



Effect of Solar Module Operating Temperature on Electric Parameters of Photovoltaic Monocrystalline Module

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Article Info	ABSTRACT
<p>Received: 04 March 2026 Revised: 30 March 2026 Accepted: 30 March 2026 Available online: 31 March 2026</p> <p>Keywords:</p> <p>Current; Open; Temperature; Short; voltage</p>	<p>50W monocrystalline silicon solar module performance is tested with experimental measurements conducted at Baghdad city /Al-Jaderia (33.26 N, 44.21E). Solar irradiance striking is subjected to more losses which after the experiments conducted resulted approximately in 15% of the total energy which is converted into electric power energy. To study the effect of temperature variations on solar performance, solar irradiance must be kept constant and vice versa. Therefore, to have of the temperature range and for more accuracy, the measurements was done for tested module with three solar radiations levels; 500, 750 and 1000 W/m². The maximum value of power (P_{max}) at solar radiation intensity 1000W/m² was 46.34 W on January 2025 at cell temperature 24.1 °C, with the corresponding the maximum open voltage, and open circuit current 18.28 V, and 2.944 A respectively. The highest value of efficiency was 13.5 % January 2025 at solar radiation 500W/m². Consequently, the minimum value of power (P_{max}) at solar radiation intensity 500W/m² was 27.54 W on October 2024 at cell temperature 40.5 °C, with the corresponding the maximum open voltage, and open circuit current 18.01 V, and 1.752 A respectively. The lowest value of efficiency was 6.9 % October 2024 at solar radiation 1000W/m². In general, the results showed slightly decrease in short circuit current with temperature increasing. With temperatures change great influence on the output voltage especially on open circuit voltage while very small decrease in the output current has been noticed.</p>

1. Introduction

Solar energy is one of the major renewable energy resources since it is silent and an environmental-friendly power-generating process. Solar module is a process to convert solar energy to electrical power using semiconducting materials [1]. Solar module power outlet is measured at room temperature and pressure; irradiance 1000 W/m², temperature 25 °C, and standard earth spectrum AM 1.5 G, where G stands for global and includes both direct and diffuse radiation [2,3,4]. Actually, part of incident light that falls on solar panel is reflected or transmitted instead of being absorbed. Such losses are referred to as optical

losses [5,6,7,8,9]. The reflection losses directly reduce the I_{sc} of solar cells. Similarly, the finite thickness or geometry of the solar cell contributes to transmission losses in a PV cell. Furthermore, the application in this field need more work in design, sizing and dimensions. This technology needs more work and information on atmospheric conditions and weather parameters; atmospheric temperature, solar irradiance, and wind speed. New research work concerned with improvement of solar module performance and efficiency. These studies need more data about solar radiation and solar module operating temperature, were carried out by many researchers [10,11]. Operating solar module temperature is considered a major parameter effect on solar cell



performance [12]. They also stated that there is a linear proportionality between outlet power and solar module operating temperature. Previously, researchers found that solar cells differed in output depending on temperature changes. Skoplaki et al. [13] stated that the power output of PV modules was seen to lessen by 0.4 - 0.5% for each degree Celsius increase in temperature beyond the predetermined operational temperature, depending on the temperature coefficient of the power of the module. It was also discovered that the desired efficiency of a PV module could be influenced by varying the temperature around it [14]. Bonkaney et al. [15] studied the influence of ambient temperature over PV efficiency and power production, the study showed that when PV temperature raises by one degree Celsius the electrical performance and power output will reduce by 0.49% and 2.6 W respectively. Al-Damook, et al., 2022 [16] Studied the photovoltaic performance in Iraq under hazardous weather, and the results showed that with the lower ambient temperature would lead to higher power production. In this paper, it will review several important studies on the impact of environmental effect on the photovoltaic cell [17,18,19]. Operating solar module temperature is considered a major parameter effect on solar cell performance. Hashim, et al., 2016 [20] found the four-parameter model using different methods: slope method, and explicit simplified method. The accuracy of these methods as it's compared with the measured data are 5%, 7.9%, and 9.3% respectively An extensive work was done on impact of temperature on solar panel performance [21,22,23,,24]. Many literatures have been examined solar module performance and power output [25,26,27,28,29]. They also stated that there is a linear proportionality between outlet power and solar module operating temperature. Katee et al., 2022 [30] made experimental measurements for current, voltage, and power for two type of solar modules. These data were used to extract four parameters model using two different extracting methods. For monocrystalline solar panel the percentage errors 5%, and 8% for iterative method and simplified explicit, while for the corresponding copper indium gallium di-selenide one are 10% and 9%. More work concerned with modeling solar module are available in these references [17,31]. More recent work was done by Abdulhadi et al.,

