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Efficiency Prediction and Performance Characterization of Photovoltaic Solar Panel at Baghdad Climate Conditions

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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 the professional testing of four solar cells at Baghdad climate conditions. Voltage -current characteristics of different area solar cells operated under solar irradiation for testing their quality and determining the optimal operational parameters for maximum electrical output were obtained. A correlation is developed between solar cell efficiency η and the corresponding solar cell parameters; solar irradiance G, maximum power P_{max}, and production date P. The average absolute error of the proposed correlation is 5.5% for 40 data points. The results also show that the new solar panels have the highest efficiency compared with the older ones.

Keywords: *Solar cell, photovoltaic performance, fill factor, efficiency.*

1. Introduction

The production of photovoltaic electricity has known in recent years an increasing of interest by a production exceeding 1800 MW throughout the world. This increase was accompanied by a revitalization of researches considered for the optimization of the energy given by solar cells.

Nowadays, the world's energy needs are growing steadily. However, the conventional sources of energy are limited. Solar energy such as photovoltaic energy (PV) is the most available energy source which is capable to provide this world's energy needs. The conversion of sunlight into electricity using solar cells system is worthwhile way of producing this alternative energy. The history of photovoltaic energy started in 1839 when Alexandre-Edmond Becquerel discovered the photovoltaic effect [1]. Photovoltaic system uses various materials and technologies such as crystalline silicon (c-Si), cadmium telluride (CdTe), gallium arsenide (GaAs), chalcopyrite films of copper-indium-selenide (CuInSe2), etc [1]. In solar technology, the main challenge of researchers is to improve solar cells efficiency. Due to this challenge, several investigations have been developed to characterize the solar cells by the determining their parameters [2],[3]. Indeed, it is important to know these parameters for estimating the degree of perfection and quality of silicon solar cells.

Solar cell efficiency is an important input parameter in PV-powered product design. Often, only limited space is available for the solar cells to be integrated. Cell efficiency can even become a criterion of principal system feasibility. As a basic parameter, cell efficiency serves as an input in calculating the optimal system configuration, e.g., as a cost related trade-off between the storage unit and its lifetime, PV size and its efficiency, although these calculations are well known for autonomous PV systems, e.g. [4] and finally the demand side with correlated consumption profiles. The objectives of the present paper are to find a functional relationship between solar cell efficiency with the solar cell parameters and characterize the performance of different types of solar cells.

2. Output Characteristics of Solar Cells

The output characteristics of solar cells are expressed in the form of an I - V curve. A typical I - V curve and the test circuit used are shown in Fig.1 (a,b) [5].

The I-V curve is produced by varying R_L (load resistance) from zero to infinity and measuring 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.

3. Experimental Measurements

The Prova 200 solar panel analyzer (Fig.3) is used for the professional testing and maintenance of solar panels and modules. Table 1 provides the general specification of Prova 200. In addition to maintenance and installation of solar panels, the Prova 200 solar panel analyzer can be used in the manufacturing and testing the solar panels and cells. The portability of this device is useful in quality assurance at various stages on the production line and can be taken from one location to another. When used in the installation of solar panels, the Prova 200 solar panel analyzer assists in determining the proper inverter size as well as optimum power output position of panels and helps identify defective cells or panels that have worn out over time. The solar panel analyzer also provides the user with current and voltage (I-V) test curves, maximum solar power as well as current and voltage. Solar cell properties are easily determined using the following units:

