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Effects of Environmental and Climatic Conditions on PV Efficiency in Qatar

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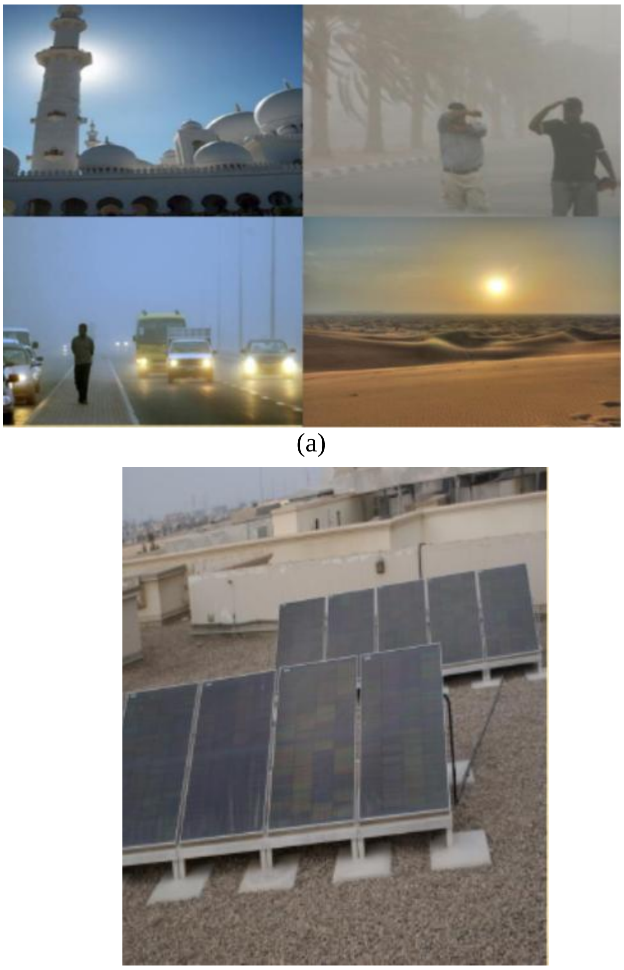
Abstract. The sensitivity of various solar photovoltaic technologies towards dust, temperature and relative humidity is investigated for Qatar's environment. Results obtained show that dust accumulation has the great effect on decreasing Amorphous and Mono-crystalline PV's efficiency than the panel's temperature augmentation or relative humidity. The study shows that Amorphous PVs are more robust against dust settlement than Mono-crystalline PVs and hence are more suitable for implementation in desert climates like Qatar. It was estimated that 100 days of dust accumulation over Mono-crystalline PV panels, caused the efficiency to decrease by 10%. This limitation makes solar PV an unreliable source of power for unattended or remote devices and thus strongly suggests the challenge of cleaning the panel's surface regularly or injecting technical modifications. Also, the study assesses how best to operate solar PV plants during peak sunlight hours to optimize production and minimize the sun's harsh effects.

Key words

PV testing, effect of dust, harsh environment, Mono-crystalline PV, Amorphous PV

1. Introduction

During the last recent years, peaks on oil prices were very sharp and destructive for the economy of many countries. Therefore, the need of more optimizing energy extraction from renewable energy sources becomes crucial. There is an increasing concern worldwide in this regard [1-6]. Through its ambitious Qatar's Vision 2030, the state of Qatar is looking for a new energy strategy where various sources form a hybrid energy grid that fosters sustainability and reduction of greenhouse gas emission levels. Interestingly, while there is plenty of solar radiation in Qatar and surrounding region (more than 6 kWh/m^2/day), its climate is very harsh and has plenty of sand and dust (see Fig. 1). Considering the fact that photovoltaic cells already have low conversion efficiencies (typically up to 20%), the harsh climate may further reduce their output efficiency and hence bring the system to an alerting situation. Several studies in the region and elsewhere were carried out to investigate the effects of environmental factors on the performance of photovoltaic (PV) systems [7-11]. However, these effects are site-specific hence deliberate study should be conducted for each region.



