

Investigation of the Effect Temperature on Photovoltaic (PV) Panel Output Performance

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Abstract— The main limit of PV systems is the low conversion efficiency of PV panels, which is strongly influenced by their operating temperature. Lack of accuracy in consideration through PV panel temperature increases the financial risk of system installation. This present study investigates the effects of operating temperature on monocrystalline PV panel at Perlis, Malaysia. A selected model of PV panel firstly was simulated using PVsyst software in order to evaluate its output performance. Meanwhile, PROVA 200 used to measure and record all electrical data for outdoor experimental during the sunniest day. Besides, the thermal distribution was analysed through PV panel temperatures and thermal imaging. Simulation results implied that the output power of PV panel decreases with increasing of its working temperature followed by the efficiency. The experimental results obviously show that the standard test condition (STC) parameters do not represent the real operating conditions of PV panel for outdoor conditions. Less output power was produced affected by the atmospheric factors such as solar irradiance and ambient temperature. These both factors strongly affected the PV panel temperature distribution. In short, the elevating of PV panel temperature contributed to the negative impact on output performance of the panel.

Keywords— PV panel; Solar irradiance; Ambient Temperature; PV Panel Temperature; Thermal Imaging

I. INTRODUCTION

Mostly, the PV panels have the major part of investment cost compared to another component in PV system installation. Thus, the return of investment for PV system depends mainly on the energy output performance of PV panels. Unfortunately, the PV panels normally operated into low conversion efficiency due the some factors of degradation. PV panel temperature considered as critical issues when forecasting energy production. For instance, long-time high temperature working conditions of PV panel can cause irreversible degradation of its electric output power. The high temperature caused by waste heat generated due to the absorption of solar irradiance. From the radiation falling onto a PV panel only up to 20% of the incident solar energy is converted to electricity [1]. The remaining major part is converted to heat. As consequences, the accumulated heat energy increases the PV panel operating temperature, hence leads to drop in its electrical efficiency. Under STC,

the conversion efficiency of the PV panel is decreased by about 0.40 - 0.50 % for each degree rise in temperature [2]. However, all data rarely meet the real sun conditions, as that depends on the specific climatic conditions of each location.

S. Chander et al. studied the effect of variation PV cell temperature under constant light intensities using a solar simulator. This study observed PV cell temperature has a crucial role in controlling the parameter's output. The temperature coefficient of the V_{oc} , P_{max} and fill factor (FF) were recognised to be negative while positive for the I_{sc} [3]. The effect of temperature on output power from different types of PV panel has been observed by P.K. Dash and N.C. Gupta [4]. By referring to the temperature coefficient of PV panel, monocrystalline experienced the highest losses in output power with average of $-0.446\%/^{\circ}C$.

Other, C. Temaneh-Nyah and L. Mukwekwe determined the ability of high temperatures which causes the power loses through PV panel. The result implied that the average energy lost by the 37.8 kW of PV system installation in

duration of 12 hours daily operation is 14.6 kWh caused by the elevated temperature. The coefficient temperature for power loss found about 0.31 % per Kelvin respectively [5]. Different type of PV panel technology has play a different role in generating output power caused by their sensitivity to the operating temperature. N. Suwapaet and P. Boonla explored that amorphous PV panel is most efficient rather than monocrystalline silicon when operated under high operating temperature condition. For instance, at the range solar irradiance of 600 W/m², the monocrystalline silicon produced less power than amorphous silicon with no differs much in PV panel temperature [6].

In this research study, temperature dependency of PV panel output performance was investigated. The remaining parts contain four sections as follows: Section 2 describes the details on a parameter of the PV panel used. Section 3 was analysed the effect of PV panel temperature on PV panel parameters using PVsyst software. Meanwhile, all measured and collected data for outdoor experimental will discuss in Section 4. The results were analysed based on the thermal and electrical aspects of PV panel performance output. Lastly, the conclusion is given in the last section.

