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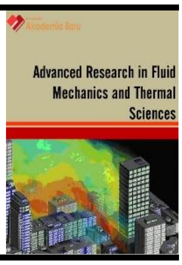

Performance Evaluation of Polycrystalline Photovoltaic Module based on Varying Temperature for Baghdad City Climate

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ABSTRACT

The impact of the solar photovoltaic cell temperature on module output performance parameters is investigated experimentally under conditions of Baghdad city climate in the present study. The tests are conducted using a test rig for Polycrystalline silicon solar panel with rated capacity 300W and equipped with measuring devices. Test conditions are based on three months duration, June, July and August of year 2019 through the period from 8AM to 4PM per day. This period represents the highest ambient temperatures through summer months in Baghdad city in Iraq. The results have shown that, under the test conditions for cell temperature with range 45-65°C a significant reduction in the output power, efficiency and fill factor with module temperature rise were observed. The loss in the open circuit voltage and output power of the photovoltaic module was about -0.104/°C and -1.3/°C respectively. The reductions in the current and voltage at maximum output power with temperature increasing were about -5.24% and -5.45% respectively. The drops in the efficiency and fill factor of the photovoltaic module due to the module temperature increase were 9.62% and 12.96% respectively compared to that at standard conditions. The temperature coefficient of the maximum power was -0.52% for the solar photovoltaic module under test conditions.

1. Introduction

The performance of the solar photovoltaic (PV) module can be significantly influenced by environment variables such as ambient temperature, wind speed, dust accumulation, and relative humidity. The efficiency and output power of the PV module are observed to be decreased with module temperature rise due to the solar radiation energy accumulated in the photovoltaic panel. This problem can be observed in hot climate regions such as in Baghdad city under current study which is located in Iraq at North West of Asia at latitude 33°19′ north and longitude 44°25′ east. At

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this city the ambient temperatures are relatively high at sunshine hours during summer months, June, July and August where the maximum daily temperature may reach more than 50 °C. At such extreme environment conditions, the reduction in efficiency and output power becomes major aspects in design of PV cell system for electrical power production.

The objective of the present study is to investigate experimentally the effect of solar PV module temperature on output power under Baghdad city climatic conditions. Many research works have focused on the effect of solar photovoltaic cell temperature on cell performance parameters [1,2]. Tiwari [3] introduced a study to evaluate the performance of the hybrid photovoltaic and thermal system for climate of India. He concluded from the results that, utilizing the thermal energy in photovoltaic module was significantly increased the overall thermal efficiency of the system. Many researchers such as Sing and Ravindra [4], Dubey *et al.,* [5], Abdullah *et al.,* [6], and Bayrakci *et al.,* [7] developed models and correlations to investigate the temperature dependence of PV module efficiency and output power. They found that the electrical power output and efficiency of PV module were significantly depended on the PV module temperature which is influenced by ambient conditions variation. Huang *et al.*, [8] introduced a method to measure the solar cell junction temperature at different environment temperature and irradiation. This method was based on indoor solar simulator tests to show the dependence of solar cell open circuit voltage on cell temperature. The effect of climatic conditions such as ambient temperature, wind speed and irradiance on solar cells performance was studied by Koehl *et al.*, [9], Chikate and Sadawarte [10], Chandra *et al.,* [11] and Jaszczur *et al.*, [12]. The experimental analysis done by the researchers was based on outdoor tests to investigate the impact of climatic conditions on performance parameters of the solar cells and to validate the related models and correlations. Among the environmental parameters that are considered in these studies, the module temperature was a key parameter in evaluation of Photovoltaic cell efficiency. Ciulla *et al.,* [13] proposed a method based on artificial neural networks to predict the operating temperature of PV module and compared with experimental data and some empirical correlations developed by many researchers. Muzathik [14], Abdullah *et al.,* [15] and Leow *et al.,* [16] developed models to estimate the operating temperature of the photovoltaic modules and PV panel behavior in different temperature and irradiance conditions based on simulations using MATLAB and ANSYS softwares. Ali et al*.,* [17] presented a study to evaluate the PV cells performance using micro-channel cooling. The method is based on experimental investigations and computational fluid dynamic approach to assess the influence of PV cell surface temperature on cell performance in hot climates such as in Pakistan. Experimental investigations to evaluate the effect of ambient and PV module temperatures on module performance parameters are carried out by Gedik [18], Adeeb *et al.,* [19], Hashim and Abbood [20] and Fahad [21]. These researches are based on real experimental data included, solar panel back surface temperature, open circuit voltage, short circuit current and output electrical power to determine the actual module efficiency at ambient temperature variations. Kazem and Chaichan [22] and Al-Kouz *et al.,* [23] carried out experimental works to evaluate the impact of PV module temperature on module efficiency beside to other environmental influences such as dust accumulation, humidity and wind speed. Their results have revealed a significant effect of temperature on the cell efficiency relative to other variables. Alshayeb and Chang [24] investigated experimentally the energy output of photovoltaic panels when installed at different building roofs to find the effect of roofs type on panel temperature. The variations of PV panel energy output for different building roofs are determined and the results have revealed higher energy output for green roofs compared to black roof. Saad and Al-Tmimi [25] used simulation model based on database of the Photovoltaic Geographical Information System to estimate the effect of environmental parameters on the monocrystalline PV cell temperature. The analysis is applied at different sites in

