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New Method to Assess the Losses Parameters of the Photovoltaic Modules

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Abstract*— *The determination of an effective method able to estimate the parameters of a photovoltaic panel is essential for the development and the performance of analysis of such equipment. In this paper, we present a new simple and effective method in order to extract the parameters of the photovoltaic modules by using the standard diode model. This model requires that the five parameters be known, the photocurrent Iph, the reverse saturation current Is, the resistance Rs, the shunt resistance Rsh and the curve fitting parameter A (the ideality factor) or the thermal voltage a. For that we formulated an equation binding only the two losses parameters Rs and Rsh. In order to solve this equation and to determine the shunt resistance and the thermal voltage, we expose the computation models of the series resistance Rs, which give excellent approximations. While the other parameters Iph and Is depend exclusively on the parameters Rs, Rsh, a and the short circuit current Isc and the open circuit voltage Voc. This method is validated experimentally by three different flat plat PV modules of various technologies (Monocrystalline, polycrystalline and thin film panels) and manufacturers.

Keyword:* *photovoltaic modelling; single diode model; parameters of the model; curves fitting.

I. INTRODUCTION

An accurate knowledge of the photovoltaic module parameters is essential for the design, quality control of solar modules and for the estimates of their performance. These parameters are often determined an experimental data under a given illumination and a temperature. Several methods for the determination of Rs, Rsh, Iph, Is and A are proposed by several authors. Some of the methods involve measurement of illuminated I-V characteristics at single or different levels of illumination [1-6]. Some one use the dark conditions [7, 8, 9, 10, 11], while other utilizes dark and illumination measurements. A review of techniques to determine the ideality factor and or the series resistance of solar cells has been given by Mialhe et al. [13] and Bashahu et al. [14, 15]. This paper addresses one of the important issues related to the photovoltaic systems namely the parameter extraction of five parameter single-diode model of photovoltaic modules based on few data available in manufacturers datasheets, i.e., Voc, Isc and the maximum power voltage Vm and the current Im. The adequate solution of this problem has several advantages for all researchers in the field.

This approach is a low cost and fast parameter identification technique and can be used in real time applications as well.

The values of PV model parameters are essential in the design, simulation and sizing of PV generators including power electronics converters and different control loops. The proposed technique can also be used for the diagnostic purposes to make an estimation of the healthy or faulty operation of the PV modules.

II. THE SINGLE DIODE MODEL

An assessment of the operation of PV modules and the design of power systems is based on the electrical characteristic, ie, the voltage – current relationships of the modules under various levels radiation and at various cell temperatures. Modelling of PV cells and modules can be carried out by means of equations that provide different degrees of approximation to the real device. In this paper the one exponential model for PN junction has been chosen. FIG. 1 shows the equivalent circuit. This circuit requires that five parameters be known: the light current Iph, the diode reverse saturation current Is , the series resistance Rs models the losses by Joule effect, which is due to a series of resistances caused by the semiconductor material resistance, the contact resistances of the electrodes and by the resistance of the collecting grid and the current collected by the bus, its value directly reflects the quality of manufacture of the solar cells and a shunt resistance Rsh is due to a leakage current on the level of the junction caused by structural defects and leakage at the edge of the cell, and a is the curve fitting parameter (thermal voltage).

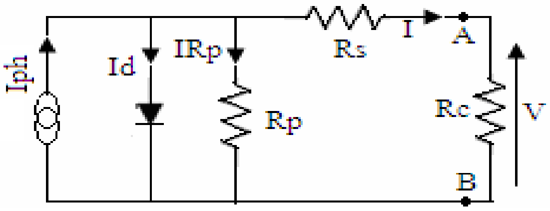

FIG.1. Equivalent circuit of the standard diode model

The equation that describes its behaviour at a fixed temperature and solar radiation is [1 to 18]:

$$I = Iph - Is\left(\exp\left(\frac{V+RsI}{a}\right)-1\right)-\frac{V+RsI}{Rsh} \qquad (1)$$

For a given irradiance and temperature, equation (1) supports different combinations of a, Rs and Rsh whose I-V curves pass in the vicinity the same points of Isc, Im, Vm and Voc. Taken separately, these values of a, Rs and Rsh are not relevant. What really makes them significant is the relationship formed by the three parameters.

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The provided power is given by:

$$P = VI \tag{2}$$

Where:

q: the elementary electric charge 1.607 10^{-19} C
A: ideality coefficient of the cell depends on material.
K: Boltzmann constant = 1.380 10^{-23} J/K
T: is the temperature in Kelvin degree
Rs: Séries résistance (Ω).
Rsh: shunt résistance (Ω).

