International Journal of Advanced Technology and Engineering Exploration, Vol 9(88)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2021.875255

Research Article

Performance evaluation of the polycrystalline photovoltaic module under Iraqi harsh weather conditions

Malik F. Jaffar[1], Ahmed Qasim Ahmed[1], Abdulrahman Th. Mohammad[2] and Wisam A M Al-Shohani[1*]
Middle Technical University, Technical Engineering College-Baghdad, Baghdad, Iraq[1]
Middle Technical University, Baqubah Technical Institute, Baghdad-Iraq[2]

Received: 29-November-2021; Revised: 16-March-2022; Accepted: 19-March-2022

Abstract
The output parameters of photovoltaic (PV) module are influenced by temperature variation. If the module temperature increases, most of parameters negatively decrease. In this work, an experimental investigation was performed to evaluate the performance of a commercial polycrystalline silicon PV module under Iraqi harsh weather conditions. The experimental test was carried out at the campus of the Middle Technical University, Baghdad, Iraq with metrological conditions at (33°.3 N 44°.4 E) during a selected day of July 2021. The temperature of PV module and electrical characteristics were measured. In addition, the current-voltage curve (I-V) and power-voltage curve (P-V) curves were drawn. The measured data showed that the PV temperature was varied from 35.2 °C at 7:00 am to 69 °C at 2:00 pm. The maximum electrical power was recorded 123 W at 12:00 pm with solar irradiance 961 W/m^2. Furthermore, the average electrical efficiency was recorded a highest value about 16.6% at the solar radiation value of 318 W/m^2 around 7:00 am. On the other side, the fill factor was recorded a maximum value about 76%.

Keywords
Photovoltaic, Solar energy, Electrical characteristic, Filling factor, Solar radiation.

1.Introduction
Among the renewable energy resources, photovoltaic (PV) cells technology plays a big and an important role in reducing the greenhouse gas emissions [1, 2]. Based on the worldwide energy production data, PV generates over 40 GW yearly and provides many job opportunities [3]. There are three traditional types of PV cells like: mono-crystalline, polycrystalline and thin film cells. Now, the researchers have developed another type of cells, such as: multi-junction, perovskite, and quantum cells [4, 5].

The PV cell/module can be characterized by the direct current (DC) electrical parameters: open circuit voltage (V_{OC}), short circuit current (I_{SC}), peak voltage (V_{mp}), peak current (I_{mp}) and peak power (P_{max}) [6] that tested at the standard test conditions (STC) (solar irradiation 1000 W/m^2, air mass 1.5 and module temperature of 25°C) [7].

In general, the performance of PV modules is determined according to the P_{max} which identifies the maximum electric power supplied by the panel at STC [8]. Increasing the operating temperature of the PV module more than 25°C has a significant passive effect on these parameters except the I_{SC}, which slightly increases [9].

The variation of module temperature depends on several parameters.

These parameters can be divided into two groups such as: environmental conditions (solar irradiance, ambient temperature and wind speed) [10] and specification of cell materials (absorption and reflectivity of materials and heat transfer coefficients for air) [11]. In most locations, the operating temperature of module varies from 0 to 60°C while in semiarid area reached to 80°C. In addition, the operating temperature of PV can be reached below 20°C [12]. In other words, long-term high-temperature operation of PV modules leads to a high degradation rate in the peak power of PV modules. The main objective of this work is to study

*Author for correspondence
This work was supported in part by the Middle Technical University, Technical Engineering College. Baghdad, Iraq.

experimentally the performance of the PV module under harsh weather conditions of Iraq with operating temperature reached to 69°C. The performance of PV module represented by the output electrical characteristics was measured and represented in tables and graphs. The previous studies in the literature that related to the current study were reviewed in section 2. The methods and experimental setup employed in testing the PV module were presented in section 3. Section 4 covers the experimental results according to the sequence of the steps of experimental setup. In addition, section 5 deals with the discussion of the results. Finally, the conclusions and future work were covered in section 6.

2.Literature review

Among the previous studies, a number of researchers were studied the performance of the PV module under different ambient conditions. For example, Feshaki et al. [13] experimentally studied the influence of cloudy weather on the efficiency of PV module. They found that the output voltage was decreased by 4.6% by increasing the module temperature while, a slight increase in the output current of the PV was recorded.

Amelia et al. [14] tested the efficiency of PV module under the influence of operating temperature using PV system simulation software. The simulation results showed that the efficiency was reached to 12.27% in the worst weather conditions at 65°C. While, it was increased to 3.08%, 13.88%, and 14.66%, at 55°C, 45°C, and 35°C respectively.

Ghazia and Ip [15] studied the effect of meteorological factors and particles deposited on the board’s surface on the PV efficiency. Their results revealed that the output power of PV module can be reduced by up to 60% in hot and dusty weather conditions.

In addition, the study of Enaganti et al. [16] showed that the natural dust deposition significantly reduces energy output of PV modules. Furthermore, Fouad et al. [17] performed an experimental study to investigate the influence of integration many factors like temperature, PV system type, installation, and cost factors on the PV efficiency. Their results show that the temperature increasing consider the main important factors that highly reduce the PV cell efficiency comparing with the others investigated factors.

Touati et al. [18] studied the sensitivity of different PV systems to the dust, ambient temperature, and relative humidity in Qatar. Their results reveal that the higher temperatures and dust accumulation have a greater effect on reducing the efficiency by 10% of the amorphous and mono-crystalline PV modules.

Adeeb et al. [19] investigated the influence of the ambient temperature on the performance of several PV modules installed in Amman, Jordan. They observed that the thin-film PV modules were less affected by temperature, with the temperature coefficients being -0.0984% for mono-crystalline and -0.109% for the poly-crystalline, respectively.

The effect of ambient temperature on the output electrical characteristics of PV cell was investigated by [20−23]. The results show that the solar cell is highly affected by the increasing temperature of the ambient air. In the same manner, the influence of ambient temperature on the performance of different grid connected PV system was presented in [24−26] studies. The results revealed that the highest average thermal losses in annual DC energy yield were 8% of mono-crystalline silicon (mono-c-Si) and 9% for multi-crystalline silicon (multi-c-Si) technologies over the evaluation period, while the average losses for thin-film technologies were 5%. When utilizing the outside temperature coefficients, similar losses were discovered. Also, they found that the increase in power attributed to thermal annealing resulted in a power increase of up to 8.4% in some cases.

In the study of Ameur et al. [27], three PV modules technologies made from silicon were selected to test and analyse their long-term performance, degradation, and economic. The PV module technologies include amorphous silicon (a-Si), polycrystalline silicon (P-Si), and monocrystalline silicon (m-Si). In terms of performance ratio, the results show that the (p-Si) and (m-Si) technologies are better than (a-Si). While, in terms of degradation, the regression results show that the a-Si degrades faster than its counterparts. In addition, the analysis of the levelized cost of energy (LOCE) showed that the p-Si technology is the most cost-effective system.