II. MATERIAL AND METHOD

Firstly, the analysis of the PV panel output performance was simulated using PVsyst simulation software. By using this software, the basic data of PV panel can be explored as shown in Fig. 1. All data were determined under standard test conditions (STC) with a rating of 25 °C, 1000 W/m², and Air Mass 1.5 [7]. Apart from this, the capability of the PV panel performance can also be analysed as the efficiency of panel area is provided. The purpose of the simulation is to observe the effect of operating temperature on PV panel output performance. After all parameters have been identified, the next method is to analyse the PV panel performance through 'Graphs' window. As shown in Fig. 2, there are various type of graph that can be explored in order to analyse the PV panel performance. Apart from that, the miscellaneous graphs of performance PV panel with respected variety curve parameters can be observed through this step.

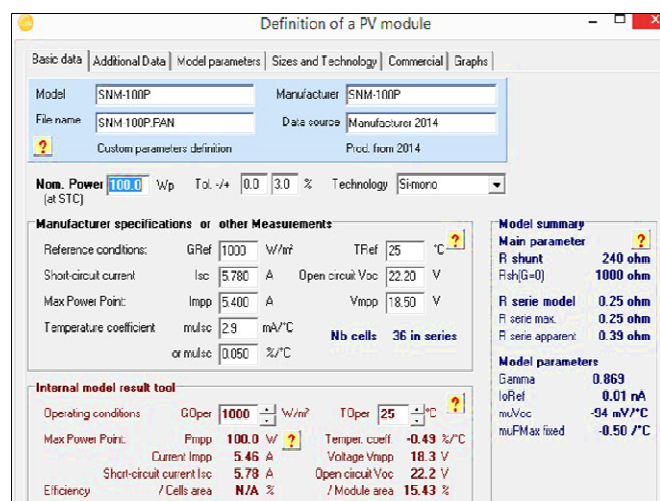


Fig. 1 Basic data of PV panel

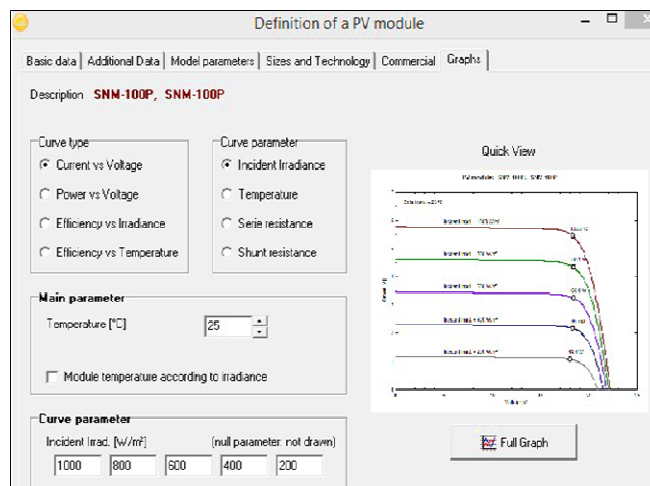


Fig. 2 Analysis of PV panel output performance through the 'Graphs' window

In this study, the PV panel output performance also was investigated under outdoor condition. Fig. 3 shows the photographic view for back side and front side PV panel through outdoor experimental. The same characteristics of PV panel as used in the previous simulation was tested at Centre of Excellence for Renewable Energy (CERE). This centre located in Malaysia lies on 6.43°N latitude and 100.19° E longitude. All data measured and recorded from 9.00 a.m. to 5.00 p.m. for 10 minutes interval. The electrical parameter generated from PV panel was measured using PROVA 200. Four units of LM 35 temperature sensors were attached at the back side surface of the PV panel in order to measure the average PV panel temperature during the day. Besides, the temperature distribution on the front side PV panel has been captured using FLIR thermal camera to observe the surface temperature of the PV panel.