Iraq and it is found that, the cell output power was significantly influenced by solar radiation compared to the cell temperature. The performance of the floating photovoltaic module (mounted near the water surface) was studied by Charles *et al.,* [26]. The study is based on experimental data to develop a predicting model to estimate the PV cell temperature and efficiency for floating PV module depending on the environmental variables.

2. Methodology

2.1 PV Module Performance Analysis

The PV module surface temperature has a significant effect on Photovoltaic performance parameters. To evaluate these parameters, the following relations are based in the analysis. The efficiency of PV module is determined as follows [27,28]:

$$\eta_{md} = \frac{P_{md}}{G\,A_{md}} \tag{1}$$

where G is solar radiation (W/m^2), A_{md} is PV module area (m^2) and P_{md} represents the maximum power of PV module which is expressed by:

$$P_{md} = I_{mp}\,V_{mp} \tag{2}$$

where, I_{mp} (Ampere) and V_{mp} (Volt) are the measured current and voltage respectively at maximum output power of the PV module as depicted in Figure 1. The efficiency of PV module can be also expressed by:

$$\eta_{md} = \frac{FF\,I_{SC}\,V_{OC}}{G\,A_{md}} \tag{3}$$

where I_{SC} is the short circuit current and V_{OC} is the open circuit voltage, and FF represents the fill factor of solar cell which is determined by [29]:

$$FF = \frac{I_{mp}\,V_{mp}}{I_{SC}\,V_{OC}} \tag{4}$$

Many researchers have derived equations and correlations to evaluate the effect of the solar cell temperature on PV module efficiency. The following equation is commonly used to estimate the actual efficiency based on solar cell temperature [30]:

$$\eta_{md} = \eta_{rf}\,[\,1 - \beta_{rf}(T_{md} - T_{rf}) + \gamma log_{10}\,G] \tag{5}$$

where η_{rf} is the module electrical efficiency at standard cell temperature T_{rf} =25°C, β_{rf} is temperature coefficient and T_{md} is the actual measured temperature of the PV module surface.
η_{rf} and β_{rf} represent typical quantities of PV module which are given in the data sheet by module manufacturer. For the PV module considered in the present study (η_{rf} = 15.6% and β_{rf} = 0.4%).

The solar radiation coefficient γ represents material property, γ = 0.12 for monocrystalline silicon cell. The latter term in Eq. (5) is usually taken as a zero and the equation is reduced to [31]

