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A Detailed Modelingof a Five Parameters Model for Photovoltaic Modules

NouarAoun[1], Boukheit Nahman[2], Rachid Chenni[3], KadaBouchouicha[4]
[1, 2] Departmentof Physics, Constantine 1 University, Algeria
[3] MoDERNa Laboratory, Constantine 1 University, Algeria
[4]Research Unit in Renewebles Energies, URER/MS, Development Centre of Renewable Energies, CDER, Adrar, Algeria.

Abstract:*In the present paper we interested at the parametric characterization of the five parameters model. However, we reductive the system of the three characteristic points under STC in one equation called* f_{Rs}*and one unknown parameter (i.e.,* R_s*). Moreover, we vary with a step of* 10^{-4}*, the ideality factor* γ *between 0.0 and 4 for each iteration in order to choose the value of* γ *which gives a minimal relative error of the maximum power point. Finally, when* γ *is known the other four parameters (i.e.,* R_s*,* I_0*,* I_{ph} *and* R_{sh}*) are known. The effectiveness of this approach is evaluated through comparison of simulation results to the data provided by product's manufacturer.*

Keywords:*photovoltaic; nonlinear equation; five parameters model.*

I. INTRODUCTION

The modeling of a photovoltaic module (of a cell) implies mainly the estimate of nonlinear curves IV. Preceding researchers [1], [2], [3] and [4] used topological circuits to model the module characteristics when it is subjected to environmental variations such as illumination and the temperature.By far, the simplest approach is the model with a diode, namely a power source simultaneously with a diode [2], [5] and [6]. In the majority of work of the literature, we find mainly the model equivalent to four parameters based on the mathematical modeling of the curve voltage [1], [3].

The model with four parameters utilizes four parameters, namely: I_{ph} (the photo current), I_0 (the saturation current), γ (the factor of the diode ideality) and R_s (resistance series). These parameters are not generally measurable quantities or included in the data of manufacture. Consequently, they must be given starting from anequations system of governing the characteristic IV at various points of operation given by the manufacturer or drawn from the experimental tests.

An extension of the model of only one diode, including an additional resistance shuntR_{sh} is proposed by many authors [7]. While adding resistance shunt, the number of parameters is changed to five.

The performances of the solar cells are normally evaluated under the standard test condition (STC), where an average solar spectrum with 1,5 AM is used and illumination is standardized with 1000W/m^2.As it is shown in Fig.1, the model with only one exponential with a parallel resistance R_{sh} described by (1) is nonlinear and implicit; therefore, a solution will be determined by iterative methods (Newton-Raphson, Levenberg Marquardt,…etc). In our work, the method of Newton-Raphson was used numerically.

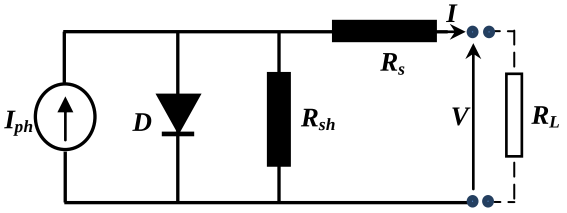

Fig. 1.Circuit equivalent of the five parameters model

The relation current-tension in the conditions (T=25°C, E=1000 W/m^2) for the equivalent circuit, fig. 1 is expressed in (1).

$$I=I_{ph}-I_0\left[\exp\left(\frac{q(V+IR_s)}{\gamma kT}\right)-1\right]-\frac{V+IR_s}{R_{sh}}\quad(1)$$

Where q the electronic load, K the Boltzmann constant, T the temperature, γ is the ideality factor, I_{ph} the power source, I_0 the reverse current of saturation of the diode, R_s resistance series and R_{sh} resistance shunt.

II. FIVE PARAMETERS MODEL

The five parameters appearing in (1) corresponding to the conditions standards are:γ, I_o, I_{ph}, R_s, and R_{sh}. These parameters are with starting from the measurement of characteristic I-V for a couple of illumination and reference temperature given to only on nominal database provided by the manufacturer. In general, these five parameters depend on the incidental solar radiation on the cell and on the temperature [8].

Three pairs of parameters of the characteristic voltage are normally provided by the manufacturer (2) to (4): the shortcircuit current I_{sc}, the open circuit voltageV_{oc} and the current and the tension at the maximum powerpoint (i. e., I_{mp}, V_{mp}), respectively. Fourth information results from the assumption that the derivation of the power at the maximum power point is null.