(a)

(b)

Figure 1: (a) A dusty day in the golf, (b) Roof-top panels affected by dust [12].

In this work, the degradation of the performance of commercial Mono-crystalline and Amorphous silicon PV technologies under a wide range of Qatar's climatic and environmental factors has been compared, aiming at providing important and useful information on the usage and maintenance of solar PVs in the country. The study focused on the effect of temperature, relative humidity and dust settlement. To the authors' knowledge, there were no such data about Qatar in the literature.

2. Methodology

During the study, we used two commercial PV modules with the characteristics shown in Table I below.

Table I. – Characteristics of used PV Modules

	MaxPower (Watt)	Area (m^2)	Voc (V)	Ish (A)
Mono-Crystaline	120	1.02	43.20	3.91
Amorphous	100	0.81	21.7	5.94

We started our study by installing the two modules in a fixed position relative to the sun. This position was chosen so that modules collect as maximum of solar radiations as possible during the day. Then, we recorded the power generated by each module separately. This enables us to estimate the degradation of panel's efficiency over the day. After that, we pointed the panels dynamically toward the sun and recorded data. Data were collected over days and scanning day times (morning, noon, afternoon) in order to expose panels to various conditions of temperature, Relative Humidity and sun. Data shown here are only typical data among obtained.

3. Experimental Data and Analysis

In this section, we studied the effect of temperature, Relative Humidity and dust on the PV panel performance for each technology.

A. Modules performance in a fixed position

Figure 2 illustrates the variation of PV output power during the day. Note that we measured the power per meter square (normalized) to avoid problem of difference in size between the two modules.

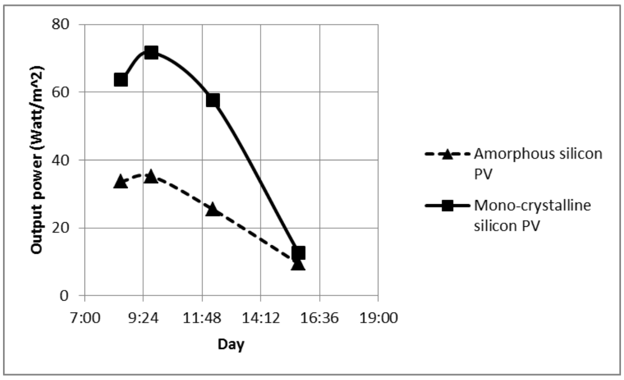


Fig. 2. Variation of power per meter square during the day.

From the modules' characteristics (Table I), we know that the maximum power per meter squares is 117.64 Watt/m^2 for the Mono-crystalline PV and 123.45 Watt/m^2 for the Amorphous PV. However, Fig. 2 shows that the maximum power recorded was quite lower; only 70 Watt/m^2 and 35 Watt/m^2, respectively. The average of power generated across the period of measure was 50.38 Watt/m^2 and 25.92 Watt/m^2, respectively, which is insufficient for usual application performed by PV with similar characteristics. This decrease in energy generated is due to the fact that PV modules are in a fixed position and thus capture maximum of radiation only over very short moments of the day.

To increase the maximum power a PV panel can collect, we chose the strategy to make the two modules move and point dynamically toward the sun. Data were plotted in Fig. 3. It is obvious that for both technologies the power obtained increases linearly with the amount of radiation received, which is in line with the results in [1].

