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The Performance of Polycrystalline and Monocrystalline Solar Modules Under The Climate Conditions of El-Kharga Oasis, New Valley Governorate, Egypt

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Abstract: This research seeks to evaluate the effectiveness of two commercially accessible photovoltaic technologies in the specific desert conditions of El-Kharga Oasis, New Valley Governorate, Egypt. The performance of photovoltaic cells is significantly affected by certain weather factors such as temperature, dust, and clouds. The photovoltaic technologies under investigation include monocrystalline and polycrystalline systems. Data collection was carried out over a period of 12 months in a systematic manner. The study places particular emphasis on analyzing how temperature, cloud cover, and dust impact the performance of PV modules. The results showed that monocrystalline and polycrystalline performed better at high irradiance levels, but they miss operated at lower irradiance levels. The loss of % in power output for polycrystalline and monocrystalline due to cloud cover is 80.503 and 79.240%, respectively. The loss percentage in power output for polycrystalline and monocrystalline due to dust accumulation were 41 and 42%, respectively. The polycrystalline module realized a decrease in open circuit voltage by 0.075 V/ºC while monocrystalline showed a reduction of 0.1666 V/ºC. The short circuit current increased slightly with temperature increasing by about 0.0082, and 0.0008 A/ºC for monocrystalline and polycrystalline, respectively. The monocrystalline had the largest drop in output power at about 0.0704 W/ºC while it was 0.0514 W/ºC for polycrystalline. It could be concluded that polycrystalline photovoltaic modules are the best choice in hot areas such as El-Kharga Oasis, New Valley Governorate, Egypt since they experience less temperature loss due to their low-temperature coefficient.

Keywords: Polycrystalline, Monocrystalline, Photovoltaic system, Temperature, Cloud cover, Dust accumulation.

1 Introduction

Owing to global climate change, energy security, and the increasingly acute shortage of fossil fuel reserves, the development of renewable energy technologies has become essential. About 80% of the world's energy consumption comes from fossil fuels, which cause serious climate changes. The application of renewable energy technologies is valuable that mitigate environmental degradation and the unlimited availability of resources [1, 2]. Among all renewable energy sources, solar energy has the greatest potential [3-8]. Solar radiation is an inexhaustible source of energy for the earth [9, 10]. Solar energy is harnessed through the utilization of two distinct technologies: photovoltaic modules and solar thermal collectors [3]. Both types have many applications in agricultural circumstances, making human life easier and increasing operation outcomes [11]. Photovoltaic (PV) modules are made of semiconductor materials. Nowadays, photovoltaic systems get a lot of attention because they are eco-friendly and safe to use. These systems allow homeowners to generate electricity in a reliable, clean, and quiet manner, which might reduce future electricity bills and lessen reliance on the lattice. Photovoltaic cells have a very long life [12].There are three major types of solar modules; monocrystalline or polycrystalline, and thin-films [13]. Monocrystalline cells are made from a high-purity cylindrical silicon alloy, which is cut into many chips to make solar cells. Its efficiency can reach up to 15%-20%. Another type of photovoltaic cell is polycrystalline modules, these cells are less efficient than monocrystalline cells and cost less [14]. Most of the parameters of the PV modules provided by the manufacturer are tested and evaluated under standard test conditions, PV cell temperatur of 25 °C, irradiance of 1000 W/m, air mass AM of 1.5. Real-time operating conditions are different from standard test conditions (STC). Module performance can be