The thermal voltage is expressed by:

$$a = \frac{NsKT}{q} A \tag{3}$$

Ns is the number of cells connected in series.

By applying the short circuit conditions to equation (1), Iph can be obtained as:

$$Iph = Isc\left(1 + \frac{Rs}{Rsh}\right) + Is\left(\exp\left(\frac{IscRs}{a}\right) - 1\right) \tag{4}$$

In the same way, the open circuit conditions lead to an equation for Iph:

$$Iph = Is\left(\exp\left(\frac{IscRs}{a}\right) - 1\right) + \frac{Voc}{Rsh} \tag{5}$$

Most times Iph is simplified by:

$$Iph \cong Isc\left(1 + \frac{Rs}{Rsh}\right) \tag{6}$$

Substituting equation (4) in (5), lead to an equation for Is:

$$Is = \frac{Isc\left(1 + \frac{Rs}{Rsh}\right) - \frac{Voc}{Rsh}}{\exp\left(\frac{Voc}{a}\right) - \exp\left(\frac{IscRs}{a}\right)} \tag{7}$$

Since, exp (Voc) >> exp (Isc Rs), this equation (7) is simplified to:

$$Is = \left(Isc - \frac{Voc}{Rsh}\right)\exp\left(-\frac{Voc}{a}\right) \tag{8}$$

Isc and Voc present respectively the short circuit current and the open circuit voltage.

III. THEORETICAL ANALYSIS

The effects of the loss resistances on the I-V characteristic have been extensively studied in several works [1 to 8]. Although in different ways, both resistances contribute to the degradation of the I-V curve. In general the current derived by the shunt resistance is very important in that the part of the I-V curve that runs from short circuit (Isc) to the vicinity of the maximum power point (Im). To the contrary, the voltage drop due to series resistance is greater at the voltages between the open circuit (Voc) and the maximum power (Pmax). In line with these observations, the point of maximum power lies in the transitional zone where there are higher effects of both resistances.

FiG. 2 shows the I-V curves for the Polycrystalline PV module MSX110 at STC, depending on the values that their losses resistances take on. The outer curve (A) is in case there is an Rs null, Rsh infinite and ideality factor equal to1 (ideal PV module). The innermost (C) is similar to that specified by the manufacturer, as it passes through the maximum power point given by them. It has been obtained by fitting the values of Rs and Rsh that appear in Table II. Each of the intermediate curves has fitted to the values (B has R=0.7Ω, Rsh = ∞ Ω□□ and D has Rs= 0.6Ω, Rsh= 290.66Ω□and E has Rs= 0.85Ω, Rsh= 290.66Ω and F has Rs=0.7Ω, Rsh=220Ω).

FiG. 2 shows that series resistance controls the position of the maximum power point; otherwise, it supervises the current and the voltage in this point. If the Rs value increases, the voltage at the maximal power point falls enormously and the maximum power point moves on the left (curve E), in the contrary case, the voltage decreases considerably and the maximum power point moves on the right (curve D), while the maximum power current changes lightly. The resistance Rs acts on the slope to which the photovoltaic module (cell) behaves like a voltage generator. As well as the value of Rs has an effect marked on characteristic I-V in the vicinity of the open circuit voltage Voc (see FiG.3). Note that series resistance does not affect the values of the current of short circuit Isc or the tension of open circuit Voc.

The shunt resistance controls the slope of characteristic IV in the conditions of the open circuit. In other words, Rsh acts on the slope with the photovoltaic module works as the generator of current. If the value of Rsh decreases, in this region the values of the current fall considerably (curve F). On the other hand if the value of Rsh is significant, the current of the maximum power increases widely (curve B).

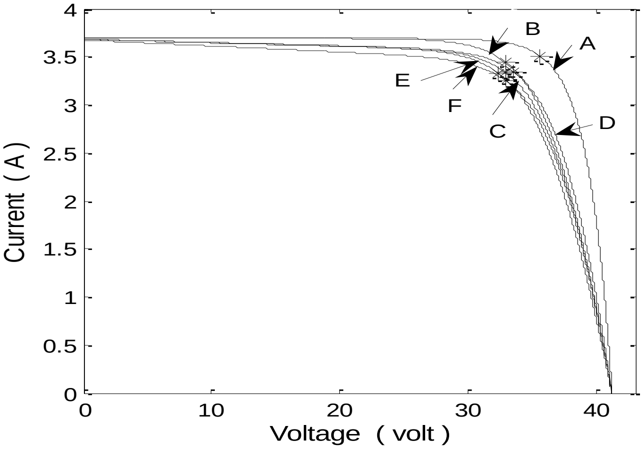

FIG.2. I-V curves plotted with different values of Rs, Rsh and a (MSX110).