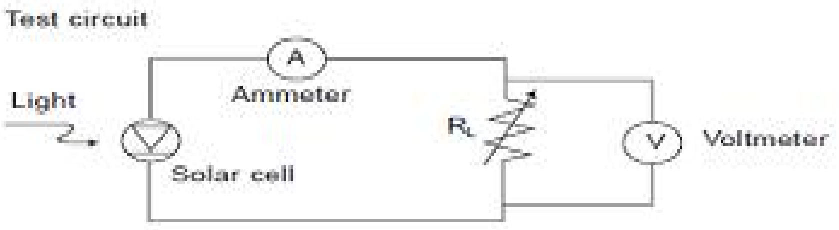
I-V Curve Test for Solar Cell, Single Point I-V Test, Maximum Solar Power (P_{max}) search by auto-scan, Maximum Voltage (V_{maxp}) at P_{max}, Maximum Current (I_{maxp}) at P_{max}, Voltage at open circuit (V_{oc}), Current at short circuit (I_{sc}), I-V curve with cursor, Efficiency (%) calculation of solar panel, Scan delay setting. (0 ~ 9999 msec), Solar panel area setting. (0.001 m^2 ~ 9999 m^2), Standard light source setting. (10 W/m^2 ~ 1000 W/m^2), Min. power setting for alarm function, Built-in Calendar Clock, Rechargeable batteries with built-in charging circuit, Optical USB cable for PC and The terminals of the solar cell are connected as shown in Fig.4. In this work, the system is consisted of four silicon solar cells (types A, B, C, and D) of different area as it is presented in Fig.5. Table 2 gives the general specification of these cells.

Table 1,
General Specifications of Prova 200.

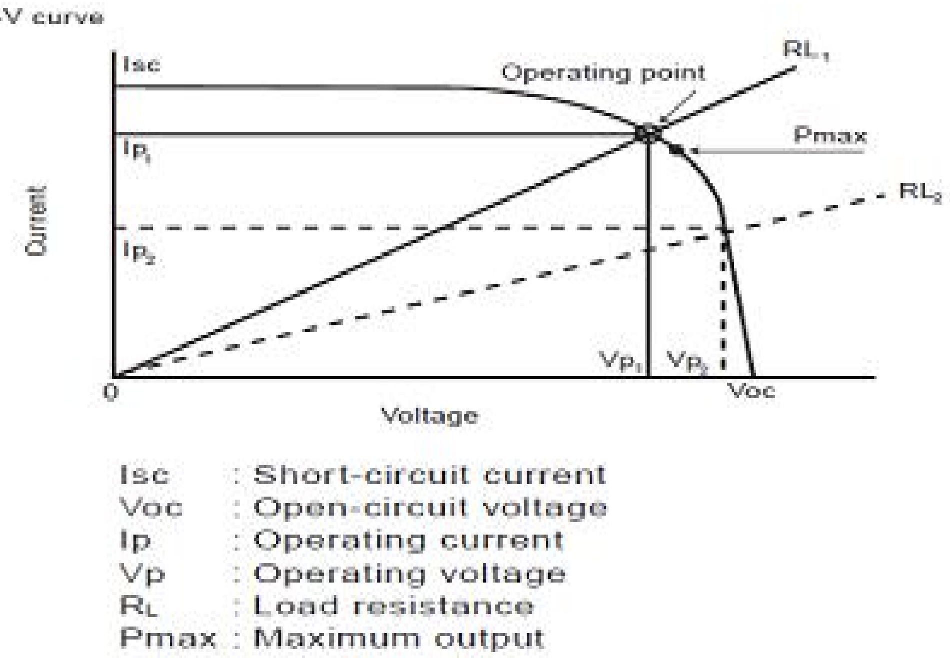
Battery type	Rechargeable, 2500Ah (1.2V) x 8
AC Adaptor	AC 110V or 220V input DC 12V / 1~3A output
Dimension	257(L) x 155(W) x 57(H) mm
Weight	1160g / 40.0oz (Batteries included)
Operation Environment	0 ~ 50, 85% RH
Temperature Coefficient	0.1% of full scale / ^{0}C (＜18 or ^{0}C＞28)
Storage Environment	-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
Solar Cell Specifications.

Type	Area m^2	$V_{oc\ V}$	$I_{sc\ A}$	Peak power w	Peak Voltage v	Peak Current A	Production date
A	0.023	11	0.33	1.8	6.6	0.28	2010
B	0.228	12	2.2	18	9.0	2.0	1980
C	0.366	19.5	2.8	35	15.8	2.3	1986
D	1	22	8.1	130	18.5	6.0	2010



(a)



(b)

Fig. 1. (a)Test Circuit (b)The I-V curve.