- ***Short-circuit Current***:

$$\mathrm{I_{sc}} = \mathrm{I_{ph}} - \mathrm{I_0}\left[\exp\left(\frac{\mathrm{qR_sI_{sc}}}{\gamma\mathrm{kT}}\right) - 1\right] - \left(\frac{\mathrm{R_sI_{sc}}}{\mathrm{R_{sh}}}\right)(2)$$

- ***Open circuitvoltage***:

$$0 = \mathrm{I_{ph}} - \mathrm{I_0}\left[\exp\left(\frac{\mathrm{qV_{oc}}}{\gamma\mathrm{kT}}\right) - 1\right] - \left(\frac{\mathrm{V_{oc}}}{\mathrm{R_{sh}}}\right)(3)$$

- ***Maximum power point:***

$$\mathrm{I_p} = \mathrm{I_{ph}} - \mathrm{I_0}\left[\exp\left(\frac{\mathrm{q}\left(\mathrm{V_p}+\mathrm{R_sI_p}\right)}{\gamma\mathrm{kT}}\right) - 1\right] - \left(\frac{\mathrm{V_p}+\mathrm{R_sI_p}}{\mathrm{R_{sh}}}\right)(4)$$

We obtain the values of four unknown factorI_{ph}, I_0, $R_{sh}$and $R_s$starting from the system of equations as (5), [11]. However, in [11] the ideality factor supposed as a constant parameter.

$$\begin{bmatrix} 0 \\ I_{sc} \\ I_p \end{bmatrix} / \begin{bmatrix} 1 & -\mathrm{C} & -\mathrm{V_{oc}} \\ 1 & -\mathrm{B} & -\mathrm{R_sI_{sc}} \\ 1 & -\mathrm{A} & -\mathrm{V_p} - \mathrm{R_sI_p} \end{bmatrix} = \begin{bmatrix} \mathrm{I_{ph}} \\ \mathrm{I_0} \\ 1 / \mathrm{R_{sh}} \end{bmatrix}(5)$$

Contrary to the various authors who treated the ideality factor as a constant parameter [9], [10] and [11], we vary with a step of 10^{-4}, the ideality factor γ between 0.0 and 4 for each iteration in order to choose the value of γ which gives a minimal relative error of the maximum power point.
Where:

$$\mathrm{A} = \exp\left(\frac{\mathrm{q}\left(\mathrm{V_p}+\mathrm{R_sI_p}\right)}{\gamma\mathrm{kT}}\right) - 1(6)$$

$$\mathrm{B} = \exp\left(\frac{\mathrm{qR_sI_{sc}}}{\gamma\mathrm{kT}}\right) - 1(7)$$

$$\mathrm{C} = \exp\left(\frac{\mathrm{qV_{oc}}}{\gamma\mathrm{kT}}\right) - 1(8)$$

$$\mathrm{I_{ph}} = \det{}^{-1}\left(\mathrm{V_{oc}I_{sc}A} - \mathrm{V_{oc}I_pB} - \mathrm{V_pI_{sc}C}\right)(9)$$

$$\mathrm{I_{sc}} = \det{}^{-1}\left(\mathrm{V_{oc}I_{sc}} - \mathrm{V_{oc}I_p} - \mathrm{V_pI_{sc}}\right)(10)$$

$$\mathrm{R_{sh}}^{-1} = \det{}^{-1}\left[\mathrm{I_{sc}A} - \mathrm{I_pB} - \left(\mathrm{I_{sc}} - \mathrm{I_p}\right)\mathrm{C}\right](11)$$

The calculation of *det* is shown in (12):

$$\det = \left(\mathrm{V_{oc}} - \mathrm{R_sI_{sc}}\right)\mathrm{A} + \left(-\mathrm{V_{oc}} + \mathrm{V_p} + \mathrm{R_sI_p}\right)\mathrm{B} + \left(-\mathrm{V_p} + \mathrm{R_s}\left[\mathrm{I_{sc}} - \mathrm{I_p}\right]\right)\mathrm{C}(12)$$

The derivative of the power at the point of maximum power is null:

$$\left.\frac{\mathrm{d(IV)}}{\mathrm{dV}}\right|_{\mathrm{p}} = \mathrm{I_p} - \mathrm{V_p}\left.\frac{\mathrm{dI}}{\mathrm{dV}}\right|_{\mathrm{p}} = 0(13)$$

