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Heat Pipe as a Passive Cooling Device for PV Panel Performance Enhancement

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ABSTRACT

Excessive operating temperature of Photovoltaic (PV) panel by high levels of solar irradiation would affect its conversion efficiency, Hence One way of improving the efficiency of photovoltaic system is to maintain a low operating temperature by introducing a passive cooling system. Subsequently, this study investigating the effect on surface temperature reduction and voltage output of PV panel, by introducing the combination of heat pipe and fin as a cooling device. Each set of the cooling devices consisted of two copper heat pipes and two units of heat sinks. Two sets of the cooling devices were installed at the back of the PV panel, and experimental work had been performed at fixed 0 ° horizontally. The experiment was conducted at a constant time under Malaysia's climate at constant ambient temperature ranging from 33 °C to 34 °C. The temperature of the panel and open-circuit voltage (VOC) was recorded before and after the installation of the cooling system by using Arduino data logger. Four thermocouples for different places and a voltage sensor were installed into the system to enable recording the data of voltage and temperature simultaneously. The results showed 4 o C or 6.6 % surface temperature reduction and 0.29 V or 2.8 % voltage gained respectively when the proposed cooling devices were installed to the PV panel.

Keywords:
Passive cooling; PV panel; heat pipe

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1. Introduction

The operating temperature is one of the crucial factors that can affect the efficiency of the PV panels. The effects of temperature on photovoltaic efficiency can attribute to the influences on the current and voltage of the PV panels [1]. The increase in surface temperature of the PV cell, increases the circuit resistance, and this limits the velocity of the electron, which directly affects the open circuit voltage besides badly influencing the cell material [2]. The voltage drop-in or temperature rise unit, called temperature coefficient, describes the temperature reliance of the material used for PV cell performance analysis and indicates the strong dependency of PV power output on the surface temperature of the PV. This can be easily found on the I-V curve of the panels. It results in a linear reduction in the efficiency of power generation as temperature increases [3]. Overall efficiency of PV cells ranges from about 5% to 20%. However, it has been shown that the overall efficiency of photovoltaic cells drops drastically with an increase in temperature. The rate of decrease

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ranges from 0.25% to 0.5% per degree Celsius, depending on the cell material used. Hasnuzaman *et al.*, [4] have shown that the various performance of different kind of PV cell correlate to their temperature coefficient. The voltage drop is about 0.12 V, and thus the temperature coefficient is 0.12 V/°C for each 1 °C increase of cell temperature in the polycrystalline PV cell. For crystalline silicon solar cells, the reduction in conversion efficiency is 0.4-0.5% for every degree of temperature rise [5].

The performance of the PV panels is mainly depending on its operating temperature. Therefore, to maintain the electrical performance of the PV module at an acceptable level, it is essential to utilize an appropriate cooling technique to lower its surface temperature, thereby prolonging its lifetime [6]. There are two classification of cooling techniques that have attract the interest of previous researchers namely active and passive cooling. In active cooling, the use of mechanical devices such as pump or fan blower are necessary to provide a continuous effect on the solar cells. But, it could reducing the net output power produced from PV cells to power the pump and fan [7]. A series of investigations have been performed previously on force air cooling that includes a practical experiment to use a number of DC fans directed at the back of the PV cell [8]. Other studies have employed an airduct underneath the PV cell to enhance the effect of cooling by force convection [9,10]. Effect of other parameters such as mass flow rate and adding and effect fin to increase the effect of force convection surface area were done experimentally [11,12]. According to their observations, adding fins resulted in 10.5% and 15% enhancement in the electrical and thermal efficiencies of the system, respectively. Moreover, increment in air mass flow rate from 0.03 to 0.15 kg/s led to significant increase in the electrical efficiency. In force water cooling, the water is force to cool the top surface of the PV panel or circulated the water at the rear of the PV panel. Cooling the top surface has shown a significant increase in power output by 15% during hot summer and 5% increments throughout the year [13,14]. The presence of water on the surface has led to removing the accumulating dust that would provide better PV cell performance. The result on force cooling at rear PV cell shows a 32% decreased of surface temperature and power output efficiency increased by 57% [15].