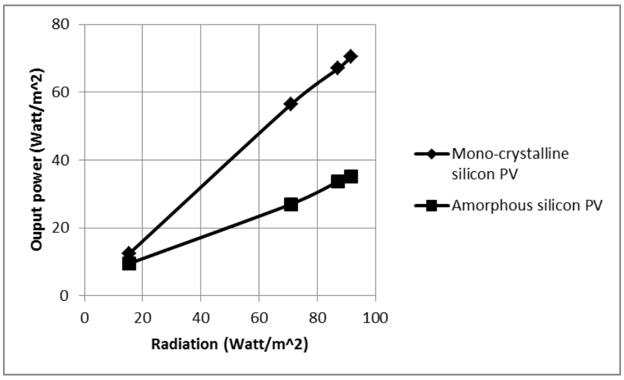


Fig. 3. Variation of generated power with the amount of incident radiation on PV panel.

B. Performance of Modules in a Moving Position

Data were collected to study the effect of temperature, Relative Humidity, and dust on panel efficiency.

1) Panel's Power increase

Figure 4 shows that the power obtained per meter square has increased as compared to the results obtained when the modules were in a fixed position (Fig. 2). Also, 85% and 70% of power ratings of Mono-crystalline and Amorphous panels could be generated, respectively.

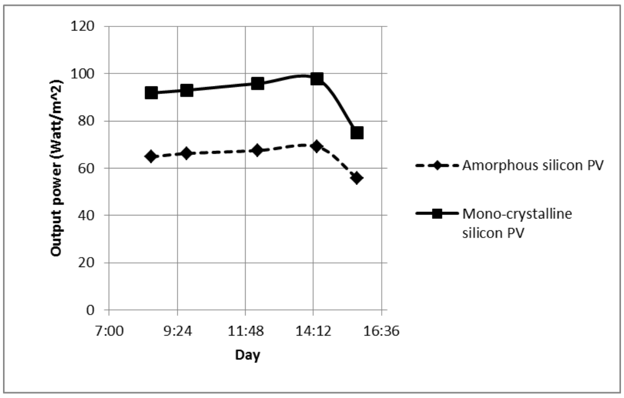


Fig. 4. Variation of power per meter square during the day.

It is obvious that the maximum of power obtained becomes greater, 99.76 Watt/m^2 and 70.00 Watt/m^2 for Mono-crystalline and Amorphous PVs, respectively. Also, the average power generated increased to 97.00

Watt/m^2 and 67.00 Watt/m^2, respectively. Interestingly, the two curves show also that generated power stay near its maximum value for a longer period (the two curves have smooth summit) and this indicates that we can rely on the obtained power to supply many applications for a long duration. Furthermore, it obvious that for both technologies the maximum power is obtained over a span of three hours between 11h:00 and 14h:00. This result is of great interest in case we want to build a hybrid system, where we could make the later be supplied by PV modules during that extended peak period.

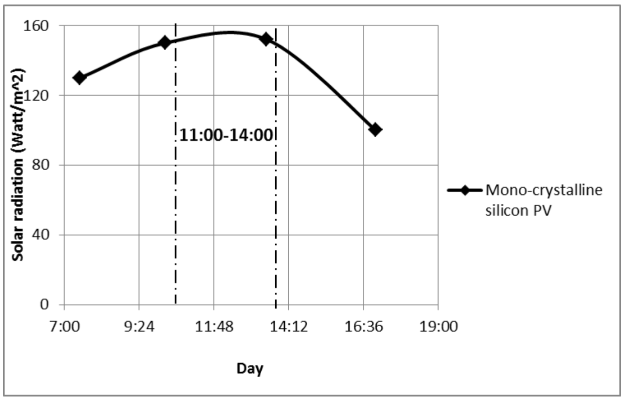


Fig. 5. Amount of radiation in Qatar during a very sunny day.

To confirm the fact that the maximum PV power can be obtained over the period from 11h:00 to 14h:00, we recorded in Fig. 5 the variation of sun radiation intensity for Mono-crystalline panels during a very sunny day in Qatar Doha. We can see that the radiation intensity is maximum over that period. Similar results were obtained for Amorphous panels. Therefore, according to the results obtained previously in Fig. 3, the PV power generated should be maximum as well over the same period of time.

