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Energy Efficiency Analysis of Photovoltaic Panel on its Operating Temperature

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Abstract: The impact and effect of photovoltaic panel temperature on the energy conversion efficiency of solar energy to electricity was studied empirically. In the analysis, the photovoltaic panel is placed under steady-state condition where the relative hvumidity and solar irradiance is assumed to be constant throughout the experiment. The preset conditions are necessary to ensure that other environmental factors such as wind velocity, ambient temperature and humidity have a negligible effect on the operating temperature of the photovoltaic module. In a steady-state controlled environment, the experimental results show that the measured voltage, current and its power decrease with time as the temperature of the photovoltaic panel increases. Consequently, the efficiency of the photovoltaic module will also decrease progressively. Thus, to maintain the efficiency of a photovoltaic panel, cooling technologies should be implemented to ensure the panel works within the optimized temperature. Therefore, the need to invent feasible solutions to decrease the operating temperature of the PV cells is vital.

Key words: Photovoltaic cell, panel temperature, solar irradiance, heating effect, efficiency

INTRODUCTION

The Photo Voltaic (PV) panel embodies a collective of photovoltaic cells assembled to transform solar irradiance into electrical energy through photovoltaic effect. The photovoltaic cells are made up of silicon and are extracted from the raw material of quartzite gravel. During the process, the quartz is crushed to obtain the silicon dioxide and the raw materials need to undergo a substantial semiconductor process until it can be used to produce photovoltaic cell.

The most essential characteristic of a photovoltaic panel is its ability to convert optimized electrical power efficiently from the amount of solar irradiance with minimal energy loss. Significant efforts have been made by researchers to improve PV panel performance such as decreasing resistive losses in series and shunt resistors (Glatthaar *et al*., 2010; Jager *et al*., 2013) reducing irradiance losses through light trapping and maximizing interband absorption (Escarre *et al*., 2012; Forbes, 2012; Luque *et al*., 2013).

The reliance between the efficiency of solar energy to electricity conversion and the operating temperature of PV cell signifies a vital research area for researchers. Many literature surveys (Fesharaki *et al*., 2011; Borkar *et al*., 2014) emphasize that the maximum power generated fluctuates almost linearly with the operating temperature. Moreover, it has also been discussed that the solar heating outcome differs with the photovoltaic materials, design parameters and ambient temperature. The quantification of PV panel temperatures is essential in determining the temperature constants that varies from PV panel design and materials. Various studies have been done to identify the optimum PV temperature in determining the robust design and sizes of PV module (Mohamed and Khatib, 2014; Skoplaki and Palyvos, 2009; Faiman, 2008). Researchers established a variety of correlations between environmental factors such as humidity, solar irradiance, wind velocity and ambient temperature effect to the heating outcome of the PV cells efficiency. Most of the predicted PV panel correlations are derived from the energy balance equation and further improved based on its suitable applications.

Despite the numerous contributions, the initiative in determining the efficiency of PV module for different operating temperature under a same solar irradiance and constant ambient temperature has not be reported so far. This research is aimed to investigate the effect of PV cell temperature on its efficiency during the conversion of solar energy to useful electricity with regards to the environmental factors such as solar irradiance, temperature and relative humidity. The behaviour and characteristics of the PV module will be investigated to determine the optimum operating temperature for the PV module during the energy conversion. The investigation is done using commercially available photovoltaic module

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in the hot wet climatic region such as Malaysia. The heating influence on the efficiency of PV cells will be evaluated based on steady-state and constant real-time solar irradiance and ambient temperature.

MATERIALS AND METHODS

A 10 W rated solar module with calculated area of 0.0735 m^2 was selected to conduct an experimental verification on the effect of the module's temperature on its efficiency. Figure 1 shows the circuit designed to measure the respective voltage, current and temperature of the solar module throughout the experiment.

In the experimental setup, the ammeter is used to measure the current, the voltmeter to measure the voltage and the solar meter to measure the solar irradiance. The solar irradiance and temperature is measured at various intervals to ensure both remain constant throughout the experiment.

The experiment is conducted in two scenarios, one without any load at the output and another has a 0.45 k Ω resistor with a LED as its load working under a controlled condition with constant illumination. The controlled condition that was setup up is to ensure that the temperature remain at 38°C with solar irradiance of 440 W/m^2 throughout the experiment. The purpose of having a controlled condition with constant illumination is due to the reasons that an increase of solar irradiance will cause an increase in the measured voltage. In fact, the intensity of solar irradiance, its surrounding temperature and speed of wind has a significant effect on the PV module temperature. Since, the purpose of the experiment is to determine the effect of solar module temperature on its efficiency, we must ensure that the solar irradiance and surrounding temperature remain constant throughout the experiment. Furthermore, an increase of solar irradiance will also cause an increased in the solar module temperature dramatically. It is also assumed that the absorption rate of solar irradiance is only 70% while the remainder of the solar energy is loss due to the reflection by the solar panel.