A mathematical model for a single diode was investigated by Gong et al. [28] to study and analyse the effect of temperature and irradiance on the performance of multicrystalline and thin-film modules. The analysis of results showed that the performance of PV modules was more sensitive to temperature than irradiance. While the performance of the thin-film module was better than the performance of the crystalline module at high-temperature conditions. Previous researches dealt with several studies on the performance of the different technologies of PV module at different ambient conditions around the world. The objective of this study is to analyze the performance of the PV module in Iraq under extreme heat conditions.

3.Materials and methods

3.1Mathematical formulations

The maximum electrical power is defined as the peak power of PV module at maximum power point voltage V_{mp} and current I_{mp} [29, 30] (Equation 1):

$$P_{max} = V_{mp} \times I_{mp} \quad (1)$$

Where: V_{mp} and I_{mp} are the maximum power point voltage and current.

The electrical efficiency (η) considers one of the important parameters employed to examine and to determine the performance of the PV module. Generally, it is defined as the ratio of energy output obtained from the PV module to the energy input of the solar irradiance [31, 32] (Equation 2).

$$\eta = P_{max}/A \times G \quad (2)$$

Where: G is the solar irradiance (W/m^2), and A is the surface area of the PV module (m^2).

Fill factor is defined as the ratio of maximum power to the theoretical power of PV [33] (Equation 3).

$$FF = I_{mp}\, V_{mp}/V_{oc}\, I_{sc} \quad (3)$$

Where: V_{oc} is the open-circuit voltage (V) and the I_{sc} is the short circuit current (A).

3.2Experimental setup

A commercial polycrystalline PV module with type Fortuner (FRS-165 W) was selected to test in this demonstration. The technical data of PV module is presented in *Table 1*. The PV module was supported on a steel frame with inclination angle 33^o towards the south as shown in *Figure 1*. The experimental work was performed on the campus of the Middle Technical University, Baghdad, Iraq at (33°.3 N 44°.4 E). Seaward PV200 Solar PV Tester and current-voltage curve (I-V) Curve Tracer was used to measure the output characteristics of PV module. The Seaward PV200 is a multifunctional portable PV power meter that can determine various measurements such as: open circuit voltage (V_{oc}), short circuit current (I_{sc}), peak voltage (V_{mp}), peak current (I_{mp}) and peak power (P_{max}) as well as draw the I-V and power-voltage curve (P-V) curves of the PV module. A solar survey 200R element was integrated and synchronized with the Seaward PV200 to measure the ambient temperature, solar radiation and back cell temperature. All measured data will be stored directly in the PV200 and then transferred to the computer to draw the I-V and P-V curves via Solarcert software. This software is attached to the PV200 and is installed on the computer to display the I-V and P-V curves as well as other PV output measurements. Additionally, the temperature distribution of the PV module was also measured by using a digital thermal camera (Fluke). The digital thermal camera was used to provide an accurate temperature distribution of the front side PV module surface during the test. Moreover, anemometer was used to measure the wind velocity. The flowchart of experimental method and sequence of measurements are represented in *Figure 2*.

As shown in *Figure 2*, the experiment procedure can be summerized as:

- Step 1: A commercial polycrystalline PV module with type Fortuner (FRS-165 W) was selected and supported on steel frame with inclination angle 33^o towards the south.
- Step 2: Four main devices of measurments were used to collect the data of test.
- Synchronization process between device (a and b) was done to consoldate the ambient conditions with the output electrical charactersictics of PV module.
- In step 2(c), the wind speed was measured and drawn with the local time.
- In step 2(d), the thermal images of the front surface for PV module were photographed from 7:00 am to 3:00 pm.
- In step 3, the output data of a and b were recorede.
- In step 4, the solarcert software was used to represent the output data in I-V and P-V curves.
- In step 5, the P_{max}, fill factor (*FF)* and η of the PV module were caculated and send to step 6.
- In step 6, the varation of ambient conditions and output characteristics of PV module with the local time were representd in graphs.