$$\eta_{md} = \eta_{rf}\,[\,1 - \beta_{rf}(T_{md} - T_{rf})] \tag{6}$$

2.2 Experimental Setup and Methodology

The experimental tests are conducted at the Renewable Energy Center of the Middle Technical University-Baghdad under the outdoor environment. Solar polycrystalline silicon module with rated capacity 300W of model Orex: AR-M300W is used in the tests with specifications listed in the Table 1. The current-voltage (I-V) and power-voltage (P-V) characteristic curves of the PV module at standard conditions, G=1000W/m^2 and T_{md} =25˚C are illustrated in Figure 1. The PV module was installed on movable steel stand and arranged at angle 35° with horizontal level to be directed toward the sun radiation as shown in Figure 2. The PV module was connected with electrical circuit with power supply to apply DC load via control board. The test rig which is fabricated during the current study was also supplied with variable speed air fan for cooling the back surface of PV module to control the module temperature. Solar PV tester of model SEAWARD PV200 was used to measure and analyze the PV module performance characteristics as illustrated in Figure 3 with the wiring diagram. This tester can provide the I-V and P-V curves with measurement range 5-1000V DC for open circuit voltage and 5-15A DC short circuit current. PV200 tester was connected with solar AC/DC clamp meter to measure DC voltage and current with range 0-999.9V and 0-99.9A for voltage and current respectively. Solar Survey irradiance meter of model SEAWARD R200 was used to measure the irradiance, ambient temperature and cell temperature simultaneously. The measuring range of this meter is 100 - 1250W/m^2 for irradiance and -30 to 125˚C for temperature. Six K-type thermocouples in range of -200 to 1250 ˚C and data logger of model PCE-T 1200 were used to measure and display the ambient and PV module temperature readings. One thermocouple was used to measure ambient temperature and five thermocouples were mounted on the back surface of PV module to measure the module temperature as shown in Figure 2. The average reading of the five thermocouples was based in the analysis of the solar cell surface temperature. The measurements of PV module performance characteristics and module temperature were conducted during three months, June, July and August of year 2019. The measurements were taken through sunshine hours of day from 8AM to 4PM at wind speed less than 5 m/s for three months and the average readings are considered in the results analysis. The PV module output performance characteristics included, open circuit voltage, short circuit current, output power, voltage and current at maximum power, ambient and module temperatures are recorded at every hour per measuring period using measuring devices. Uncertainty in the experimental measurements is illustrated in the Table 2.

Table 1
Specifications of the solar polycrystalline silicon module of model Orex: AR- M300W at standard conditions

Rated maximum power	300W
Tolerance (%)	0 ~ +3%
Voltage at P_{mp} (V_{mp})	36V
Current at P_{mp} (I_{mp})	8.33A
Open circuit voltage (Voc)	42.8V
Short circuit current (I_{sc})	9A
Temperature coefficient of P_{max}	-0.4% /oC
Size	1955x990x40 mm

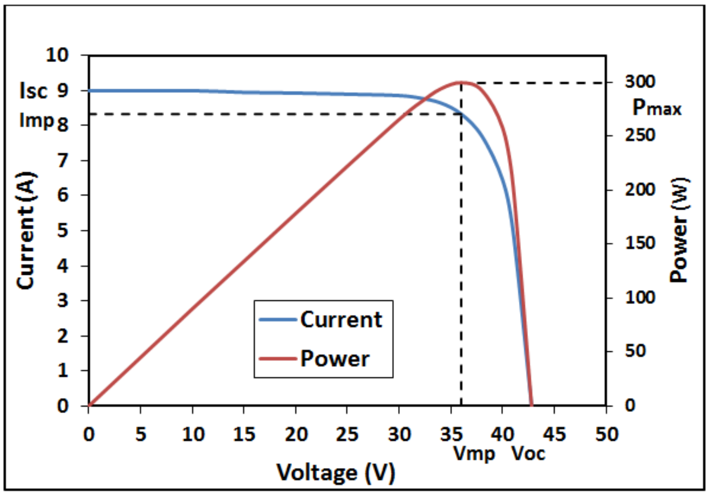

Fig. 1. Characteristic curves P-V and I-V of the solar PV module

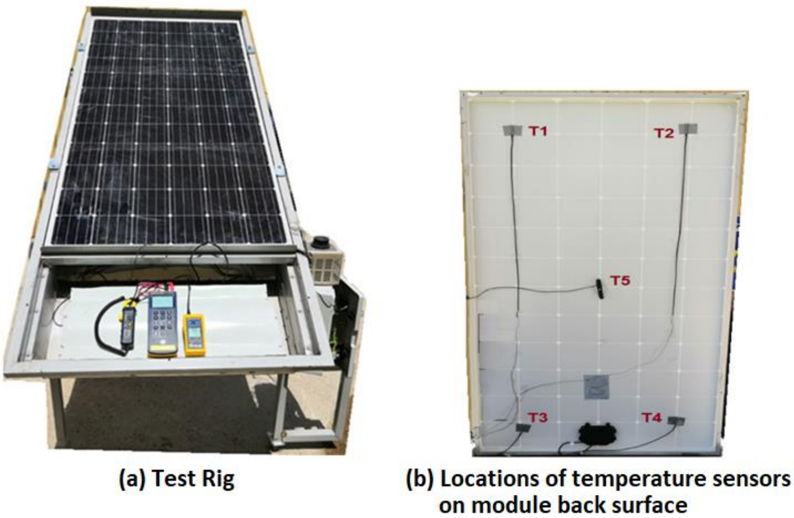

Fig. 2. Experimental setup, (a) Test rig, (b) Locations of temperature sensors on module back surface