The FIG.3 exposes the two characteristics IV of the two modules AP165 and BP570S at the STC theirs remarkable points Isc, Voc, Im and Vm are 7.40 A, 32V, 6.6A and 25 V for AP165 and 5 A, 44.2V, 4.72A and 36V for BP570S, traced by the resistive data of FiG.3 exposes the two characteristics I-V of the two modules AP165 and BP570S at the STC. Theirs remarkable points Isc, Voc, Im and Vm are respectively 7.40 A, 32V, 6.6A and 25 V for AP165 and 5 A, 44.2V, 4.72A and 36V for BP570S, traced by the resistive data of the two parameters Rs and Rsh and the thermal voltage a, published by C. Carrero, J. Rodriguez, D. Ramirez and C. Platero [12], extracted by their proposed method, the issued values of the losses resistance Rs and Rsh and the thermal voltage a (ideality factor A=1 for the both modules) of the module AP165 are 0.4676Ω, 61.8Ω and 0.9253V and for the module BP570S, 0.5840Ω, 1965Ω and 0.9253V.

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FIG.3 shows that the two characteristics pass by or in the vicinity of the point of the maximum power; the current Im and voltage Vm obtained by this method are 6.61A and 24.96V for the AP165 and 4.72A and 36V for BP570S. But these two curves have irregular form in the vicinity of Voc; this proves that the two obtained values of Rs resistance are not the suitable values. While the FIG.4 displays the curves of the two modules plotted by using the extracted parameters by the method that we propose later, the obtained current Im and voltage Vm are, AP165; 6.60A, 25V and BP570S; 4.72A and 36V, the extracted values of the series resistance Rs and the shunt resistance Rsh and the thermal voltage a are, 0.2969Ω, 103.7344Ω, 1.9514V, 0.5225Ω, Rp= ∞ Ω and 1.9893V of the both modules AP165 and BP570S respectively. The difference between the two methods is clear by watching the two figures.

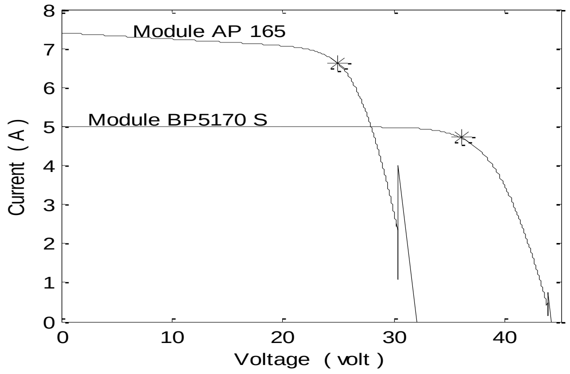

FIG.3. I-V curves evaluated by the issued values of Rs, Rsh and a.

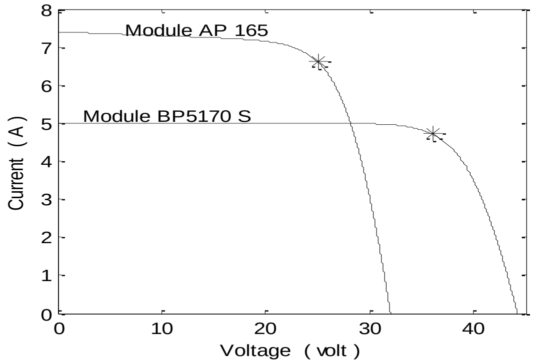

FIG.4. I-V curves evaluated by the calculated values of Rs, Rsh and a, (proposed method).

The purpose of the analysis which has been done is to assess the effect of the loss resistances on the maximum power point (voltage and current). With the help of the model and the equations of Section 4 and 5, expressions for the current and voltage of maximum power will be sought where only data available in advance (Isc, Vm, Im, Voc) and the loss resistances take part. Also, throughout the study it will be assumed that the series resistance Rs depends on the values that take Isc and Voc (section 5).