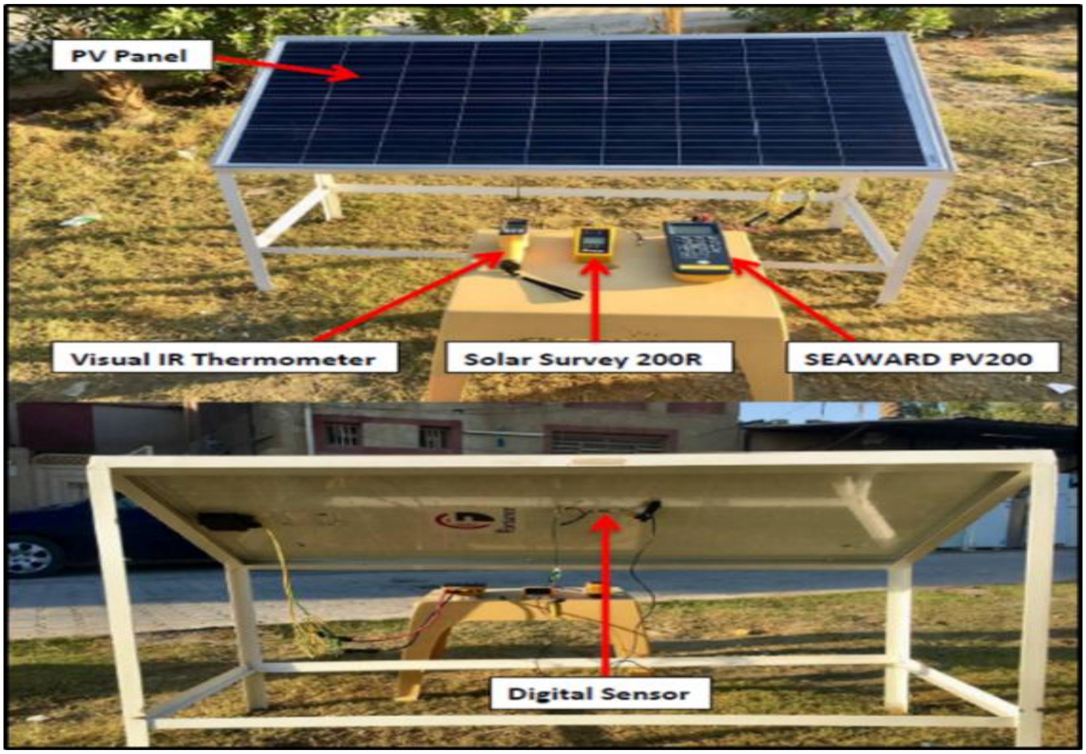

Figure 1 Photograph of PV module with test rig

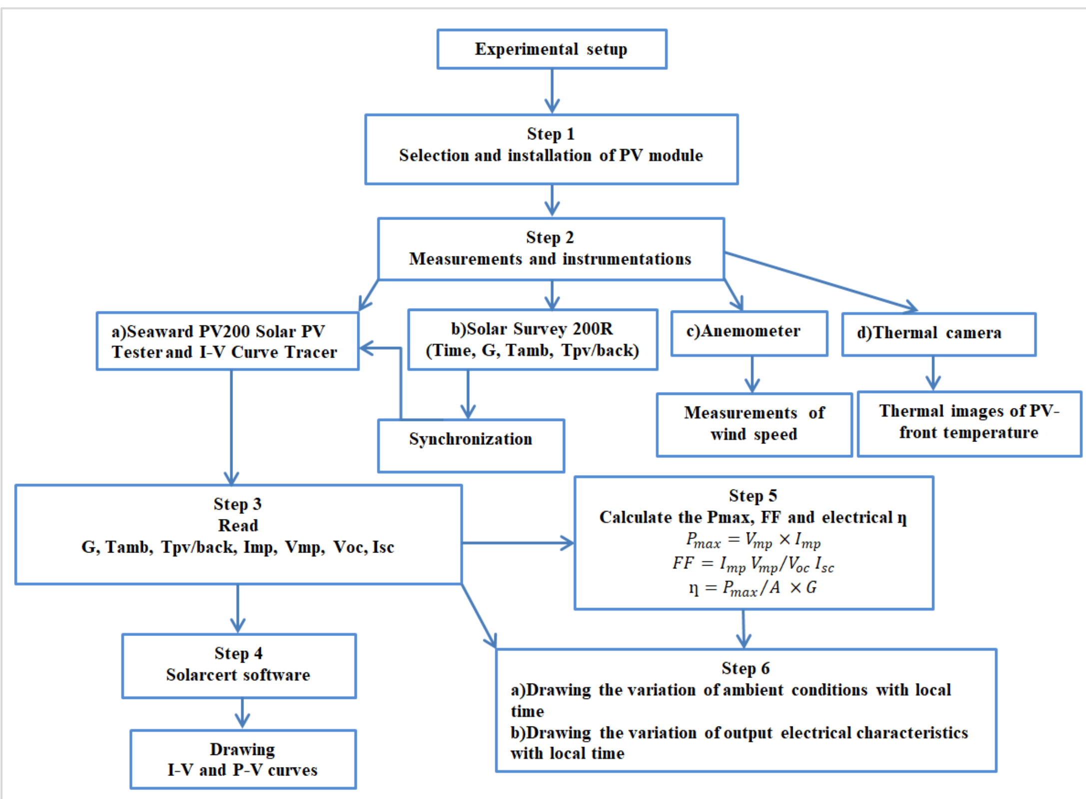

Figure 2 Flowchart of experimental setup

Table 1 Technical data of PV module

PV characteristics	Values
Panel dimensions	(149 x 67) cm
Peak Power (P_{max})	165 W
Short Circuit Current (I_{sc})	9.81 A
Open Current Voltage (V_{oc})	22.05 V
Peak Current (I_{mp})	9.17 A
Peak Voltage (V_{mp})	18 V

4.Results

Iraq is located at (33.3 E, 44.3 N) and considered as a one of the rich countries in solar radiation around the world due to has lengthy periods of daylights. Therefore, it collects more than 3,000 hour/year of irradiance in the capital city-Baghdad [34]. The intensity of solar irradiation is very high during the summer due to the sunshine hours are in the range of about 12 hours. The total solar radiation from July to September showed a rising trend and reached the peak. In this work, the experimental test was performed on July 2021 over four days (5th, 11th, 19th, and 20th). The measured data of ambient conditions including the ambient temperature, solar irradiance and wind speed are represented as an average value for four days of tests from 7:00 am to 6:00 pm. During the days of experimental tests, the amount of incoming solar irradiance is substantially higher from 12:00 pm to 2:00 pm, which is considered the peak of the day as shown in *Figure* 3. It is observed that the maximum amount of solar irradiance was recorded 961 W/m^2 at 12:00 pm, while the lowest amount was 318 W/m^2 at 7.00 am. In addition, *Figure 3* shows the ambient temperature which the maximum ambient temperature was found to be 49 °C. It is clear that the higher solar irradiance leads to an increase in the ambient temperature. In the early morning hours and due to the low-intensity solar irradiance of 318 W/m^2, the ambient temperature was at a low level with a value of 37 °C and increased to a maximum value about 49 °C due to increasing the solar irradiance to 961 W/m^2. *Figure 4* shows the wind speed throughout the experimental test hours. Where, the average wind speed was ranged between (1.1-2.6) m/s. Wind speed plays a major factor in raising and lowering the ambient temperature.

4.1Temperature of PV module

The variation of PV back temperature ($T_{PV/back}$) with local time was represented in *Figure 5*. As shown in *Figure 5*, when the solar radiation and the ambient temperature increase, the temperature of the PV panel increases rapidly and it is easy to see that there is a large temperature difference between these two values during the peak solar period. Where, the $T_{PV/back}$ was varied from a minimum value of 35.2^{o}C at 7:00 am to a maximum value of 69^{o}C at 2:00 pm when the ambient temperature varied between 37^{o}C to 49^{o}C. In other words, the maximum temperature difference between the ambient temperature and $T_{PV/back}$ was recorded about (ΔT=20^{o}C) at 2:00 pm.

The temperature distribution of the front surface of PV panel ($T_{PV/front}$) was measured by using a digital thermal camera (Fluke) to provide an accurate distribution during the period of test. Nine hours between (7:00 am to 3:00 pm) were used to photographed the front surface of PV as shown in *Figure 6*. It was observed that the $T_{PV/front}$ was varied between 39°C at 7:00 am to 69.2°C at 3:00 pm. In summary, the maximum temperature difference between the ambient temperature and $T_{PV/front}$ was recorded about (ΔT=19.2^{o}C) at 2:00 pm. To summarize the variation of PV temperature ($T_{PV/front}$ and $T_{PV/back}$) and the ambient temperature along the period of test, *Figure 7* shows that the $T_{PV/front}$ was recorded a higher than the $T_{PV/back}$ and the maximum difference between the values was recorded 5.6^{o}C at 12:00 pm.