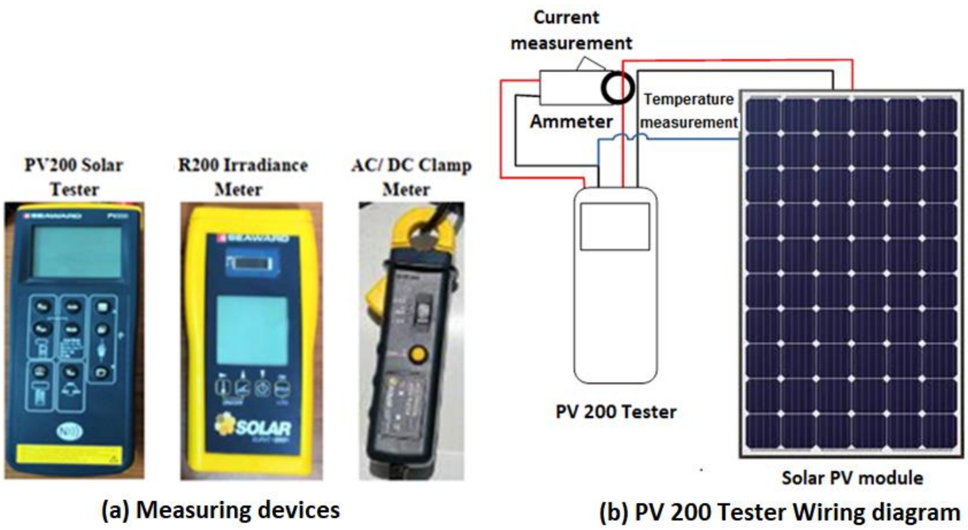

Fig. 3. (a) Measuring devices, (b) PV 200 solar tester wiring diagram

Table 2
Accuracy of the experimental measurements

Variables	Accuracy
Temperature readers (°C)	± 0.02
DC Voltage (V)	± 0.01 V
DC Current (A)	± 0.01 A
Irradiance (W/m2)	± 5 W/m^2
PV module power (W)	± 0.02 W

3. Results

To investigate actually the impact of PV module temperature on photovoltaic performance parameters, the results analysis is based on experimental tests taken through the peak sun duration per day from 8AM to 4PM for three months, June, July and August. This duration represents the highest ambient temperatures through summer months in Baghdad city in Iraq. The variations of ambient temperatures with time per day during the test period are illustrated in Figure 4. Relatively higher temperatures (greater than 40°C) were observed during the hours 11-16 per day. Figure 5 shows the variation of the module temperature with hours per day recorded for months June, July and August. The main reasons behind the module temperature increasing are due to the change in ambient temperature, wind speed and heat transfer rate between module surface and ambient.

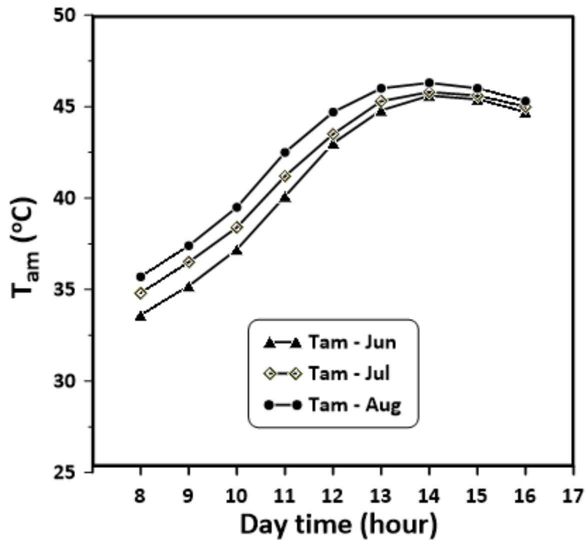

Fig. 4. Variation of the ambient temperature T_{am} with day time for months June, July and August

The variations of global solar radiations with time through the test duration were recorded using R200 solar irradiance meter as illustrated in Figure 6. Solar radiations during month June reflected higher rates compared to the other months which are came approximately identical with the statistical data of radiation rates for Baghdad city. Average ambient and module temperatures variation with time for the three months of tests are considered for the purpose of PV module performance parameters analysis as illustrated in Figure 7. Module temperatures greater than 60°C were noticed during the hours 13-15 per day which represent the peak hot period during summer months in Baghdad city.