In passive cooling method, the PV cell is cooled without the need to provide additional power source. The cooling technique could be achieved naturally with water, air, and heat pipe. The improvement of PV panel efficiency could be lesser compared to active technique but the element of cost-effective and minimal energy consumption are the main focus. The fins and heat sink were used to utilise the effect of surface area toward increasing the effect of convection by air. These devices were attached to the rear of PV cell, to conduct the heat from top surface and release it by the effect of natural convection. The used of fin were able to increase the power output efficiency up to 2% by reducing the surface temperature between 3 °C to 6 °C [16,17]. The installation of heat sink has shown an increase of 4% efficiency in power output and reducing the surface temperature about 10 °C [18]. The passive water cooling that utilised the effect of the elevation head by gravity have shown a promising result as investigated by Wilson, (2009) [19]. Another technique is dipping, where the PV cell is immersed in the water basin [20]. Both techniques have shown an increase of output power 12% and 17.8% respectively.

Heat Pipe is a simple but efficient heat transfer device without a moving part. Heat pipe has been used widely as a cooling device on computer, workstation and laptop. Hence, it has attracted quite a number of researchers globally to investigate the capability of heat pipe in cooling of PV cells. Sharaf *et. al.*, [2] have reported, that heat pipe was the interest of some researchers to cool down the PV cell surface temperature passively. The obtained results from the studies shown an increment of the power output. The comparison between the difference of PV cells cooling technique has been discussed based on the PV surface temperature, initial cost, heat transfer rate, the power required and the life time of each technique [2]. Despite of high initial cost, the heat pipe proved to be low in maintenance cost, hight heat transfer, zero additional power required and longer lifetime. Therefore, the effect of greater heat removal rate is expected when the heat pipes and fin heat sink are combined as a cooling device. Hence, the current study is conducted to investigate the impact on PV cell performance when heat pipe is coupled with heat sink to cool the surface temperature passively.

2. Methodology

Two units of experimental PV panel 234 x 340 x 3 mm model HQST were used in this study. The specification of the PV panel is shown in Table 1.

Table 1
The specification of experimental PV panel

Specification of experimental solar panel	
Dimension	234 x 340 x 3mm
Maximum Power at STC (Pmax)	10W
Type of cell	Monocrystalline
Optimum operating voltage (Vmp)	9.8v
Optimum operating current (Imp)	1.02A
Open circuit Voltage (Voc)	12.5v
Short circuit Current (Isc)	1.12A
Temp Coefficient of Pmax	-0.23%/°C
Temp Coefficient of Voc	-0.33%/°C
Temp Coefficient of Isc	0.05%/°C
Standard Test Condition (STC)	Irradiance 1000W/m2, T=25°C, AM-1.5

The passive cooling system that integrates two unit of flat heat pipes and two unit of heat sinks were designed as shown in Figure 1 to accommodate the experimental PV panel. The passive cooling system is fabricated based on the approved design as shown in Figure 2. Two cooling units were fabricated and attached at the back of the PV panel. Each cooling unit consist of two flat heat pipes and placed as a bridge to link between two aluminum heat sinks. The purpose of heat sink is to accelerate the heat removal by conduction that transferred from heat pipes. The combination of these two device makes the system work efficiently to remove the heat.

