Pisco Med Publishing
doi:10.18282/ser.v1.i1.41

ORIGINAL RESEARCH ARTICLE

The impact of air mass on photovoltaic panel performance

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Abstract: Photovoltaic (PV) modules convert light directly into electricity using semiconductor technology. As it is installed outdoors, it is exposed to different weather conditions. There are many atmospheric parameters which influence the performance of PV modules such as dust, temperature, pollution, humidity, and solar radiation. The solar spectrum is affected by a large number of variables as indicated by atmospheric scientists. Some of these factors are dust, air pollutants, clouds, absolute air mass, perceptible water, *etc*. All of these parameter affects and are being affected by air mass. This paper describes the air mass concept which characterizes the effect of a bright atmosphere on sunlight. The air mass' major influence appeared clearly on PV short circuit current. Also, the effect of air mass on monocrystalline panels was relatively higher than that for polycrystalline panels.

Keywords: Air mass; Short circuit current; Open circuit voltage; Fill factor

Citation: Rida KS, Al-Waeli AAK, and Al-Asadi KAH. The impact of air mass on photovoltaic panel performance. Eng Sci Rep 2016; 1(1): http://dx.doi.org/10.18282/ser.v1.i1.41.

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Received: 15th May 2016; **Accepted:** 1st June 2016; **Published Online:** 15th December 2016

Introduction

Photovoltaic (PV) cells are devices that convert sunlight directly into electricity. These cells combine to form panels or arrays. A PV cell is essentially a semiconductor which produces electricity when exposed to light[1]. They are manufactured from several types of semiconductors using different manufacturing processes. PV systems are now widespread and can be obtained at commercial levels[2].

The performance and efficiency of solar cells are determined at standard conditions which are made by the manufacturer or in the laboratory[3]. The standard test conditions for PV panels are as defined by the International Electrotechnical Commission (IEC 60904–3): solar irradiance = 1000 W/m^2, cell temperature = 25 ℃, and air mass = 1.5[4]. In this study, we will focus on the air mass (AM). Riordan and Hulstron have explained the meaning of the AM1.5 spectra, how it is related to the spectral distributions in the outdoors, and its effect on the PV performance[5].

Solar spectrum is an environmental factor that affects the performance of PV panels. Air mass is one of the factors that influence solar spectrum. Air mass can be defined as a parameter that shows the effect of wavelength distribution on the flow of photons, which varies depending on weather conditions such as water vapor and dust[6]. This affects transfer intensity of electron flow in the PV device. The importance of this factor has made manufacturers to take it into account[7].

Many studies have discussed and investigated the effect of air mass on PV performance. Riordan and Hulstron demonstrated that air mass, as well as atmospheric conditions, vary with location, date, and time[5]. Riordan *et al*.[8] analyzed the movement of the sun and its relation with air mass and isolated them to predict the amount of solar isolation on a surface. The standard test conditions are defined at AM1.5. The author claimed that the increase of air mass has the effect of decreasing solar irradiance from the sun. This explains why isolation changes with the season.

Kenny *et al*. studied the effects of AM on PV systems, performance and concluded that air mass has a major effect on the spectral mismatch factor (K). This effect can be represented when air mass moves away from AM1.5. The response of the PV varies from the referenced situation, of which the influence of air mass on PV performances is known as variance factor[9].

Chegaar *et al*.[10] investigated the impact of air mass on parameters such as current, voltage, and efficiency for polycrystalline silicon PV panels. The study revealed that short circuit current, open circuit voltage, and energy would increase with an increase in air mass.

The main objective of this study is to identify the impact of air mass on two types of PV panels: polycrystalline and monocrystalline panels. This work is a result of sustained efforts by the Iraqi Organization for Desertification and Pollution and the Energy and Renewable Energy Technology Center at the University of Technology, Iraq, to discover the best methods for renewable energy in the Arabian Gulf countries and Iraq[11–66].