2025 [32] on floating Photovoltaic Solar System of of some Iraq water infrastructure and also solar photovoltaic Systems a 100 MW system done by Faisal et al., 2025 [33]. The aim of this study is to study the effect of operating solar temperature on module electric parameters; open circuit voltage and short circuit current.

2. Experimental work

Monocrystalline solar module had been examined, which is from the first-generation solar module family. Table 1 gives the panel properties at reference Standard Test Conditions STC. The solar module is calibrated in fixed procedure in Energy Department Laboratory. The Wireless Weather Sensor have 19 measurements; weather, light, and GPS. More details for The Wireless Weather Sensor are available in Figure 1 and Table 2.

Table 1. Mono crystalline silicon solar panel properties

Area, m ²	V _{oc} , V	I _{sc} , A	Peak power, W	Peak voltage, V	Peak current, A	No. of cells
0.46	21.8	3.25	50	17.2	2.9	36



Figure 1. Wireless Weather Sensor with 19 measurements.

Solar module analyzer PROVA 210A is used to test the characteristics solar panel electric parameters (V_{oc} , I_{sc} , V_m , I_m and P_m). PROVA 210A generates the I-V curve by variable internal resistive load in ohm (Ω) (0 to ∞) with time (10sec) therefore for each value of load there is a value for voltage and current from (0, I_{sc}) to (V_{oc} , 0). The device has an option to setup the values of both solar radiation and the area of the solar module (Figure 2).



Figure 2. Prova 210A Solar Module Analyzer .

The present work was done during July 2024 to April 2025. The experimental work was obtained under the outdoor exposure in Baghdad-Al-Jaderia. The readings were taken in a selected days, where the atmospheric conditions of clear sky. To study the effect of temperature variations on solar performance, solar irradiance must be kept constant and vice versa. Therefore, to have the temperature range and for more accuracy, the measurements was done for tested module with three solar radiations levels; 500, 750, and 1000 W/m²

The solar module is cleaned before the tests. The solar module is fixed to the south direction with tilted angle 33° then recording the temperature of the back side of the module (using thermocouple) and start the IV scanning process which is done by the Solar Module Analyzer then save the data in the computer (see Figure 3).



Figure 3. Setup of the experiment

3. Result and discussions

3.1 Solar module electrical parameters

Tables 2-4 show solar module parameters (T_c (°C), V_{oc} (V), I_{sc} (A), P_{max} (W), V_{max} (V), I_{max} (A), η (%), and FF) with measured solar module operation temperature for solar irradiance of 500, 750 and 1000 W/m² respectively. Tables 3-5 also some contain environment conditions; ambient temperature (T_a) and wind velocity. The module operating temperature is usually determined by the heat balance between the heat generated in the bulk material of the module and the heat lost to the surrounding. The heat generated in the module depends on the amount of solar radiation incident on the module, conversion efficiency.

The maximum value of power (P_{max}) at solar radiation intensity 1000W/m² was 46.34 W on January 2025 at cell temperature 24.1 °C, with the corresponding the maximum open voltage, and open circuit current 18.28 V, and 2.944 A respectively. The highest value of efficiency was 13.5 % January 2025 at solar radiation 500W/m². Consequently, The minimum value of power (P_{max}) at solar radiation intensity 500W/m² was 27.54 W on October 2024 at cell temperature 40.5 °C, with the corresponding the maximum open voltage, and open circuit current 18.01 V, and 1.752 A respectively. The lowest value of efficiency was 6.9 % October 2024 at solar radiation 1000W/m².