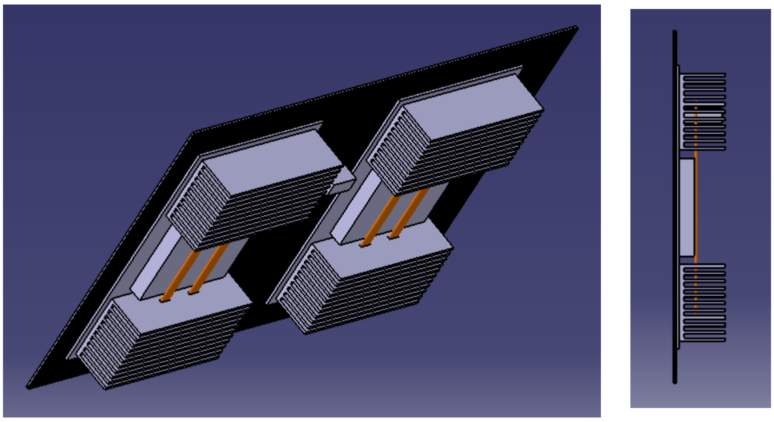

Fig. 1. The design of passive cooling (integration of Heat pipe and heat sink)

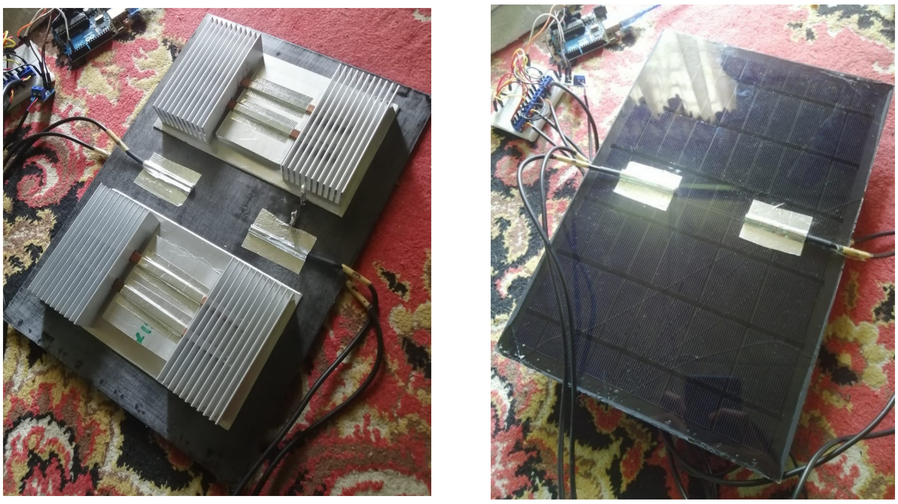

Fig. 2. Fabrication of passive cooling system (left) and placing the temperature sensor (right)

The experimental set-up to connect the PV panel, temperature sensors to data logger and laptop was done prior to the experimental work is shown in Figure 3. Four temperature sensors were attached to the PV panel. Two sensors were placed on surface and the other two were places at the back. The temperature sensors were connected to the data logger. The data logger is connected to the laptop for data retrieval. The experimental work was conducted in Ayer Keroh, Malacca at latitude of 4°. Therefore, the inclination of the PV panel is 0° horizontally to maximize the effect of the radiation intensity on PV panel. Location of four temperature sensors to detect the surface and back PV panel temperature are shown in Figure 4.

