The Iraqi Journal For Mechanical And Material Engineering, Vol.13, No4, 2013

EFFECT OF DUST AND SHADOW ON THE EFFICIENCY OF PHOTOVOLTAIC SOLAR MODULE AT BAGHDAD CLIMATE CONDITIONS

Emad Talib Hashim
Energy Engineering Department, Engineering College, Baghdad University

ABSTRACT

The performance of a solar cell under sun radiation is necessary to describe the electrical parameters of the cell. The Prova 200 solar panel analyzer is used for to test a solar cell at Baghdad climate conditions (the experimental measurements had been made at weather temperature in the range between 20-28^{o}C and average wind speed 2.5 km/hr). The results showed that as dust accumulated the solar panel loose power for the first three days, but when the dust had created several layers the power dropped in smaller intervals for the forth days to two weeks. More power and efficiency lose for more exposure days and tilt angle $0^o \geq 30^o \geq 60^o \geq 90^o$(The results show that modules tilted with larger angles let less dust get accumulated on surfaces) at a fixed time (exposure days) for the fourth angles respectively.

Sharp reduction of energy (power) is yield up to 63.2-99.8% of PV (photovoltaic) solar cell under 5Ω resistance load was observed as a result of corresponding shaded percentage area of the cells 5.6-50% from the total cell area.

Keywords*:* photovoltaic, solar cell, dust, shadow, power, efficiency

الخلاصة :-

اداء الخلية الشمسية تحت الاشعاع الشمسي ضروري لوصف الخلية . لقد استعمل جهاز محلل اداء الخلية بروفا 200 لاختبار لوح شمسي عند الظروف المناخية لمنطقة بغداد (القياسات العملية كانت ضمن مدى لدرجة حرارة الجو يتراوح بين 20 الى 28 درجة مئوية) . النتائج بينت ان تراكم الغبار يفقد بعض من قدرة الخلية وللايام الثلاث الاولى وعند تراكم طبقات اخرى من الغبار يكون انخفاض القدرة بقيمة اقل ابتداً من اليوم الرابع الى مدة اسبوعين . يزداد نقصان القدرة والكفاءة مع زيادة تعرض الخلية للايام المغبرة وزاوية الميل عند $0 \leq 30 \leq 60 \leq 90$ درجة (النتائج بينت انه كلما كانت زاوية ميلان الخلية عالية كلما كان تراكم الغبار على سطحها قليل) وعند زمن ثابت للزوايا الاربعة وعلى التوالي.

نقصان كبير وحاد لقدرة الخلية المربوطة مع حمل 5 أوم ، يتراوح بين 62.2- 99.8 % من قدرة الخلية يمكن مشاهدته كنتيجة لمساحة تظليل ما يقابل 5.6- 50 % من مساحة الخلية الكلية.

NOMENCLATURE

FF	Fill factor
G	Solar radiation, W/m^2
I_L	Photocurrent, A
I_{maxp} , I_{mp}	Maximum Current at P_{max} , mA
I_o	Saturation current, A
I_P	Operating current, A
I_{sc}	Current at short circuit, mA
P	production date
P_L	Power of Solar radiation, W
P_{max}	Maximum Solar Power, W
R_L	Load resistance, Ω
V_{maxp} , V_{mp}	Maximum Voltage at P_{max}, V
V_{oc}	Voltage at open circuit, V
θ	tilt angle, degree
η	Efficiency, %

INTRODUCTION

The accumulation of dust particles on the surface of photovoltaic (PV) panel greatly affects its performance especially in the desert areas. But desert countries are of course best suited to photovoltaic power generation due to abundant availability of sunlight throughout the year. Nowadays the idea for setting up vast solar arrays in desert countries and exporting the power to other countries are being discussed. In a bigger PV solar plants, more work force and machines will be needed to keep making the rounds and cleaning the panels, especially after a sand storm. The dust accumulation on the PV panel surface depends on different parameters like PV panel inclination, kind of installation (stand alone or on tracker), humidity etc. Many research results discuss the performance of panel with dust concentration on the surface in g/m^2. However for a common PV user it is important to know how frequent the panel has to be cleaned. In case if the frequent cleaning is not feasible, it is important to know the performance loss due to dust for additional estimation to compensate the loss.

A numerical algorithm, which considers the mismatch in individual PV cells and their shading levels, has also been proposed (Quaschning and Hanitsch, 1996) to simulate the complex characteristics of a PV array. It requires each element (each cell of the module, bypass diode, blocking diode, etc.) to be represented by a mathematical expression.

Over years, several researchers have studied the characteristics of PV modules and the factors that affect them. (Walker, 2001) has proposed a MATLAB-based model of a PV module to simulate its characteristics to study the effect of temperature, insolation, and load variation on the available power. The mono crystalline and poly crystalline panels output are greatly dependent on the light radiation perpendicular to the panels, whereas the amorphous panel works even with the diffused radiation. Though the efficiency of the amorphous panels is less but their energy yield is high compared to the others in some cases. Moreover the output of crystalline panels suffers more from dust accumulation as compared to the amorphous panels. Research results reveal “A dust layer of one seventh of an ounce per square yard decreases solar power conversion by 40 percent in certain cases” (Castaner and Silvestre, 2002). Same technology PV panel from different manufacturers suffers in completely different pattern. The study on effect of dust on the PV panel will help to select panel technology for particular type of application and location (Castaner and Silvestre, 2002).