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affected by temperature fluctuations, sunlight, cloudiness, wind, relative humidity (RH), dust, and rain [15]. Therefore, testing PV modules outdoors is essential [16].When the module temperature gets higher than 25 ºC (STC), the output power of the PV module will be decreased. Among the electrical parameters of the PV module, its output voltage is very dependent on the module temperature so the increase in the module temperature decreases its output voltage [17]. The average temperature coefficients of power for monocrystalline, polycrystalline, and CdTe-based modules were 0.0446, -0.387 % and -0.172%/ºC, respectively [18]. In the case of an amorphous silicon module, the temperature coefficient is -0.172%/ºC. The efficiency of both monocrystalline and polycrystalline silicon solar cells experiences a reduction of approximately 0.45% with each degree increase in temperature [19]. Cloud cover has a significant effect on the performance of solar modules. It was noticed that the loss percent in power output of modules due to heavy cloud cover ranges between 23 and 67% of the maximum power output to be generated by solar modules under full irradiance [20]. According to reports, photovoltaic modules in Baghdad city, Iraq, are significantly impacted by dust accumulation [21]. Identifying the most appropriate photovoltaic technology that is well-suited for the local environment holds paramount importance. The climate of El-Kharga Oasis is an arid desert environment. El-Kharga Oasis has a continental climate with hot summers and extreme daytime temperatures. The hottest month is July, while January is the coolest. The average annual temperature is 23 ºC. The annual average relative RH is 35.5%, and the annual average wind speed is 6 km/h. New Valley is one of the highest-ranked provinces in Egypt in terms of solar radiation intensity [22]. The average annual sunshine hours in the southern desert region of Egypt range from about 9 h to 11 h, which means that there are more investment opportunities in various solar energy applications. Distinct photovoltaic technologies react differently to this climate, in which different types perform dissimilar patterns for specific climates. The performance of three different types of solar modules monocrystalline, polycrystalline, and triple junction amorphous silicon under Norway climate condition have been investigated [23]. The research revealed that monocrystalline solar modules outperformed polycrystalline and amorphous silicon modules in terms of both average output power and module efficiency. Dash and Gupta [18] conducted an analysis of the performance of crystalline and amorphous solar modules in the context of South African climate conditions. The study revealed that both technologies demonstrated similar and satisfactory performance levels in this specific region. In a separate study comparing polycrystalline, monocrystalline, and amorphous silicon solar cells in desert climates [24], the researchers recommended the use of polycrystalline cells for photovoltaic applications in such environments. Another investigation focused on the performance of four distinct types of solar modules—monocrystalline, polycrystalline, amorphous silicon, and copper indium di-selenide (CIS)—under outdoor conditions in Malaysia [25]. The results indicated that monocrystalline and polycrystalline modules exhibited superior performance at high temperatures, while amorphous silicon modules performed better in cloudy weather conditions [25].

This study presents the measurements and analysis of data obtained by outdoor testing of two photovoltaic modules with two different technologies from October 2021 to October 2022. The aim of this study is to determine the impact of certain weather factors such as temperature, dust, and cloud on the performance of different types of photovoltaic cells, namely monocrystalline and polycrystalline silicon, to identify the most suitable climatic conditions in Al-Kharga city.

2 Material and methods

2.1 The study area

The research was conducted in El-Kharga, New Valley Governorate, Egypt, which is bordered by longitudes 30.20 and 30.40 E and latitudes 25.05 and 25.30 N (Fig. 1 [26]).

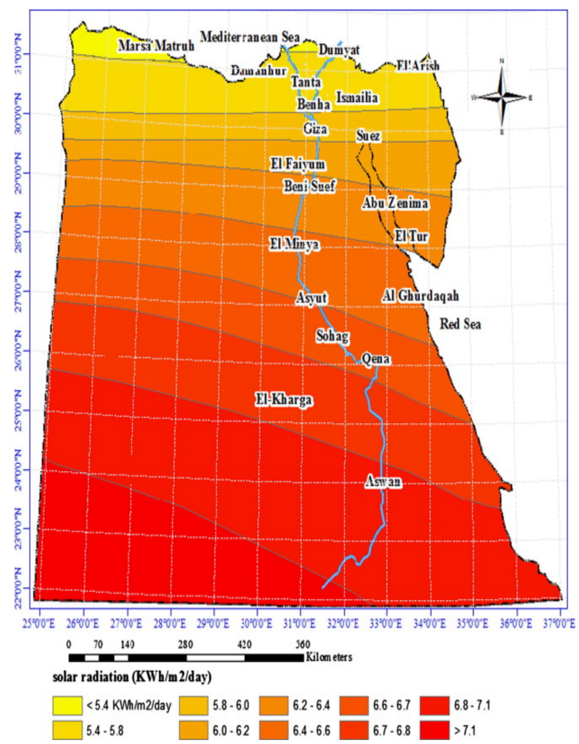

Fig. 1: Solar radiation map in Egypt [26].

From 2/10/2021 to 30/9/2022, each module's temperature, open circuit voltage (V_{oc}), short circuit current (I_{sc}), and power (P) were measured once a week from 8 am to 5 pm. Temperature, RH, rain, wind, cloud cover, maximum temperature, and minimum temperature were obtained from a weather website (https://www.accuweather.com).