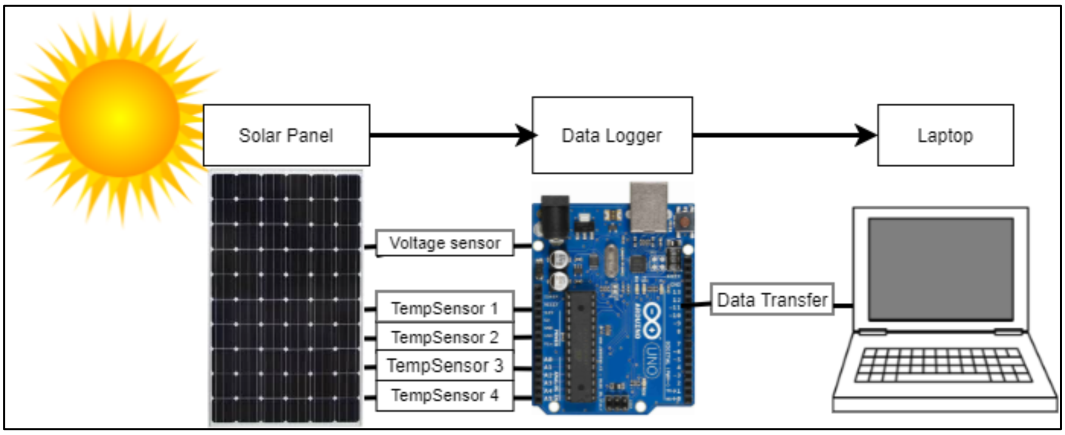

Fig. 3. Schematic diagram of experimental set-up

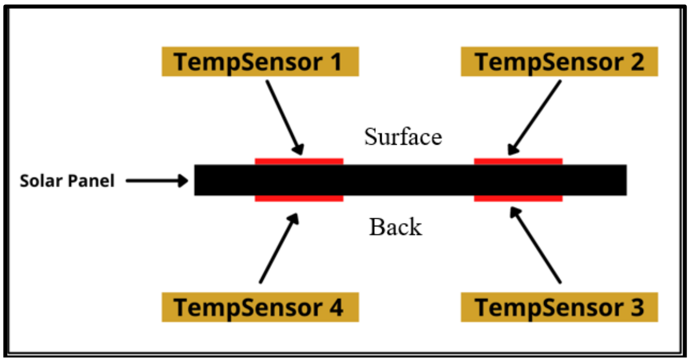

Fig. 4. Location of temperature sensors

The pre-test to observe the voltage output was done prior to the experimental work for six hours from 10.30 to 16.30. The result shows that the voltage output rather stable from 13.30 to 16.30 as shown in Fig. 5. This is to be used as a guide to choose the right time to carry out the experimental work when the Voltage output at the peak.

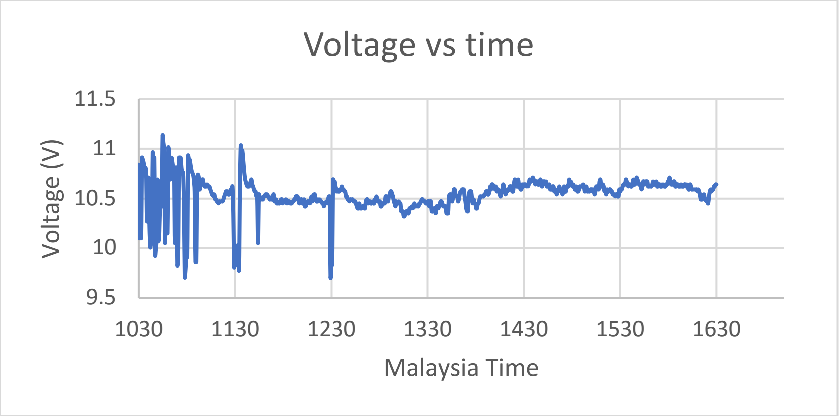

Fig. 5. Voltage output in six hours

3. Results

3.1 SurfaceTemperature

This section discusses the results obtained from the surface temperature measurement. The effects of angle passive cooling by heat pipe couple with heat sink is observed. Figure 6 shows the reading of three times PV panel surface temperatures at difference dates. There were variations in in each reading due to difference ambient temperature due to irradiance received by the PV panel. The obvious observation shows that the surface temperatures were decreased significantly after passive cooling system was installed to the back of PV panel. In average the surface temperature is rise to 57.8 °C without cooling system. After installing the passive cooling system, the average surface temperature was drop to 55.4 °C.