However, (Kawamura et al., 2003) have also investigated the effect of shading on the output of the PV modules and the associated change in their *I–V* characteristics. However, the *I–V* and *P–V (power-voltage)* characteristics of the single module, considered in their study, do not predict the presence of multiple steps and peaks, which are common in the *I–V* and *P–V* characteristics of large PV arrays that receive nonuniform insolation. (Gracia et al., 2006) have experimentally obtained the *I–V (current-voltage)* characteristics of the PV module and the constituent cells to study the effect of partial shading. However, their work is limited to module-level study and does not discuss the shading effects on an entire PV array. The aim of this work is to investigate and study effect of dust and shadow on the performance of solar module at Baghdad climate condition.

Effect of Dust on PV Cell Performance

Dust is defined as the minute solid particles with less than 500 μm in diameter. Minute pollens such as bacteria and fungi, and microfibers separated from clothes, carpets and fabrics are also known as dust when settled on surfaces. Dust deposition is a function of various environmental and weather conditions. Pedestrian and vehicular activities, volcanic eruptions, pollution and wind can lift up dust and scatter it into the atmosphere (Mani and Pillai, 2010). Dust settlement mainly relies on the dust properties (chemical properties, size, shape, weight, etc.) as well as on the environmental conditions (site-specific factors, environmental features and weather conditions). The surface finish, tilt angle, humidity and wind speed also affect the dust settlement (Mani and Pillai, 2010). There have been different studies conducted to investigate the effect of dust on solar cells. A wide range of reduction in performance have been reported including average reduction of 1% with a peak of 4.7% in a two-month period in united states (Hottel and Woertz, 1942) 40% degradation in a 6-month period in Saudi Arabia, 32% reduction in a 8-month time again in Saudi Arabia (Mani and Pillai, 2010), 17%–65% reduction depending on the tilt angle in 38 days in Kuwait. In another study done in Egypt 33.5%–65.8% reductions in performance have been announced in duration of one to six months exposure respectively. More specifically in the tropical climate of Thailand, 11% reduction in transmittance for a period of one month has been reported. The direct beam solar radiation on tilted panels covered with dust is formulated for design purpose calculations (Al-Hasan, 1998).Thus, it can be concluded from the results that modules tilted with larger angles let less dust get accumulated on surfaces, leading to less transmittance drop. It can also be concluded that finer particles affect the PV efficiency more considerably than coarser particles. As the wind speed increases, more dust deposition will occur while the dust deposition relative to the ground decreases (due to wind effect; that work as cleaner for the cell surface with wind speed increasing) (Goossens and Van Kerschaever, 1999). Excessive dust accumulation results in deterioration of solar cell's quality and fill factor. Dust promotes dust, so that the performance of PV modules declines exponentially with more dust piles up. High humidity also helps formation of dew on the solar cell surface leading to more facile dust coagulation (Mani and Pillai, 2010).

Output Characteristics of Solar Cells

The output characteristics of solar cells are expressed in the form of I - V curve. A test circuit and typical I - V curve produced are shown in **Fig.1**. The I-V curve is produced by varying R_L (load resistance) from zero to infinity and measure the current and voltage along the way. The point at which the I-V curve and resistance (R_L) intersect is the operating point of the solar cell. The current and voltage at this point are Ip and Vp, respectively. The largest operating point in the square area is the maximum output of the solar cell as it's demonstrated in **Fig.2**.

Fill factor (FF) is the relation between the maximum power that the panel can actually provide and the product I_{SC} . V_{OC}. This gives you an idea of the quality of the panel because it is an indication of the type of IV characteristic curve. The closer FF is to 1, the more power a panel can provide. Common values usually are between 0.7 and 0.8. The ratio between the maximum electrical power that the panel can give to the load and the power of the solar radiation (P_L) incident on the panel. This is normally around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film). Considering the definitions of point of maximum power and the fill factor we see that:

$$\eta = P_{max} / P_L = FF \cdot I_{SC} \cdot V_{OC} / P_L \qquad (1)$$

$$FF = I_{mp} V_{mp} / (I_{sc} V_{sc}) \qquad (2)$$

EXPERIMENTAL MEASUREMENTS

The Prova 200 solar panel analyzer (**Fig.3**) is used for the professional test, maintenance, manufacture and research of solar panels and cells. **Table 1,2,3 and 4** provides the general and electrical specification of Prova 200. The (I-V) test curves, maximum solar power as well as current and voltage can be obtained by this analyzer.

Connecting Wires (Connectors)

The terminals of the solar cell are connected as in **Fig.4**. In this work, the system of measurements consists of silicon solar cell as it is presented in **Fig.5**. The general specifications of this cell are given in **Table 5**

RESULTS AND DISCUSSION

Dust effect on solar cell efficiency

The purpose of our calculations is to measure our results with intensive observations during the dust period 19/2/2012 to 22/4/2012. All the experimental measurements had been made at weather temperature in the range between 20-28^{o}C and average wind speed 2.5 km/hr. The dust accumulation effect on solar cell efficiency is measured with time and the tilt angle (θ) is measured. The initial step of the experiment involves determining the maximum power point when there is no dust accumulation on the panel (Different values of maximum power point and the other cell characteristic parameters for this initial steps due to climate change conditions; temperature, humidity …etc which effect solar cell output parameters, during the period 19/2/2012 to 22/4/2012). Prior to starting the experiment, the tilt angle was varied between 0^o to 90^o in 30^o step, and then it fixed at different tilt angle (θ); 60^o .