2.2 Photovoltaic modules

Two photovoltaic (PV) modules were used to originate a system in El-Kharga Oasis (polycrystalline modules, Table 1, and Fig. 2a and monocrystalline, Table 2 and Fig. 2b). To maintain a 30-degree angle towards the south to face the sun, two modules were fastened to a wooden frame. These modules are 1.0 and 1.35 m front and back height, respectively from the floor. V_{oc} and I_{sc} were measured using digital thermometer and multimeter (Fig. 2c,d) and the power (P) was determined by multiplying Vmax by Imax [27]:

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

2.3 Measurement tools

The temperature of the module was measured using a thermometer (Fig. 2). To predict the temperature effect on both polycrystalline and monocrystalline modules, the performance of monocrystalline and polycrystalline are tested for twelve months from October 2021 to September 2022 under solar radiation of 1000 W/m^2. To assess the impact of clouds on the performance of monocrystalline and polycrystalline solar modules, a comprehensive study was conducted, which involved the daily recording of various properties at 10 different points. These properties included V_{oc}, I_{sc}, and output power. Additionally, detailed weather conditions were also noted as a crucial factor in understanding the cloud effects on the solar modules' performance. Since it is difficult to realize both sunny and cloudy days appear on the same day, the solar modules on sunny days are used as the control test, and the solar modules on cloudy days are used as the test objects. The shortage output power (P) percentage due to cloud cover is expressed as follows [20]:

$$(P\ non\ cloud - P\ cloud\ cover / P\ non\ cloud)*100 \quad (2)$$

To anticipate the impact of dusty days on the performance of monocrystalline and polycrystalline solar modules, various parameters were recorded daily at 1 pm. These parameters included V_{oc}, I_{sc}, and output power. Furthermore, weather conditions were closely monitored as they play a significant role in understanding how dust affects the solar modules' efficiency and performance on such days. Since it is difficult to realize both dustless day and dusty day occur in alike day, the solar modules on a dustless day are used as a control test, and solar modules on a dusty day are used as test objects. The degradation rate resulting from dust storms of cells was chosen as a comparison criterion according to [28, 29] as follows:

Current degradation rate= $I_{dusty}I_{clean}$
Voltage degradation rate = V_{dusty}/V_{Clean}
Power degradation rate = P_{dusty}/P_{clean}
Power loss = $(P_{clean} - P_{dust}/P_{clean})*100$ (3)

To predict the effect of dust in monocrystalline and polycrystalline, it should put the PV under the same conditions, while the modules weren't cleaned for a certain period. The recorded parameters are the experiment day, the time, ambient temperature, RH, rain, I_{sc}, V_{oc} before cleaning and after cleaning modules for both monocrystalline and polycrystalline modules. The power produced form the module before cleaning. The power produced form the module after cleaning. The power difference and the relative difference, which is the ratio of the difference of power for the modules before and after cleaning, were calculated.

Fig. 2: The photovoltaic (a) polycrystalline, (b) monocrystalline modules, (d) digital thermometer (c), and multimeter (d) used for testing.

Table 1: Electrical and physical characteristics of polycrystalline PV modules.

Company	A proflex
Model	PRO (P roflex solar)
Standard	ICE 61215
Tracking NO	PRPV-61215
Rated power	50 W
Rated voltage	17.8 V
Rated current	2.81 A
Open circuit voltage	22.1 V
Short circuit current	2.98 A
Photovoltaic module rated at	1000 W/M
Solar irradiance	1.5 AM
Cell temperature	25 ºC
Maximum series fuse rating	10 A
Maximum system open circuit voltage	750 VDC
Cell type	Polycrystalline

Table 2: Electrical and physical characteristics of monocrystalline PV module.

Dan Yang Ri Shang lighting technology	Company
50 W	Rated power
18 V	Rated voltage
20 open	Peak voltage
20 V	Circuit voltage
18 V	Peak voltage
10 October 2018	Production date

3 Results and discussion

3.1 *Effect of ambient temperature on monocrystalline and polycrystalline performance*

Scatter plots were employed as a data analysis method to examine the relationship between output power, V_{oc}, and I_{sc} concerning the operating module temperature. The scatter plots demonstrated a linear correlation between these variables and the operating temperature of the modules. To quantify this relationship, the temperature coefficient (TCO) was introduced, which represents the change in V_{oc}, I_{sc}, or output power (P) with respect to temperature variations. The TCO was determined to be equal to the slope of the linear equations, denoted as equation (4). The slope values for each line equation were calculated using Microsoft Office/Excel's linear regression fit option, providing valuable insights into the extent of temperature influence on the mentioned parameters. The TCO symbols for P, I_{sc} or V_{oc} are as follows [28]:

$$V_{oc} = \Delta V_{oc}/\Delta T, \quad I_{sc} = \Delta I_{sc}/\Delta T, \quad P = \Delta P/\Delta T \quad (4)$$