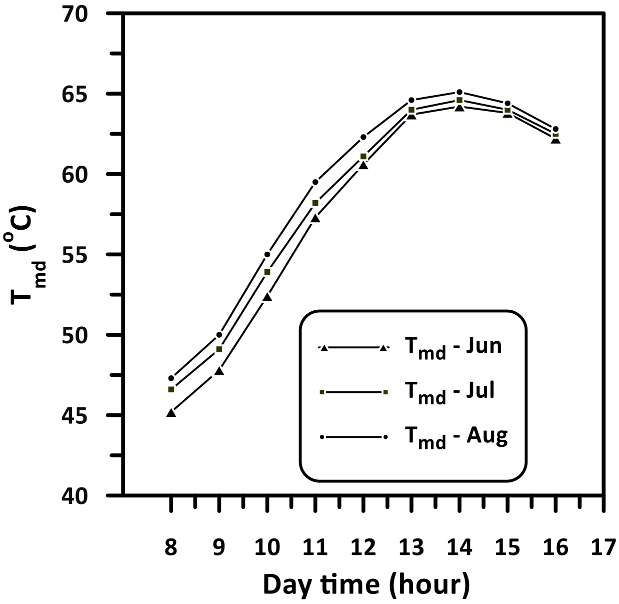

Fig. 5. Variation of the solar PV module temperature T_{md} with day time for months June, July and August

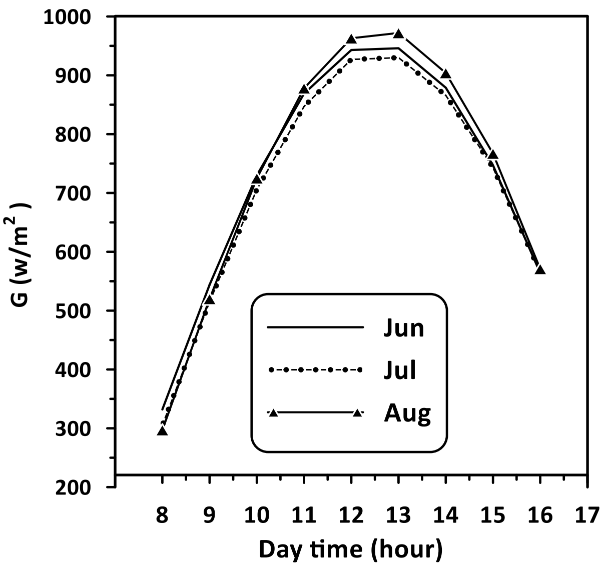

Fig. 6. Variation of the solar radiations with day time for months June, July and August

The power-voltage (P-V) characteristic curves of the PV module at different irradiance are shown in Figure 8. The P-V characteristic curves are plotted for three prescribed values of the irradiance 700, 800 and 900W/m^2 which reflected the higher irradiance through the test period for hours 10-15 per day and compared with that at standard conditions 1000 W/m^2. The variation in the irradiance will yield a change in the accumulated solar energy received by PV module and increases the module temperature which is result in reduction in module output power. The influence of PV module temperature on output power can be clearly noticed in Figure 9. Based on relatively higher cell temperature in range 45-65°C recorded during the PV module tests, a significant drop in the output power with module temperature compared to that at standard conditions 1000W/m^2 can be observed in this figure.