The data obtained for I-V characteristics and P-V curve for the solar cell under the specific solar radiation intensity (1000 W/m^2) are shown in **Tables 6-9**. To get the constant radiation intensity (1000 W/m^2); (standard values (ISO) for solar module performance and maintenance), the measurement made at 12:00am and the solar cell panel moved within few second to justify the ration intensity value (1000 W/m^2) and then return it back to it back to the fixed angle. **Table 10** shows variation of the solar cell efficiency with tilt angle (θ) and number of exposure days. Generally, less dust accumulation effect on solar cell power when the module tilted with larger angles. (i.e. the highest power and efficiency for vertical position, θ=90^o while more power and efficiency are lost for tilt angle 60^o, 30^o, and 0^o (horizontal position) respectively). **Fig.6** shows variation of the solar cell efficiency with tilt angle (θ) and number of exposure days. **Fig.7** shows effect of tilt angle (θ) on the solar cell efficiency after 3 days. On the other hand, the tilt angle and its effects on dust accumulation on the glass cover a photovoltaic solar cell after 8 days is shown in **Fig.8**. More power and efficiency lose for more exposure days and tilt angle $0^o \geq 30^o \geq 60^o \geq 90^o$ (This can be concluded from the results that modules tilted with larger angles let less dust get accumulated on surfaces) at a fixed time (exposure days) for the fourth angles respectively.

The results showed that as dust accumulated the solar panel lost power for the first three days, but when the dust had created several layers the power dropped in smaller intervals for time period more than three days. (see **Fig.7**) .

Shadow Effect on Solar Cell Efficiency

The performance of PV (photovoltaic) is affected by many factors either natural like clouds, dust, temperature, and wind speed or artificial like air pollutants produced from different factories. These effects may cause variation on the PV electrical output due to spectrum, intensity, local shadowing or reflection and variations of solar radiation distribution falling on it.

Shadow parts of the module causing what is so-called hot spot which causes a general reduction of the PV output. Another type of shadowing is the edge shadowing which may happen in PV field due to dust accumulated on the tilted PV array. Sharp reduction of energy (power) with yield up to 63.2-99.8% of PV cell was (5Ω load resistance) observed as a result of corresponding shaded cells percentage 5.6-50%.

The influence of module shading on voltage (V), current (A), and power (W) of solar cell is shown in **Table 11** and **Fig.9**. Solar cell (with 5Ω fixed load resistance) Voltages, current and power percentage reduction with the percentage shaded cells are summarized in **Table 11** and **Fig.10**.

For the series connection of the modules (n=72; number cells of the solar module), the loss of power was 63.2% when four cells were shaded. The losses increased to 88.6 % for 8 and 94.7% for 16 cells under shade. The loss of power can reach 98.88 % can be observed when 24 cells are shaded (33.3% shaded cell percentage).

CONCLUSION

From the previous discussion it can be concluded that a solar panel exposed to more dusty area like the desert are more likely to lose power and require regular cleanings. What this means for solar panel owners is that they can lose up to 10% power with only a small amount of dust (for the first days of the accumulated dust on solar panel surface).

As dust accumulated the solar panel lost power for the first three days, but when the dust had created several layers the power dropped in smaller intervals form the 4^{th} day or more. More power and efficiency lose for more exposure days and tilt angle $0^o \geq 30^o \geq 60^o \geq 90^o$ (This can be concluded from the results that modules tilted with larger angles let less dust get accumulated on surfaces) at a fixed time (exposure days) for the fourth angles respectively.

Sharp reduction of energy (power) yield up to 63.2 - 99.8% of PV (photovoltaic) cell was observed as a result of corresponding shaded cells percentage 5.6-50%.

Table 1: General Specifications of Prova 200

Battery Type:	Rechargeable, 2500mAh (1.2V) x 8
AC Adaptor:	AC 110V or 220V input DC 12V / 1~3A output
Dimension:	257(L) x 155(W) x 57(H) mm
Weight:	1160g / 40.0oz (Batteries included)
Operation Environment:	0℃ ~ 50℃, 85% RH
Temperature Coefficient:	0.1% of full scale / ℃ (＜18℃ or ＞28℃)
Storage Environment:	-20℃ ~ 60℃, 75% RH
Accessories:	User Manual x 1, AC adaptor x 1 Optical USB cable x 1 Rechargeable batteries x 8 Software CD x 1, Software Manual x 1 Kelvin Clips (6A max) x 1 set

Table 2: DC voltage measurement

Range (60V / 6A)	Resolution	Accuracy
0 ~ 6 V	0.001 V	± 1 % ± (1 % of Vopen ± 9 mV)
6 ~ 10 V	0.001 V	± 1 % ± (1 % of Vopen ± 0.09 V)
10 ~ 60 V	0.01 V	± 1 % ± (1 % of Vopen ± 0.09 V)

Vopen: open circuit voltage of solar cell or module.

If users use alligator clips to measure voltage only, they must make V+ clip connect with I+ clip; V- clip connect with I- clip. Thus, 4-wire measurement is converted to 2-wire measurement.