At the maximum power point the following condition is met:

$$\frac{\partial P}{\partial I}=\frac{\partial}{\partial I}(I.V)=V+I\frac{\partial V}{\partial I}=0\Rightarrow\frac{\partial V}{\partial I}=-\frac{V}{I}\qquad(9)$$

On the other hand, on deriving I with respect to V in the equation (1), it is obtained:

$$\frac{\partial I}{\partial V}=-\frac{1+\frac{IsRs}{a}\exp\left(\frac{V+RsI}{a}\right)+\frac{Rs}{Rsh}}{\frac{Is}{a}\exp\left(\frac{V+RsI}{a}\right)+\frac{1}{Rsh}}\qquad(10)$$

The term in numerator Rs/Rsh and 1/Rsh in the denominator of Eq. (10) can be neglected with respect to the first terms, we get:

$$\frac{\partial I}{\partial V}=-\frac{\left[1+\frac{IsRs}{a}\exp\left(\frac{V+RsI}{a}\right)\right]}{\frac{Is}{a}\exp\left(\frac{V+RsI}{a}\right)}\qquad(11)$$

Arranging equation (11):

$$\frac{\partial V}{\partial I}=-\frac{a+IsRs\exp\left(\frac{V+RsI}{a}\right)}{Is\exp\left(\frac{V+RsI}{a}\right)}\qquad(12)$$

Comparing equations (9) and (12) at maximum power point, gives:

$$Vm=\mathrm{Im}\frac{a+IsRs\exp\left(\frac{Vm+Rs\,\mathrm{Im}}{a}\right)}{Is\exp\left(\frac{Vm+Rs\,\mathrm{Im}}{a}\right)}\qquad(13)$$

Nevertheless, due to the presence exponential term in the voltage form can be deduced from the equation (1) assessed at the maximum power:

$$Is\exp\left(\frac{Vm+Rs\,\mathrm{Im}}{a}\right)=Iph-\mathrm{Im}-\frac{Vm+Rs\,\mathrm{Im}}{Rsh}\qquad(14)$$

The equation (13) takes the following form:

$$Vm=\mathrm{Im}\frac{a+Rs\left(Iph-\mathrm{Im}-\frac{Vm+Rs\,\mathrm{Im}}{Rsh}\right)}{\left(Iph-\mathrm{Im}-\frac{Vm+Rs\,\mathrm{Im}}{Rsh}\right)}\qquad(15)$$

IV. EQUATION BINDING THE RESISTIVE PARAMETERS

The voltage at the maximum power point deduced from the implicit diode model Eq. (1) is given by:

$$Vm=a\log\left(\frac{Iph-\mathrm{Im}-\left[\frac{Vm+Rs\,\mathrm{Im}}{Rsh}\right]}{Is}\right)\qquad(16)$$

Substituting equation (6) and (8) in (16), we get:

$$Vm=Voc-Rs\,\mathrm{Im}+a\log\left(\frac{Isc-\mathrm{Im}-\frac{Vm+Rs(\mathrm{Im}-Isc)}{Rsh}}{Isc-\frac{Vco}{Rsh}}\right)\qquad(17)$$

The term Voc/Rsh can be neglected in front of Isc, we obtain:

$$Vm=Voc-Rs\,\mathrm{Im}+a\log\left(\frac{Isc-\mathrm{Im}-\frac{Vm+Rs(\mathrm{Im}-Isc)}{Rsh}}{Isc}\right)\qquad(18)$$

The thermal voltage extracted from the Eq. (15) is:

$$a=\frac{\left(Iph-\mathrm{Im}-\dfrac{Vm+Rs(Isc-\mathrm{Im})}{Rsh}\right)(Vm-Rs\,\mathrm{Im})}{\mathrm{Im}} \qquad (19)$$

Substituting (19) in (18), one can obtain:

$$Vm=Voc-Rs\,\mathrm{Im}+\frac{\left(Iph-\mathrm{Im}-\dfrac{Vm+Rs(Isc-\mathrm{Im})}{Rsh}\right)(Vm-Rs\,\mathrm{Im})}{\mathrm{Im}}$$

$$\times\log\left(\frac{1}{Isc}\left[Isc-\mathrm{Im}-\frac{Vm+Rs(\mathrm{Im}-Isc)}{Rsh}\right]\right) \qquad (20)$$

Rearranging this equation:

$$\mathrm{Im}\left(\frac{Vm-Voc+Rs\,\mathrm{Im}}{(Vm-Rs\,\mathrm{Im})}\right)=\left(Iph-\mathrm{Im}-\frac{Vm+Rs(Isc-\mathrm{Im})}{Rsh}\right)$$

$$\times\log\left(\frac{1}{Isc}\left[Isc-\mathrm{Im}-\frac{Vm+Rs(\mathrm{Im}-Isc)}{Rsh}\right]\right) \qquad (21)$$