With$\mathrm{dI/dV}|_{\mathrm{p}}$ is given by the following relation:

$$\left.\frac{\mathrm{dI}}{\mathrm{dV}}\right|_{\mathrm{p}} = \left\{\frac{-\mathrm{qI_0}}{\gamma\mathrm{kT}}\exp\frac{\mathrm{q}\left(\mathrm{V_p}+\mathrm{I_pR_s}\right)}{\gamma\mathrm{kT}} - \frac{1}{\mathrm{R_{sh}}} / 1 + \frac{\mathrm{qI_0R_s}}{\gamma\mathrm{kT}}\exp\frac{\mathrm{q}\left(\mathrm{V_p}+\mathrm{I_pR_s}\right)}{\gamma\mathrm{kT}} + \frac{\mathrm{R_s}}{\mathrm{R_{sh}}}\right\}(14)$$

The derivative of (1) compared to the voltage can be expressed by:

$$\frac{\mathrm{dI}}{\mathrm{dV}} = -\left\{\mathrm{R_s} + \left(\frac{\mathrm{qI_0}}{\gamma\mathrm{kT}}\exp\frac{\mathrm{q(V+R_sI)}}{\gamma\mathrm{kT}} + \frac{1}{\mathrm{R_{sh}}}\right)^{-1}\right\}^{-1}(15)$$

We introduce (13) in (15), then we define a function f_{Rs} given by:

$$f_{R_s} = I_p - (V_p - R_s I_p)\left(\frac{qI_0}{\gamma kT}\exp\frac{q(V_p + R_s I_p)}{\gamma kT} + \frac{1}{R_{sh}}\right) (16)$$

As I_0 and R_{sh} depend on R_s, the functionf_{Rs} is also. The resolution of $f_{Rs}=0$ with the algorithm of Newton-Raphson implies the calculation of its derivative; that is to say:

$$\frac{df_{R_s}}{dR_s} = -\frac{V_T I_p I_{sc}(V_p - R_s I_p)(A - B)}{det} + \frac{1}{R_{sh}}\left[I_M + \left(\frac{V_p - R_s I_p}{det}\right)\frac{d_{det}}{dR_s}\right] + V_T I_0 \exp\frac{q(V_p + R_s I_p)}{\gamma kT} \ldots$$

$$\left[I_M\left(1 - \frac{q(V_p - R_s I_p)}{\gamma kT}\right) + \left(\frac{V_p - R_s I_p}{\gamma kT}\right)\frac{d_{det}}{dR_s}\right] (17)$$

With:

$$\frac{d_{det}}{dR_s} = (V_T I_p (V_{oc} - R_s I_{sc}) - I_{sc})A + (V_T I_{sc}(-V_{oc} + V_p + R_s I_p) + I_p)B + (I_{sc} - I_p)C + V_T \ldots$$

$$\left(V_p I_{sc} - V_{oc}(I_{sc} - I_p)\right) (18)$$

$$V_T = \frac{q}{\gamma kT} (19)$$

III. RESULTS AND DISCUSSIONS

The precision of process of modeling described in this document is validated by the parameters of datasheet of selected photovoltaic modules.Three modules of different technologies are used for the checking; the multi and the single-crystal one like that of thin films type. The characteristics of the modules are summarized in Tab. 1.

TABLE 1. CHARACTERISTICS OF VARIOUS MODULES STUDIED UNDER STC

	BP solar MSX-60	**Siemens SM55**	**Shell S36**	**Shell SP-70**	**Shell ST40**
		multi-crystalline		**mono-crystalline**	**couche mince**
I_{sc} (A)	3.8	3.45	2.3	4.7	2.68
V_{oc} (V)	21.1	21.7	21.4	21.4	21.3
I_p (A)	3.5	3.15	2.18	4.25	2.41
V_p (V)	17.1	17.4	16.5	16.5	16.6

We measured the curves voltage and power-voltage of the photovoltaic module for various weather conditions (solar illumination and temperature) and we calculated the statistical parameters in order to estimate the validity of the model used. Tab. 2 shows calculated parameters for the five parameters model.

Fig. 2, show the characteristics power-voltage and current-voltage comparison, respectively, of the five parameters model and the experimental points extracted from the datasheet for the Solarex MSX60 module at various operating temperatures.

