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Effect of illumination intensity on solar cells parameters

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Abstract

This work presents the influence of the irradiance intensity level on different parameters (ideality factor, saturation current, series resistance, shunt resistance…) of polycrystalline silicon solar cells. I-V characteristics of these cells were plotted with measurements done at room temperature, and were modeled using the single diode model. We find that the short circuit current, the photocurrent and the ideality factor increase linearly with the irradiation level intensity while the open circuit voltage and efficiency increase logarithmically. The fill factor increases slightly for low intensities, and then it decreases with higher intensities of irradiation. The saturation current increases exponentially. The series resistance remains invariant and the shunt resistance decreases linearly.

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Keywords: Solar cell; intensity; irradiance; silicon; parameters.

1. Introduction

Polycrystalline silicon solar cells constitute one of the main solar cell branches of the photovoltaic industry; therefore, it is important to analyze the effect of the irradiance on the performances of the polycrystalline silicon solar cells. When solar cells are utilized for indoor applications or integrated into a building, they are generally exposed to variable irradiance intensity. The performance of a solar cell is influenced by this variation as its performance parameters, viz. open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), fill factor (FF) and efficiency (η). These performance parameters are in direct relationship to

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the cell characteristics, viz. series resistance (Rs), shunt resistance ($R_{sh}=1/G_{sh}$), diode ideality factor (n) and reverse saturation current (Is).

Nomenclature

FF	Fill factor
I	Current
I_{ph}	Photocurrent
Is	Saturation current
I_{sc}	Short circuit current
k	Boltzmann Constant
n	Ideality factor
q	Electron charge
R_s	Series resistance
R_{sh}	Shunt resistance
T	Absolute temperature
T_{ref}	Reference temperature
V	Voltage
V_{oc}	Open circuit voltage
η	Conversion efficiency of the solar cell

Variation of Rs and R_{sh} with irradiance intensity has been investigated by several researchers [1-4]. However, the studies on the effect of irradiation intensity on the cell saturation current and its ideality factor are rather scarce in literature [2-5]. Khan et al [2] applied the variation of slopes of the I-V curves of a cell at short circuit and open circuit conditions to determine the parameters of the cell, namely the series resistance R_s, shunt resistance R_{sh}, the ideality factor, n, and the saturation current, Is, the of a cell of mono-crystalline silicon solar cell. But the work is much more descriptive, because there are no details of the physical phenomena that describe the variation of the intrinsic parameters of the cell as a function of irradiation. In this work, we investigated the variation of cell parameters viz. R_s, R_{sh}, Is and n, considering the one diode model, in the irradiance intensity range 160–1000 W/m^2 for single polycrystalline silicon solar cell with (12.5 x12.5) cm^2 of area, under room temperature.

2. Calculation procedure

The illuminated current-voltage characteristics of a PN junction solar cell can simply be described using single exponential model as:

$$I = I_{ph} - I_s\left[\exp\frac{q(V+R_sI)}{nKT} - 1\right] - \frac{V+R_sI}{R_{sh}} \tag{1}$$

Where I_{ph}, Is, n, K, q, R_s, R_{sh} and T represents the photogenerated current, the reverse saturation current, the ideality factor, the Boltzmann constant, the absolute value of electron's charge, the series resistance, the shunt resistance and the temperature of the cell, respectively [6].

An accurate calculation of solar cell parameters from experimental data is of vital importance for the optimized design of solar cell fabrication process. A variety of methods have been proposed by several authors to device ways for determining the parameters under different irradiance and temperature levels. These parameters are principally the saturation current, the series resistance, the ideality factor, the shunt resistance and the photocurrent. Several methods to determine these parameters, have been extensively discussed and compared in other works [7- 9].