Table 3: DC current measurement

Range (60V / 6A)	Resolution	Accuracy
0.01 ~ 0.6 A	0.1 mA	± 1 % ± (1 % of Ishort ± 0.9 mA)
0.6 ~ 1 A	0.1 mA	± 1 % ± (1 % of Ishort ± 9 mA)
1 ~ 6 A	1 mA	± 1 % ± (1 % of Ishort ± 9 mA)

Ishort: short circuit current of solar cell or module.

Internal Resistance at Ishort: 0.05 Ohm.

Ishort is measured with internal resistance, circuit resistance, and test lead resistance.

Table 4:DC current simulation

Range (60V / 6A)	Resolution	Accuracy
0.01 ~ 1 A	0.1 mA	± 1 % ± 0.9 mA
1 ~ 6 A	1 mA	± 1 % ± 9 mA

* If Current is greater than 6A, test (Auto-Scan, Scan, or Test) can not be Performed.
* Maximum duration of simulation is 9.999 seconds if power is less than 100 W.
* Duration of simulation is 10m seconds if power is greater than 100 W.

Table 5: Solar module specifications

Area , m^2	V_{oc} , v	I_{sc} , A	Peak power , w	Peak voltage , v	Peak current , A	Production date	number cells of the solar module
1	22	8.1	130	18.5	6.0	2010	72

Table 6: Characteristic Prova 200 output of solar cell parameters at irradiance 1000 W/m^2 and tilt angle θ= 0^o

Date	V^*_{now}, v	V_{oc}, v	I_{sc}, A	P_{max}, W	V_{max}, v	I_{max}, A	η, %	FF
10/4/2012	41.29	39.52	2.477	60.07	31.09	1.932	6.00	0.600
16/4/2012	38.16	38.54	2.482	55.78	29.87	1.87	5.59	0.520
17/4/2012	38.52	38.11	2.472	50.21	27.81	1.80	5.02	0.533
18/4/2012	37.75	38.20	2.468	50.00	27.80	1.79	5.00	0.530
19/4/2012	37.00	37.40	2.400	48.00	28.24	1. 70	4.80	0.534
22/4/2012	36.80	37.00	2.000	35.88	27.60	1.30	3.59	0.480

*solar cell voltage value at the initial scanning

Table 7: Characteristic Prova 200 output of solar cell parameters at irradiance 1000 W/m^2 and tilt angle θ= 30^o.

Date	V_{now}, v	V_{oc}, v	I_{sc}, A	P_{max}, W	V_{max}, v	I_{max}, A	η, %	FF
28/2/2012	40.77	41.18	2.611	65.41	33.18	2.164	6.54	0.608
29/2/2012	40.10	41.01	2.623	65.01	33.12	2.121	6.50	0.604
02/3/2012	40.01	40.00	2.145	64.50	33.02	2.101	6.45	0.751
04/3/2012	39.10	39.30	2.000	56.00	30.00	1.866	5.60	0.712
05/3/2012	39.40	39.22	2.011	43.01	30.60	1.511	4.30	0.545
06/3/2012	40.77	40.66	1.873	44.54	31.84	1.399	4.45	0.584
07/3/2012	40.75	40.63	1.733	44.11	31.77	1.381	4.41	0.626

Table 8: Characteristic Prova 200 output of solar cell parameters at irradiance 1000 W/m^2 and tilt angle θ= 60^o.

Date	V_{now}, v	V_{oc}, v	I_{sc}, A	P_{max}, W	V_{max}, v	I_{max}, A	η, %	FF
19/2/2012	39.46	39.52	2.477	60.07	31.09	1.932	6.01	0.600
20/2/2012	41.29	41.27	2.36	60.72	32.93	1.843	6.07	0.622
21/2/2012	40.21	39.40	2.32	58.12	30.7	1.543	5.81	0.635
22/2/2012	40.20	39.40	2.31	58.07	30.71	1.52	5.81	0.630
23/2/2012	40.00	39.22	2.12	58.00	30.22	1.4	5.80	0.690
24/2/2012	40.31	39.11	2.01	57.6	30.12	1.33	5.76	0.732
27/2/2012	40.12	39.02	2.00	57.1	30.01	1.03	5.71	0.731

Table 9: Characteristic Prova 200 output of solar cell parameters at irradiance 1000 W/m^2 and tilt angle θ= 90^o.

Date	V_{now}, v	V_{oc}, v	I_{sc}, A	P_{max}, W	V_{max}, v	I_{max}, A	η, %	FF
19/3/2012	41.77	41.28	2.624	68.30	33.08	2.064	6.83	0.622
20/3/2012	40.16	40.18	2.656	65.75	31.20	2.107	6.58	0.616
22/3/2012	40.10	40.14	2.600	65.00	31.00	2.096	6.50	0.620
25/3/2012	40.00	40.13	2.500	63.00	30.8	2.045	6.30	0.627

Table 10: Variation of the solar cell efficiency with tilt angle (θ) and number of exposure days.

No. of days	0	1	2	3	4	5	6	7	8	9	10	13
η, % at θ=0^o	6.00♣	*	*	*	*	*	*	5.59	5.02	5.00	4.80	3.59
η, % at θ=30^o	6.54♣	6.50	*	6.45	*	5.60	4.30	4.45	4.41	*	*	*
η, % at θ=60^o	6.00♣	6.07	5.81	5.80	5.80	5.76	*	*	5.71	*	*	*
η, % at θ=90^o	6.83♣	6.57	*	6.50	*	*	6.30	*	*	*	*	*

***** cloudy day or week end. ♣ these values must be constant, but these variations due to change in climate condition along the time period (19/2/2012 to 22/4/2012)

Table 11: Solar cell (5Ω load resistance) voltage, current and power percentage reduction with shading cells percentage.