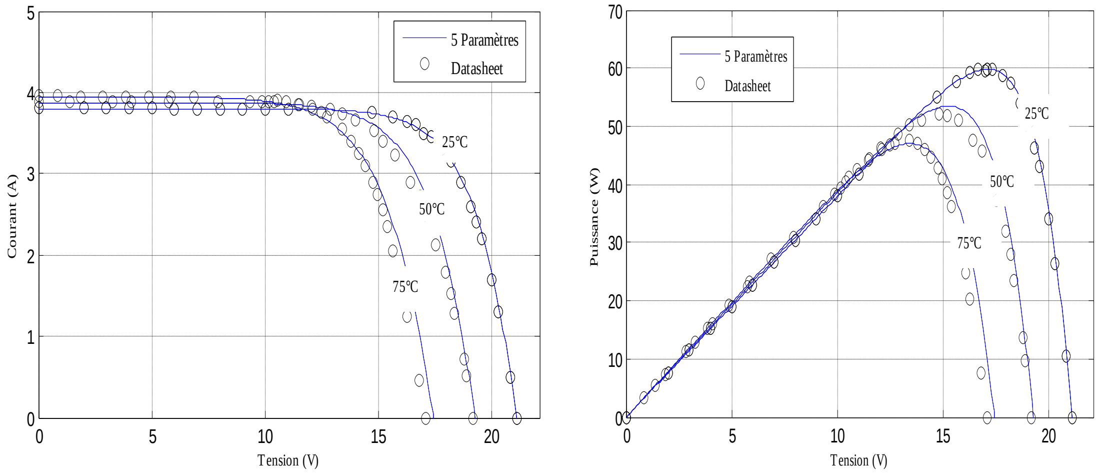

Fig. 2.CurvesI-V and P-V of SOLAREX MSX60 Module in Fixeillumination 1KW/m$^{2.}$

Fig. 3, show the characteristics power-voltage and current-voltage comparison, respectively, of the five parameters model and the experimental points extracted from the datasheet for photovoltaic cell Q6LM at various levels of illuminations.

TABLE 2. ELECTRIC PARAMETERS OF THE MODEL PROPOSES

	BP solar MSX-60	**Siemens SM55**	**Shell S36**	**Shell SP-70**	**Shell ST40**
		multi-crystalline		**mono-crystalline**	**couche mince**
γ	1.5	1.7	1.2588	1.7	2.097
I_{ph} (A)	3.8003	3.4503	2.30023	4.7003	2.6804
I_0 (A)	9.4607e-7	3.5065e-6	2.40919e-8	5.7971e-6	1.6315e-5
R_s (mΩ)	0.0034	0.0036	0.01831	0.0078	0.0257
R_{sh}(mΩ)	43.0744	43.7167	179.783	110.6362	215.3892

We observe on Figs 2 to 3 that the two curves appear identical to the points of standard condition of reference. On the other hand, more the temperature and illumination are far away from the standard conditions of reference, more there are divergences in the elbow of the curves and at the point of open circuit voltage.

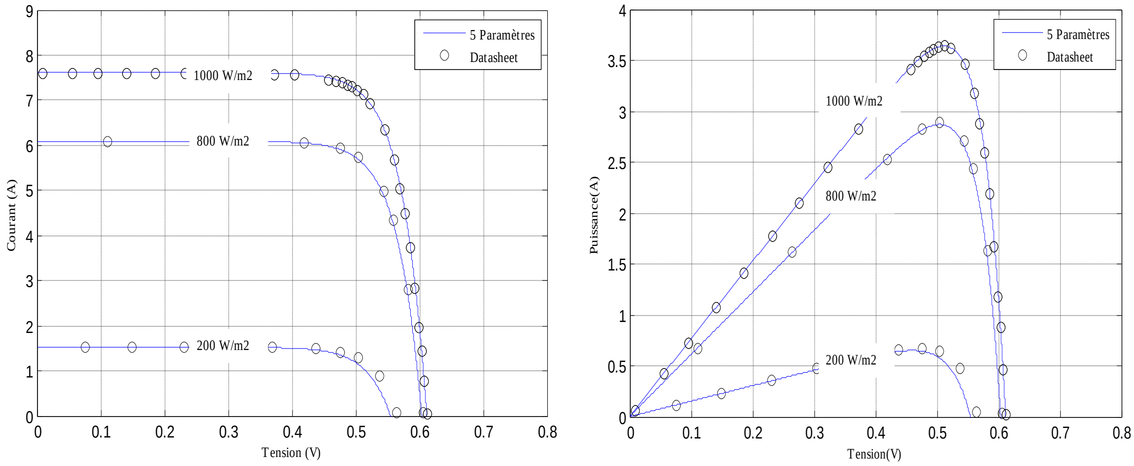

Fig. 3.Curve P-V of Q6LM Cell in Fixe Temperature 25°C

The differences between the data of the datasheet and the computed values occur because of the limitations in the model of the cells themselves, as well as in the calculating methods [12]. Moreover, there are uncertainties inherent in the experimental data. The experimental data points are extracted from datasheet and from [2] and [14].