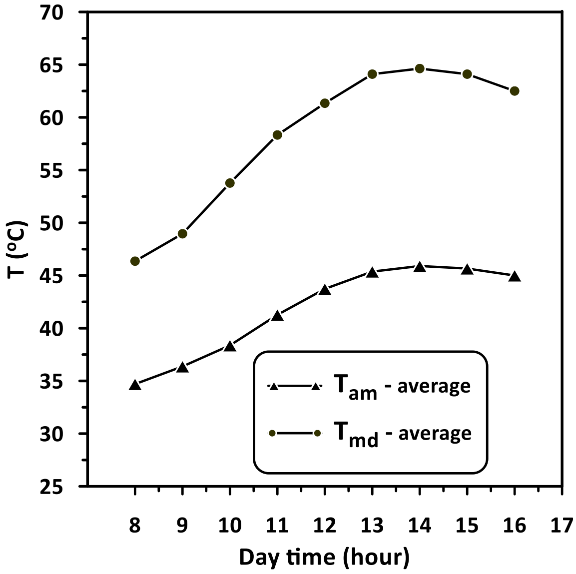

Fig. 7. Variation of the average ambient temperature T_{am} and PV module Temperature T_{md} with time during the test period

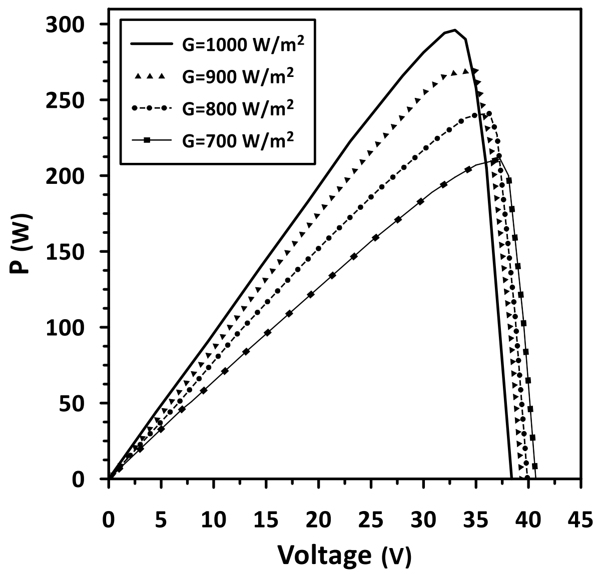

Fig. 8. Power-voltage characteristic curves at different solar irradiance

For the purpose of PV cell performance comparison at different cell temperatures, irradiance in range of 900-1000W/m^2 and relatively higher module temperatures 45, 55 and 65°C are based in the analysis as illustrated in the Figures 10, 11, 12, 13 and 14. Figure 10 shows the current-voltage characteristic curves at different module temperatures 45, 55 and 65°C compared to that at standard conditions temperature 25°C. A significant loss in open circuit voltage and slight increase in short circuit current as the temperature of the PV module rise above 25°C can be observed in this figure. The semiconductor material in the solar cell is sensitive to the temperature, where a decrease in the band gap of a semiconductor can be occurred with increasing temperature. This behavior will increase the energy of the electrons in the semiconductor of the solar cell and then reduces the output power of the PV module as shown in Figure 11.

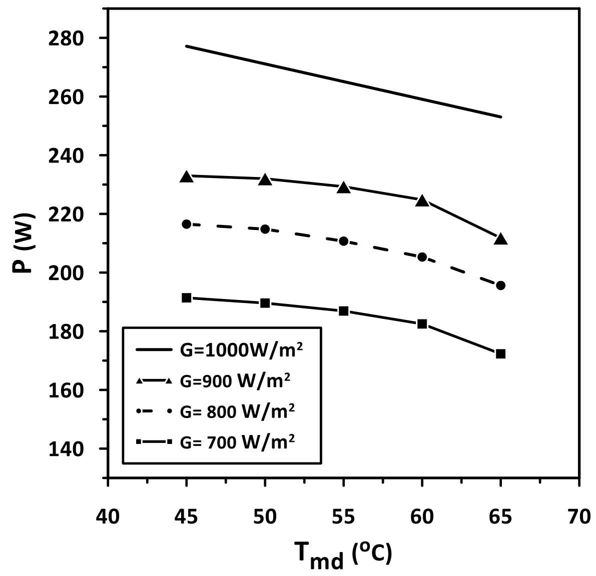

Fig. 9. Variation of the PV module output power with module temperature at different solar irradiance