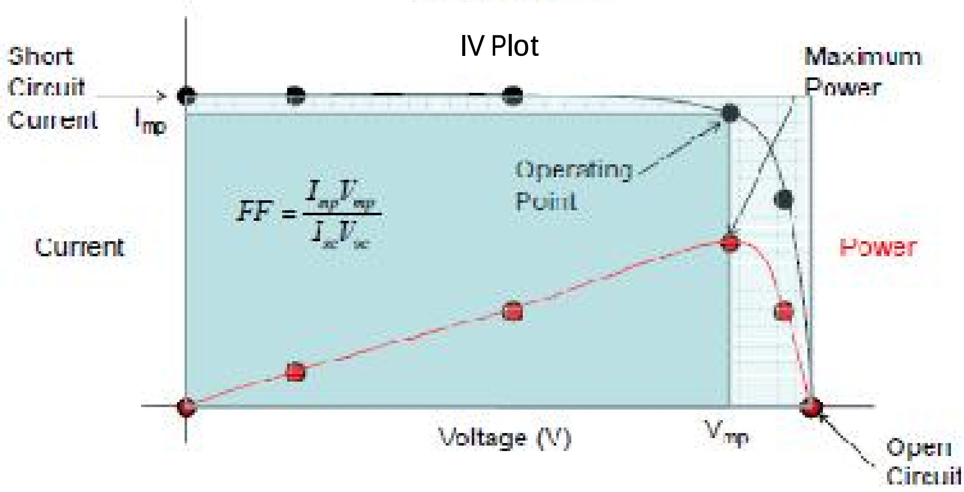
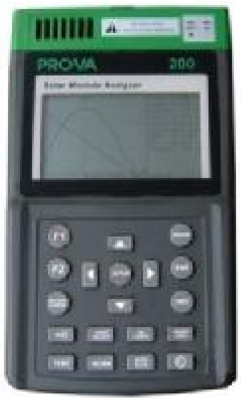


Fig .2. Square Area is The Maximum Power Output of the Solar Cell.



(a)

(b)

Fig. 3. The Prova 200 Solar Panel Analyzer :(a) Front View (b) Top View.

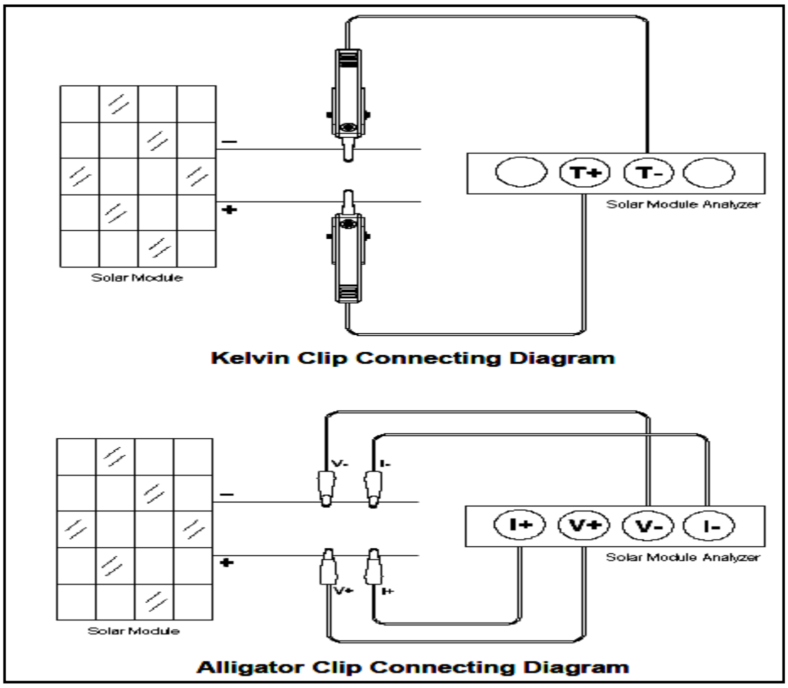


Fig. 4. Wires Connections.