Table 2. Solar module parameters with module operation temperature for solar irradiance of 500 W/m²

T _{am} , °C	v, m/s	T _c , °C	V _{oc} , V	I _{sc} , A	P _{max} , W	V _{max} , V	I _{max} , A	η, %	Date
40.5	2.3	42.3	18.01	1.752	27.54	15.85	1.738	11.7	10/2024
24.7	4.1	25.8	19.85	1.821	29.20	16.88	1.730	12.7	11/2024
18.6	3.6	20.4	20.37	1.852	30.78	17.52	1.757	13.4	12/2024
15.9	1.5	18.7	20.76	2.019	31.00	18.06	1.716	13.5	1/2025
23.2	2.2	24.0	20.22	1.847	30.69	17.05	1.707	13.3	2/2025
27.0	5.2	28.3	19.62	1.810	29.07	15.53	1.871	12.6	3/2025
28.5	4.5	30.8	19.00	1.796	28.41	16.41	1.731	12.4	3/2025

Table 3. Solar module parameters with module operation temperature for solar irradiance of 750 W/m²

T _{am} , °C	v, m/s	T _c , °C	V _{oc} , V	I _{sc} , A	P _{max} , W	V _{max} , V	I _{max} , A	η, %	Date
40.5	2.3	43.9	19.04	2.188	31.76	16.34	1.944	9.2	10/2024
24.7	4.1	28.0	19.96	2.192	35.83	17.59	2.037	10.4	11/2024
18.6	3.6	22.7	20.34	2.200	36.22	17.88	2.025	10.5	12/2024
15.9	1.5	20.3	20.86	2.220	36.36	18.30	1.987	10.5	1/2025
23.2	2.2	26.0	20.65	2.192	35.98	17.42	2.065	10.4	2/2025
27.0	5.2	30.4	20.11	2.171	35.78	17.22	2.078	10.4	3/2025
28.5	4.5	32.9	20.20	2.179	32.52	16.76	1.940	9.4	3/2025

Table 4. Solar module parameters with module operation temperature for solar irradiance of 1000 W/m²

T _{am} , °C	v, m/s	T _c , °C	V _{oc} , V	I _{sc} , A	P _{max} , w	V _{max} , v	I _{max} , A	η, %	Date
40.5	2.3	47.0	19.20	2.702	36.95	16.44	2.247	6.9	10/2024
24.7	4.1	31.1	20.83	2.811	43.86	17.62	2.489	9.5	11/2024
18.6	3.6	27.0	21.00	2.902	44.87	17.98	2.495	9.7	12/2024
15.9	1.5	24.1	21.64	2.944	46.34	18.28	2.535	10.1	1/2025
23.2	2.2	29.7	21.13	2.890	45.81	17.37	2.637	10.0	2/2025
27.0	5.2	32.9	20.31	2.785	43.20	17.25	2.504	9.4	3/2025
28.5	4.5	35.5	20.29	2.738	37.95	16.78	2.261	8.3	3/2025

3.2 Open circuit voltage and short circuit current changes with temperature

Solar module operating temperature sensitivity of photovoltaic panel is critical aspects of module electric output performance. When solar module operates a part of solar isolation will be converted to useful electric power, typically around 15%, and the remainder is dissipated as heat. This dissipated heat will increase module operating temperature, which in turn affects the module's electrical parameters, particularly the open-circuit voltage (V_{oc}). An elevated operating temperature can have detrimental effects on the performance of PV modules. Higher temperatures generally reduce the V_{oc}, which is an essential parameter for optimizing the system's power output. A lower V_{oc} means that the module needs to apply more voltage to initiate electricity generation, leading

to a decrease in overall power output. This reduction in power output can significantly impact the efficiency and profitability of solar energy systems. Moreover, the temperature variation also affects other electrical parameters of monocrystalline silicon solar modules, such as short-circuit current (I_{sc}) and fill factor (FF).

To analyze the data a scatter plot used between V_{oc} and I_{sc} for different solar irradiances: 500, 750, and 1000 W/m² and the corresponding module temperatures (available in Figure 1 and 2). It will be seen that there is a linear relation, so a linear regression was used to find a relation between them and the temperature.

The open circuit voltage has a logarithmic relationship with the solar radiation and has a little change with radiation variation at high radiation levels. The negative slope of the linear

fitting in Figure 4 represents the temperature coefficient (TCO) of V_{oc} . In general, the results showed decrease in short circuit current with temperature increasing.