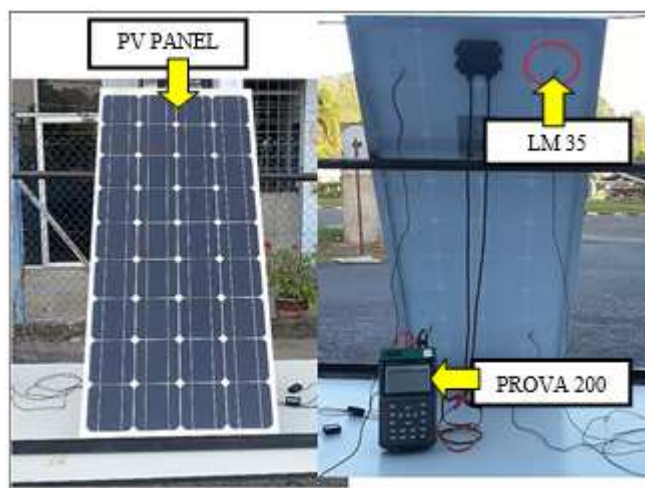
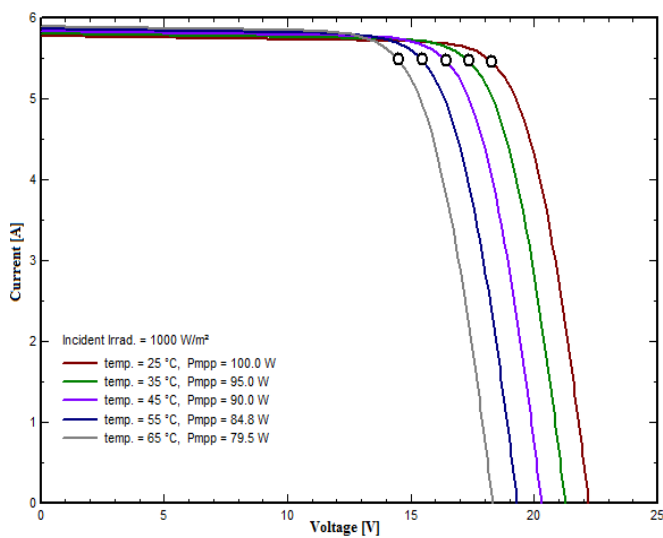


Fig. 3 Photographic view for outdoor experimental

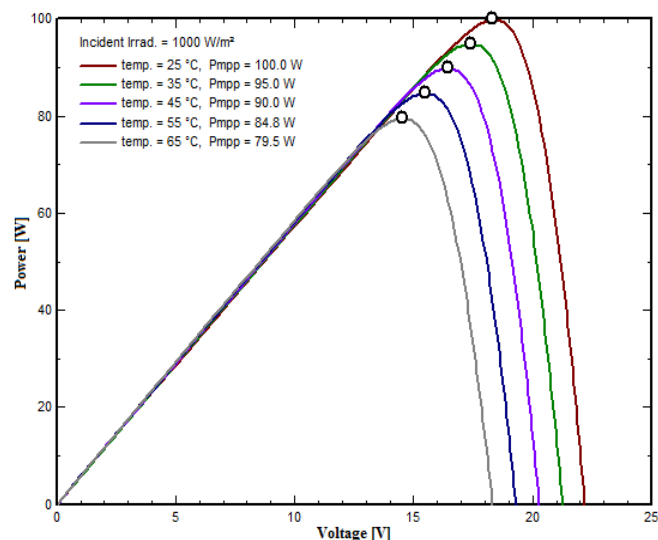
III. RESULTS AND DISCUSSION

A. PV panel output performance based on the PVsyst software

Fig. 4 shows the output power of PV panel with distribution PV panel temperatures at constant solar irradiance. These figures show the characteristics of current-voltage (I-V) and power-voltage (P-V) curves based on the various PV panel temperatures. Analyzing the both figures, if the PV panel temperature increased, it would cause the output voltage to decrease gradually. However, only slightly changes in the output current of PV panel with the increasing temperature. These figures observed increasing in 10 °C of temperature decreasing the output power about 5 W or 5%. Analyzing these figures, the minimum output power of PV panel was 79.5 W with the PV panel temperature of 65 °C. Meanwhile, its maximum was 100 W when the PV panel temperature was decreased to 25 °C.