A B C D

Fig.5: Solar Cells Tested type A, B, C and D

4. Solar Panel Parameters Measurements

The main parameters that characterize a photovoltaic panel (Fig.5) [4] are:

- Short circuit current (I_{SC}): the maximum current provided by the panel when the connectors are short circuited.
- Open circuit voltage (VOC): the maximum voltage that the panel provides when the terminals are not connected to any load (an open circuit).
- Maximum power point (Pmax): the point where the power supplied by the panel is at maximum, where Pmax = Imax x Vmax. The maximum power point of a panel is measured in Watts (W) or peak Watts (Wp). It is important to know that in normal conditions the panel will not work at peak conditions, as the voltage of operation is fixed by the load or the regulator. Typical values of Vmax and Imax should be a bit smaller than the ISC and VOC.
- Fill factorn(FF): the relation between the maximum power that the panel can actually provide and the product ISC. VOC. This gives 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.
- Efficiency (η): the ratio between the maximum electrical power that the panel can give to the load and the power of the solar radiation (PL) incident on the panel. This is normally around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film). The definitions of point of maximum power and the fill factor are:

η = Pmax/PL=FF . ISC . VOC / PL …(1)

5. Result and Discussion

The measuring results of the commercial available solar cells from different manufacturers are presented. Cell samples have been investigated regarding their IV-characteristics at different solar intensities in a range 100-1000 W/$m^2$and the ambient temperature between (22-26 ºC). All the measurements and the characteristics of these cells have been made within the date of February and March 2012.

The data obtained for I-V characteristics and P-V curve for the silicon solar cell under the specific solar radiation intensities are shown in Tables 3 to 6.

A comparison is done between the cell parameters and performance of the solar cell. Fig.6 shows the dependence of solar cell maximum power with solar radiation intensity for the four solar cell types.

According to Fig.7 solar cell type A and D have the high solar output efficiency due to earlier production date as compared the other two types B and C.

One can see in Fig. 8 that the variation of fill factor of solar cells B,C, and D fluctuated, increased with maximum power increasing while fill factor of type A decreases with increasing maximum power.

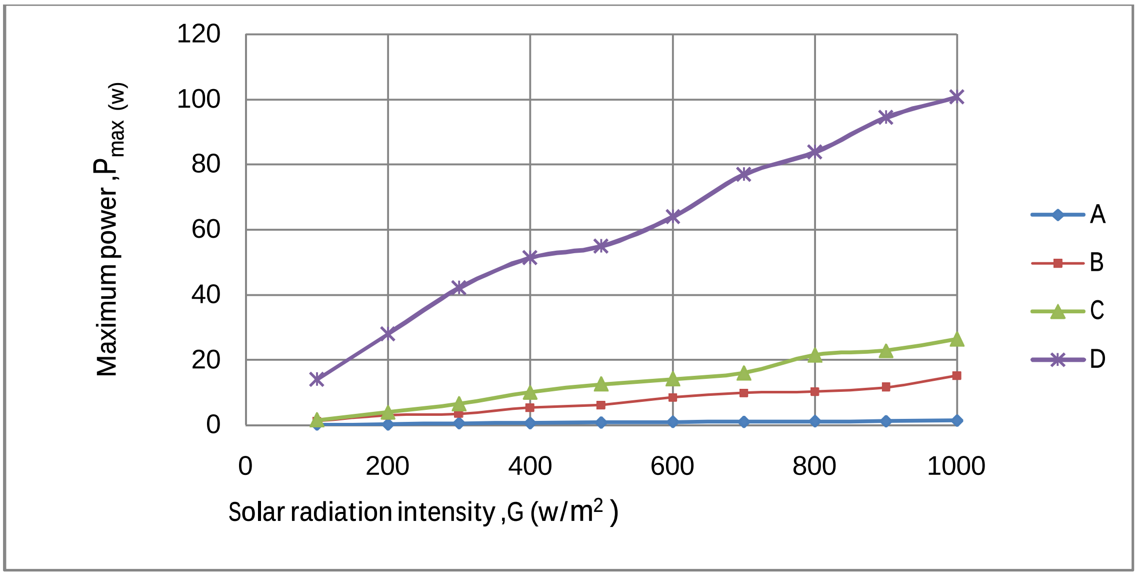


Fig. 6. Variation of Solar Cell Maximum Power with Solar Radiation Intensity for the Four Solar Cell Types.

