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Physics

THE INTENSITY DEPENDENCY OF THE SERIES RESISTANCE AND OTHER PARAMETERS OF A PHOTOVOLTAIC SILICON SOLAR CELL IN RELATION TO ITS PERFORMANCE

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ABSTRACT Measurements of global solar irradiance on a horizontal surface is made and compared with a published prediction model .The parameters of an amorphous silicon solar cell are extracted from a set of irradiated current-voltage characteristic curves. I-V characteristic curves obtained at different illumination levels. Two points-single I-V curve (EL-Adawi) method is considered to estimate the series resistance of the cell .The heat balance equation is solved to determine the cell temperature. The functional temperature and intensity level dependency of the cell parameters are revealed. Computations to reveal the variation of the cell efficiency along the solar day as an illustrative example is also given. It is revealed that the parameters and the efficiency are temperature dependent and vary with the intensity of solar insulation with different rates. Cooling condition to get higher efficiency is recommended .

KEYWORDS : Series resistance measurements , silicon solar cell I-V characteristics, solar cell parameters ,solar cell temperature and efficiency.

1.INTRODUCTION

Increasing the efficiency of a photovoltaic solar cell has aroused the interest of many investigators. Information on the cell series resistance and other solar cell parameters are of vital importance in designing solar cell concentrators and other solar systems that depend on the solar photovoltaic cells [1-18].

The dependence of such parameters on the intensity of solar illumination and operating conditions has to be clarified [1,2,1,4,8]. The temperature of a solar cell exposed to incident solar insolation varies with local day time.This factor affects its performance [5,6,7,8,9].The series resistance R_s of a solar cell is an important parameter[8,10,11].

There are several trials to determine R_s. Many of such trials [2- 4,10-15] make use of the cell I-V characteristics based on a single diode model under a steady state in the IV^{th} guardant . The two –curve method [12] consider two different I-V curves for the same cell under different illumination levels.

EL-Adawi through an analytical method [11] succeeded to determine the series resistance and the shunt resistance, considering a single I-V curve .This method is now well known as two points-single curve I-V method [3]or shunt resistance(EL-Adawi)method [16].Suresh et al [16] considered five $R_s$estimation methods,namely,onecurve method,two characteristics method , maximum power point method, Δ i method and shunt resistance method.

The comparison with the series resistance specified in the designer's manual [16] shows large variation in the obtained values. The authors [16] decided that El-Adawi method [11]is reasonably accurate among all others because it also takes care of shunt resistance while deriving their expression for the series resistance. It is worth to note that Silicon solar cells are still the most promising substance in the field of photovoltaic applications [13,14].This type is considered in the present study.

The aim of the present trial is to extract the parameters of an amorphous Silicon solar cell under different illumination levels. . These parameter , are the short circuit current I_{sc} , the open circuit voltage V_{oc} ,the filling factor FF, and the series resistance R_s . Different I-V characteristic curves are obtained corresponding to different illumination levels .Moreover, for each curve the temperature of the irradiated cell is determined .Authors of the present trail solved the heat balance equation for the considered cell to obtain an analytical expression that determines the cell temperature under illumination.This makes it possible to investigate the influence of both the temperature and the illumination on the cell parameters . Finally, the efficiency of the cell is evaluated as a function of these two factors to reveal its variation with time along the local day time .

2.Experimental Setup

An experiment was performed, the setup of which is shown in figure (1). An amorphous Silicon solar cell [dimensions 5.5×11cm, thickness 0.35cm]is considered. The circuit to measure I and V is shown in figure (2).The cell is exposed to the incident global solar radiation ,the irradiance of which is measured by a luxmeter [a digital luxmeter 4F-172]. The measurements are made along the local day time. The cell governing equation is as follows [4,10,11,13,17,18] :

$$I = I_{ph} - I_0[\exp \lambda (v + I R_s) - 1] - \frac{v + I R_s}{R_{SH}} \rangle 0 \qquad (1)$$

Where, I_{ph} – cell photo current, I_o –the reverse saturation current $\frac{q}{nkT} = \lambda$, and $\frac{kT}{q}$, is the thermal voltage, and q is the electron charge, n is the diode ideality factor .