It is found that the method of Bouzidi et al gives reliable results under irradiation [9]. This method is based on the current-voltage characteristic under irradiation of a solar cell for the evaluation of its characteristic parameters with the mathematical single diode model. This method includes the presentation of the standard relation I=f(V) (1) as V=f(I) and then determining the factors C_0, C_1, C_2 of this function that provide the calculation of parameters of the solar cell. Therefore, Eq. (1) can be written as:

$$I = I_{pA} - I_0\left[exp\left(\frac{\beta}{n}(V+IR_s)\right) - 1\right] - G_AV \tag{2}$$

Where

$$\begin{cases} I_{pA} = \dfrac{I_{ph}}{1+G_{sh}R_s} \\ I_0 = \dfrac{I_s}{1+G_{sh}R_s} \\ G_A = \dfrac{G_{sh}}{1+G_{sh}R_s} \end{cases} \tag{3}$$

For low bias voltages, the linear part dominates and Eq. (2) can be written as

$$I_c = I + G_AV \tag{4}$$

Under forward bias for ($V+R_s I$) >> kT the current across the device is given by

$$I_c = I_{pA} - I_0\left[exp\left(\frac{\beta}{n}(V+IR_s)\right)\right] \tag{5}$$

The current (I) is used instead of the voltage (V) as the independent variable in Eq. (5), to evaluate the series resistance, the ideality factor and the diode saturation current allowing a new formulation as:

$$V = \frac{n}{\beta} \ln \frac{I_{pA}}{I_0} - R_s I + \frac{n}{\beta} \ln \left(1 - \frac{I_c}{I_{pA}}\right) \tag{6}$$

This expression can be presented in the common form

$$F(I) = C_0 + C_1 I + C_2 \ln \left(1 - \frac{I_c}{I_{pA}}\right) \tag{7}$$

Where

$$\begin{cases} C_0 = \frac{n}{\beta} \ln \frac{I_{pA}}{I_0} \\ C_1 = -R_s \\ C_2 = \frac{n}{\beta} \end{cases} \tag{8}$$

The values of factors C_0, C_1, C_2 can be obtained by means of the experimental current–voltage data array using a least-squares method. The series resistance, the ideality factor and the current, I_0, values are then determined from the following equations:

$$\begin{cases} R_s = -C_1 \\ n = \beta C_2 \\ I_0 = I_{pA}\, exp\left(\frac{-C_0}{C_2}\right) \end{cases} \tag{9}$$

Substituting the values of R_s and I_0 obtained in Eq. (9), the shunt conductance G_{sh}, the photocurrent, and the diode saturation current values are determined from

$$\begin{cases} G_{sh} = \frac{G_A}{1-G_A R_s} = {}^{1}/_{R_{sh}} \\ I_{ph} = \frac{I_{pA}}{1-G_A R_s} \\ I_s = \frac{I_0}{1-G_A R_s} \end{cases} \tag{10}$$

3. Results and discussion

The variation of the illumination intensity affects significantly the short circuit current I_{sc}. Any change of the irradiation causes a proportional change in the short circuit current as shown in Fig. 1.

We also observed a linear increase in I_{sc} with irradiation in the range 160-1000W/m^2. Indeed the extent of variation of the current I_{sc} according to the irradiation is bounded by the values 0.8232A for 160W/m^2 irradiance and 5.1465A for 1000 W/m^2. The short circuit current is practically equal to the photocurrent. The relationship linking I_{sc} to the irradiance can be written [10]:

$$\boldsymbol{I_{cc}} = K_E * E \tag{11}$$

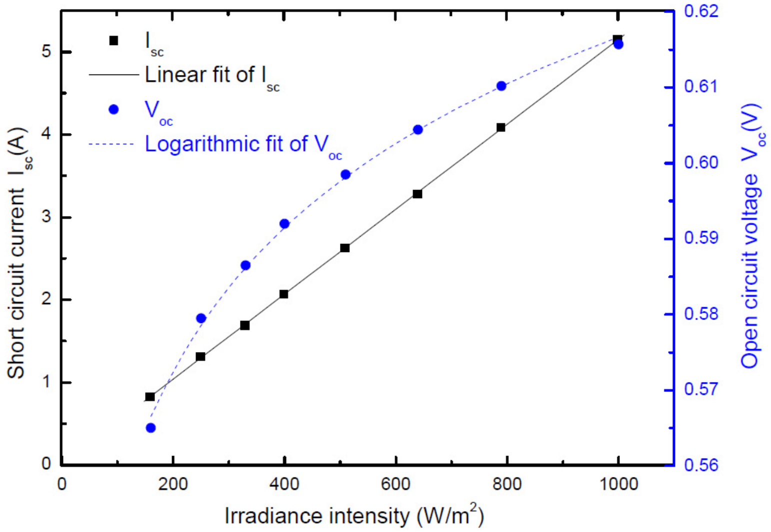

Fig.1. Open-circuit voltage and short-circuit current as function of irradiance for a polycrystalline silicon solar cell