No. of shaded cells	Shaded cells , %	Voltage, V	Current, A	Power, W	Voltage reduction, %	Current reduction, %	Power reduction, %
0	0.0	10.6	2.15	22.79	0	0	0
4	5.6	6.4	1.31	8.384	36.6	39	63.2
8	11.1	3.5	0.74	2.59	66.98	65	88.6
12	16.7	2.4	0.5	1.2	77.35	76.74	94.7
16	22.2	1.5	0.33	0.495	85.8	84.65	97.8
20	27.8	1.4	0.3	0.42	86.79	86	98.15
24	33.3	1.1	0.23	0.253	89.62	89.3	98.88
28	38.9	0.8	0.19	0.152	92.45	91.16	99.33
32	44.4	0.5	0.13	0.065	95.28	93.95	99.7
36	50.0	0.4	0.11	0.044	96.22	94.88	99.8
40	55.6	0.2	0.07	0.014	98.11	96.7	99.93
44	61.1	0.1	0.05	0.005	99	97.6	99.97
48	66.7	0.1	0.04	0.004	99	98.13	99.98
52	72.2	0	0.03	0	100	98.6	100
56	77.8	0	0.02	0	100	99	100
60	83.3	0	0.01	0	100	99.53	100
64	88.9	0	0	0	100	100	100
68	94.4	0	0	0	100	100	100
72	100.0	0	0	0	100	100	100

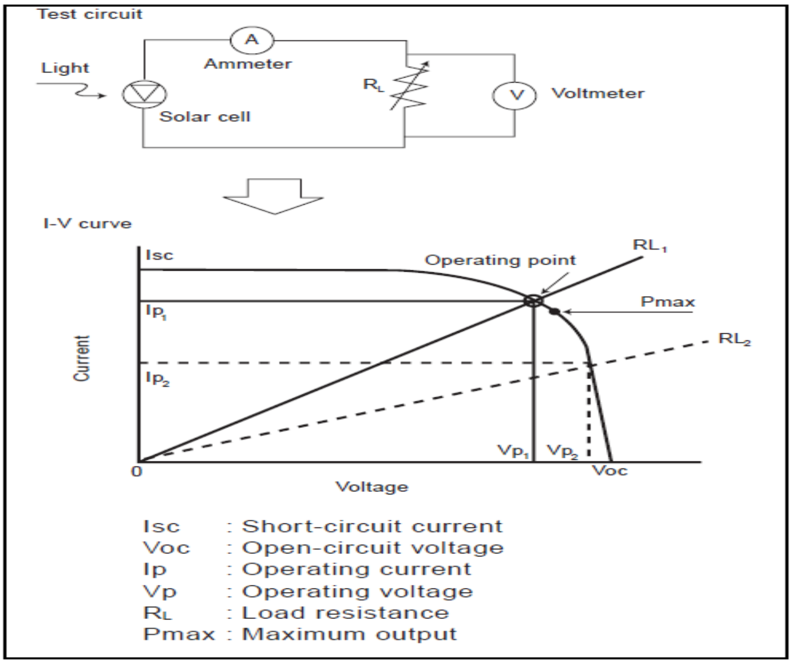

Fig.1: The I-V curve is produced by varying R_L (load resistance) from zero to infinity (Gracia et al., 2006).

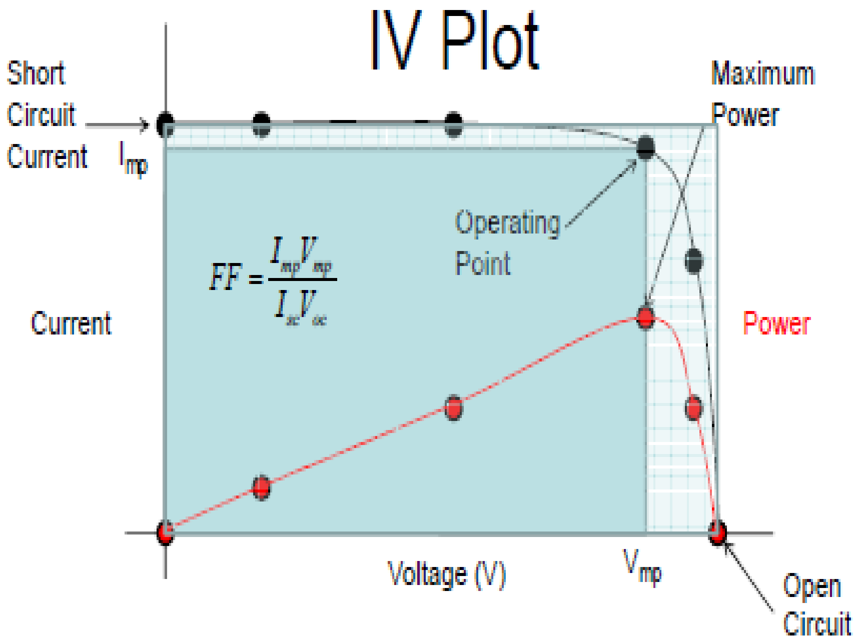

Fig.2: Square area is the maximum power output of the solar cell (Gracia et al., 2006).