(a) I-V curve



(b) P-V curve

Fig. 4 The characteristic of PV panel at constant 1000 Wm² solar irradiance with different PV panel temperatures

The potential of ambient temperature through a day usually dependent upon the variation of solar irradiance intensity. Site location which abundance with solar irradiance has a high potential in developing PV system with maximum output generated. Fig. 5 shows the characteristics of P-V curves at variation solar irradiance with constant ambient temperature and heat transfer rate. The average ambient temperature for surrounding environment was assumed to be 35 °C [8]. Meanwhile, the heat transfers coefficient (h_c) for free convection for PV panel was calculated to be 15 W/m² by using Equation (1) [9] with the average wind speed (v) of 2.5 m/s [10].

$$h_c = 5.7 + 3.8v \quad (1)$$

The simulated graph observed the increase solar irradiance increasing the PV panel temperature. Highest temperature found at maximum solar irradiance of 1000 W/m² and the lowest observed at low level radiation which is 200 W/m². There is about 49.43% differ in temperature between this two different level of solar irradiance. Besides, solar irradiance also has been a crucial factor for electrical power production of PV panel. As can be observed in this figure, the maximum output powers were increased with the increment of solar irradiance. Unfortunately, the rating power cannot perform 100% caused by the elevated PV panel temperature. The output power was observed in worse condition at a low solar irradiance.

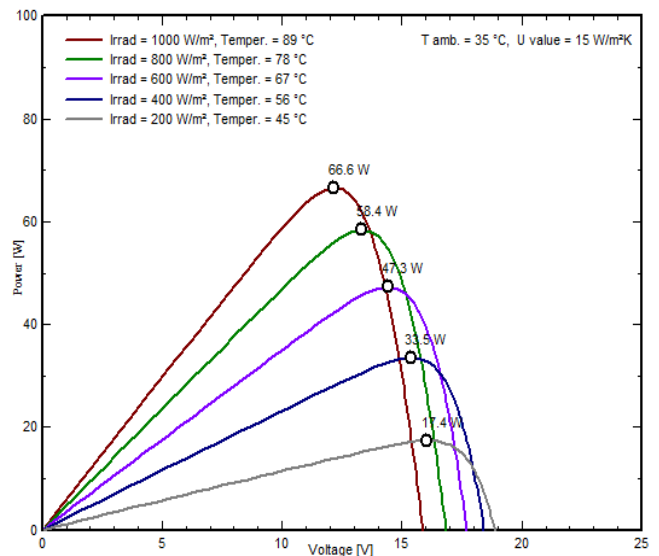


Fig. 5 P-V characteristics at various temperature and solar irradiance

The payback time of an integrated PV system is mainly determined by the efficient output power from PV panel. It is because PV panel was considered to be the main crucial component. Fig. 6 displays the effect of PV panel temperature on output performance of PV panel at different solar irradiance intensity. The highest output power of PV panel will be produced by a combination of high solar irradiance and low temperature. As illustrated in this figure, the most efficient power production by PV panel was 15.43 % when PV panel temperature was 25 °C at 1000 Wm². All these values were similar with the standard

test condition (STC) of the PV panel. Unfortunately, the efficiency of PV panel was decreased when it was exposed to high PV panel temperature. The efficiency was found in the worst condition by 12.27 % when PV panel temperature was 65 °C. Meanwhile, the efficiency became 13.08 %, 13.88 % and 14.66 % when the PV panel temperatures were 55 °C, 45 °C and 35 °C, respectively.

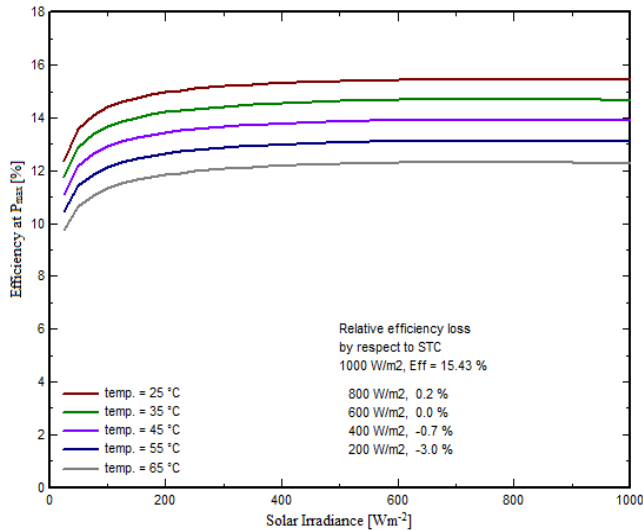


Fig. 6 Efficiency of output power at various PV panel temperatures and solar irradiance