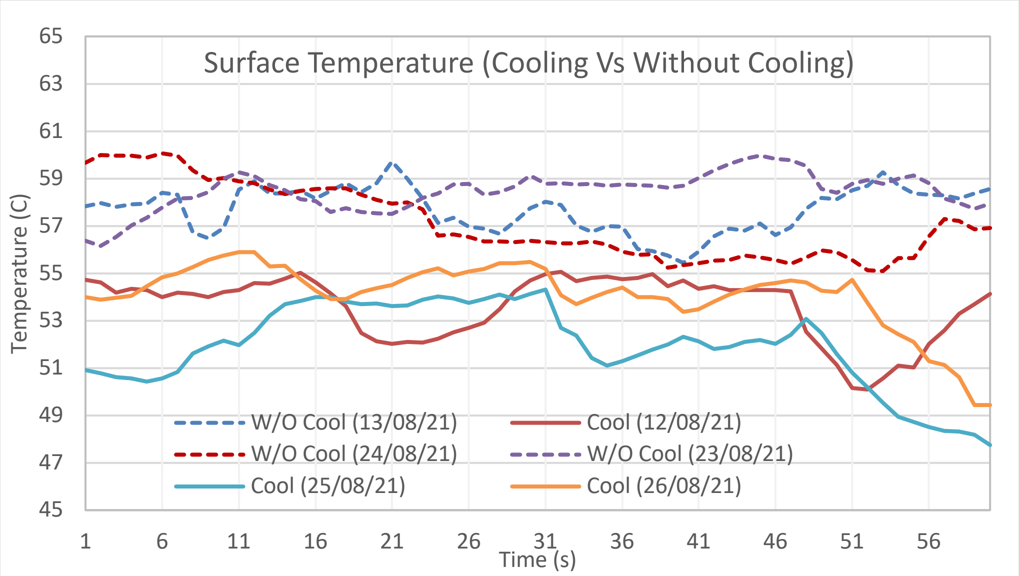

Fig. 6. The effect of passive cooling system on PV panel surface temperature

The bar chart in Figure 7 shows the average temperature difference between operating PV panel with cooling and without cooling system. It has clearly showed that, average temperature difference of 2.38 ^{o}C is achieved that contributes to 4.12% improvement.

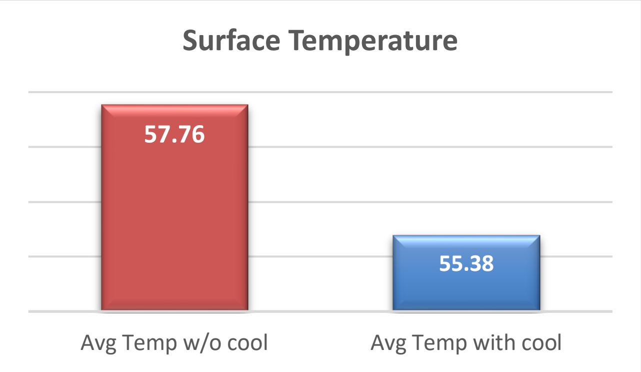

Fig. 7. The average surface temperature of PV panel

3.2 Voltage Output

The most important aspect that need to be measured is the power output improvement from PV panel. The study has used the voltage output as an indicator of power output. Figure 8 shows the voltage output of three set test for PV panel operating with and without passive cooling system. The result clearly shows that the higher voltage output was produced when the PV panel is equipped with passive cooling system compared to without cooling system. The inconsistency of the voltage output is very much related to the amount of radiation intensity during testing period.