3.Results and computations

I) I-V curves: A family of I-V characteristic curves are obtained . The obtained curves are shown in Figure (3).From each curve one can estimate V_{oc} ,I_{sc} , the filling factor FF. Moreover, applyingEl-Adawi method [11], the series resistance Rs of the considered cell is evaluated for each curve corresponding to a certain global solar irradiance. The obtained results are given in table(1) .The maximum value of the received solar irradiance q_{max} at mid-day time is also recorded .

ii)Determination of the cell temperature:

The first step : One has to choose a formula to predict the received solar irradiances .The following expression is considered :

$$q_0(t) = 4\, q_{\max} \left(\frac{t}{t_d}\right)\left(1 - \frac{t}{t_d}\right) \qquad (2)[19]$$

Where q_{max} is the maximum value of the received incident solar irradiance along the local day time, t_d is the length of solar day time given as:[20]

$$t_d = \frac{2}{15} \cos^{-1}(-\tan\varphi \tan\delta)$$

Where, φ is the Latitude and δ is the solar declination angle given as :

$$\delta = 23.4 \sin 360\left(\frac{284+n}{365}\right) \quad , (1 \le n \le 365) \text{ , starting from 1 january} \qquad [20]$$

A comparison between the measured values of $q_{exp}(t)$ recorded in the present trial and the computed values q(t) according to equation (2) is made.The results are given in table (2) and are illustrated in figure (4) .Asatisfactory fitting degree is obtained (8%).

The second step :

One has to obtain analytically the temperature of the cell.This is done as follows :

Let us assume that the received by the cell solar radiation is partly absorbed and partly reflected. One can write a heat balance equation in the form [5] :

$$\alpha\, S\, A\, q_0(t) - S\, h\, \theta(t) = S\, \ell\, \rho \frac{d\theta}{dt} \qquad (3)$$

Where , α ,is the ratio of the absorbed energy consumed in heating the cell, *A* is the absorption coefficient of the front surface , $q_0(t)$ is the received solar irradiance , *S* is the area of the front surface of the cell , *h* the heat transfer coefficient of the cell front surface [W/m^2 K], ℓ is the cell thickness , ρ (kg /m^3) is the density of the cell material and θ = (T – T0)represents the cell excess temperature relative to the ambient temperature T_0 ($\mathring{k}$) .

The first term in the left hand side of equation (3) represents the absorbed solar energy consumed in the heating process and the second term represents the heat lost by convection at the front surface ……..while the term on the right hand side represents the rate of increase of the enthalpy of the considered target .

Equation(3) can be rearranged to be in the form:

$$\frac{d\theta(t)}{dt} + c_1\, \theta(t) = c_2\, q_0(t) \qquad (4)$$

Where $c_1 = \frac{h}{\ell \rho c_p}$, $c_2 = \frac{(\alpha A)}{\ell \rho c_p}$ (5)

Substituting the expression of qo(t) (equation (2)) into equation (4) and then applying the method of integrating factor ,one gets the solution in the form[21],[22] :

$$\theta(t) = 4 c_2\, q_{\max} [\{\frac{1}{c_1 t_d}(t - \frac{1}{c_1}(1 - e^{-c_1 t}))\} - \{\frac{1}{c_1 t_d^{\,2}}(t^2 - 2(\frac{t}{c_1} - (\frac{1}{c_1^2} - \frac{e^{-c_1 t}}{c_1^2}))))\}] \quad [6]$$

In the present trial for each (I – V) curve corresponding to a certain value of *q(t)* the cell temperature is estimated using equation (6).The results are given in the table(1).

This makes it possible to indicate the different cell's parameters as function of the temperature , namely :I_{sc}(T) , V_{oc}(T) , R_s(T)for each I-V curve .

The results are also given in table(1) and are illustrated graphically in figure (5) .

In the computations the following geometrical ,physical, thermal and optical properties for the solar silicon cell are considered :

l=0.35cm ,ρ=2280kg/m^3 c_p=840j/kg K a=0.67[23]
α=0.8 and h=10W/m^{2}K

4.Evaluation of the cell efficiency η

The cell efficiency is defined as :

$$\eta = \frac{FF\, I_{sc}\, V_{0c}}{P_{in}} \qquad (7) \quad [24]$$

Where, *FF* is the filling factor and P_{in} the solar energy received by the cell. The efficiency η is also calculated for each curve corresponding to its cell temperature. Thus, the temperature functional dependence of the cell efficiency η (*T*) is also clarified.

The obtained results are tabulated also in table (1) and are graphically illustrated in figure (6) .

The variations of the series resistances ,V_{oc},I_{sc} with the local day time are illustrated in figure(7), figure(8)and figure(9) respectively.