Let us pose:

$$X=Isc-\mathrm{Im}-\frac{Vm+Rs(\mathrm{Im}-Isc)}{Rsh} \qquad (22)$$

$$Y=\mathrm{Im}\left[\frac{Vm-Voc+Rs\,\mathrm{Im}}{(Vm-Rs\,\mathrm{Im})}\right] \qquad (23)$$

We lead to an outstanding equation connecting only the two parameters Rs and Rsh.

$$X\log\frac{X}{Isc}-Y=0 \qquad (24)$$

This equation gathers the main parameter Rs, Rsh and a of the one diode model. Its solution requires only the data appears in the catalogue of modules (Isc, Im, Voc and Vm) at standard test condition (STC), or those obtained under other conditions or through testing and the series resistance value. The resolution of this equation can be solved using tools, like Matematica and Matlab. The solution of this equation imposes that X is always positive, which is obvious from where X< Isc-Im; our choice is related to the measurement of the series resistance Rs, which plays a role striking in the diode model and which has an outstanding effect on characteristic I-V.

V. DETERMINING THE SERIES RESISTANCE RS

In order to obtain the five parameters by using the Eq (24), it's necessary to know the value of the fundamental losses parameter Rs (Eq. (23)).

A method to obtain a good estimate of Rs was proposed by Gow and Manning [18], consists in differentiating the diode model, by evaluating it in the vicinity of the open circuit and by rearranging it in terms of Rs.

Like application to this method, we developed an explicit model deduced of the model developed by Borowy and Salameh (1996) [19], which depends only on the four specified data Isc, Im, Vm and Voc and of two constants C and b. In the aim of having better an approximation of the maximum power point on the characteristic I-V and in order to the part of the curve between the maximum power point and open circuit point given by this model is confused to the curve given by the diode model especially in the vicinity of Voc, in order to deduce the compute expression of the series resistance Rs.

*A. **Explicit Model***

Borowy and Salameh Explicit Model:

$$I=Isc\left(1-C1\left(\exp\left(\frac{V}{C2Voc}\right)-1\right)\right) \qquad (25)$$

Where:

$$C1=(1-\frac{\mathrm{Im}}{Icc})\exp(-\frac{Vm}{C2Voc}) \qquad C2=\frac{\dfrac{Vm}{Voc}-1}{\log\left(1-\dfrac{\mathrm{Im}}{Icc}\right)} \qquad (26)$$

The equation of the developed explicit model is:

$$I=Isc\left(1-\exp\left(-\frac{1}{C}\right)\left(\exp\left(V\left[\frac{1}{CVoc}+\frac{C^b}{Vm}\right]\right)-1\right)\right) \qquad (27)$$

The parameters C [19] and b are expressed by:

$$C=C2 \qquad b=\left(-1.2+\frac{Voc}{Vm}+\frac{Isc}{\mathrm{Im}}\right) \qquad (28)$$

Fig. 5 displays the fitted curve and the curve of the proposed explicit model of the two PV modules MSX110 and NA-F135, the parts of the two curves between the open circuit (Voc) and the maximum power are practically confused in the vicinity of Voc.

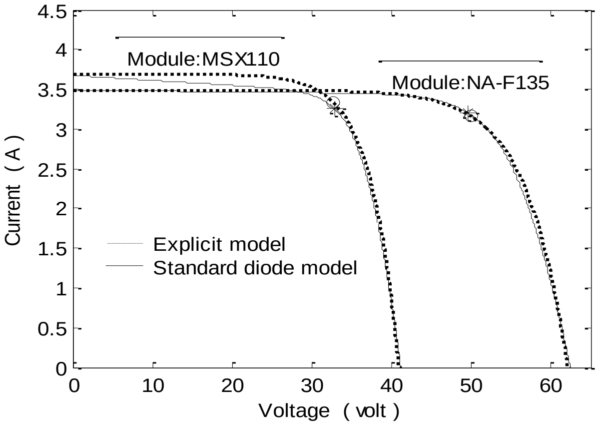

FIG.5. Simulated I-V curves

In the vicinity of Voc the derivative dI/dV of the developed explicit model is equal to:

$$\frac{dI}{dV}\Big|_{V\approx Vco}=-Icc\left(\frac{1}{CVoc}+\frac{C^b}{Vm}\right)\exp\left(\left[\frac{VocC^b}{Vm}\right]\right) \qquad (29)$$

The inverse proportion of dI/dV has the dimension of a resistance; its expression is given by:

$$Rso=-\frac{CVocVm\exp\left(-\left[\dfrac{VocC^b}{Vm}\right]\right)}{\left(C^{b+1}Voc+Vm\right)Isc} \qquad (30)$$