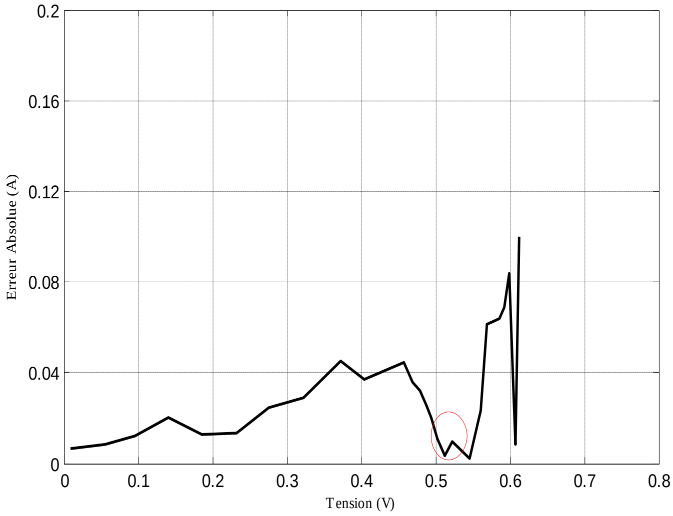

Fig4.. Absolute error For Q6LM Cell in 25 °C, 1000 W/m^2

To show the effectiveness of the studied models, the photovoltaic modules: Shell S36, Shell SP70 and Shell ST40 are used of which Tab. 3 to 5 show the relative errors on the maximum power point for different temperature (0°C to 50°C). Figs 4 and 5 show successively the absolute error of the current according to the tension for the Solarex MSX60 module and Q6LM cell.

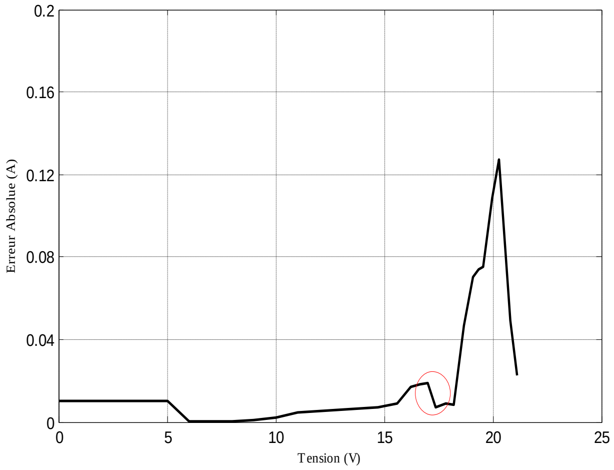

Fig5..Absolute error For the Solarex MSX60 Module in25 °C, 1000 W/m^2

This calculation considers the standard conditions, illumination and temperature STC (25°C, 1000W/m^2). The model with five parameters gives incorrect results in the vicinity of the open circuit voltage. It must be provided that our model does not take account of the coefficient of open circuit voltage [1].The circle represents the zone where normally the point of the maximum power of module. It is observed that this zone represents an absolute error which can be considered negligible (<0.02). Lastly, our model gives a good agreement with the data of datasheet.

Table 3.Relative Errors of Multi-Crystalline Silicon (Shell S36)

Temperature	Cinq Paramètres	Datasheet	Erreur -Relative(%)
0° C	39.5228	40.05	1.3164
25° C	36.0317	36	0.0882
50° C	32.3981	31.95	1.4026

Table 4.Relative Errors of Mono-Crystalline Silicon (Shell Sp70)

Temperature	FiveParameters	Datasheet	Erreur-Relative(%)
0° C	75.1311	77.88	3.5297
25° C	70.0067	70	0.0096
50° C	64.1841	62.13	3.3062

Table 5.Relative Errors of Thin-Film (Shell St40)

Temperature	Five parameters	Datasheet	Erreur -Relative(%)
0° C	44.4188	46.00	3.4374
25° C	40.0369	40.00	0.0923
50° C	35.6734	34.00	4.9216

IV. CONCLUSION

In this article, a general approach on the photovoltaic modules modeling is presented. The five parameters model uses abundant data only by the manufacturer. The chosen points for the determination of the parameters are the short-circuit current I_{sc}, the open circuit voltageV_{oc}, and the maximum power point (V_p, I_P). The model requires a calculation of these parameters (γ, I_0, I_{ph}, R_s, and R_{sh}) at the reference conditions STC (25°C, 1000 W/m^2). These values are then used in the model to calculate the parameters with real conditions. Three types of photovoltaic modules were modeled and evaluated (CIS, multi-crystalline silicon, and mono-crystalline silicon). We vary the ideality factor γ between 0.0 and 4 with a step of 10^{-4}, for each iteration in order to choose the value of γ which gives a minimal relative error of the maximum power point. The precision of the model is also analyzed by the comparison between the data of the product and the results of simulation. Lastly, our model gives a good agreement with the data of datasheet.

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