B. PV panel output performance under outdoor condition

The output power of PV panel strongly depends on solar irradiance falling upon its surface. Fig. 7 shows the solar irradiance intensity during the experimental day. The amount of incoming solar irradiance is much higher in duration 11 a.m. until 2 p.m. which can be determined as the peak sun during the day. Thereby, it can be considered the site location has a big potential in installing the PV system [12]. The highest amount of solar irradiance was found at 12.40 p.m. with 899.49 W/m² where the minimum was 155.50 W/m² at 9.00 a.m. The low solar irradiance intensity might be due to a very short and a sudden blockage of the Sun disk with too heavy clouds.

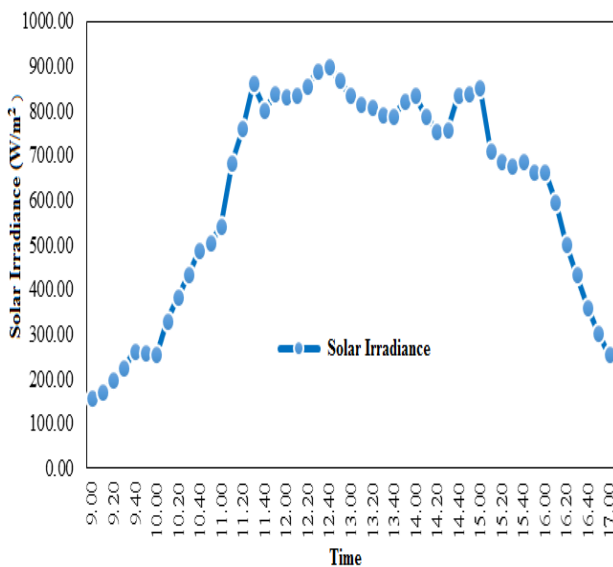


Fig. 7 The solar irradiance intensity through the experimental day.

Fig. 8 shows the potential of ambient and PV panel temperature affected by the solar irradiance intensity. Normally, high solar irradiance leads to the high ambient temperature. As observed in this figure, the ambient temperature was at low temperature in the early morning with 28 °C caused by the low solar irradiance intensity of 155.50 W/m². The ambient temperature during the experimental day starts to be increase with the increasing solar irradiance. The maximum ambient temperature was found at 899.49 W/m² by 38.99 °C, while the average for a day was 33.21 °C. In real working operation, the majority of solar energy productions occurs when the PV panel temperature is mostly higher than ambient temperature. The PV panel temperature starts to increase when solar irradiance was increased as well as the ambient temperature. There are so much differed between these two temperatures during peaks sun duration. The maximum PV panel temperature found at 890.12 W/m² by 63.20 °C while the minimum was 34.90 °C at the lowest solar irradiance. Besides, the average PV panel temperature throughout the day was determined by 56.96 °C. The increase of PV panel temperature was due to higher insolation heating, low wind speed with the consequent low heat transferred from the panel to the ambient.