Moreover, the variation of R_s with the cell temperature along the local day time is illustrated in figure (10) from which one concludes that the series resistance decreases with the raise of the cell temperature .Moreover, the variation of V_{oc} , I_{sc} , with the cell temperature along the local day time are also revealed in figures (11) and (12) ,from which it is clear that the V_{oc} is less dependent on the cell temperature than I_{sc}.

Thus I_{sc}(T) , has predominant effect on the efficiency of the cell compared to V_{oc} .

5.Conclusions

The obtained results make it possible to summarize the following conclusions :

1. Good agreement between the measured solar irradiance and that predicted through equation (2) is obtained.
2. The temperature of the solar cell subjected to incident solar insulation increases with local day time and passes through a maximum value about the mid-day time then it decreases gradually towards sunset.
3. The cell parameters V_{oc} , I_{sc} , and the efficiency h are functions of the cell temperature .
4. The efficiency h of the cell decreases with the cell temperature in general.Thus cooling conditions are recommended.
5. The series resistance R_s , decreases with the cell temperature.It passes through minimum values along the local daytime .For this small interval more efficient conversion of solar energy is obtained .
6. Both V_{oc} ,I_{sc} functions increase with temperature but with different rates. The increase in V_{oc} is slower than that for I_{sc}. The behavior is not monotonous .

Table.1 Values of R_S, V_{oc}, , I_{sc} and Efficiency η % of the investigated solar cell.

t′ local day time(shifted)	V_{oc},volts	I_{sc}, mA	R_S,Ω	θ, °c	η %
0	9.5	14.91	1020	14.63	73.5
1	9.64	27.1	1052	33.27	11
2	9.91	41.9	800	48.10	9.66
3	10.26	51.7	110	58.56	8
4	10.72	54	110	62.14	8.75
4.5	10.96	58	200	64.61	3.93
5	10.43	60.5	250	65.99	4.88
5.5	9.6	59.2	840	66.27	1.43
6	7.07	34.5	1880	56.36	1.23
8	6.32	23.3	2580	51.13	0.96
8.5	6.13	15.6	3310	44.80	0.76
11	5.95	7.8	5000	28.84	0.181

Table.2 Experimental and calculated values of the intensity of sun light

′ local day time(shifted)	t′ local day time(shifted)	q_{exp} (W/m^2)	q_{cal} (W/m^2)	Relative error
6.0	0	0	0	0
7.0	1	159.2	133.70	0.16
8.0	2	244	265.09	0.08
9.0	3	382.4	387.00	0.01
10.0	4	518.4	494.61	0.045
10.5	4.5	562.4	534.00	0.05
11.0	5	588	581.30	0.011
11.5	5.5	624.4	624.40	0
12.0	6	596.8	580.38	0.027
14.0	8	363.2	387.00	0.06
14.5	8.5	317.6	341.12	0.07
17.0	11	0	0	0

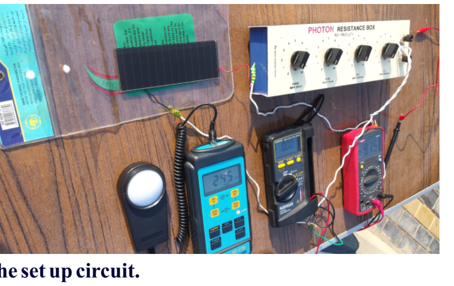

Fig.1. The set up circuit.

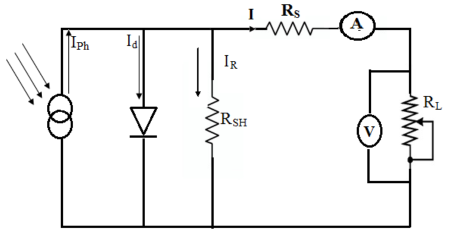

Fig.2. The equivalent circuit of set up

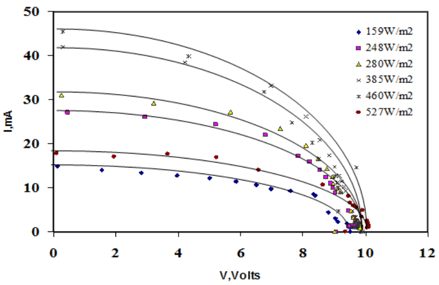

Fig.3. Current-Voltage characteristic curves of solar cell under different intensity of illumination of the sun.