Where K_E is a constant that characterizes the relative variation of short circuit current as a function of irradiation. In this work K_E=0.0051(A.m^2/W). Note that the coefficient K_E of short circuit current obtained by Stamenic et al [11] is K_E =0.0037 (A.m^2/W) for a panel of monocrystalline silicon under the same operating conditions and that obtained by Bayhan and Bayhan [5] is K_E=0.0025 (A.m^2/W) for *CIGS* technology under the same conditions.

In Fig. 1, we also present the evolution of the open circuit voltage as a function of irradiation. From this figure, we obtained a very good correlation between measurements and calculation using the following equation.

$$V_{oc} \approx V_{ocn} + \frac{nkT}{q} \ln\left(\frac{E}{E_n}\right) \tag{12}$$

Where: V_{ocn} and E_n are the open circuit voltage and the irradiation under nominal conditions.

We note that the open circuit voltage increases with increasing irradiation, but it is less sensitive to light intensity than the short circuit current. La valeur de la tension de circuit ouvert V_{oc} , ne peut pas être considérée comme arbitraire car elle dépend de la structure interne de la photopile, des phénomènes de conduction et de recombinaison [12]. The variation of the open circuit voltage V_{oc} is from 0.565V for 160 W/m^2 irradiation to 0.616V for an irradiation of 1000 W/m^2.

The fill factor *FF* slightly increases with the intensity for low irradiation (E<500W/m^2), and then it decreases for higher intensities of irradiation (E>500W/m^2) (Fig. 2) due to the influence of series resistance [13]. Our results are similar to those obtained by Khan et al for monocrystalline silicon technology [2]. Fig.2 also illustrates the efficiency dependence on the illumination intensity; two ranges of variation are observed, when the irradiation is greater than 400W/m^2, the efficiency varies little with the illumination intensity. In the area where the irradiance is below 400W/m^2, the efficiency increases logarithmically, because the open circuit voltage depends logarithmically as a function of short circuit current [3]. The efficiency ranges from 3.14% to 15.59%, when the irradiation varies from 160 to 1000W/m^2.

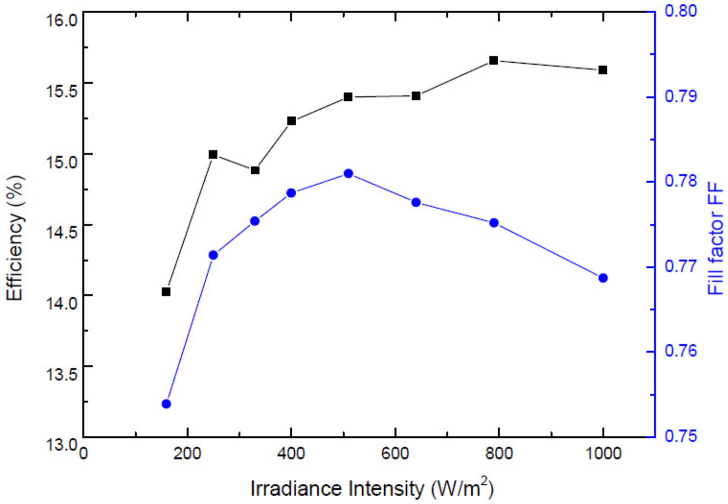

Fig.2. Fill factor and efficiency as a function of irradiance

Fig. 3 shows the variations of the ideality factor and saturation current, respectively, depending on the intensity of irradiation. The ideality factor *n* increases linearly with irradiation to radiation above 350 W/m^2. The saturation current increases exponentially with the irradiation in the range (160-1000W/m^2) according to the following relation [14].

$$I_s = C.exp(\varepsilon.E) \tag{13}$$

In this case, we find C=0.007. 10^{-6}A/m^2 and ε=0.004.

The increase in ideality factor and saturation current is caused by the increase in the recombination current. The increase of the latter is linked with increasing density of defect states in the band gap.