The output voltage is significantly influenced by large temperature fluctuations due to the logarithmic relationship between the V_{oc} and the inverse of the reverse saturation current. Temperature strongly affects the reverse saturation current, leading to notable variations in the V_{oc}. Understanding this logarithmic relationship is crucial when analyzing the impact of temperature on solar module performance and designing efficient photovoltaic systems. The polycrystalline module drops 0.075 V/ºC, and the monocrystalline module drops 0.1666 V/ºC (Fig. 3). This result corresponds to what was explained [28]. According to the reported findings, the polycrystalline module exhibited a decline in V_{oc} with a temperature coefficient of -0.0912 V/ºC, while both monocrystalline and a-Si (amorphous silicon) showed a slightly lower temperature coefficient of approximately -0.07 V/ºC. The variation in Voc between the two module types can be attributed to the distinct changes in the band gap energy value and recombination rate of each semiconductor material as the temperature levels fluctuate. These factors play a significant role in determining the response of the solar modules to temperature variations. Another factor affecting the decrease in V_{oc} is impurities and strain in the semiconductor crystal, which are sources of recombination [28].

The scatter plot illustrates the linear relationship represented by the positive-sloping linear regression equation, showing that Isc increases slightly with increasing temperature, and this effect is negligible, as shown in Fig. 4. Monocrystalline silicon has a larger Isc than polycrystalline silicon. The results showed a slight increase in I_{sc} with temperature; such increase was about 0.0082 A/ºC and 0.0008 A/ºC for monocrystalline, and polycrystalline, respectively.

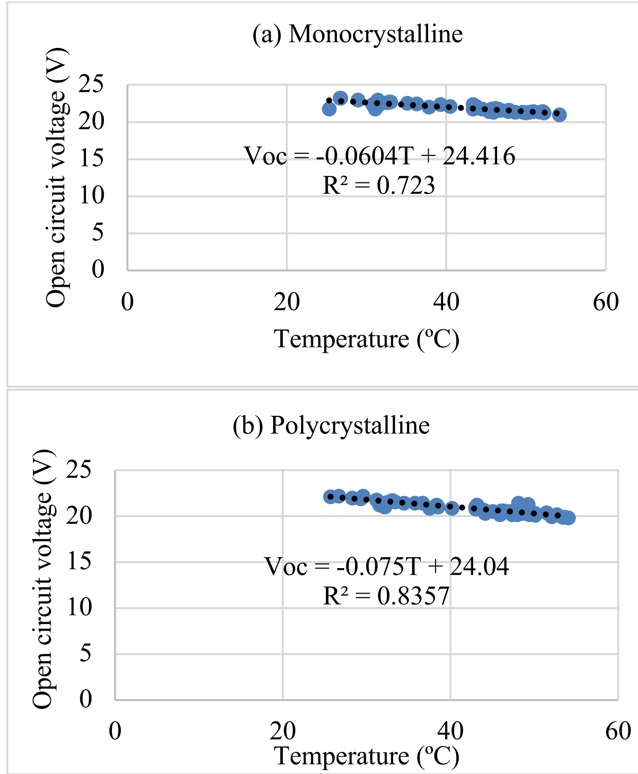

Fig. 3: Experimental open circuit voltage and module temperature of monocrystalline (a) and polycrystalline (b).

This result corresponds to what was explained [28] which reported that the results showed a slight increase in I_{sc} with temperature such increase was about 0.3 mA/ºC and, 4.4 mA/ºC for monocrystalline and polycrystalline respectively. The increase in output current is a result of the decrease in band gap energy as electrons gain thermal energy which is added to the electromagnetic radiation energy required to release electrons from the valence band in the semiconductor material to the conduction band where they reside; move freely and generate electricity. This increase is still relatively small and slightly compensates for the apparent voltage drop in the polycrystalline module, where the temperature influence I_{sc} can be ignored.

When the power is plotted against the module temperature, monocrystalline showed a degradation of 0.0704 W for each degree centigrade (Fig. 5) and polycrystalline has P of -0. 0514 W. This result corresponds to what was explained [28] and it was found that the monocrystalline had the largest drop in output power of about -0.1353 W/ºC while it was -0.0915 for polycrystalline. The comparison between temperature coefficients for monocrystalline and polycrystalline modules is shown in Table 3.