Fig.3: The Prova 200 solar panel analyzer

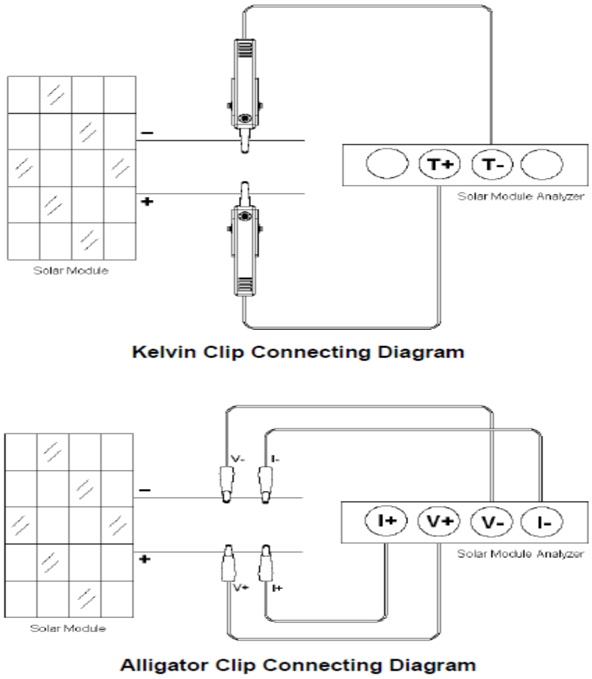

Fig.4: Wires connections

Fig.5: Solar panel tested.

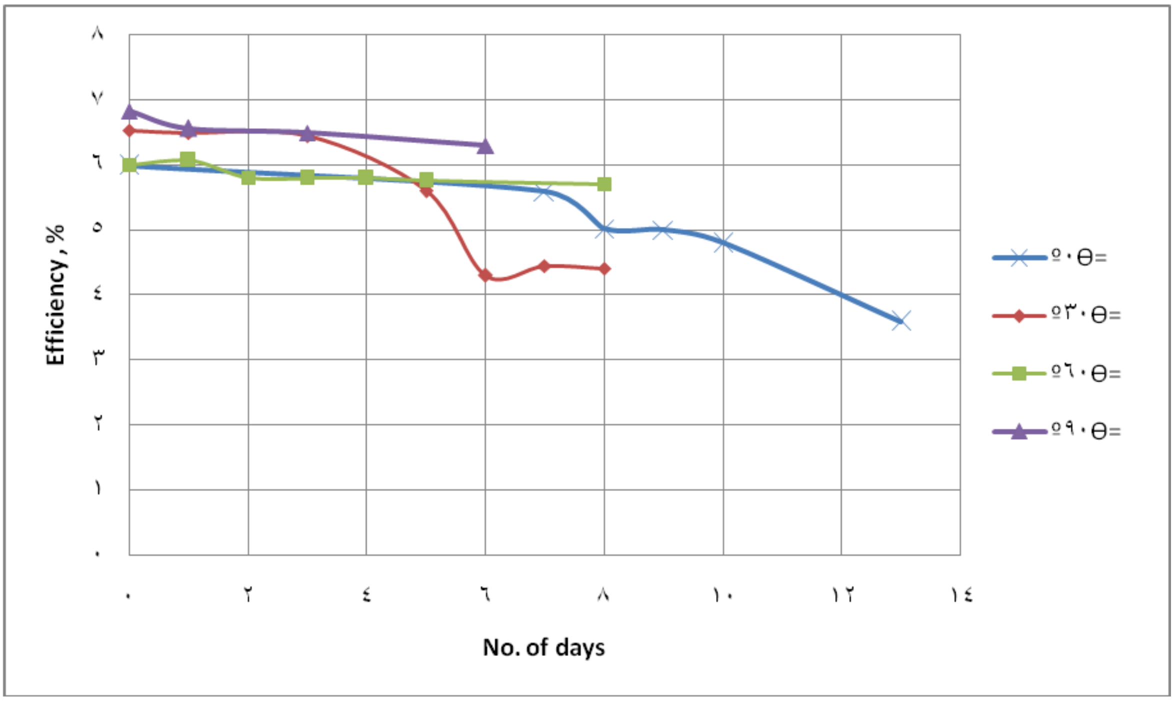

Fig.6: Variation of the solar cell efficiency with tilt angle (θ) and number of exposure days