Theoretical Calculation

Air mass depends on the sun's location and we can calculate it by defining the system site, the time of day, and the day of the year. The absolute air mass (AMa) term is used to distinguish between other sites at altitudes not at sea level. The AMa can be obtained from multiplying AM by the ratio of (P/P0), which represents the ratio of the site's atmospheric pressure (P) to the sea level pressure (P0). In the case of measuring difficulties for the atmospheric pressure at the site, there is a possibility of using a simple exponential relationship modified by the meteorological community to evaluate the pressure ratio depending on the site's altitude[5].

Absolute air mass can be calculated using **Equation 1**. In this equation, the air mass is considered as a function of the solar zenith angle (Z_s).

$$AM = \{\cos(Z_s) + 0.5057(96.080 - Z_s) - 1.634\} - 1 \tag{1}$$

$$\text{AMa} = (P/P0)\ \text{AM} \qquad \text{where: } P0 = 760 \text{ mm Hg} \tag{2}$$

$$P/P0 \approx e\ (-0.0001184\ h) \qquad \text{where: } h = \text{altitude (m)} \tag{3}$$

If the solar radiation length through the atmosphere is expressed as L, the solar radiation incident relative to the normal to the Earth's surface at angle of Z, the air mass coefficient is:

$$AM = \frac{L}{L_o} \approx \frac{1}{\cos Z} \tag{4}$$

Where:

L_o = is the length of the zenith route at sea level normal to the Earth's surface

Z = is the zenith angle in degrees[4].

Kasten and Young[68] have presented the method to predict an accurate path thickness model towards the horizon. They used the following equation for calculating air mass (AM):

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$$AM = \frac{1}{\cos Z + 0.50572(96.07995 - Z) - 1.6364} \tag{5}$$

At the horizon where (Z = 90°), the air mass is approximately 38. So, we can represent the atmosphere as a simple spherical shell, which will provide an acceptable approximation:

$$AM = \sqrt{(r\cos Z)^2 + 2r + 1} - r\cos Z \tag{6}$$

Where:

The radius of the Earth R_E = 6371 km, the effective height of the atmosphere $y_{atm} \approx 9$ km, and their ratio r = RE/y_{atm} ≈ 708[4]

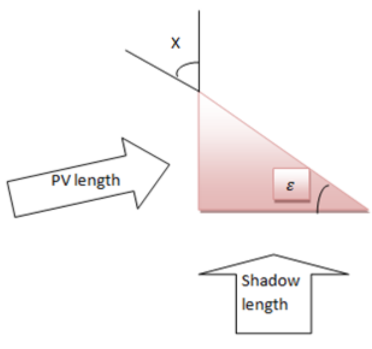
Experimental Setup

Two PV panels were used: one was monocrystalline and the other was polycrystalline PV. The PV panels' specifications are listed in **Table 1**.

Table 1. Specifications the PV panels used in the study

Parameters	Units	Poly-c	Mono-c
Out peak power	Wp	10	10
Open circuit voltage	V	21.3	21.9
Short circuit current	A	0.66	0.63
No. Of cells	-	36	36
Power tolerance	%	0/+3%	0/+3%
Max. Power voltage	V	17.3	17.5
Max. Power current	A	0.58	0.57
Size of module	mm	440 × 282 × 28	475 × 282 × 28
Weight of module	kg	1.5	1.61

The following is a calculation sample:



Hour angle (α) = 360/24(t – 12)

tan ε = Length of PV / Shadow

Zenith angle (x) = 90 - ε

$I_{sc}(T_r) = I_{sc}(T) + (E/E_o)\ \alpha\ I_{sc}(T_r - T)$

AM= [cos (Z_s) + 0.5057(96.080-Z_s) - 1.634] - 1

Sample of calculation (polycrystalline):

At 2:20PM: Length of polycrystalline photovoltaic = 0.44m E_o = 1000 W/m^2

Length of shadow at this time = 0.48m T0 = 25 °C

1) $$t = \frac{Hour \times 60 + \min}{60}$$
$$t_1 = 2 \times 60 + \frac{20}{60} = 2.33$$