2) Effect of Temperature and Humidity on PV efficiency

In this phase, the panels were pointed to the sun. Temperature and Relative Humidity were recorded over whole days. Table II presents experimental data obtained for each panel. It is worth reminding that efficiencies of 100% are achievable only under specific climatic conditions (specified at panel back) and panel loading (maximum power transfer).

Table II. - Different variables measured for each Panel

	Time of the day	Temperature C°	Relative Humidity (%)	Efficiency
Mono-crystalline PV	8:30	41.9	28	0.71
	9:45	48	25	0.76
	12:45	49.9	24	0.78
	15:45	40.4	22	0.8
Amorphous PV	8:30	42.9	28	0.385
	9:45	48.4	25	0.383
	12:45	45.4	24	0.358
	15:45	40.9	22	0.616

The rationale to separate between temperature and relative humidity effects was proved by calculating the correlation between measured values of these two parameters. Let's set T_{mono} = [40.9 48 50 40.4], T_{semi} = [42.9 48.4 45.4 40.9] and H = [28 25 24 22] be vectors of the measured temperatures (in degree Celsius) (respectively, of Mono-crystalline and Amorphous silicon PVs) and relative humidity (in percent) during the experiments. The correlation between (T_{mono} and H) and (T_{semi} and H) were calculated using MATLAB by applying the Pearson's correlation operator as follows:

$$\text{corr}(T_{mono}, H) = T_{mono}{*}H' = \begin{bmatrix} 1 & -0.1001 \\ -0.1001 & 1 \end{bmatrix},$$

$$\text{corr}(T_{semi}, H) = T_{semi}{*}H' = \begin{bmatrix} 1 & 0.2057 \\ 0.2057 & 1 \end{bmatrix}.$$

where H' denotes the transpose of the vector H.

The correlation coefficient is always between -1.0 and +1.0. If the coefficient is positive, we have a positive relationship between the two variables. If it is negative, the relationship is negative. The number 1 appearing in the results represents the correlation coefficient of T_{mono} or T_{semi} with itself, whereas the other coefficients (i.e. -0.1001 and 0.2057) represent that of T_{mono} or T_{semi} with H. It is obvious that, for both PV technologies, the correlation between temperature and relative humidity is very weak (i.e. quite smaller than unity) and hence can be rigorously considered as uncorrelated. Figures 6 and 7 show the variation of efficiency with the panel temperature and Relative Humidity for both technologies.

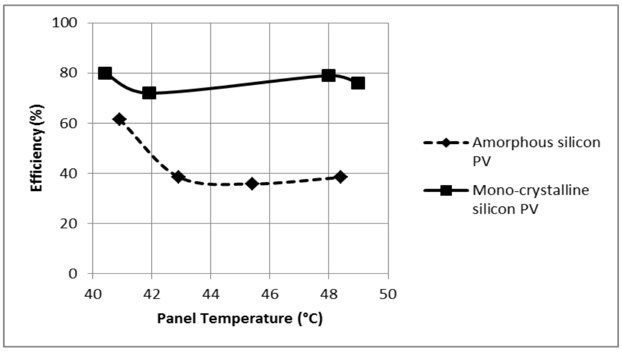


Fig. 6. Temperature effect on efficiency Mono-crystalline and Amorphous silicon PV panels.

To compare the effect of temperature and Relative Humidity on PVs modules rigorously, we defined two parameters: (*ΔEfficiency/1%RH*) which is the variation of efficiency for an increase of 1% of the Relative Humidity, and (*ΔEfficiency/1℃*) which is the variation of efficiency for an increase of 1° C of the temperature. The results are shown in Table III.