B. Determining the series resistance Rs

The series resistance Rs of Eq. (1) is correlative to the resistance Rso given at Eq. (30):

$$Rs=CoRso \qquad (31)$$

The parameter Co also depends on Isc, Im, Voc and Vm, is given by the following expression:

$$Co=-\frac{bC^{b-1}(C^{b+1}Voc+Vm)}{(C^bVoc+Vm)}\exp\left(\left[\frac{VocC^b}{Vm}\right]\right) \qquad (32)$$

Substituting the relation of Co in the Rs equation; we obtain the equation to estimate the value of the series resistance Rs of a photovoltaic module.

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$$Rs=\frac{bC^{b}VocVm}{(C^{b}Voc+Vm)Isc} \qquad (33)$$

We obtain another equation extracted of the first Rs model and by simulation of characteristics I-V of the modules, which provides approximate Rs values in relation to the first expression given at Eq (34), this expression is as follows:

$$Rs=\frac{C^{\frac{Isc}{\mathrm{Im}}}VmVoc}{Isc\left(C^{\frac{Isc}{\mathrm{Im}}}Voc+Vm\right)} \qquad (34)$$

In the case or, Isc-Im-X<0, this result does not have a physical sense because Vm/Rsh is always positive, what leaves only one possibility that Rsh is infinite (high value), therefore the relation of Isc-Im-X tends towards zero. Consequently in this case the expression of the maximal voltage is rewritten:

$$Vm=Voc-Rs\,\mathrm{Im}+a\log\left(1-\frac{\mathrm{Im}}{Isc}\right) \qquad (35)$$

The voltage of the maximal power is still expressed by using the Equation of C:

$$Vm=Voc+CVoc\log\left(1-\frac{\mathrm{Im}}{Isc}\right) \qquad (36)$$

The thermal voltage is reduced to the following form (see Eq. (19)):

$$a=(Isc-\mathrm{Im})\left(\frac{Vm}{\mathrm{Im}}-Rs\right) \qquad (37)$$

Of its three equations or Rsh is supposed to be infinite, we draw the relation from Rs.

$$Rs=\frac{\left(Vm(Isc-\mathrm{Im})-C\,\mathrm{Im}\,Voc\right)\log(1-\frac{\mathrm{Im}}{Isc})}{\mathrm{Im}\left(\mathrm{Im}+(Isc-\mathrm{Im})\log(1-\frac{\mathrm{Im}}{Isc})\right)} \qquad (38)$$

The thermal voltage for which Rsh is infinite; its value is calculated by the Eq. (37) or by the following equations:

$$a=\frac{Rs\,\mathrm{Im}}{\log\left(1-\frac{\mathrm{Im}}{Isc}\right)}+CVoc \qquad (39)$$

V. APPLICATION METHOD OF THE MODELS

In the first, the resolution of the Eq (24) this fact by the calculation of the series resistance value by the model given to the Eq (33). If this solution fills up the condition imposed by X, then the shunt resistance is calculated by the following equation:

$$Rsh=\frac{Vm+Rs(\mathrm{Im}-Isc)}{Icc-\mathrm{Im}-X} \qquad (40)$$

The shunt resistance can be appreciating by following expression [12]:

$$Rsh=\frac{(Vm-a)(Vm-Rs\,\mathrm{Im})}{(Vm-Rs\,\mathrm{Im})(Icc-\mathrm{Im})-a\,\mathrm{Im}} \qquad (41)$$

If the first model of Rs provides a solution which does not achieve the condition Isc-Im-X>0, we use the second model of Rs model given to the equation (34). While Rsh and a are calculated by the two Eqs (40) and (19). If the Rs value provides by the two models (33) and (34) does not satisfy the condition Isc-Im-X>0, then Rsh is of very high value, we use the model of Rs given at the equation (38) and the value of the thermal voltage is appreciate by the Eq (37) or (39). Preferably we use the two models of Rs, after calculation of the other parameters; we take the value of the model, which provides a good approximation to the values of Im and Vm.

VI. EXPERIMENTAL VALIDATION OF THE MODELS AND THE METHOD

To evaluate the performance of the proposed model of series resistance estimation method and the rest of the parameters, a variety of experiments (35) including both numerical simulation and field tests with respect to PV modules, various irradiation intensities and temperatures were conducted in this work. The generated data were used to verify the performance of the proposed method.