These defects are caused by the energy released from the recombination of electron-hole pairs. Therefore, while the electrons and holes recombine, the atomic bonds are broken by low energy released. These broken links are fault states, creating more sites of recombination. The increase in locations of recombination, in turn, increases the recombination of electron-hole pairs [15].

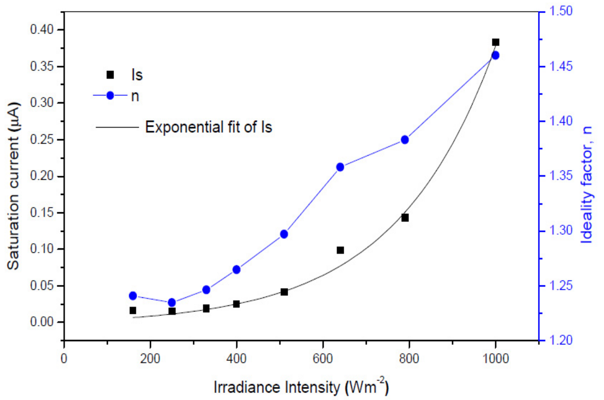

Fig.3. Diode ideality factor and reverse saturation current as a function of irradiance

Fig.4 shows a small change in the series resistance, we can say that it is invariant with respect to light intensity in the range from 160W/m^2 to 1000 W/m^2. These results are consistent with those found by Kassis and Saad [16] for the same technology and the range of irradiation from 0 to 200 W/m^2 [16], and Chan and Phang [17].

The evolution of the shunt resistance as a function of irradiation between 0 and 200W/m^2 is almost constant. Then it decreases linearly with irradiation between 200 and 1000 W/m^2. These results are similar to those obtained by Kassis and Saad [16] and Eikelboom and Reinders [1].

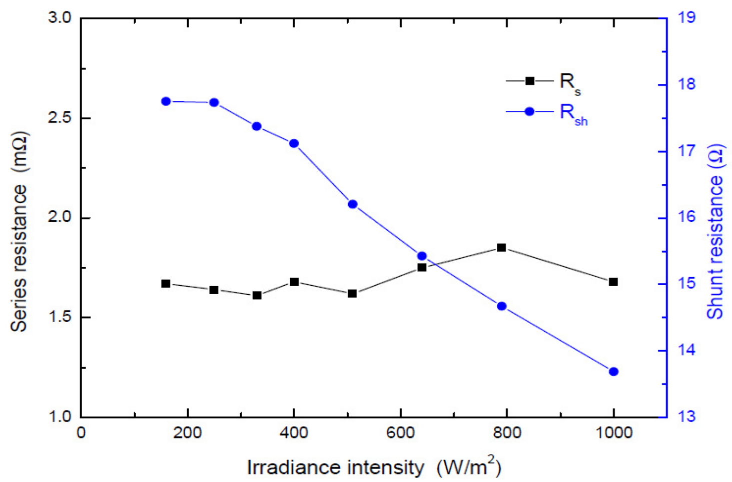

Fig.4. Series resistance and shunt resistance as a function of irradiance

4. Conclusion

We have investigated the variation of cell parameters viz. R_s, R_{sh}, Is and n, considering the one diode model, in the irradiance intensity range 160–1000 W/m^2 for single polycrystalline silicon solar cell with (12.5x12.5) cm^2 of area, under room temperature. The main results are as follow: The short circuit

current, the photocurrent, the ideality factor and the maximum power increase linearly with increasing irradiance intensity in the considered irradiance intensity range, at room temperature. The open circuit voltage increases logarithmically. The fill factor increases slightly (E $<500W/m^2$), and then it decreases at higher intensities of irradiation ($E>500W/m^2$). The conversion efficiency increases logarithmically for $E<400W/m^2$, but when the irradiation is greater than $400W/m^2$, it is almost invariable. The saturation current increases exponentially. The series resistance is invariant with respect to irradiation. Shunt resistance is almost constant ($E<200W/m^2$), but it begins to drop linearly between 200 and $1000W/m^2$.
The results show the importance of taking into account the kind of application of such solar cells under low and high illumination intensities, i.e. for indoor or outdoor use.

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