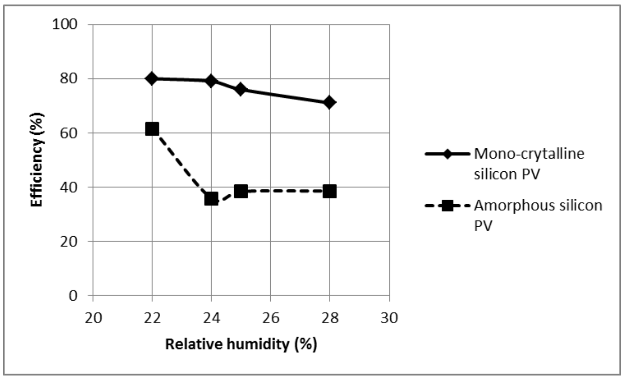


Fig. 7. Effect of Relative Humidity on efficiency of Mono-crystalline and Amorphous panels.

Table III – Measure of Efficiency variation for the two PV modules.

	ΔEfficiency/1%RH	*ΔEfficiency/1℃*
Mono-crystalline PV	-0.015	-0.010
Amorphous PV	-0.043	-0.030

Table III shows that for both PVs when their temperature or Relative Humidity increases, the efficiency decreases (all the parameters are negative). However, this decrease is sharper for the Amorphous PV than Mono-crystalline PV. This indicates that the latter is less sensitive to temperature or humidity variation. Also, variation in Relative Humidity shows greater effect on efficiency than that in temperature for both PVs (0.015 > 0.010 and 0.043 > 0.030).

3) *Effect of Dust on PV performance*

As in the previous section, to study the effect of dust we defined the following metric: *Δ(Efficiency)/(119g/m²)* which represents the variation of generated power per meter square for an increase of 119g per meter square of dust.

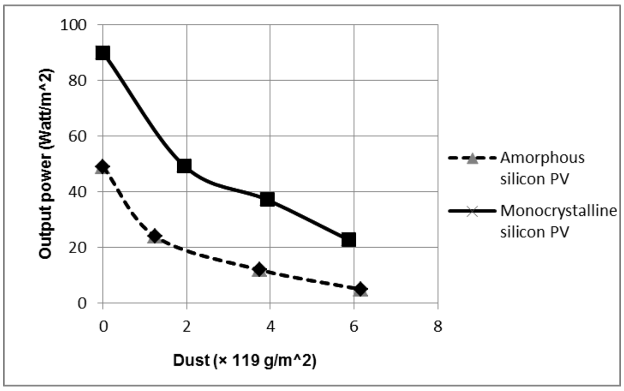


Fig. 8. PV power as a function of density of dust settled on the PV panel for Mono-crystalline and Amorphous technologies.

Figure 8 shows the variation of power generated as a function of dust settlement. Note that during the experience PV modules were set in a horizontal position and the radiation intensity was 130 Watt/m^2. From Fig. 8, our defined metric is -0.095 and -0.071 for Mono-crystalline and Amorphous PVs, respectively. This means that Dust settlement on PV decreases the generated power (-0.095 and -0.071 are negatives). The results also show that Mono-crystalline PV is more sensitive regarding dust accumulation than Amorphous (since 0.104 > 0.07).

C. *Discussion of Results*

The above results suggest that by making solar PVs pointing dynamically toward the sun, we maximize the amount of radiation received and thus we increase the panel efficiency up to about 85% and 70%, respectively, for Mono-crystalline and Amorphous PVs.

Also, the study showed a decrease in panel efficiency when Relative Humidity and PV panel temperature increased from the minimum recorded values of 22% and 40.4 ℃, respectively. This decrease was sharper for the Amorphous PV, which means that Mono-crystalline PVs are more robust against variation in environmental temperature and relative humidity. Nonetheless, we saw that the performance of Amorphous PV panels decreases less than Mono-crystalline PV when equal quantity of dust settles above. In general, it can be concluded that PV plants in Doha would have better performance at temperatures in the vicinity of 40°C, at low relative humidity, and with no dust settled on panels.