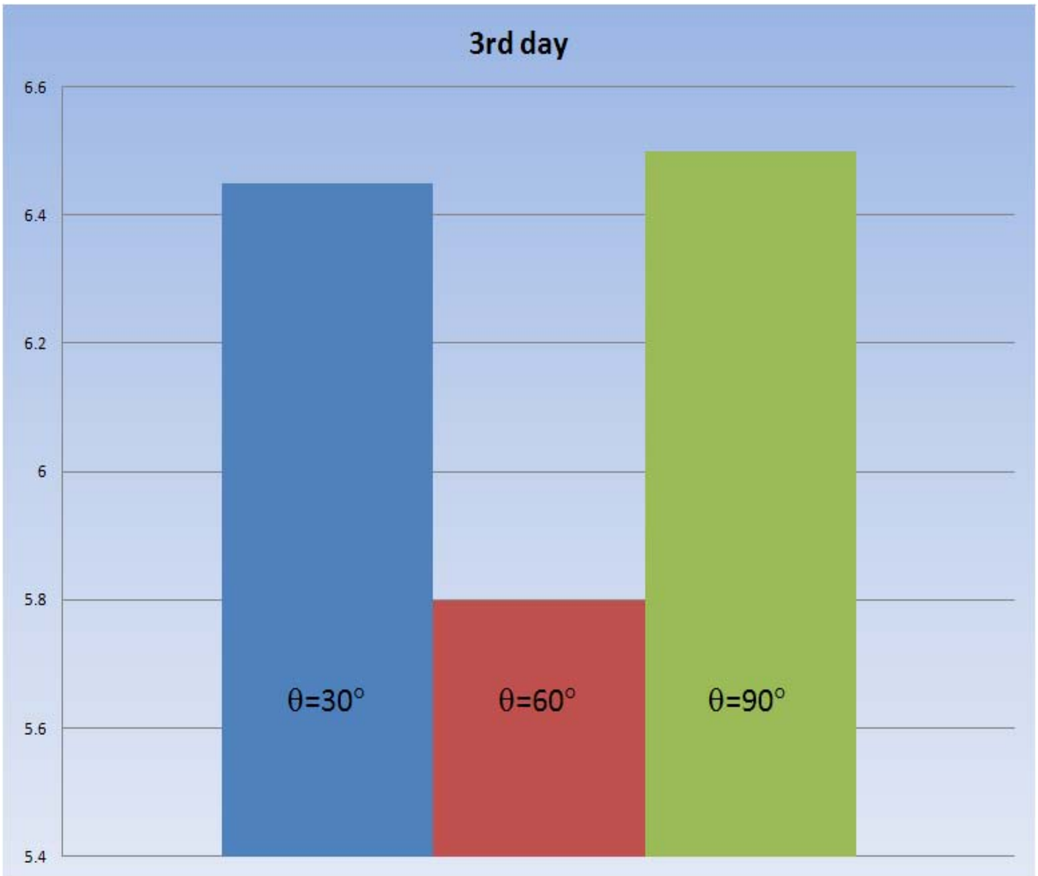

Fig.7: Effect of tilt angle (θ) on the solar cell efficiency after 3 exposure days.

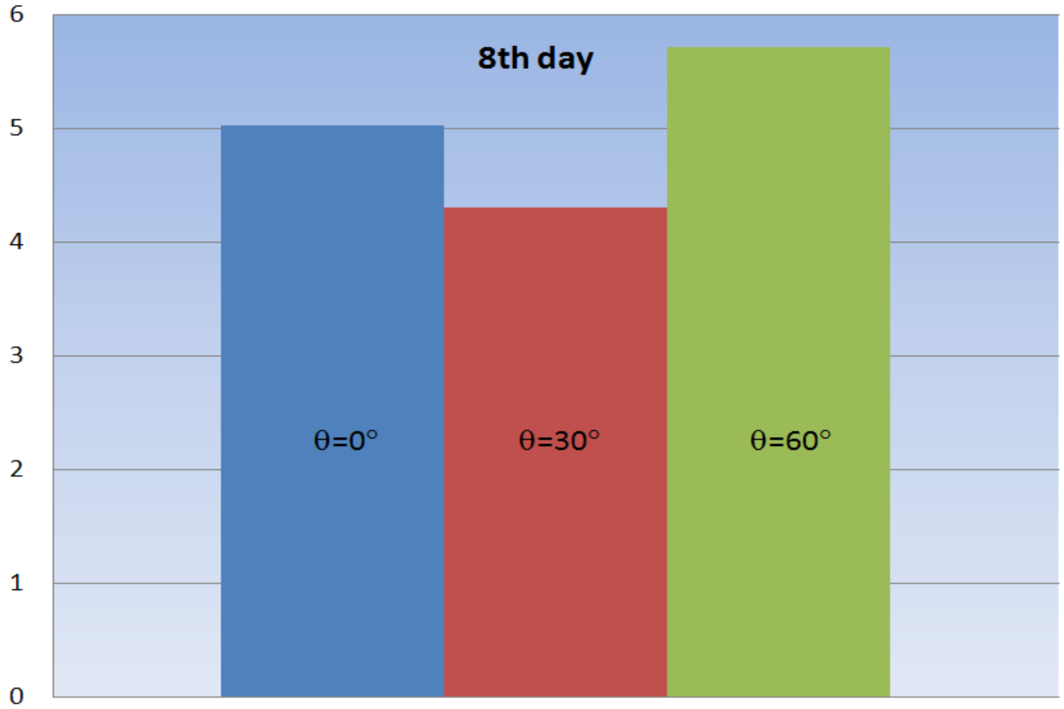

Fig.8: Effect of tilt angle (θ) on the solar cell efficiency after 8 exposure days