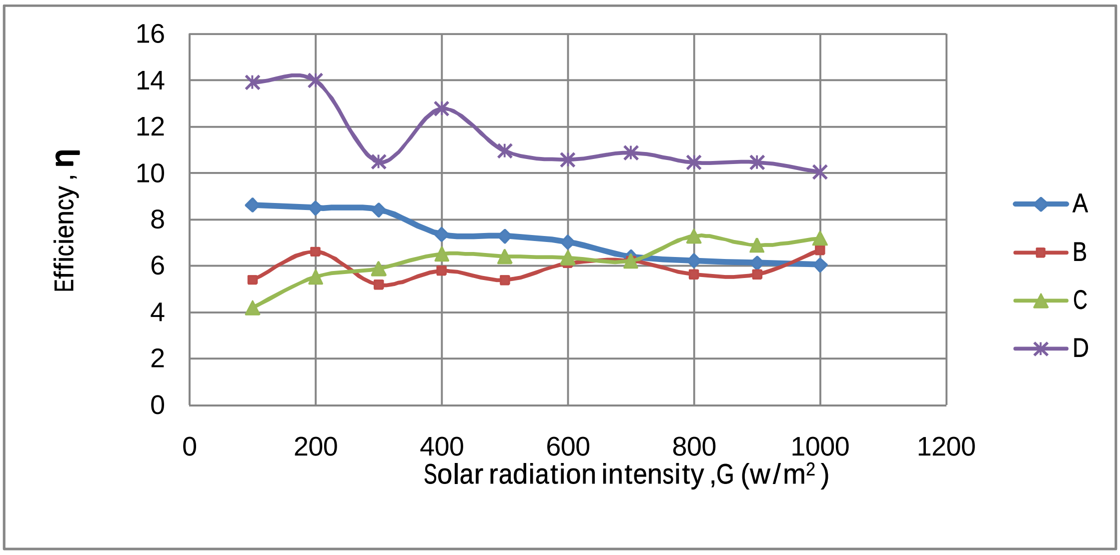


Fig. 7. Variation of Solar Cell Efficiency with Solar Radiation Intensity for the Four Solar Cell Types.

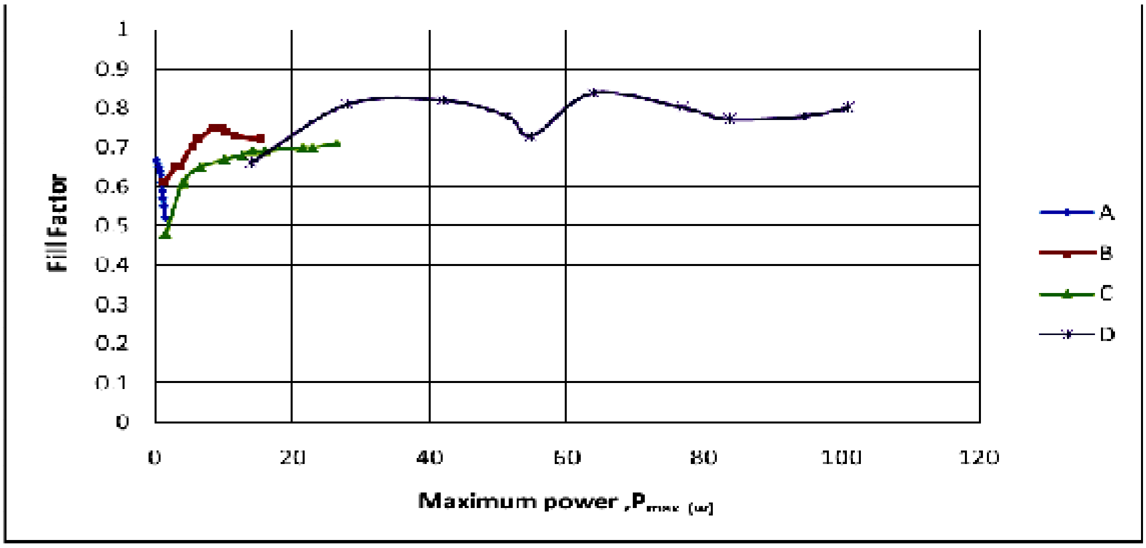


Fig. 8. Variation of Solar Cell Fill Factor with Maximum Power for the Four Solar Cell Types.