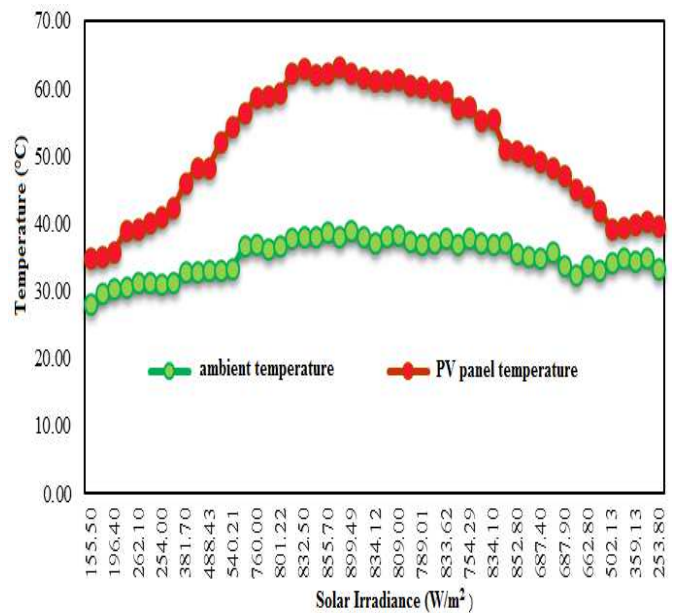


Fig. 8 The effect of solar irradiance on ambient and PV panel temperature

To ensure reliable operation during the lifetime cycle of a PV panel, thermal imaging camera plays a crucial role in identify any fault or damage. Variation temperature over the surface PV panel were captured during the peak sun hours was presented in Fig. 9. Thermography technique utilizes the cooler spots of the system by looking at the purple colored areas within the system as compared to the red zones. The results reported that measured temperature ranges distributed from 33.45 °C to 66.15 °C, respectively.

Fig. 9 (a) displays thermal imaging at 11.00 a.m. when solar irradiance was about 540.21 W/m² with ambient temperature of 33.45 °C. During this period, the average temperature (T_{av}) over surface of PV panel was 57.97 °C whereas maximum (T_{max}) value that a peak at 59 °C, while

the minimum temperature goes down to 34.67 °C. Hence, the temperature difference (ΔT) between surrounding and PV panel temperature was about 24.52 °C. In Fig. 9 (b), $T_{av} = 66.15$ °C was captured at the ambient temperature of 37.99 °C. This figure was captured at 12.00 p.m with solar irradiance intensity about 832.50 W/m². The ΔT was calculated to be 31.48 °C which by means the PV panel was considered operated poorly at the period of time.

Others, through Fig. 9 (c), at 1.00 p.m., a large ΔT between ambient and PV panel was observed. There was about 27.53 °C differ in temperature. With solar irradiance intensity of 834.12 W/m² and ambient temperature of 38.11 °C, the surface of PV panel temperature was increased to 65.41 °C. Fig. 9 (d) as well shows with solar irradiance intensity of 833.62 W/m² and ambient temperature of 37.13 °C, about 26.62 °C different in temperature can be calculated with PV panel temperature was 63.75 °C.

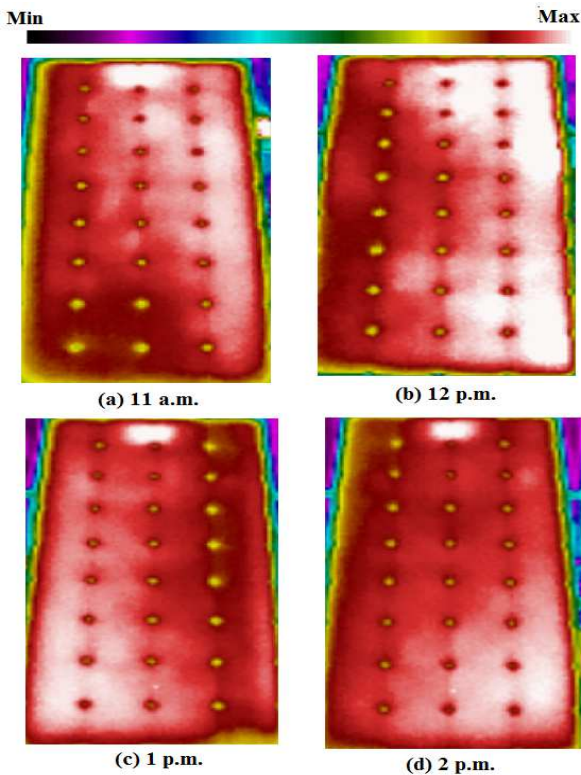


Fig. 9 Temperature distribution throughout surface PV panel during peak sun

The current-voltage (I-V) was measured in order to calculate the output power produced from PV panel. Fig. 10 shows the I-V characteristics of the PV panel throughout the experimental day. As can be observed, the output current obtained from the PV panel was slightly increased with the increasing of PV panel temperature. The output current seen starts to be increased from 11.00 a.m. to 2.00 p.m. which is at peak solar irradiance. The maximum output current was produced at 59.03 °C by 4.01 A. But only 0.78 A can be produced at 28.20 °C of PV panel temperature. A low amount of output current can be observed in minimum PV panel temperature, which means at low level radiation. Thus, the output current produced from the PV panel was changed in parallel with solar irradiance. The increasing output

current of PV panel generated with more incident energy absorbed during high temperature.