On the other hand, from the definition of *Δ(Efficiency)/(119g/m²)*, *Δ(Efficiency)/(1%)* and *Δ(Efficiency)/(1°C)* and knowing that during a sunny day in Doha we can get up to 10°C of variation in PV temperature, 6% of variation in Relative Humidity and accumulation of 119 g/m^2 of dust (see Table II), we can estimate how much decrease in the efficiency of PV panel these environmental factors cause during a day for both Mono-crystalline and Amorphous PVs . The results are summarized in Table IV.

Table IV - Decrease in efficiency (in %), during a day in Doha, due to increase in dust accumulation, temperature or Relative Humidity for Mono-crystalline and Amorphous Panels.

	Dust (%)	PV temperature (%)	Relative Humidity (%)
Mono-crystalline PV	0.095	0.15	0.06
Amorphous PV	0.071	0.43	0.18

Table IV obviously shows that the PV panel temperature has the main role in decreasing the efficiency during a day, since it causes the greater amount of decrease

(0.15% and 0.43% for Mono-crystalline and Amorphous silicon, respectively). However, for a longer period, the effect of dust becomes more and more important and overcome the effects of temperature or Relative Humidity. For 100 days of accumulation of dust, for example, the decrease in efficiency for the Mono-crystalline PV panel may amount to 0.095%×100 = 9.5%, which degrades enormously the performance of the PVs. It is worthwhile mentioning that this degradation in PV performance proceeds rapidly during the first four weeks of exposure to dust. Hassan et al. has revealed a higher degradation on PV performance (from 33.5% to 65.8% for an exposure of 1-6 months) due to airborne dust for a case study done in Egypt [13]. Also, Elminir et al. showed a decrease in the output power of 17.4% per month [7]. Furthermore, the results indicate that Mono-crystalline PV is more sensitive to dust accumulation than Amorphous PV. It follows that, due to the frequent sand storms and dust in Doha, Amorphous PVs look more adequate to adopt unless appropriate measures for panel cleaning are devised.

Table IV. – Amount of decrease in efficiency in percent, during a day, caused by dust accumulation, PVs' temperature or relative humidity.

	Dust (%)	PV temperature (%)	Relative humidity (%)
Mono-crystalline PV	0.095	0.15	0.06
Amorphous PV	0.071	0.43	0.18

From Table IV, we can see that the PV temperature has the main role in decreasing the efficiency during the day, because it causes the greater amount of decrease 0.15% and 0.43%. But, for a longer period, the effect of dust becomes more and more important and overcome temperature or relative humidity effects. For 100 days of accumulation of dust, for example, the decrease in efficiency becomes 0.095%× 100 = 9.5% which degrades enormously the performance of the PVs. Hassan et al. has revealed a higher degradation on PVs performance due to dust, the study was done in Egypt [3].

Figure 8 shows recent mono-crystalline P-V curves taken on 15 January 2013 at different times for PV panels of 120 W. These curves were taken using a buck-boost converter as the load to the PV panels. This technique is very effective to trace P-V curves very easily and replaces using electronic loads.