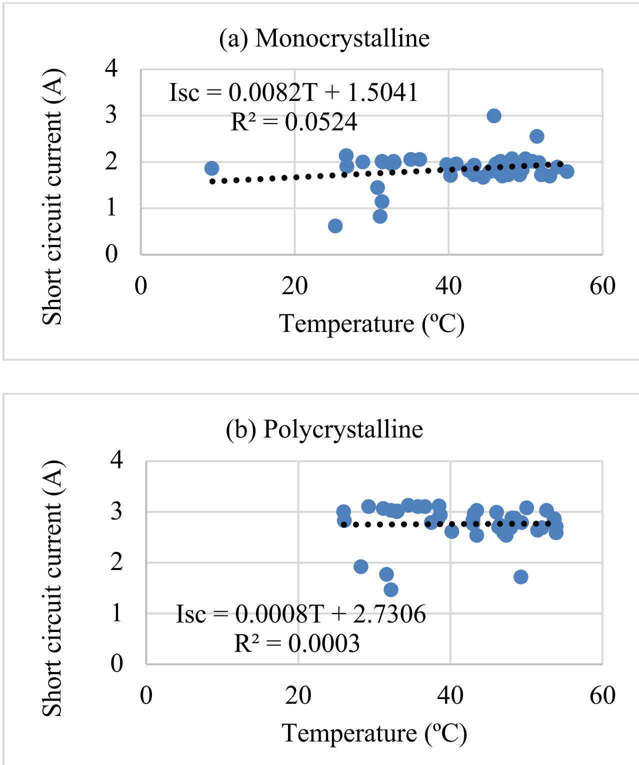

Fig. 4: Experimental short circuit current and module temperature for monocrystalline (a) and polycrystalline (b).

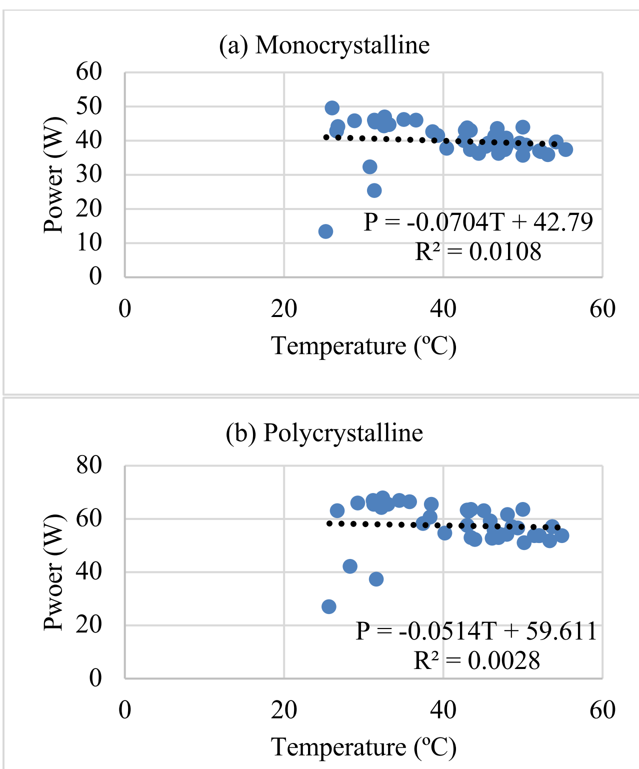

Figure 5. Power output and module temperature for monocrystalline (a) and polycrystalline (b).

Table 3. Temperature coefficients summary.

Parameters	Monocrystalline	Polycrystalline
V_{OC} (V/°C)	-0.1666	-0.075
I_{SC} (A/°C)	0.0082	0.0008
P (W/°C)	-0.0704	-.0514

3.2 Effect of cloud cover on monocrystalline and polycrystalline performance

Compares the output power against the time of the day in-situ for cloudy weather and no-cloud weather for monocrystalline at 8 am, the power was 9.45 W during a cloudy day but it was 14.982 W during a sunny day (Fig. 6). At 12 pm, the power was 44.08 W on a sunny day and it was 32.335 W, on a cloudy day. At 2 pm, the power was 36.252 W on a sunny day and it was 7.524 W on a cloudy day. Comparison of the output power against the time of the day in-situ for cloudy weather and no-cloud weather for polycrystalline at 8 am, the power was 13.33 W during the cloudy day but it was 19.069 W during the sunny day (Fig. 6). At 12 pm, the power was 42.267 W during cloudy days and it was 63.04 W during a sunny day. At 2 pm, the power was 10.45 W during a cloudy day and 53.6 W during a sunny day.