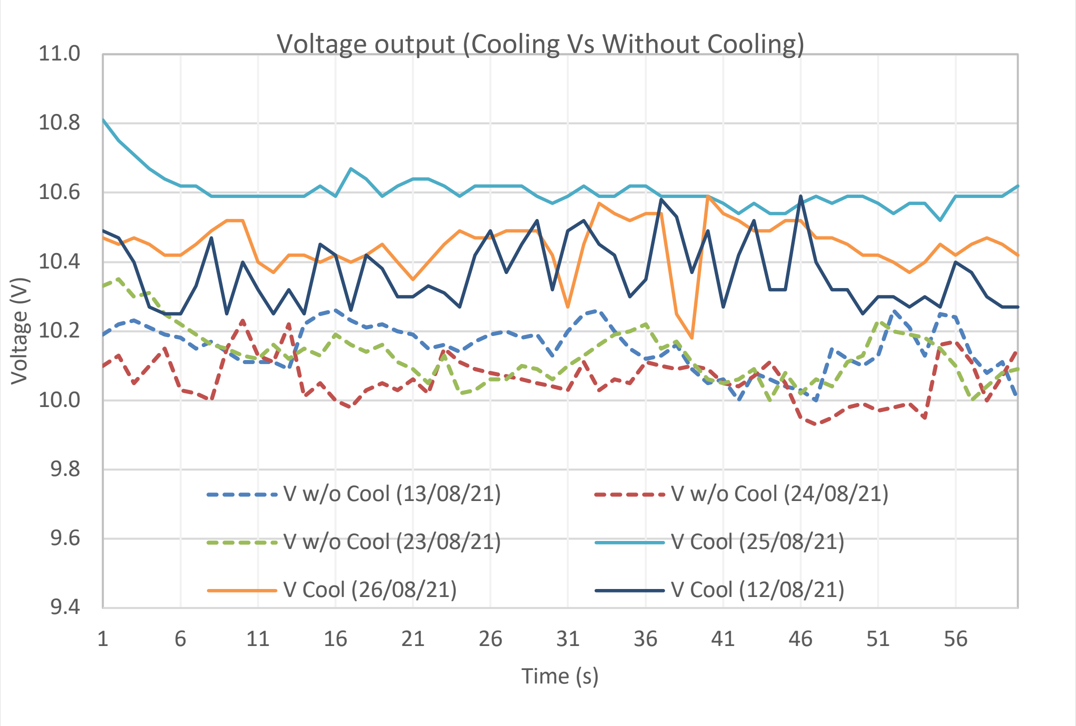

Fig. 8. The variation of voltage output after passive cooling system implementation

The average voltage output of PV panel with passive cooling system was 10.47 V compared to 10.12 V when PV panel is operating without the cooling system. These results accounted 0.36 V increment of voltage output that contributed to 3.53% voltage output improvement.

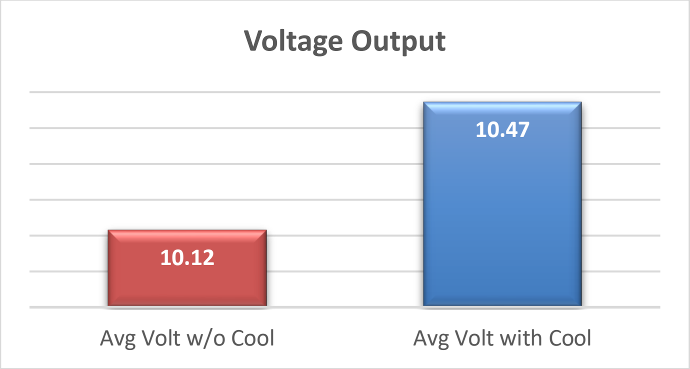

Fig. 9. The average voltage output of PV panel

As a verification, the result has been compared to the previous study that has been conducted by Koundiya *et al.*, in 2017 [21]. A similar trend was observed where the effect of cooling by heat pipe and fin has reduce the surface temperature and directly increase the power output of the PV panel.

4. Conclusions

The experimental data of passive cooling of PV panel using combination of heat pipe and heat sink is presented here. A small experimental PV panel size 234 x 340 x 3 mm with surface area of 0.08 m^2 is used in this study. The objective of this study is to enhance the PV panel power output by reducing the excessive surface temperature by passive cooling method. The comparison results between operating PV panel with passive cooling and without cooling is evaluated. The result has clearly shown that the passive cooling technique using combination of heat pipe and heat sink has able to reduce the surface temperature of 2.38 °C from 57.8 °C to 55.4 °C that contributes to the 4.12% surface reduction improvement. The reduction of the surface temperature has directly impact on the power output. The measured voltage shows that the installation of the passive cooling technique has increased the voltage output of 0.36 V from 10.12 V to 10.47 V that contributes to 3.53% voltage output improvement. The effect on power output improvement could be further increased if the surface area of the PV panel is larger if compared to the current size of PV panel. It means that the proposed passive cooling method has shown a promising potential to enhance the power output of PV panel in future.

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