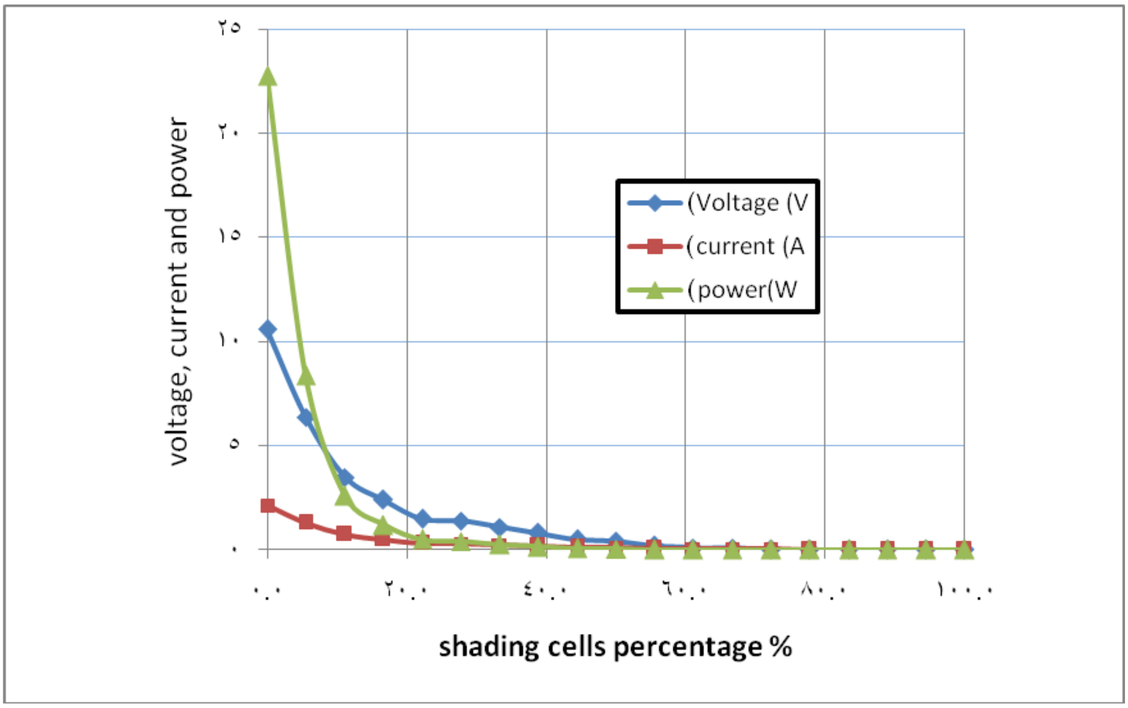

Fig.9: Variation of voltage (V), current (A), and power (W) of solar cell with shading cells percentage.

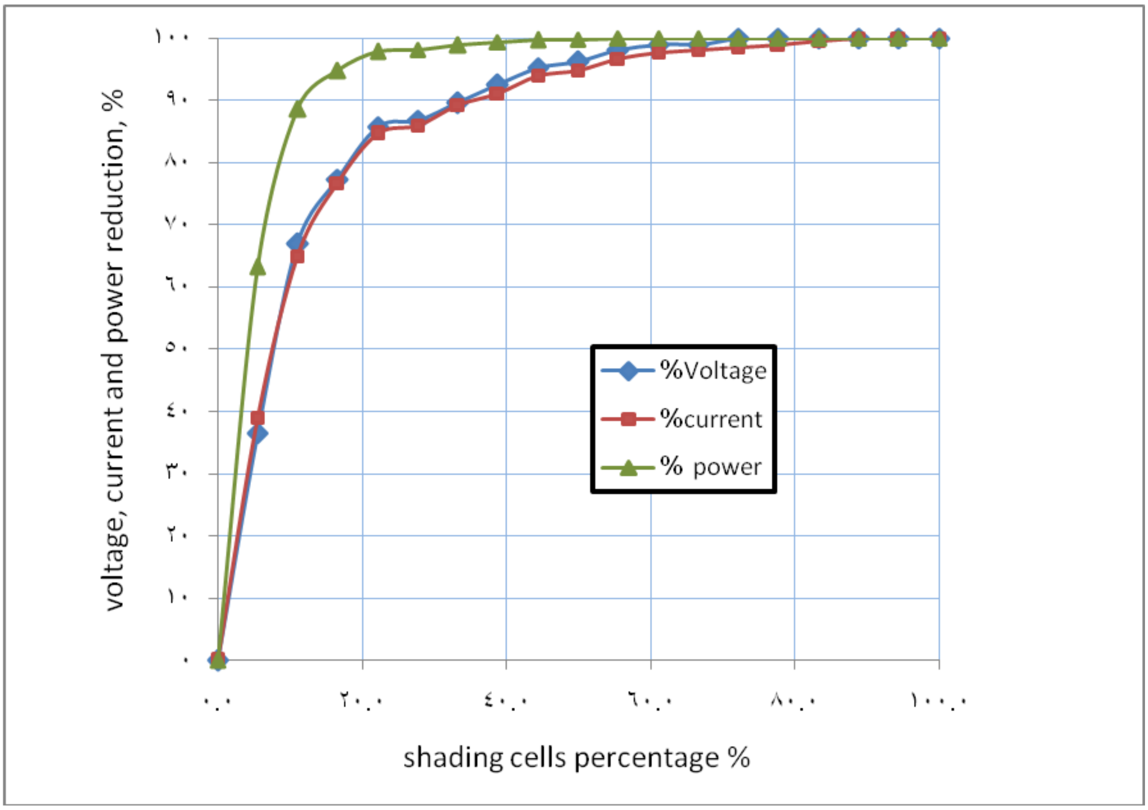

Fig.10: Voltage, current and power percentage reduction with shading cells percentage

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