Table I contains the catalogue data of the three flat plat PV modules available in laboratory used in this study. At all times it is assumed that their experimental I-V curves (STC) verify the specified points, also in the Table II lists the values of the losses resistances calculated of the models of the PV modules so that their I-V curves contain the given points using the values issued by the manufacturers at standard test conditions of irradiance and temperature (Table I). These parameters have been calculated using the proposed equations (24) and those of section 5.

The modules have been selected with the intention of making this study was as general as possible. To achieve this, they have been chosen so that their data and technology are very different. The chosen modules are; the Monocrystalline, Hareon model HR-185, Polycristalline, Solarex model MSX110, Sharp model NA-F135 and which have a maximum power of 185W ± 10%, 110W ± 5%, 158.9 ± 10% and 70± 10% at STC respectively.

TABLE I: Manufacturers data of the modules at STC

Electrical specification	No cells	Isc (A)	Voc (V)	Im (A)	Vm (V)
Monocrystalline PV module					
HR-185	72	5.41	45.05	5.08	36.42
Polycrystalline PV module					
MSX110	72	3.69	41.20	3.34	32.90
Thin film PV module					
NA-F135	180	3.49	62.50	3.20	49.70

By applying the procedure described in the previous paragraph, the parameters of the equivalent electrical circuit in Table II were obtained. The comparison between the calculated current and voltage of the maximum power by means of the extracted parameters Rs, Rsh and the thermal voltage a of Table II with those issued by the manufacturers at the standard test conditions of the panels, deferred in Table I shows an extremely weak difference.

TABLE II: Calculated parameters at STC

Modules	Im (A)	Vm (V)	Rs (Ω)	Rsh (Ω)	a (V)
HR-185	5.080	36.42	0.4846	infinity	2.2061
MSX110	3.339	32.91	0.7000	290.66	2.1736
NA-F135	3.200	49.71	1.0912	1020.50	3.4829

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The equations (19), (33), (37), (38) and (40) have been used to estimate Rs and Rsh and thermal voltage a of the modules from the experimental data collected in Table III, with the purpose of simulating its I-V curve. The test was conducted with an irradiance of 980 W/m^2 and a cells temperature of 48.8 ^{0}C, 50^{0}C and 47.6^{0}C of the three panels HR-185, MSX110 and NA-F135 respectively. Also the experiments for these field tests were conducted to two illumination levels of 400 and 250 W/m^2 and Also the experiments for these field tests were conducted to two illumination levels of 400 and 250 W/m^2 with two temperatures of cells of 45 and 50 ^{0}C for the module MSX110 and 200 W/m^2 with cells temperature of 25 ^{0}C for the module NA-F135.

The actual data of the test for short circuit, open circuit and the maximum power current Im and voltage Vm determined at different illumination levels and temperatures are reported in Table III. They were used to calculate the loss resistances and the thermal voltage a and the other parameters Iph and Is.

TABLE III: Experimental measurements of the specified point different irradiances level and temperatures

PV Panels	E W/m^2	T ºC	Isc (A)	Voc (V)	Im (A)	Vm (V)
HR-185	980	48.8	5.360	44.7790	4.9800	35.650
MSX110	980	50.0	3.660	37.8600	3.2800	29.550
	400	50.0	1.5080	37.2000	1.3483	28.910
	400	45.0	1.5000	37.7900	1.3442	29.520
	250	45.0	0.9260	36.4900	0.8290	28.320
NA-F135	980	47.6	3.4600	57.6300	3.1400	44.800
	200	25.0	0.7031	53.8000	0.6380	41.880

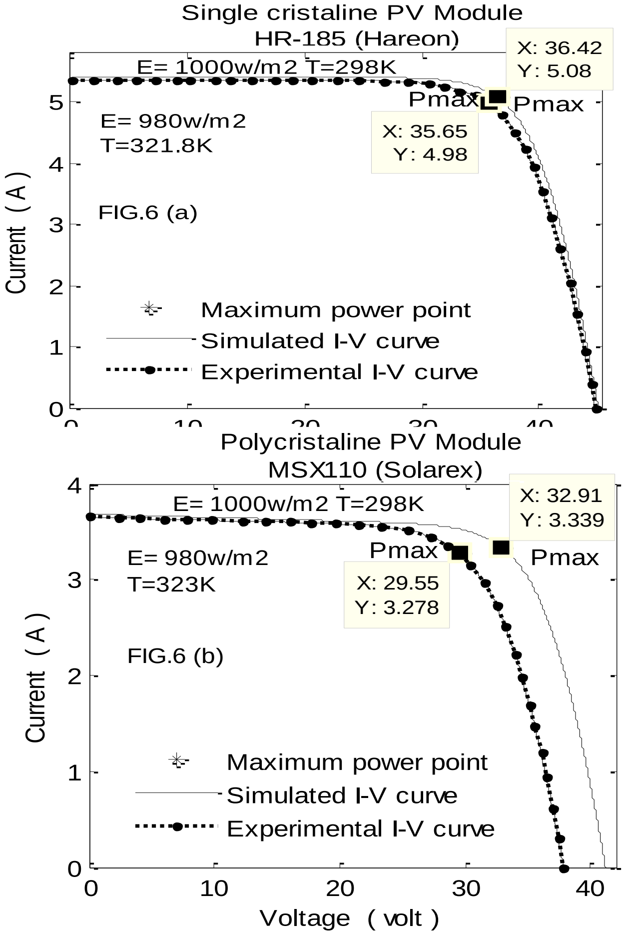
Table IV contains the extracted values of the losses resistances and the thermal voltage by using the experimental data gathered in Table III.