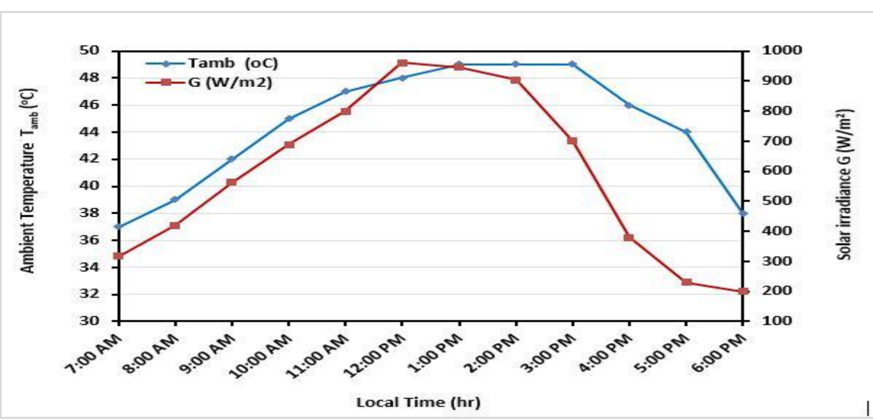

Figure 3 Variation of ambient temperature and solar irradiance with local time

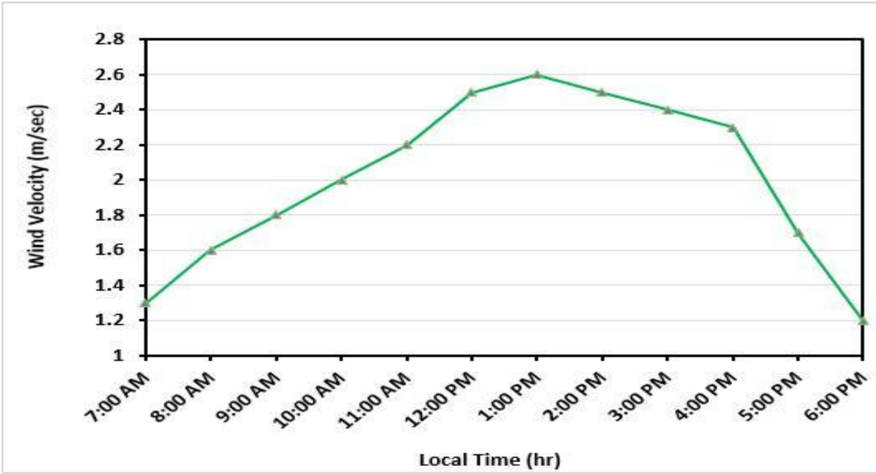

Figure 4 Variation of wind speed with local time

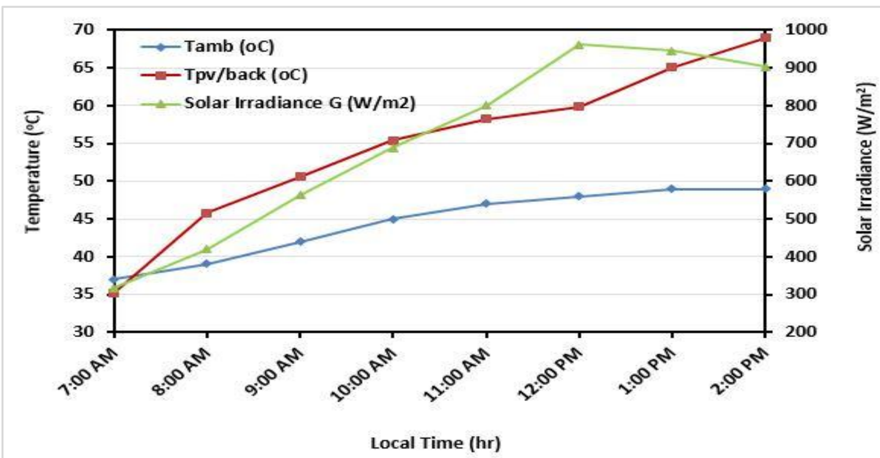

Figure 5 Variation of PV temperature with ambient temperature and solar irradiance

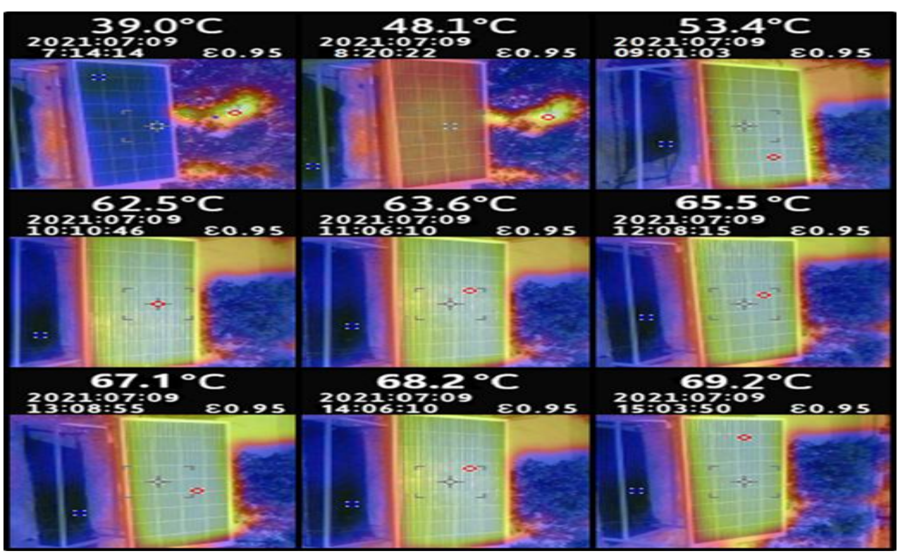

Figure 6 Thermal images of PV front surface

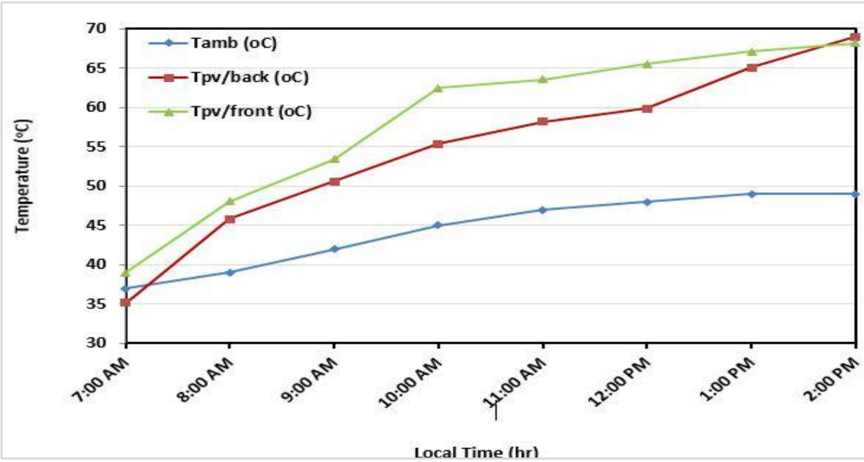

Figure 7 Variation of PV surface temperature (back/front) with ambient temperature