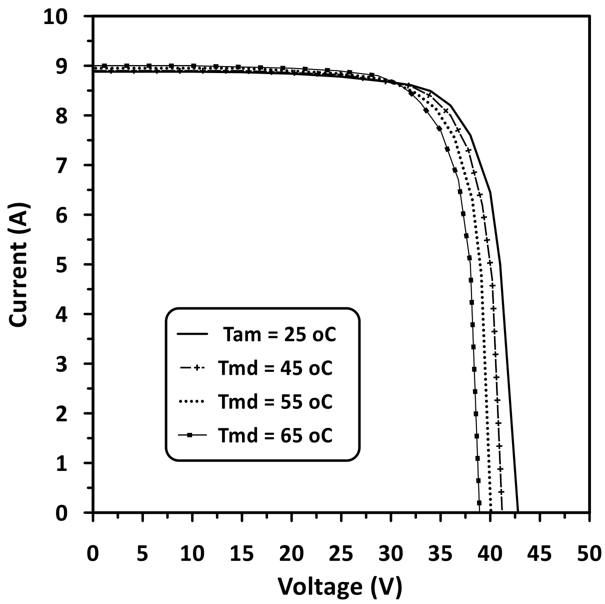

Fig. 10. Current-voltage characteristic curves different PV module temperatures

The effect of module temperature on output power is clearly depicted in the power-voltage characteristic curves as illustrated in Figure 11. The reduction in measured open circuit voltage and output power due to the module temperature increase was about -0.104/°C and -1.3/°C respectively. Variations of the measured PV module current and voltage at maximum output power with module temperature are depicted in Figure 12. The drops in current and voltage at maximum output power caused by the increase in the cell temperature are about -5.24% and -5.45% respectively. Efficiency and fill factor of the PV module at module temperature in range of 45-65°C are evaluated as illustrated in Figure 13. A significant reduction in the PV module performance with temperature can be observed compared to the module efficiency 15.6% and fill factor 0.779 at standard conditions. Based on the actual measurements of module performance parameters, the reductions in the efficiency and Fill factor were 9.62% and 12.96% respectively compared to that at standard conditions. The rate of maximum output power drop with module temperature increasing is depicted in Figure 14. Under the actual ambient conditions considered in the tests, the temperature coefficient of the maximum output power was -0.52% for the PV module. This value of output power temperature coefficient seems higher than that recommended for the solar photovoltaic cells at standard conditions (-0.4%) due to the extreme hot test conditions based in the current study.