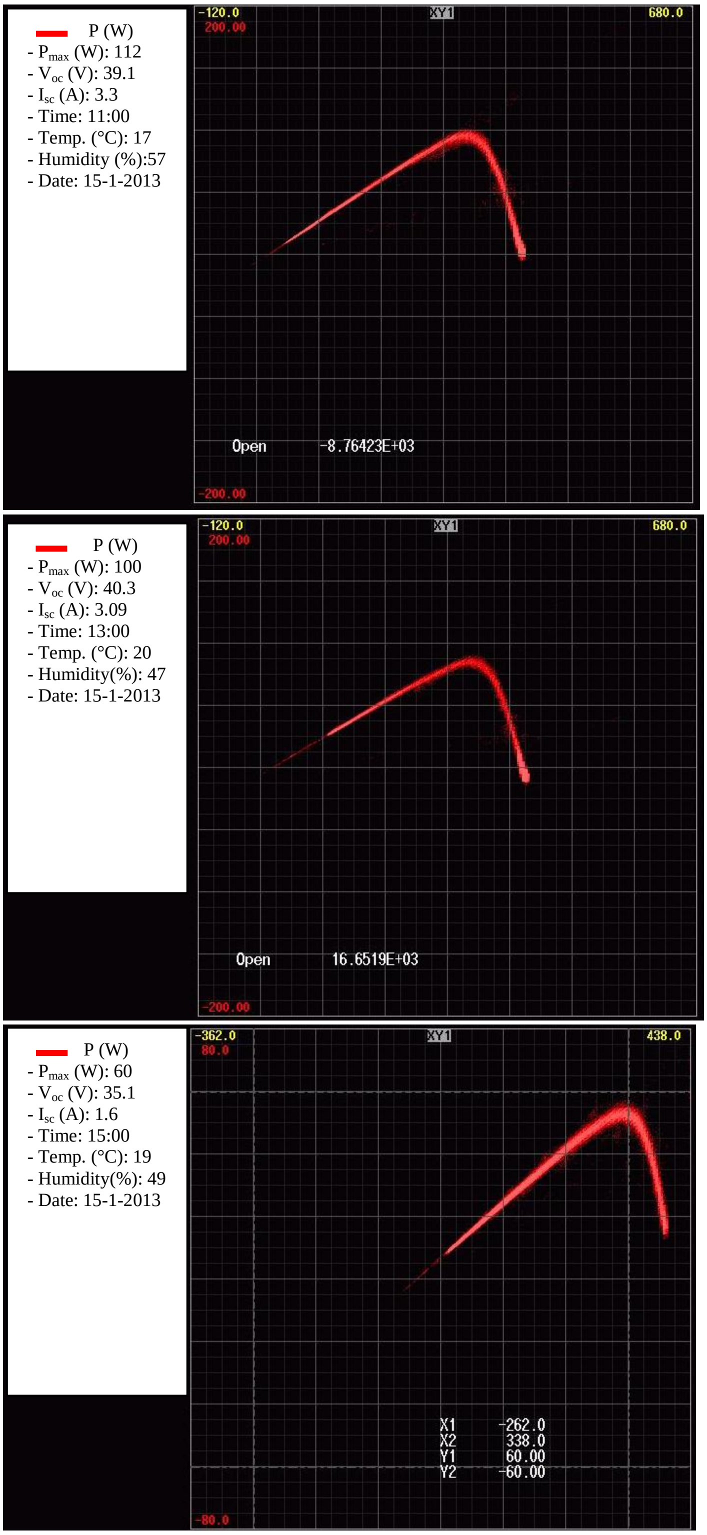


Fig. 8. P-V curves for poly-crystalline 120W-PV at different times on January 15, 2013.

4. Conclusion

This paper has successfully pinpointed the climatic and environmental issues that can affect the performance of solar technologies in harsh environments like that of Qatar. The effects of dust, temperature, and relative humidity on the power efficiency of Mono-crystalline and Amorphous solar photovoltaic have been deliberately studied. Experimental results showed that for both technologies the effect of dust accumulation is much greater than the relative humidity and ambient temperature. In particular, power efficiency of Mono-crystalline panels deteriorated by around 10% for a dust exposure of 100 days only. However, Amorphous PVs were more affected for increasing temperatures above 40 °C. Aggregating the effects of dust and temperature, it was concluded that Amorphous PVs are superior in harsh environment. Nonetheless, this does not eliminate the need to devise clear strategies for cleaning PV panels or implementing cooling systems that can be powered by the PVs themselves, if reliable PV systems are sought. Also, the study showed when best to operate PV plants in harsh conditions. The outcome of this work helps in preventing costly damage and power breakage in hybrid systems under harsh environments.

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