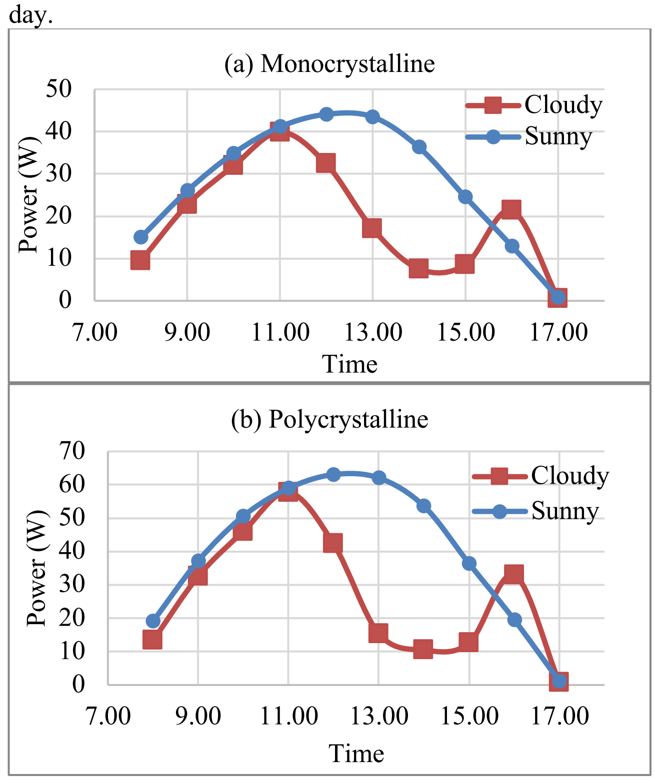

Figure 6. Comparison of output power by the module during no-cloud and cloudy days for monocrystalline (a) and polycrystalline (b).

Figure 7 compares the V_{oc} against the time of the day in-situ for cloudy weather and no-cloud weather for monocrystalline at 8 am, the V_{oc} was 22.5 V during a cloudy day, but it was 22.7 V during a sunny day. At 12 pm, the V_{oc} was 23.2 V on a sunny day, and it was 22.2 V on a cloudy day. At 2 pm, the V_{oc} was 22.8 V on a sunny day, and it was

21.8 V on a cloudy day. Comparing the V_{oc} against the time of the day in-situ for cloudy weather and no-cloud weather for polycrystalline at 8 am, the V_{oc} was 21.5 V during a cloudy day, but it was 21.7 V during a sunny day (Fig. 7). At 12 pm, the V_{oc} was 22.2 V on a sunny day, and it was 21.3 V on a cloudy day. At 2 pm, the V_{oc} was 21.8 V on sunny days, and it was 20.9 V on cloudy days.

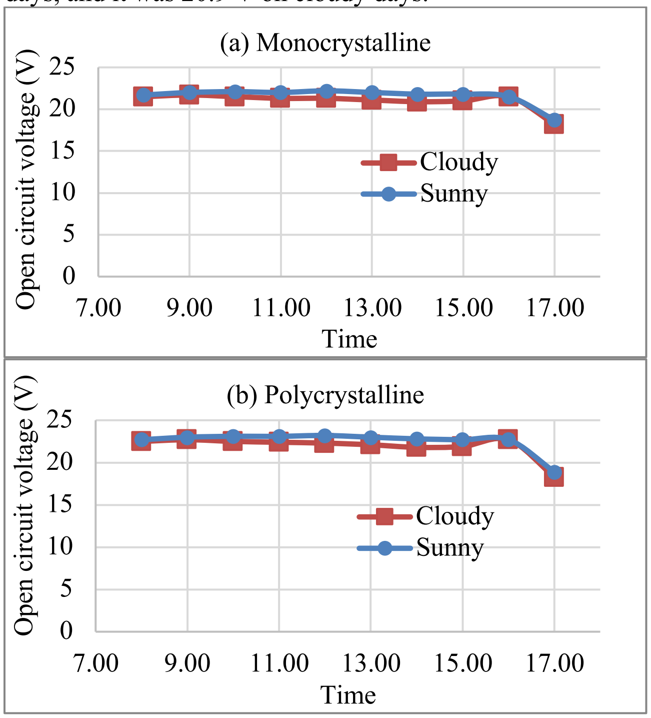

Figure 7. Comparison of the output open circuit voltage against the time of the day in-situ for cloudy weather and no-cloud weather for monocrystalline (a) and polycrystalline (b).