4.2Electrical performance

The output electrical characteristics of PV were represented as an average value for the days of test from 7:00 am to 2:00 pm. In the start of test at 7:00 am with ambient temperature 35.2°C and an irradiance 318 W/m^2, the short circuit current (I_{sc}) was recorded 3.15 A and increase to a maximum value about 8.45 A at 12:00 pm with ambient temperature and solar irradiance 48°C and 961 W/m^2 respectively. As shown in *Figure 8*, it is clear that the increasing of the (I_{sc}) depends on the increasing of the ambient temperature. In the same manner, the maximum power point current (I_{mp}) was increased from 2.92 A at 7:00 am to maximum value about 7.98 A at 12:00 pm. The increase of short circuit current of PV module can be discussed as follows: The increase in PV temperature led to decreasing the energy of band gap and then increasing the intrinsic carrier concentration due to the inversely exponentially with the energy of band gap [9]. Therefore, the number of electrons that have enough energy to create electron-hole pairs will increase. As compared between the measured current and the current in technical data of PV, the percentage reduction of (I_{sc}) was recorded about 16% while about 15% in (I_{mp}). On other side, the voltage of PV module was sharply decreased with increasing the ambient temperature. As shown in *Figure 9*, the open circuit voltage (V_{oc}) was reached a maximum value about 21 V at 7:00 am and then dropped to a minimum value about 19.3 V at 2:00 pm. In addition, the maximum power point voltage was recorded a maximum value about 17.7 V and then dropped to reach a minimum value about 15.1 V at 2:00 pm. This sharply drop in PV voltage can be explained as follows: As a consequence of the band gap energy reduction, the open circuit voltage will decrease with increasing the module temperature. The comparison between the measured value of voltage and technical data voltage showed that the reduction percentage was 5% in (V_{oc}) and 1.7% in (V_{mp}).

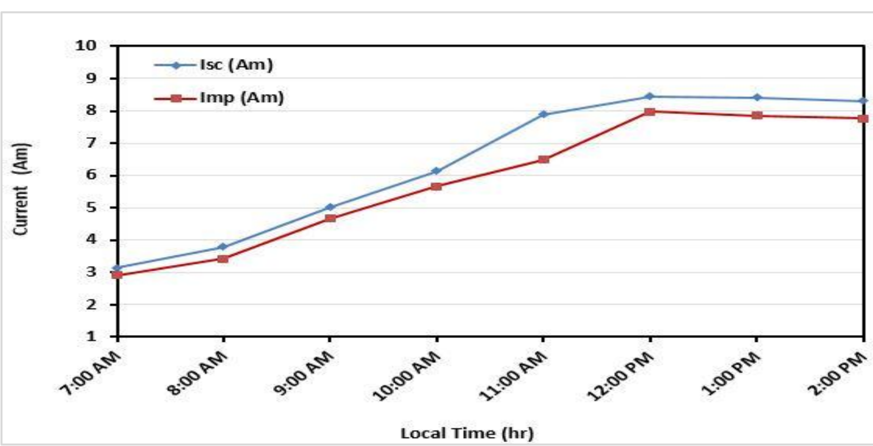

Figure 8 Variation of PV current with local time

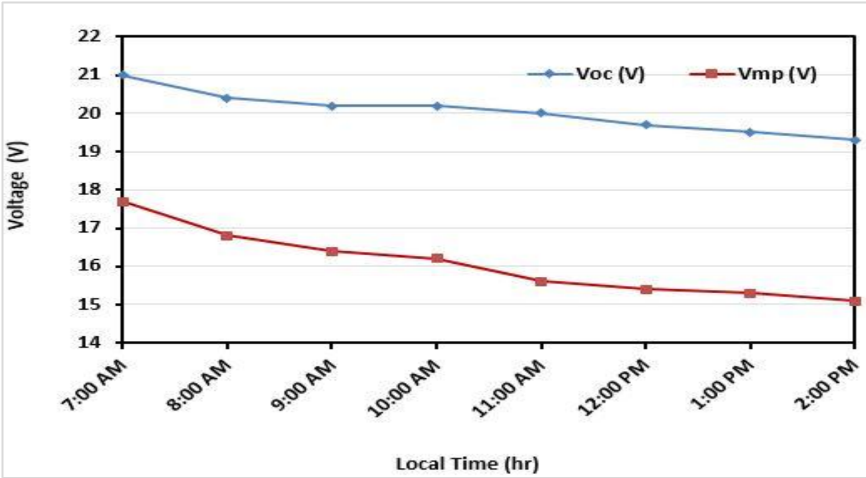

Figure 9 Variation of PV voltage with local time

The maximum electrical power was calculated from the measured voltage and current of PV. As shown in *Figure 10*, the P_{max} is proportional to the solar irradiance (G) over the hours of test. At 7:00 am, the P_{max} is recorded a low value about 52 W due to the low solar irradiance 318 W/m^2, then, as time passes, it starts to increase until reaching the peak value 123 W at 12:00 PM with solar irradiance 961 W/m^2. After 12:00 pm, the P_{max} decreases as a result of the decreasing the solar irradiance until the 2:00 pm with a value of 903 W/m^2. Generally, the output power of PV module decreases when its temperature increases because the increasing of the maximum power point current does not compensate the decreasing in the maximum power point voltage.

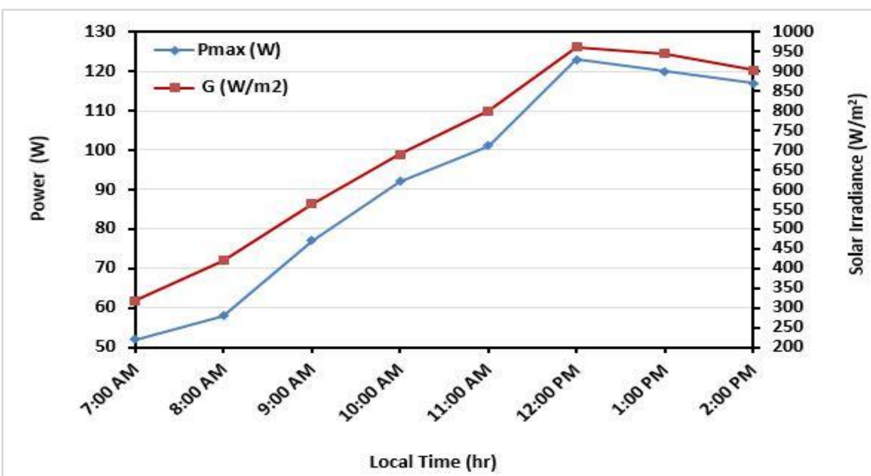

Figure 10 Variation of PV power and irradiance power with local time

The average electrical efficiency (η) was recorded a highest value about 16.6% at the solar irradiance value of 318 W/m^2 around 7:00 am and it was recorded lowest value about 12.8% at the solar irradiance value of 800 W/m^2 around 11:00 am as shown in *Figure 11*. Although, the P_{max} of the PV increased due to the increase in the solar irradiance, the η of PV decreased due to the highest ambient temperature and then highest PV temperature. On the other side, the *FF* was recorded a maximum value about 76% at 7:00 am and a minimum value about 71% at 2:00 pm.