In order to observe the behaviour of the solar module based on the increased of its module temperature, the generated voltage and current of solar module will be measured respectively with its temperature. The efficiency of the solar panel η will be calculated using Eq. 1:

$$\eta = \frac{I_m V_m}{RA} \times 100\% \quad (1)$$

Where:

I_m = The measured current (A)
V_m = The measured voltage (V)
R = The solar irradiance (W/m^2)
A = The area of the solar cell (m^2)

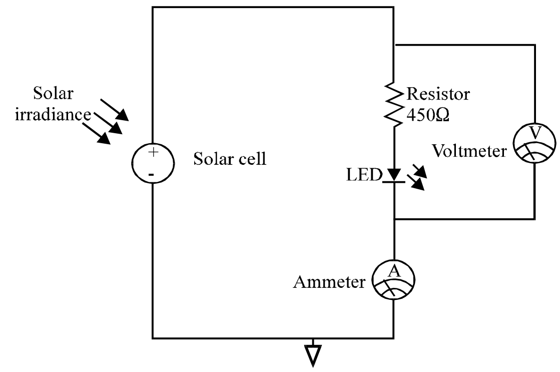

Fig. 1: A circuit diagram for measuring voltage, current and temperature of the solar module

Equation 2 gives the fill factor of the current-voltage characteristics of the solar panel, fill factor:

$$\alpha = \frac{I_m V_m}{I_{sc} V_{oc}} \quad (2)$$

Where :

I_{sc} = The short circuit current [A]
V_{oc} = The open circuit voltage [V] measured under the controlled condition

The effective power of the solar panel can also be calculated and is given by:

$$P_{eff} = \alpha I_{sc} V_{oc} \quad (3)$$

RESULTS AND DISCUSSION

In the experimental analysis, the change of the panel temperature under a constant irradiance and ambient temperature was observed. The response of the photovoltaic solar module to the variations of its temperature for the unloaded circuit and loaded circuit are measured and plotted accordingly as shown in Fig. 2. Both curves are showing a decreasing trend from the initial voltage of 21.1 and 18.9 V at the temperature of 34°C to 18.6 and 16.1 V at the temperature of 64°C, respectively. Even though the solar irradiance remains constant throughout the experiment, the PV cell temperature continues to increase due to the surplus heat accumulated on the module. This excess heat will provide energy to the intrinsic carrier in the semiconductor and causes an increase of dark saturation current.

The current of the solar panel is also measured throughout the experiment and is plotted accordingly as shown in Fig. 3. The current shows a step response downward trend for the unloaded circuit and a decreasing

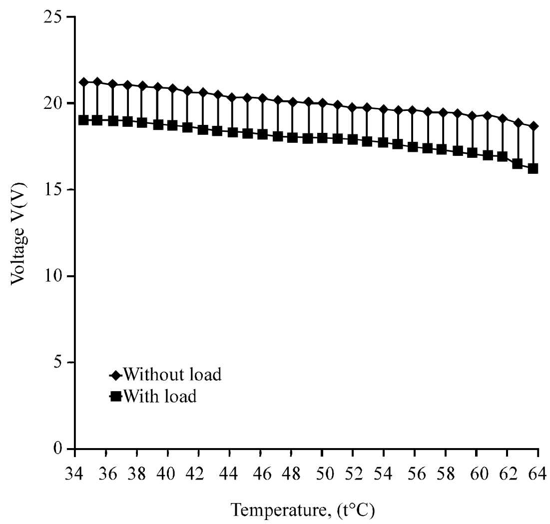

Fig. 2: Changes of voltage against panel temperature for solar module with and without load

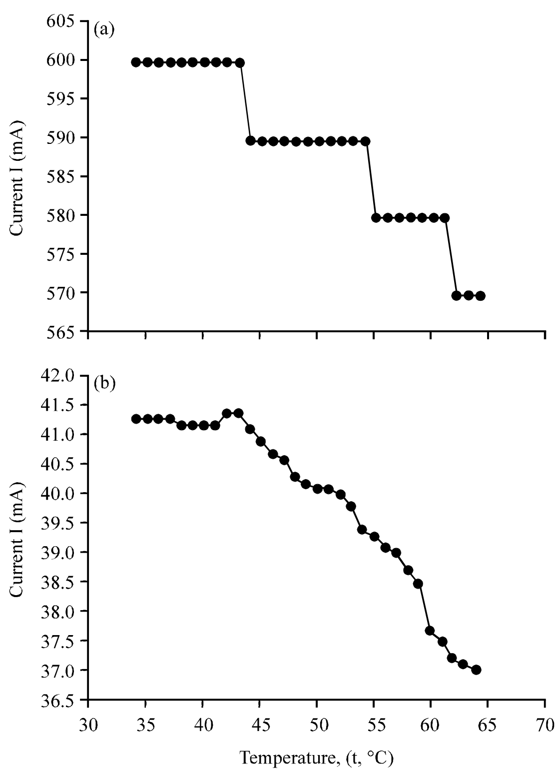

Fig. 3: Changes of current against panel temperature for the solar module: a) without load and b) with load

trend for the loaded circuit as the panel temperature increases, respectively. Theoretically, the current of the PV panel should increase with the increase of solar irradiance. This is due to the reason that as the heat