PROVA 210A measures the short circuit current of a solar module at the beginning of the I-V curve where the resistive load is zero. The short circuit current is linearly proportional with the solar radiation and occasionally it is considered to be equal to the photo-generated current. A scatter plot illustrates the linear relationship represented by a linear regression equation where the positive slope is TCO of I_{sc} (see Figure 5). In general, the results showed slightly decrease in short circuit current with temperature increasing.

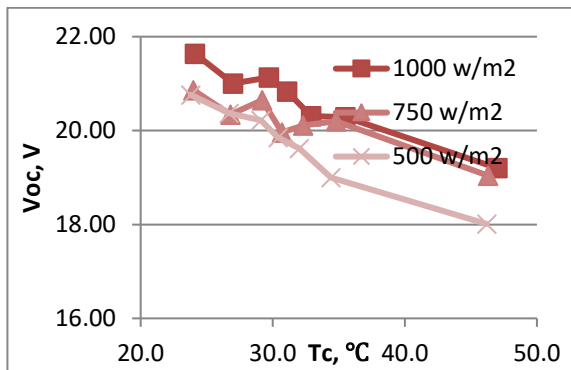


Figure 4. Variation of open circuit voltage with solar module operating temperature.

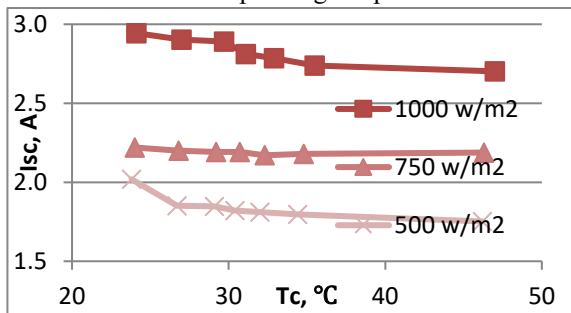


Figure 5. Variation of short circuit current with solar module operating temperature.

With temperatures change great change on the outlet voltage especially on open circuit voltage while very small decrease in the outlet current has been recognized. A plot is used to analyze the practical measurements of the open circuit voltage and short circuit current with panel temperatures. A linear regression analysis between V_{oc} and I_{sc} with the corresponding operating panel temperature. The major power drop in voltage values had been happen with

increasing operating panel temperature. The temperature coefficient (TCO) is defined as the amount of change in, or with temperature. TCO considered being equal to the slope of the linear equation as given in Equations 1 and 2, the value of the slope of each straight line equation is calculated. The TCOs of, or are symbolized as the following:

$$TCO_{V_{oc}} = \frac{\Delta V_{oc}}{\Delta T} \quad (1)$$

$$TCO_{I_{oc}} = \frac{\Delta I_{oc}}{\Delta T} \quad (2)$$

Where $TCO_{V_{oc}}$ and $TCO_{I_{sc}}$ are temperature coefficients of open circuit voltage and short circuit current respectively, ΔV_{oc} is the open circuit voltage difference, ΔI_{sc} : short circuit current difference and ΔT : temperature difference in °C.

The measured data explain that monocrystalline module showed a decrease in open circuit voltage by $-0.1140 \text{ V/}^\circ\text{C}$ (average value). The outlet results showed a slightly decrease in short circuit current with temperature increasing about $-0.0065 \text{ A/}^\circ\text{C}$ (average value).

4. Conclusions

The temperature sensitivity of PV modules is a critical aspect of their electrical output performance. Higher temperatures generally reduce the V_{oc} , which is an essential parameter for optimizing the system's power output. The temperature variation also affects other electrical parameters of monocrystalline solar module, such as short-circuit current (I_{sc}) and fill factor (FF). Reduction in power output can significantly impact the efficiency and profitability of solar energy systems, this reduction in outlet power of solar module is function of decreasing of solar irradiance values. It is proved that increasing solar irradiance will increase module temperature at constant ambient temperature and also increased value of module temperature with increasing ambient temperature at constant solar irradiance.

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Conflict of interest

The authors declare no conflicts of interest concerning this research.

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Author Contribution

N.F. Kadhun proposed the research problem. E.T. Hashim developed the theoretical framework. N.F. Kadhun, E.T. Hashim verified the analytical methods and participated in the discussion of the results and contributed to writing the manuscript.

AI Declaration Statement

The authors confirm that the manuscript has been written without the assistance of generative AI or AI-based writing tools.

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