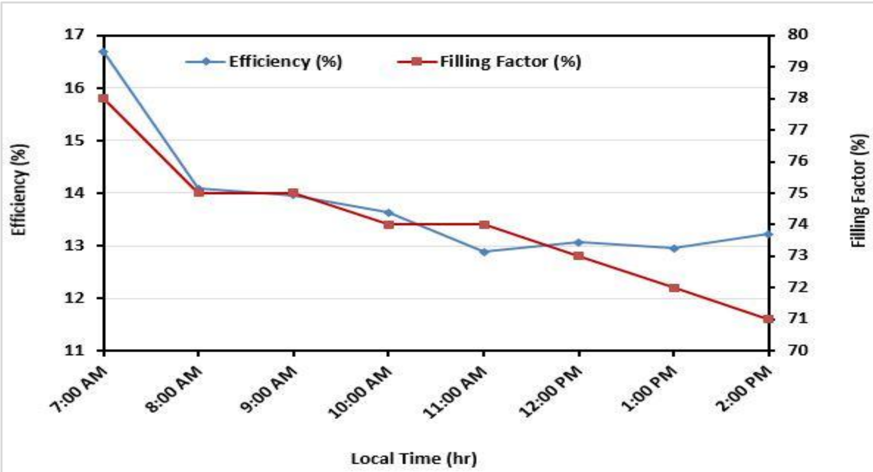

Figure 11 Variation of electrical efficiency and fill factor of PV with local time

4.3I-V/P-V curves

The measured data of 19th July was chosen to draw the (I-V) and (P-V) curves of PV as shown in *Figure 12*. Seven strings were selected to cover the ranges of solar irradiance and ambient temperature from 7:00 am to 2:00 pm. The output electrical characteristics of strings under the influence the outdoor conditions were summarized in *Table 2*. It is clear that the ambient temperature has a large significant on the performance of PV module. Although, the solar irradiance was recorded a high value about 951.9 W/m^2 in string 64 with 5% less than standard solar irradiance 1000 W/m^2 but the maximum power of the PV module was recorded 119.29 W. This mean that the increasing of PV temperature from 25^{o}C to 63.2^{o}C leads to decrease the maximum power of PV by 38.8% as compared with maximum power supported in technical data of PV. In other words, the maximum power of PV module decreases with increasing the temperature by 1.2 W for each 1 ^{o}C.

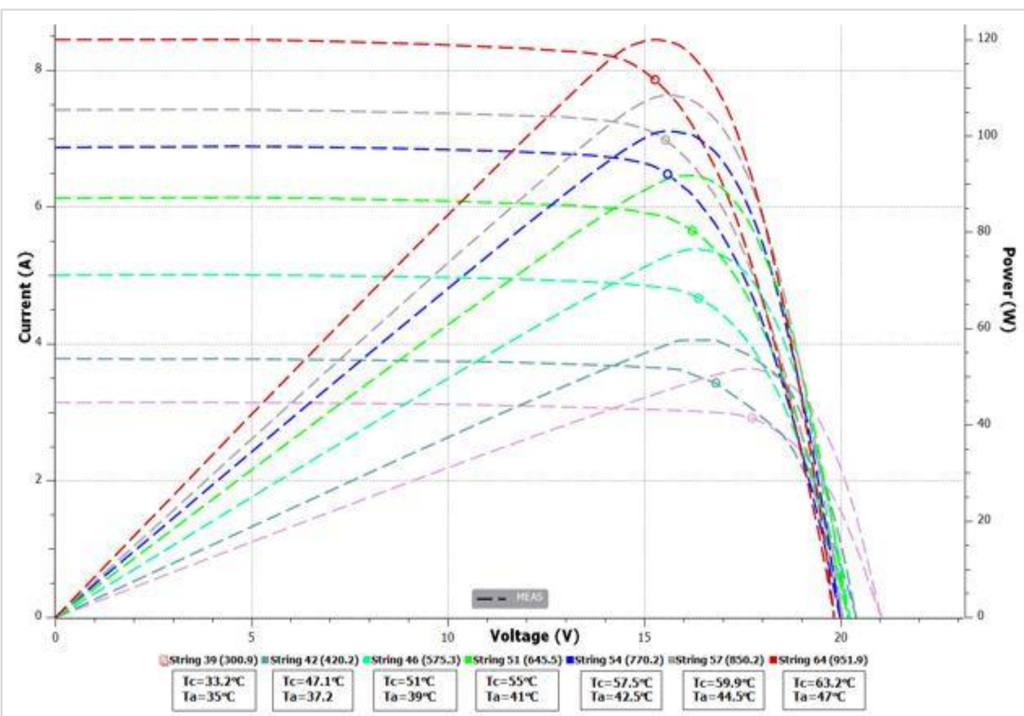

Figure 12 I-V and P-V curves for PV panel

Table 2 The output electrical characteristics

St	Outdoor conditions		$T_{PV/\,back}$ °C	Electrical characteristics				
	T_{amb} °C	G W/m^2		V_{oc}(V)	I_{sc}(A)	V_{mp}(V)	I_{mp}(A)	P_{max}(W)
9	35.0	300	33.2	21.0	3.2	17.8	3.0	53.40
42	37.2	420	47.1	20.5	3.8	16.7	3.5	58.45
46	39.0	575	51.0	20.3	5.0	16.5	4.7	77.55
51	41.0	645	55.0	20.2	6.2	16.4	5.6	91.84
54	42.5	770	57.5	20.0	6.8	15.3	6.5	99.45
57	44.5	850	59.9	20.0	7.4	15.3	7.0	107.1
64	45.0	951	63.2	19.8	8.4	15.1	7.9	119.2

5.Discussion

From the analysis of experimental results, it is observed that the short circuit current (I_{sc}) was recorded a maximum value about 8.45 A with increasing the PV module temperature to 69°C due to the increase of ambient temperature to 48°C. In the same manner, the maximum power point current (I_{mp}) trends the same behaviour and increases to record a maximum value about 7.98 A. While, the voltage of PV module sharply decreased with increasing the PV temperature. The open circuit voltage (V_{oc}) was reached a minimum value about 19.3 V. In addition, the maximum power point voltage (V_{mp}) was recorded a minimum value about 15.1 V. This sharp drop in PV voltage can be explained as follows. Increasing the ambient temperature and solar irradiance lead to increase the PV temperature which leads to drop the PV voltage. The comparison between the measured value of voltage and technical data voltage showed that the reduction percentage was 5% in V_{oc} and 1.7% in V_{mp}. The maximum electrical power (P_{max}) was increased until reaching the peak value 123 W at 12:00 PM due to increasing the solar irradiance to 961 W/m^2 over the hours of test. As a result, the average electrical (η) was recorded a highest value about 16.6% and the FF was recorded a maximum value about 76% at 7:00 am and a minimum value about 71% at 2:00 pm.

The performance of the present study was compared with study of Sani and Sule [35] in Nigeria. This study was selected because the weather conditions are close to weather conditions of this study, the same type of polycrystalline module, and the convergance between the maximum out power of the two modules. The technical data of their module were (V_{oc}=44.3 V, I_{sc}=4.6 A, V_{mp}=36.6 V, I_{mp}=4.3 A and P_{max}=160 W). As shown in *Figure 13*, despite the convergence of the air temperature at most hours of the day, but the module temperature in Iraq was recorded an increase between 9 to 18 °C more than the module temperature in Nigeria which is resulting a negative effect on the output power of the module.