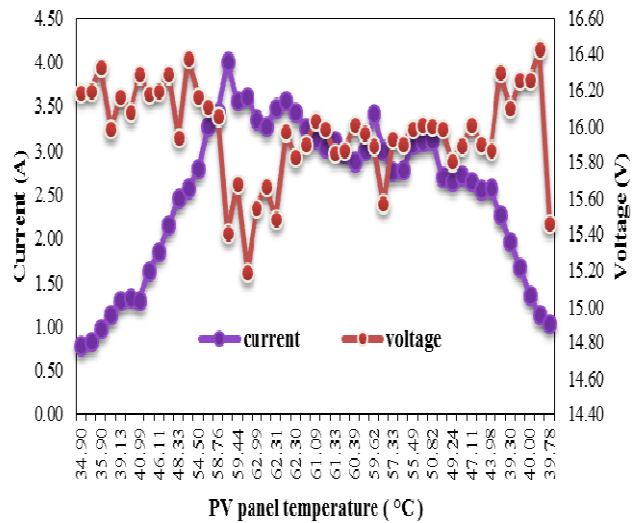


Fig. 10 Influenced PV panel temperature on I-V characteristics

Fig. 11 describes the overall total of output power generated by PV panel during the experimental. As shown in this figure, the maximum output power was found at 59.03 °C with 61.76 W whereas the minimum was identified at 34.90 °C which is 12.65 W. It can be observed output power of PV panel increase parallel with output current as well as solar irradiance. However, the output power from PV panel cannot fully be performed at its rated because of the existing elevated temperature throughout PV panel. Not efficient output power generated caused by the total production from the high output current and low output voltage. Davud et al. proved that the elevated temperature leads the voltage decreased but slightly increase the output current [14]. The increase of output current with the decreasing output voltage resulted in low production of electrical efficiencies of PV panel. Thus, the negative temperature coefficient of power resulted for PV panel [15].

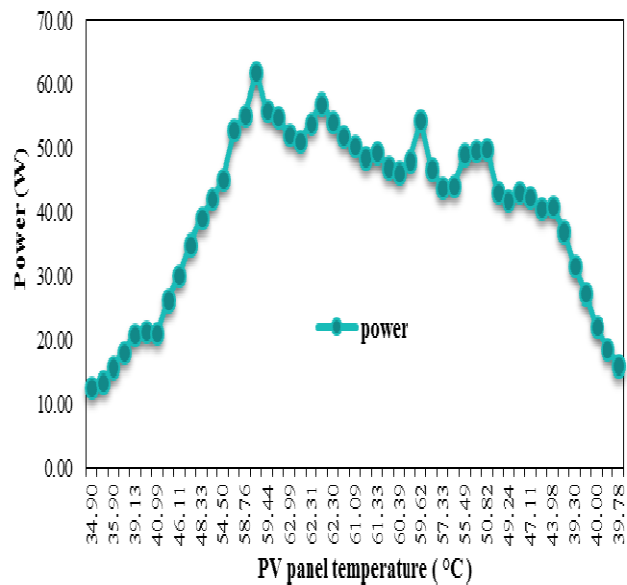


Fig. 11 Influenced PV panel temperature on output power of PV panel

Efficiency is the fraction of solar energy falling on the panel that is converted into electricity. Fig. 12 describes the efficiency PV panel output performance depending on PV panel temperatures. This figure discusses that the elevated temperature causes the efficiency of output power generated throughout PV panel decrease gradually. It well means the solar irradiance during peak sun period does not necessarily lead PV panel operated efficiently. High solar irradiance possibly increases the output power, but this effect was counterbalanced by the effect of the PV panel temperature which reduced the efficiency. Therefore, PV panel temperature can be considered as critical issues when forecasting energy production.