6. Correlation Development

In order to find a functional relationship between solar cell efficiency η with the corresponding solar cell parameters ; solar irradiance G ,maximum power P_{max} and production date P, non-linear regression analysis have been used to available experimental data of solar cell as shown in Tables 3 to 6 . The obtained correlation of the computer software program (statistica) is:

$$\eta=(A_1+A_2G)(B_1+B_2P+B_3P^2)/(D_1+D_2(Pmax+D_3P_{max}^2))+C_1+C_2G+C_3+C_4P_{max}+C_5P_{max}^2 \quad \ldots (2)$$

A_1= -1.227832 A_2= -0.00608 B_1=23102.47
B_2=-21273.8 B_3= 5297.8 C1=-608.795
C_2=0.000785 C_3=311.7824 C_4=-0.166576
C_5=0.000844 D_1=-0.545443 D_2=-0.007904
Correlation coefficient (R) = 0.9777

Table 7 shows the calculated solar cell efficiency and the corresponding percentage error. The average absolute error is 5.5% for 40 data point.

Table 3,
Solar Cell Type A with Surface Area 0.0237 m^2 .

G w/m^2	V_{now} v	V_{OC} V	I_{SC} mA	P_{max} W	V_{max} v	I_{max} mA	η%	FF
100	9.24	9.22	30.6	0.19	7.12	26.7	8.63	0.67
200	9.44	9.41	46.4	0.298	7.48	40.8	8.51	0.66
300	9.84	9.81	90.1	0.583	7.41	78.6	8.43	0.65
400	9.92	9.91	105.5	0.678	7.31	92.8	7.37	0.64
500	10.04	10.01	133.6	0.843	7.17	117.5	7.30	0.63
600	10.11	10.09	157.9	0.970	6.93	140.0	7.03	0.61
700	10.14	10.12	173.2	1.039	6.92	150.0	6.4	0.59
800	10.20	10.18	196.8	1.146	6.73	170.5	6.23	0.57
900	10.23	10.22	217.3	1.229	6.58	186.8	6.14	0.55
1000	10.37	10.36	256.7	1.394	6.42	217.3	6.06	0.52

Table 4,
Solar Cell Type B with Surface Area 0.228 m^2.

G w/m2	Vnow v	VOC v	ISC mA	Pmax W	Vmax v	Imax mA	η%	FF
100	9.39	9.29	217.3	1.23	7.19	172	5.41	0.61
200	10.09	10.07	458.9	3.02	8.97	337	6.62	0.65
300	10.18	10.16	536.9	3.50	9.14	393	5.2	0.65
400	10.34	10.32	732.6	5.36	9.14	586	5.8	0.70
500	10.40	10.39	823.0	6.16	9.05	680	5.4	0.72
600	10.56	10.54	1086	8.52	8.91	956	6.12	0.75
700	10.65	10.63	1240	9.94	8.75	1130	6.23	0.75
800	10.68	10.67	1300	10.29	8.79	1170	5.64	0.74
900	10.78	10.78	1450	11.58	8.79	1310	5.64	0.73
1000	11.02	11.03	1910	15.20	8.91	1710	6.69	0.72

Table 5,
Solar Cell Type B with Surface Area 0.366 m^2.

G w/m2	Vnow v	VOC v	ISC mA	Pmax W	Vmax v	Imax mA	η%	FF
100	16.20	16.19	196	1.50	11.70	131	4.21	0.48
200	17.42	17.40	383	4.05	13.58	299	5.54	0.61
300	17.99	17.94	556	6.52	14.40	426	5.90	0.65
400	18.20	18.18	825	10.1	14.63	693	6.53	0.67
500	18.30	18.25	972	12.6	14.71	730	6.42	0.79
600	18.40	18.36	1106	14.1	14.81	952	6.37	0.69
700	18.50	18.49	1230	15.97	15.03	1060	6.23	0.69
800	18.80	18.79	1620	21.5	15.30	1400	7.30	0.70
900	18.89	18.88	1710	22.9	15.20	1507	6.90	0.70
1000	19.05	19.05	1950	26.4	15.40	1720	7.20	0.71

Table 6,
Solar Cell Type D with Surface Area 1 m^2.