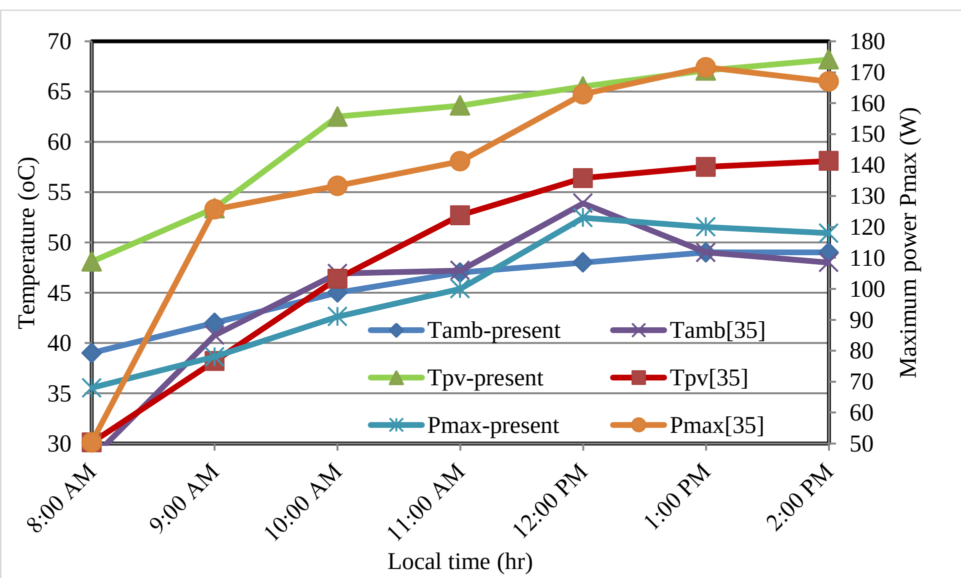

Figure 13 Comparative of the Tpv and pmax of present study

In this paper, the outdoor test of PV module cannot exactly compare with the standard test conditions to analyse the power degradation of PV module. Therefore, we investigated and represented the measurement of output electrical characteristic of PV module at variation of ambient temperature and solar irradiance with time. A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

This work was performed to evaluate the performance of a commercial polycrystalline silicon PV panel under the influence of Iraqi harsh weather conditions. From the analysis of the measured data, the following conclusions can be summarized:

- The maximum temperature in front and back surface of PV panel was reached around 69°C with increasing the ambient temperature around 49°C.
- The percentage reduction of I_{sc} was recorded about 16% while recorded about 15% in I_{mp}.
- The open circuit voltage (V_{oc}) was reached a maximum value about 21 V at 7:00 am and then dropped to minimum value about 19.3 V at 2:00 pm.
- The maximum power point voltage (V_{mp}) was recorded a maximum value about 17.7 V and then dropped to reach a minimum value about 15.1 V at 2:00 pm.
- The maximum electrical power (P_{max}) starts to increase until reaching the peak value 123 W at 12:00 PM with solar irradiance 961 W/m^2.
- The average electrical efficiency (η) was recorded a highest value about 16.6% at the solar irradiance value of 318 W/m^2 around 7:00 am and it was recorded lowest value about 12.8% at the solar irradiance value of 800 W/m^2 around 11:00 am.
- The (FF) was recorded a maximum value about 76% at 7:00 am and a minimum value about 71% at 2:00 pm.

The future work can include a numerical study to solve the performance of PV module and experimental study to analyse the degradation of the PV output power and compare it with the output power at standard test conditions.

Acknowledgment

The authors would like to thank the Middle Technical University for the financial support of this project.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Malik F. Jaffar, **Ahmed Qasim Ahmed:** Carried out, collected and reviewed the results of the experimental part. Additionally, they wrote the introduction and experimental sections of the manuscript. **Abdulrahman Th. Mohammad**, **Wisam A M Al-Shohani:** Analyzed the results and wrote the whole manuscript. All authors participated in reading, reviewing and agreeing to publish this manuscript version.

References

[1] Cotfas DT, Cotfas PA, Machidon OM. Study of temperature coefficients for parameters of photovoltaic cells. International Journal of Photoenergy. 2018.

[2] Behura AK, Kumar A, Rajak DK, Pruncu CI, Lamberti L. Towards better performances for a novel rooftop solar PV system. Solar Energy. 2021; 216:518-29.

[3] Asaduzzaman M, Bahar AN, Bhuiyan MM, Habib MA. Impacts of temperature on the performance of CdTe based thin-film solar cell. In IOP conference series: materials science and engineering 2017 (p. 1-8). IOP Publishing.

[4] Zhang PP, Zhou ZJ, Kou DX, Wu SX. Perovskite thin film solar cells based on inorganic hole conducting materials. International Journal of Photoenergy. 2017.

[5] Aly AE, Nasr A. Theoretical study of one-intermediate band quantum dot solar cell. International Journal of Photoenergy. 2014.

[6] Cotfas DT, Cotfas PA, Kaplanis S. Methods to determine the dc parameters of solar cells: a critical review. Renewable and Sustainable Energy Reviews. 2013; 28:588-96.

[7] Hamadeh H. Temperature dependence of pin solar cell parameters with intrinsic layers made of pm-Si: H and low crystalline volume fraction μc-Si: H. Renewable Energy. 2010; 35(7):1419-23.

[8] Cellura M, Brano VL, Marvuglia A. 582.A photovoltaic panel coupled with a phase changing material heat storage system in hot climates. Conference on passive and low energy architecture. 2008.

[9] Or AB, Appelbaum J. Dependence of multi-junction solar cells parameters on concentration and temperature. Solar Energy Materials and Solar Cells. 2014; 130:234-40.

[10] Ameur A, Berrada A, Loudiyi K, Aggour M. Forecast modeling and performance assessment of solar PV systems. Journal of Cleaner Production. 2020.

[11] Berthod C, Strandberg R, Yordanov GH, Beyer HG, Odden JO. On the variability of the temperature coefficients of mc-Si solar cells with irradiance. Energy Procedia. 2016; 92:2-9.

[12] Benghanem M, Al-mashraqi AA, Daffallah KO. Performance of solar cells using thermoelectric module in hot sites. Renewable Energy. 2016; 89:51-9.

