maximum temperature at the top of the PV was 51.8°C, while the bottom of the PV was 40.6°C. As the overall temperature dropped, the temperature at the top of the PV was measured to be 51.5°C, which caused the temperature at the bottom of the PV to fall to 39.9°C. Figure 7 demonstrates that the efficiency of the PV module increases when the PV temperature drops; the maximum PV efficiency calculated reached 9.96%. By comparing the performance of the 5mm filtered PV with and without water, it was found that its efficiency with water is higher by 0.35%.

Finally, the average voltage, current, irradiation, and temperature for both sides of the PV panel (filter with and without water) were calculated and summarised in Table 1. Based on the results presented, the average temperature for the filtered PV without water is higher than the filtered PV with water. This might be due to the fact that the filtered PV without water is still unable to eliminate some of the components of solar radiation, such as gamma radiation, x-ray radiation, ultraviolet radiation, visible radiation, infrared radiation, microwave radiation, and radio wave radiation. Therefore, the components of radiation which are not converted to electricity will remain in the PV module and generate heat. Meanwhile, the filtered PV with water absorbs selected bands of wavelength which are converted into electricity, and the remaining wavelengths are eliminated by water filtration. Thus, the filtered PV with water generates less heat.
Fig. 6: Transmitted Irradiation and Current vs Time (5mm filtered PV with water)

Fig. 7: Average temperature and PV Efficiency vs Time (5mm filtered PV with water)

Table 1 Results for 5mm Filtered PV Panel

| Results / Conditions                     | Filter with water | Filter without water |
|------------------------------------------|-------------------|----------------------|
| Average temperature at the top of PV panel (°C) | 46.26             | 48.64                |
| Average temperature at the bottom of PV panel (°C) | 45.90             | 49.25                |
| Average current generated (A)            | 3.040             | 3.345                |
| Average voltage generated (V)            | 19.57             | 18.96                |
| Average Incident Irradiation (W/m²)      | 781.95            | 861.04               |
| Average Transmitted Irradiation (W/m²)   | 616.45            | 680.44               |
| PV Efficiency (%)                        | 9.96              | 9.61                 |

4. Conclusion and Future Recommendations

The performance of the filtered PV module with and without water has shown to have a significant impact on the PV efficiency compared to the non-filtered PV. The calculated PV efficiency is greater than 9%; the filtered PV module with water achieved a higher performance with a PV efficiency of 9.96% compared to the filtered PV module without water, which only managed 9.61%. As the PV efficiency can reach 12% to 14% as proven in the air-cooling method, further experimental study is required by using water filters of varying thicknesses to study its effect on PV efficiency.
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