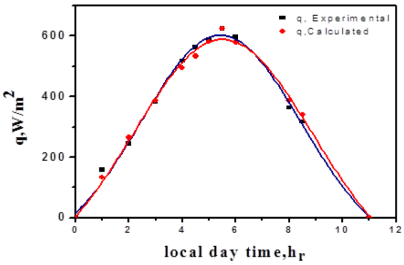

Fig.4. experimental and calculated intensity of light versus the time

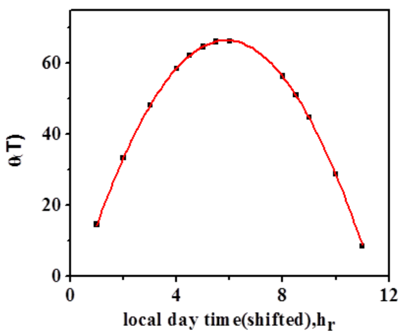

Fig.5. The temperature of the solar cell variation with time along day

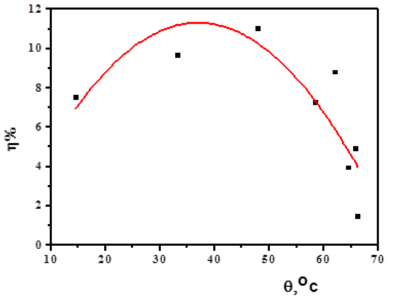

Fig.6. The temperature dependence of the efficiency of the investigated solar cell

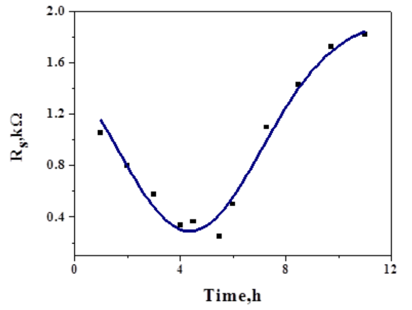

Fig.7. The variation of series resistance Rs with time along day of the investigated solar cell.

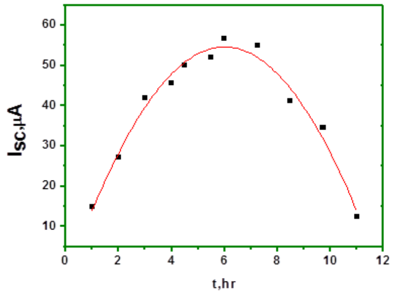

Fig.8. The variation of the short circuit current I_{sc} with time along day of the investigated solar cell.

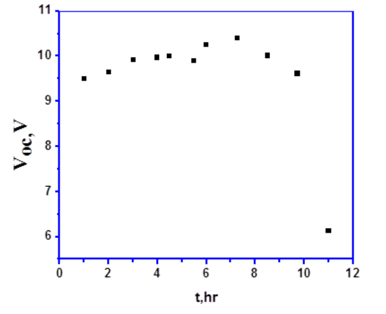

Fig.9. The variation of open circuit voltage V_{OC} with time along day of the investigated solar cell.

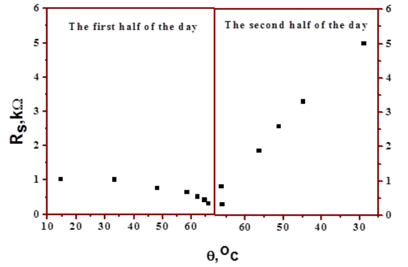

Fig.10.The temperature dependence of the series resistance Rs of the investigated solar cell.

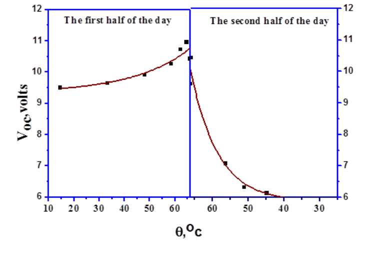

Fig.11. The temperature dependence of the open circuit voltage Voc of the investigated solar cell.

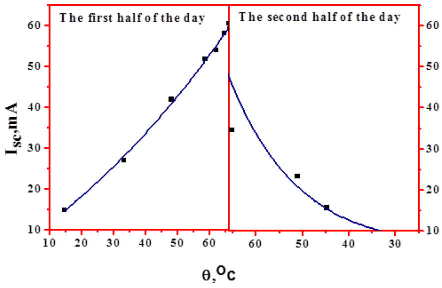

Fig.12. The temperature dependence of the short circuit current Isc of the investigated solar cell.

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