Figure 8 shows the cloud cover has a slight effect on the V_{oc} for monocrystalline and polycrystalline. Figure (8) compares the I_{sc} for the time of the day in situ for cloudy weather and no-cloud weather for monocrystalline. At 8 am, the I_{sc} was 0.42 A, during a cloudy day but it was 0.66 A during a sunny day. At 12 pm, the I_{sc} was 1.9 A on a sunny day, and it was 1.66 A on a cloudy day. At 2 pm, the I_{sc} was 1.59 on a sunny day and it was 0.33 A on a cloudy day. At the cloudiness cover the I_{sc} was 78%. Figure (8) shows the I_{sc} against the time of the day in situ for cloudy weather and no-cloud weather for polycrystalline. At 8 am, the I_{sc} was 0.62 A during cloudy days, but it was 0.88 A during sunny days (Fig. 8). At 12 pm, the I_{sc} was 2.84 A on a sunny day, and it was 1.93 A on a cloudy day. At 2 pm, the I_{sc} was 2.46 A during a sunny day, and it was 0.5 during a cloudy day at cloudiness cover was 78%. The loss percentage in power output of monocrystalline and polycrystalline due to cloud cover:

The loss power percentage of monocrystalline = (36.252 - 7.524 / 36.252) * 100 = 79.24%

The loss power percentage of polycrystalline =(53.6-10.45/10.45) * 100= 80.503%

According to the above analysis, cloudy causes a significant decrease in the power generation of the solar modules of monocrystalline and polycrystalline, because most of the sunlight is transmitted since the loss percentage of cloud was 79.24 % for monocrystalline and 80.503% for polycrystalline. The previous results indicated that the clouds had the same effect on the polycrystalline and monocrystalline.

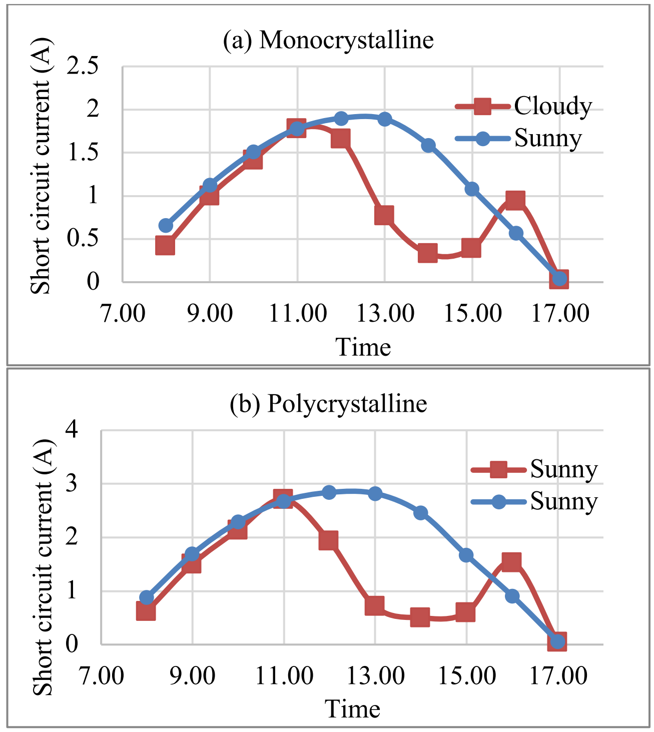

Figure 8. Comparison of short circuit current by the module during sunny and cloudy days for monocrystalline (a) and polycrystalline (b).

3.3 Effect of dust on monocrystalline and polycrystalline performance

Figure 7 compares the V_{oc} against the time of the day in-situ The dust density was in the range of 0.014-0.057 g/m^2 over a year in El-Kharga city in the New Valley Governorate which caused a reduction in the I_{sc}, V_{oc}, and power for both monocrystalline and polycrystalline. Table 4 shows a comparison between V_{oc}, I_{sc}, P, module temperature (T) for monocrystalline and polycrystalline on Sunday 13th March 2022 (dusty day) and on Saturday 12th March 2022 (dustless day). Table 5 shows the changes in ratios of V_{oc} dusty/V_{oc} clear, I_{sc} dusty/I_{sc} clear, P_{dusty}/P_{clear} for monocrystalline and polycrystalline on Saturday 12th March 2022 and Sunday 13th March 2022. The loss power percentage for monocrystalline and polycrystalline was 42 and 41%, respectively.

3.4 Effect of dust accumulation on monocrystalline and polycrystalline performance

Tables 7 and 8 show that dust accumulation doesn't have a substantial impact on the V_{oc} of monocrystalline and polycrystalline. Dust accumulation has a significant effect on I_{sc} and the power of monocrystalline and polycrystalline materials. This might be due to the deposition of dust on the module decreasing the solar radiation transmittance to the solar cell and resulting in a marked deterioration in the conversion of solar energy into electricity. This result corresponds to what was explained [14]. The results indicated that dust accumulation on the PV module had an impact on cell operating temperatures. The clean module temperature was observed to be higher compared with the dusty one of monocrystalline and polycrystalline due to less light entering the module. This result corresponds to what was explained [30]. On the other hand, the result was different from what was explained, and it was found that the clean module temperature was noticed to be lower compared with the dusty one. The previous results indicate that dust accumulation realized the same effect on the polycrystalline and monocrystalline. Tables 6 and 7 compare the module before and after cleaning for monocrystalline and polycrystalline, respectively.