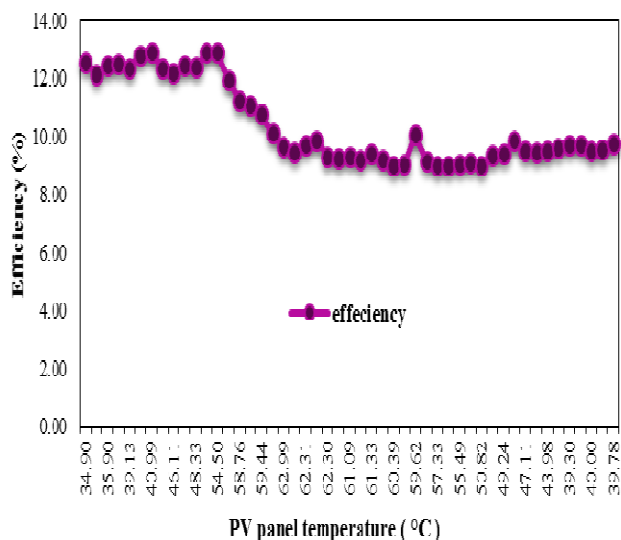


Fig. 12 Influenced PV panel temperatures on efficiency of PV panel

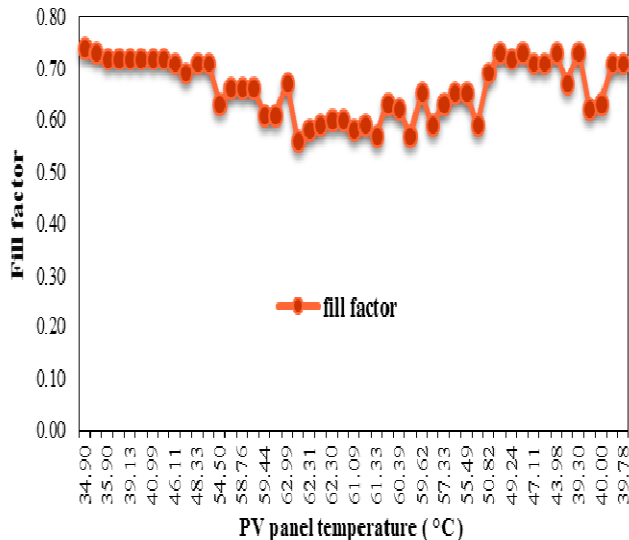


Fig. 13 Influenced PV panel temperatures on fill factor

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Fill factor is classified as an indicator in determined quality of PV panel. Typical fill factor values range is between 0.6 and 0.7. Fig. 13 shows the quality of PV module by analysing the range of fill factor. The figure indicates the PV panel performed in good quality firstly with the range above 0.7. Unfortunately, when the PV panel temperature

starts to increase, the value was dropped to the range between 0.5 and 0.6. Decreases in fill factor may indicate problems of the cell in the PV panel. The lowest fill factor found when the PV panel temperature reached at 62.10 °C with 0.56. Meanwhile, the high fill factor detected in the early morning with 0.74 when the PV panel temperature experienced in low value. For silicon PV panel, the fill factor is strongly affected by recombination current and ohms resistance.

IV. CONCLUSIONS

In this paper, the effect of PV panel temperature on its parameters was reported through simulation software and outdoor experimental. The effects of environmental factors such as ambient temperature and solar irradiance also were examined in order to investigate their effect on temperature and output performance of PV panel. Throughout simulation and experimental, there is strongly proved that the PV panel temperature plays a crucial role in output power production. Both methods show that the most significant changed by temperature was output voltage which reduces with the elevated PV panel temperatures. Reduction in output voltage causes the production output power of PV panel cannot be generated efficiently even there has increases of the output current. Furthermore, the quality operation of PV panel also decreases with the increasing of PV panel temperatures.

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