[13] Fesharaki VJ, Dehghani M, Fesharaki JJ, Tavasoli H. The effect of temperature on photovoltaic cell

efficiency. In proceedings of the 1st international conference on emerging trends in energy conservation–ETEC, Tehran, Iran 2011 (pp. 1-6).
[14] Amelia AR, Irwan YM, Leow WZ, Irwanto M, Safwati I, Zhafarina M. Investigation of the effect temperature on photovoltaic (PV) panel output performance. International Journal on Advanced Science Engineering Information Technology. 2016; 6(5):682-8.
[15] Ghazi S, Ip K. The effect of weather conditions on the efficiency of PV panels in the southeast of UK. Renewable Energy. 2014; 69:50-9.
[16] Enaganti PK, Bhattacharjee A, Ghosh A, Chanchangi YN, Chakraborty C, Mallick TK, et al. Experimental investigations for dust build-up on low-iron glass exterior and its effects on the performance of solar PV systems. Energy. 2022.
[17] Fouad MM, Shihata LA, Morgan EI. An integrated review of factors influencing the performance of photovoltaic panels. Renewable and Sustainable Energy Reviews. 2017; 80:1499-511.
[18] Touati F, Massoud A, Hamad JA, Saeed SA. Effects of environmental and climatic conditions on PV efficiency in Qatar. In international conference on renewable energies and power quality 2013 (pp. 1-6).
[19] Adeeb J, Farhan A, Al-salaymeh A. Temperature effect on performance of different solar cell technologies. Journal of Ecological Engineering. 2019; 20(5):249-54.
[20] Javed A. The effect of temperatures on the silicon solar cell. International Association of Scientific Innovation and Research. 2014; 9(3):305-8.
[21] Mustapha ID, Dikwa MK, Musa BU, Abbagana M. Performance evaluation of polycrystalline solar photovoltaic module in weather conditions of Maiduguri, Nigeria. Arid Zone Journal of Engineering, Technology and Environment. 2013; 9:69-81.
[22] Suwapaet N, Boonla P. The investigation of produced power output during high operating temperature occurrences of monocrystalline and amorphous photovoltaic modules. Energy Procedia. 2014; 52:459-65.
[23] Tanno K, Isire-wilfred VE. The effect of temperature variations on solar cell efficiency. Innovative Journal of Engineering. 2020; 1(1):105-11.
[24] Jaszczur M, Teneta J, Hassan Q, Majewska E, Hanus R. An experimental and numerical investigation of photovoltaic module temperature under varying environmental conditions. Heat Transfer Engineering. 2021; 42(3-4):354-67.
[25] Makrides G, Zinsser B, Phinikarides A, Schubert M, Georghiou GE. Temperature and thermal annealing effects on different photovoltaic technologies. Renewable Energy. 2012; 43:407-17.
[26] Ahmed A, Zhang G, Shanks K, Sundaram S, Ding Y, Mallick T. Performance evaluation of single multi-junction solar cell for high concentrator photovoltaics using minichannel heat sink with nanofluids. Applied Thermal Engineering. 2021.
[27] Ameur A, Berrada A, Bouaichi A, Loudiyi K. Long-term performance and degradation analysis of different PV modules under temperate climate. Renewable Energy. 2022; 188:37-51.
[28] Gong Y, Wang Z, Lai Z, Jiang M. TVACPSO-assisted analysis of the effects of temperature and irradiance on the PV module performances. Energy. 2021.
[29] Khan MA, Ko B, Alois NE, Park SE, Kim HJ. Performance evaluation of photovoltaic solar system with different cooling methods and a bi-reflector PV system (BRPVS): an experimental study and comparative analysis. Energies. 2017; 10(6):1-23.
[30] Abdolzadeh M, Ameri M, Mehrabian MA. Effects of water spray over the photovoltaic modules on the performance of a photovoltaic water pumping system under different operating conditions. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2011; 33(16):1546-55.
[31] Cox ICH, Raghuraman P. Design considerations for flat-plate-photovoltaic/thermal collectors. Solar Energy. 1985; 35(3):227-41.
[32] Fébba DM, Rubinger RM, Oliveira AF, Bortoni EC. Impacts of temperature and irradiance on polycrystalline silicon solar cells parameters. Solar Energy. 2018; 174:628-39.
[33] Qu H, Li X. Temperature dependency of the fill factor in PV modules between 6 and 40° C. Journal of Mechanical Science and Technology. 2019; 33(4):1981-6.
[34] Al-kayiem HH, Mohammad ST. Potential of renewable energy resources with an emphasis on solar power in Iraq: an outlook. Resources. 2019; 8(1):1-20.
[35] Sani M, Sule A. Effect of temperature on the performance of photovoltaic module. International Journal of Innovative Science and Research Technology. 2020; 5(9):670-6.

Malik F. Jaffar obtained his B.Sc. degree in Mechanical Engineering. He is M.Sc student in thermal engineering at the Technical Engineering College of Baghdad. His interests in Solar energy, Renewable Energy and HVAC system.
Email: malikaltaee1978@gmail.com

Ahmed Qasim Ahmed obtained his B.Sc. degree in Mechanical Engineering, Refrigeration and air-conditioning from the Middle Technical University, Iraq in 2004. M.Sc degree in thermal engineering from the Technical Engineering College of Baghdad in 2007. PhD in Mechanical Engineering from University of Leicester in the UK in 2017. Currently he is working as a lecturer in the Technical College of Baghdad in Mechanical Power Engineering Department. His interests in ventilation and HVAC system as well as CFD. He has authored and co-authored more than 10 articles in high quality international

journals/conferences and having a good citation in Scopus and Google scholar.
Email: en_ahmed82@yahoo.com

Abdulrahman Th. Mohammad obtained his B.Sc. degree in Mechanical Engineering from University of Technology, Iraq. M.Sc degree in Mechanical Engineering/Power from University of Technology, Iraq. His PhD in Renewable Energy from National University of Malaysia. Currently, works at the Renewable Energy Department, Baqubah Technical Institute, Middle Technical University, Iraq. His interests in Solar and Renewable Energy. He has authored and co-authored more than 70 articles in high quality international journals/conferences and having a good number of Scopus and Google scholar citations.
Email: abd20091976@mtu.edu.iq

Wisam A M Al-Shohani obtained his B.Sc. degree in Mechanical Engineering from Al Mustansiriya University Iraq in 2006. M.Sc degree in Renewable energy from Jordan University of Science and Technology, Jordan in 2010. PhD in Mechanical Engineering from University of Birmingham, UK in 2018. Currently he is working as a lecturer in a Technical College of Baghdad in Fuel and Energy Engineering Department. His interests in solar energy, renewable Energy and HVAC system. He has authored and co-authored more than 10 articles in high quality international journals/conferences and having a good citation of Scopus and Google scholar.
Email: wabd1984@gmail.com

Appendix I

S. No.	Abbreviation	Description
1	a-Si	Amorphous Silicon
2	A	PV Module Area
3	DC	Direct Current
4	FF	Fill Factor
5	G	Solar Irradiance
6	I-V	Current-Voltage Curve
7	LOCE	Levelized Cost of Energy
8	mono-c-Si	Mono-Crystalline Silicon
9	multi-c-Si	Multi-Crystalline Silicon
10	p-Si	Polycrystalline Silicon
11	PV	Photovoltaic
12	P-V	Power-Voltage Curve
13	STC	Standard Test Conditions
14	η	Electrical Efficiency