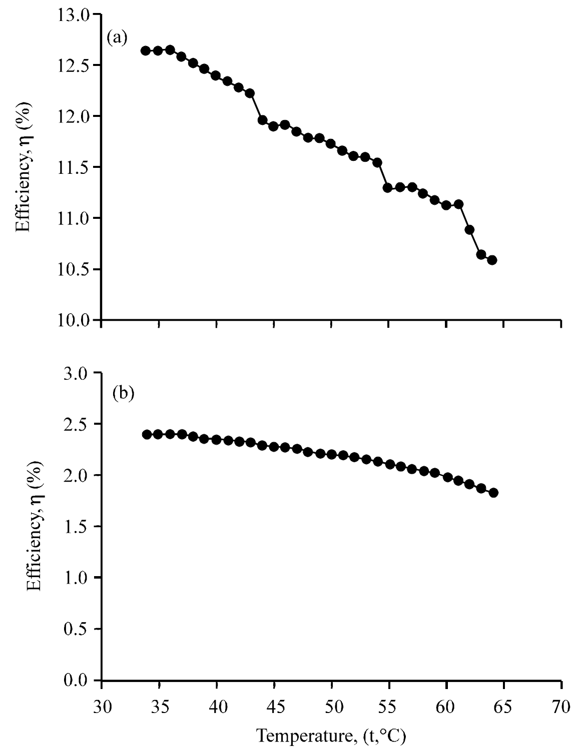

Fig. 4: Efficiency loss of solar modules due to panel temperature: a) without load and b) with load

increases, the silicon band gap will be reduced which in turn causes the photon generation rate to surge rapidly and causes reverse saturation current to increase. However, for this experiment, the solar irradiance is ensured to remain constant throughout the measurements as the characteristics of the current is observed. It seems that the current remain constant throughout 10°C and then decreases by about 10 mA for the unloaded circuit. Moreover, the loaded circuit also shows a progressive decrease of current as the panel temperature increases.

It is observed in the experiments that as the temperature of the solar panel increases, the measured voltage and its respective power decrease with time. This phenomenon causes a loss of efficiency in the solar module. The band gap in the silicon layer of the solar module will be reduced when the panel temperature increases. Consequently, it causes an increase of dark saturation current as the concentration of intrinsic carrier in the semiconductor increases. In order to further relate the influence of the module temperature on the efficiency of the solar panel, the measured voltages and current is re-plotted as power against panel temperature. Figure 4 shows the efficiency losses of the solar panel due to the increase of panel temperature. The efficiency of the solar

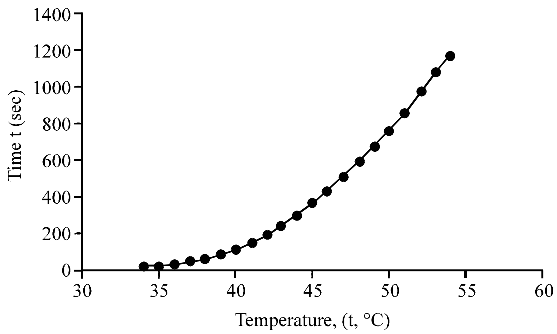

Fig. 5: Time taken for the PV panel temperature to reduce its efficiency by 10%

panel reduces by approximately 0.27-0.77% with an increase of 1°C in the panel temperature. Different photovoltaic modules will react differently with the change of panel temperature as the temperature coefficient changes substantially based on the materials and design of the solar module. Therefore, additional cooling mechanism should be applied appropriately in recovering the PV module efficiency.

The results had shown that if the solar panel is being used directly under the sun with constant irradiance, the PV panel temperature will increases progressively and indirectly causes the efficiency to decrease by approximately, 23.69% when it the circuit is connected with a load. Similarly, if the same solar module is applied to charge up the storage cells, it is reasonable to assume that the efficiency of the solar panel will also decrease by 23.69% or more.

Subsequent to this experiment, the time taken for the PV temperature to increase and causes an efficiency loss of at least 10% is also measured accordingly. The initial power generated by the circuit with load is 0.781 W at the PV panel temperature of 34°C. It is observed that when the PV panel temperature increases up to 54°C, the efficiency drops to 0.7029 W about 10% loss from the initial power generated. Figure 5 shows the time taken for the PV panel temperature to increase from 34-54°C. The results shows that the PV panel temperature increases exponentially with time. Theoretically, the PV panel should reach a steady state condition and remain saturated within definite time frame. Therefore, in order for the PV panel to retain its efficiency, cooling measures and mechanism should be activated within 15-20 min to ensure power loss does not exceed 10% of its initial power generated.

CONCLUSION

The effect of the PV panel temperature on its output current, voltage, power and panel efficiency under constant solar irradiance and ambient temperature has been studied and analyzed. The time required for the PV module to yield a power loss of at least 10% of its initial power is also evaluated to facilitate the implementation of the cooling mechanism to aid in improvement of the PV module efficiency. Thus, since the efficiency of the PV module is directly affected by its operating temperature, attentiveness in keeping the PV module temperature within an allowable range is essential to ensure that the solar energy harvesting module is harnessing and producing optimized electrical power throughout the day.

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