2) $$\alpha = \frac{360}{24}(t - 12)$$
$$\alpha_1 = \frac{360}{24}(2.33 - 12) = -145.05$$

3) $$\tan \varepsilon = \frac{\text{length of PV}}{\text{length of shadow}}$$
$$\tan \varepsilon_1 = \frac{0.44}{-0.48}$$
$$\varepsilon_1 = 42.5°$$

4) $$X = 90 - \varepsilon$$
$$X_1 = 90 - 42.5 = 47.8°$$

5) $$\mathrm{I}_{sc} = I + \frac{E}{E_o}\alpha(T0 - T)$$
$$\mathrm{I}_{sc1} = 0.480 + \frac{8.4}{1000} * (-145.05)(25 - 44) = 23.629A$$

6) $$AM = \left(\cos X + 0.5057(96.080 - X)^{-1.634}\right)^{-1}$$
$$AM_1 = \left(\cos 47.48 + 0.5057(96.080 - 47.48)^{-1.634}\right)^{-1} = 1.4776$$

Results and discussions

Tables 2 and **Table 3** represent the measurements obtained from the two panels in the outdoor climate condition of Sohar City, Oman. The results listed in the tables were clarified in the following figures. *Figure 1* shows the effect of air mass on the short circuit current of the tested panels. The figure describes the relation between I_{sc} changes for the tested panels during the course of one day (starting from sunrise to sunset).

The monocrystalline panel showed the higher response for air mass variation. The maximum values of I_{sc} were calculated near AM1.5 for both panels. The monocrystalline panel had higher I_{sc} by about 3%, compared to the polycrystalline panel. **Figure 1** demonstrates that PV cell type has an effect on the I_{sc} as well as the air mass. This result confirms what Al-Waeli *et al*.[66] observed about the relation between $I_{sc\backslash}$ and air mass. The International Electrotechnical Commission (IEC) identified the precise value of air mass that gives the highest I_{sc} value, and moving away from this value will reduce the resulting I_{sc}.

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Table 2. Measurements obtained for the monocrystalline PV panel

Time (min)	Current (Amp)	Zenith angle (Z_s)	E (W/m^2)	T (℃)	I_{sc} (Amp)	AM	Voltage (V)	α_{Isc}
13:00	0.380	39.644	9.082	44	28.852	1.297	23.90	-165.0
13:10	0.495	40.601	120.68	45	39.957	1.316	24.38	-163.5
13:20	0.486	43.320	11.265	44	35.159	1.373	23.18	-162.0
13:30	0.472	44.171	7.783	42	21.700	1.393	16.46	-160.5
13:40	0.457	45.810	7.399	45	23.986	1.433	16.19	-159.0
13:50	0.400	46.590	6.618	43	17.886	1.453	15.42	-157.5
14:00	0.322	47.390	1.853	42	4.847	1.474	15.19	-150.0

Table 3. Measurements obtained with the polycrystalline PV panel

Time (min)	Current (Amp)	Zenith angle (Z_s)	E (W/m^2)	T (℃)	I_{sc} (Amp)	AM	Voltage (V)	α_{Isc}
14:00	0.358	46.780	7.45	43	31.01	1.423	17.8	-151
14:10	0.415	47.200	6.11	45	28.40	1.473	17.7	-149
14:20	0.480	47.480	8.40	44	23.63	1.477	17.5	-145
14:30	0.347	47.480	6.00	43	15.74	1.477	17.3	-142
14:40	0.193	39.289	3.26	40	7.04	1.291	16.9	-140
14:50	0.180	37.690	2.82	40	6.00	1.262	15.7	-137
15:00	0.127	35.240	3.20	40	5.70	1.223	15.9	-135