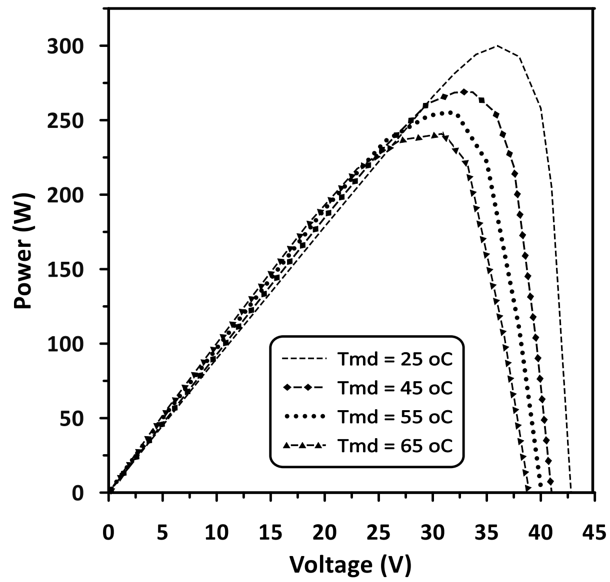

Fig. 11. Power-voltage characteristic curves at different PV module temperatures

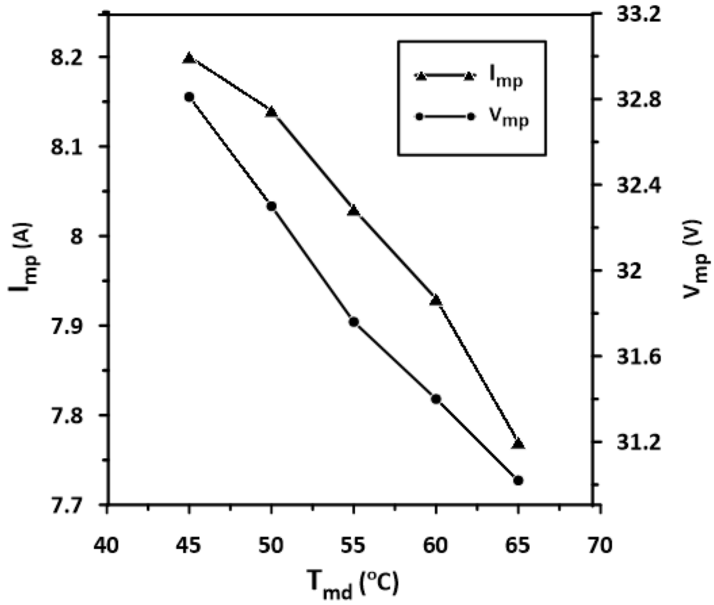

Fig. 12. Variations of the current and voltage at maximum output power with module temperature

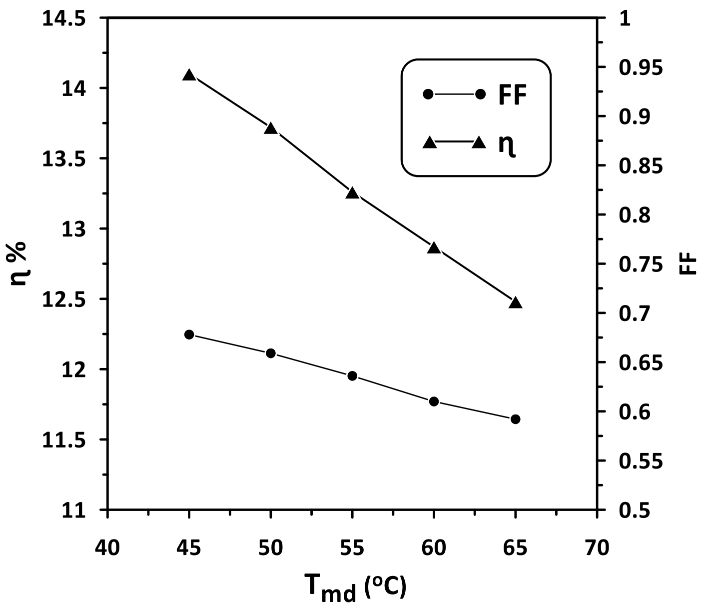

Fig. 13. Variations of the PV module efficiency fill factor with module temperature

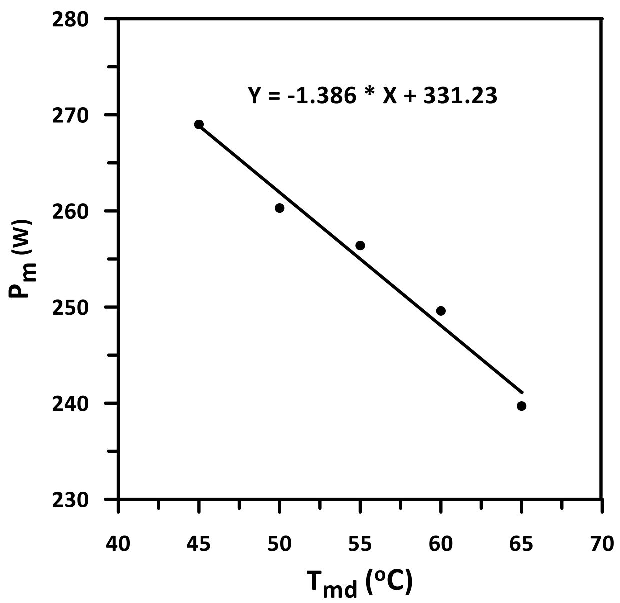

Fig. 14. Maximum output power versus PV module temperature

4. Conclusions

The efficiency and output power of the PV module are observed to be decreased with module temperature rise due to the solar radiation energy accumulated in the photovoltaic panel. The results have shown that, at cell temperatures with the range 45-65°C a significant reduction in the output power, efficiency and fill factor with module temperature rise were observed. The loss in the open circuit voltage and output power of the PV module was about -0.104/°C and -1.3/°C respectively. The reductions in current and voltage at maximum output power due to the temperature increase were about -5.24% and -5.45% respectively. The drops in the efficiency and fill factor of the PV module due to the module temperature increase were 9.62% and 12.96% respectively compared to that at standard conditions. Under the test conditions, the temperature coefficient of the maximum output power was -0.52% for the solar photovoltaic module which seems higher than that at standard conditions (-0.4%).

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