Table 4. The function of both monocrystalline and polycrystalline on a dusty day and a dustless day.

Parameters						Monocrystalline				Polycrystalline			
	Time	T	Wind	RH	Clouds	V_{oc}	I_{sc}	P	T	V_{oc}	I_{sc}	P	T
Dusty day	1:00 PM	21	52 km/h	22%	68%	22.7	1.21	27.47	28	21.7	1.85	40	27
Dustless	1:00 PM	18	54 km/h	23%	51%	23.3	2.03	47.3	28	22.3	3.06	68	27

Table 5. Ratio of voltage, current and power of both monocrystalline and polycrystalline on a dusty day and a dustless day.

Monocrystalline			Polycrystalline		
$V_{dusty}/V_{dustless}$	$I_{dusty}/I_{dustless}$	$P_{dusty}/P_{dustless}$	$V_{dusty}/V_{dustless}$	$I_{dusty}/I_{dustless}$	$P_{dusty}/P_{dustless}$
97%	60%	58%	97%	60%	59%

Table 6. Comparison between the module before and after cleaning for polycrystalline.

Parameters						Dusty				Clean				Relative diff.
Day	Time	T (ºC)	Wind (km/h)	Rain (%)	RH (%)	I_{sc}	V_{oc}	P1	T	I_{sc}	V_{oc}	P2	T	
4/12/2021	12	23	8	0	30	3.03	20.8	63.02	45.5	3.09	20.9	64.581	47	2.41%
15/1/2022	12	18	13	0	45	2.99	21.5	64.285	32.4	3.02	21.5	65.36	33	1.64%
26/2/2022	12	19	15	0	41	3.01	21.7	65.317	32.4	3.16	21.5	67.943	33	3.86%
26/3/2022	12	33	22	0	28	3.07	21.8	66.925	31.2	3.16	21.7	68.572	32	2.40%
11/7/2022	10	34	11	0	14	1.89	20.6	38.934	39	1.97	21.3	41.961	42.3	7.21%

Table 7. Comparison between the module before and after cleaning for monocrystalline.

Parameters						Dusty				Clean				Relative diff.
Day	Time	T (ºC)	Wind (km/h)	Rain (%)	RH (%)	I_{sc}	V_{oc}	P1	T	I_{sc}	V_{oc}	P2	T	
4/12/2021	12	23	8	0	30	1.94	21.3	41.322	46.5	2	21.5	43	49	3.90%
15/1/2022	12	18	13	0	45	1.96	22.6	44.296	32.6	1.99	22.6	44.974	33	1.50%
26/2/2022	12	33	15	0	41	1.98	22.7	44.946	32.7	2.08	22.6	47.008	33	4.38%
26/3/2022	12	19	22	0	28	2.01	22.9	46.029	31.4	2.08	22.7	47.216	32.2	2.51%
11/7/2022	10	34	11	0	14	1.25	21.6	27	40	1.35	22	29.7	42.3	9.09%

4 Conclusions

It could be concluded that polycrystalline photovoltaic modules are the best choice in hot areas such as El-Kharga Oasis, New Valley Governorate, Egypt since they experience less temperature loss due to their low-temperature coefficient. The accumulation of dust and cloud cover realized the same effect on monocrystalline and polycrystalline materials. The polycrystalline module demonstrated a temperature-dependent decrease in V/ºC of 0.075 V/ºC, while the monocrystalline module exhibited a greater reduction of 0.1666 V/ºC. As for the I_{sc}, a slight increase was observed with rising temperatures, approximately 0.0082 A/ºC for monocrystalline and 0.0008 A/ºC for polycrystalline. Regarding the output power, the monocrystalline module showed a more significant decline, about 0.0704 W/ºC, compared to the polycrystalline module which experienced a slightly lower decrease of 0.0514 W/ºC. Considering these findings, it can be concluded that in hot areas like El-Kharga Oasis, New Valley Governorate, Egypt, polycrystalline photovoltaic modules are the more favorable choice. This is due to their lower temperature coefficient, which results in less power loss as the temperature rises.

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