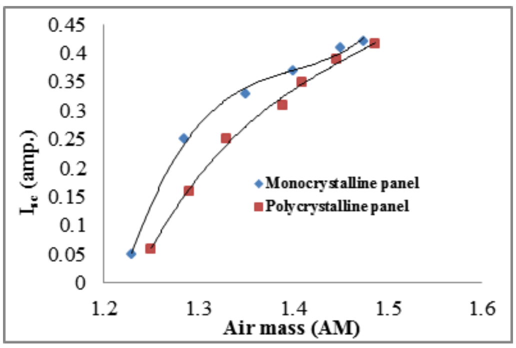

Figure 1. The impact of air mass on I_{sc} for the tested panels

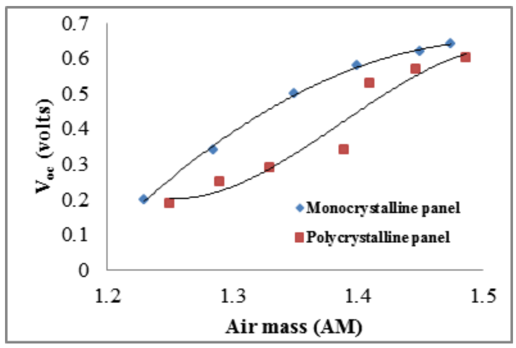

Figure 2. The impact of air mass on V_{oc} for the tested panels

Figure 2 manifests the impact of air mass variation on the open circuit voltage (V_{oc}) for the two tested panels. V_{oc} increased relatively with air mass increasing. The figure reveals that V_{oc} is less sensitive to air mass variation than the I_{sc}. The monocrystalline panel V_{oc} increased more than that for the polycrystalline panel by about 12.5%.

Figure 3 illustrates the impact of air mass variation on the tested solar panels efficiency. The results indicate that the efficiency increased a little with air mass approaching AM1.5. The efficiency difference between the two tested panels was 0.87% higher for the monocrystalline panels.

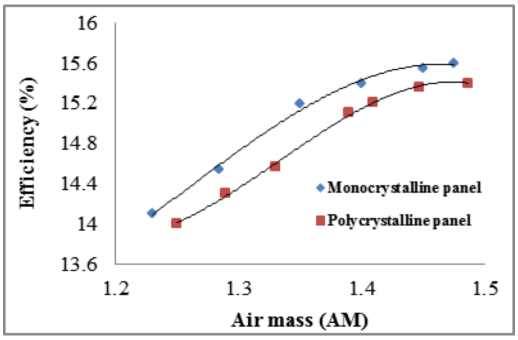

Figure 3. The impact of air mass on efficiency of the tested panels

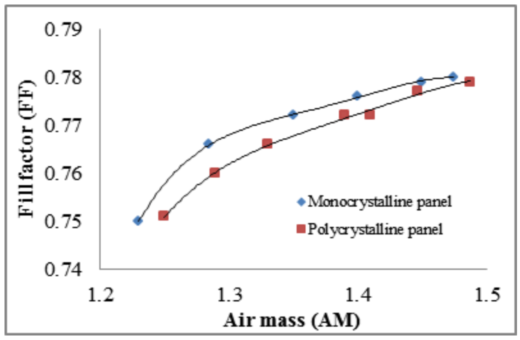

Figure 4. The impact of air mass on the fill factor of the tested panels

The fill factor (FF) slightly increased with the air mass increasing to about AM1.5, and then it decreased as the air mass increased (**Figure 4**). The fill factor depends on both the I_{sc} and V_{oc}, and as they both increased with air mass increase, this result is acceptable. These results indicate that the optimum air mass value is 1.5 and the change in this value due to solar radiation zenith angle during the day affects the productivity and efficiency of the used PV panel.

Conclusion

Performance variations of two types of solar cells were investigated with respect to changing air mass. The monocrystalline and polycrystalline silicon solar cells were tested under Sohar City climate conditions to verify the effect air mass on them. The main results are as follows: the short circuit current increased slightly with air mass increasing from 1.25 to 1.50; the monocrystalline panel's I_{sc} increased more than the polycrystalline; the open circuit voltage increased with less sensitivity for both cases and as a result of this increase, the panels' efficiency was raised relatively; and the fill factor increased slightly with air mass increasing from 1.25 to 1.50.

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