G w/m2	Vnow v	VOC v	ISC mA	Pmax W	Vmax v	Imax mA	η %	FF
100	17.60	17.50	1200	13.92	17.40	800	13.92	0.66
200	19.10	19.00	1800	28.00	17.50	1600	14.00	0.81
300	20.50	20.50	2500	42.05	17.52	2400	10.50	0.82
400	21.01	21.00	3100	51.30	17.70	2900	12.80	0.78
500	21.09	21.08	3520	54.90	17.72	3100	10.98	0.73
600	21.14	21.13	3560	63.90	17.76	3500	10.60	0.84
700	21.25	21.24	4500	76.90	17.80	4300	10.90	0.80
800	21.40	21.39	5060	83.84	17.84	4700	10.48	0.77
900	21.51	21.52	5600	94.42	18.02	5240	10.49	0.78
1000	21.60	21.59	5800	100.70	18.31	5500	10.07	0.80

Table 7,
The Calculated Solar Cell Efficiency and the Corresponding Percentage Error.

Cell type	G	100	200	300	400	500	600	700	800	900	1000
A	ηc	8.7	8.4	8.1	7.8	7.5	7.2	6.7	6.3	6.0	5.7
	%E	-1.1	1.4	4.2	-5.3	-2.2	-1.9	-4.4	-1.8	2.3	6.6
B	ηc	5.6	5.6	5.6	5.8	5.8	6.0	6.1	6.1	6.1	6.1
	%E	-3.4	15.5	-7.7	0.8	-7.7	2.0	2.6	-8.2	-8.9	9.1
C	ηc	4.5	5.0	5.7	6.5	6.8	6.9	6.9	6.8	6.8	6.6
	%E	-6.5	9.6	3.0	0.5	-5.5	-7.9	-11.4	6.2	1.3	7.8
D	ηc	13.5	13.3	12.2	11.6	11.4	11.0	10.5	10.4	10.3	10.4
	%E	3.0	5.1	-16.7	9.3	-4.4	-3.6	3.8	1.1	1.8	-3.0

7. Conclusions

The performance of a solar cell under sun radiation is necessary to describe the electrical parameters of the cell. Effect of production date on the performance of a photovoltaic solar system was investigated. A correlation is developed between solar cell efficiency η and with the corresponding solar cell parameters; solar irradiance G, maximum power P_{max} and production date P. The average absolute error of the proposed correlation is 5.5% for 40 data points. The results show that there is a fluctuated in solar cell efficiency with the values of irradiance.

Notation

A	ideality factor
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
η	Efficiency, %

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التكهن بكفاءة الخلية الشمسية وتقييم ادائها في الظروف الجوية لمدينة بغداد

عباس حميد سليمون عماد طالب هاشم شيماء علاء الدين مهدي
قسم هندسة الطاقة / كلية الهندسة / جامعة بغداد

الخلاصة

ان اداء الخلية الشمسية تحت الاشعاع الشمسي ضروري لوصف معالم الخلية. لقد استعمل جهاز محلل اداء الخلية بروفا 200 لاختبار اربع الواح شمسية نوع سيليكون متعدد التبلور عند الظروف المناخية لمنطقة بغداد. لقد تم فحص خصائص الفولطية- تيار لخلايا شمسية مختلفة وتحت تاثير الاشعاع الشمسي لتحديد العوامل المثلى التي تعطي اعلى قدرة. تم ايجاد علاقة بين كفاءة الخلية مع ما يقبلها من معاملات الخلية والتي هي : شدة الاشعاع الشمسي، اعلى قدرة وتاريخ الانتاج. معدل نسبة الخطأ المطلق يساوي ٥,٥% لاربعين نقطة عملية، لقد بينت نتائج البحث ان الالواح الشمسية حديثة الصنع اكثر كفاءة من نظيراتها قديمة الصنع.