TABLE IV: Calculated parameters and the maximum power current and voltage at different irradiances level and temperatures

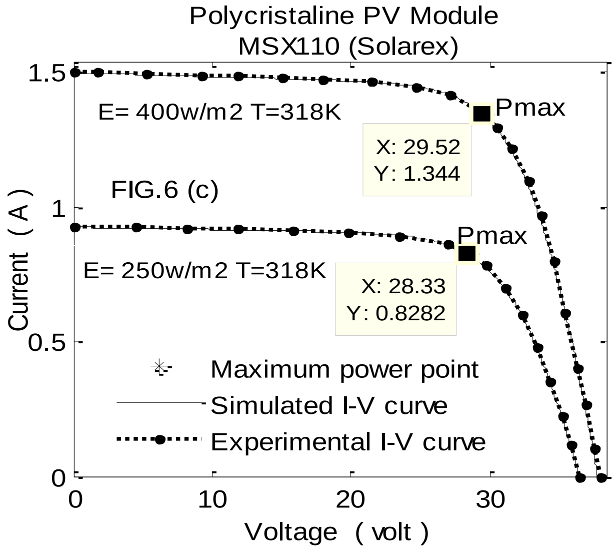
PV Panels	E W/m^2	T ºC	Im (A)	Vm (V)	Rs (Ω)	Rsh (Ω)	a (V)
HR-185	980	48.8	4.98	35.65	0.4855	infinity	2.5363
MSX110	980	50.0	3.278	29.55	0.7027	300.00	2.3522
	400	50.0	1.348	28.90	1.7016	728.21	2.3684
	400	45.0	1.344	29.52	1.7100	725.00	2.3289
	250	45.0	0.828	28.33	2.7700	1180.20	2.3231
NA-F135	980	47.6	3.140	44.81	1.1038	1060.00	3.7451
	200	25.0	0.638	41.87	5.0409	5369.20	3.4845

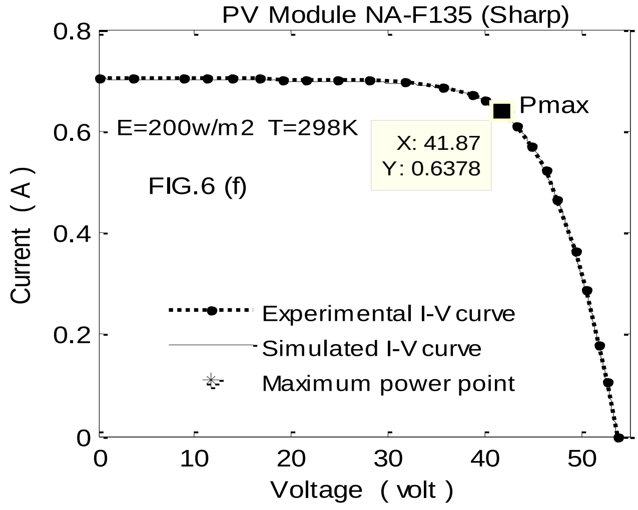
In figures 6 (a), (b), (c), (d), (e) and (f) display the current-voltage characteristic evaluated with the calculated parameters listed in Table II and IV are compared with the experimental characteristics. Where the experimental data were presented on the figures by the bold points and the dotted line, the simulated curves were obtained by the standard diode model with the help of the extracted parameters, which are presented on the figures by the continuous black line.

Figures 6 (a), (b), (c), (d), (e) and (f) show a good agreement between the experimental and calculated data. Some little inaccuracies still occur for the maximum power current and voltage, with a small absolute difference and relative error of the current and voltage of the maximum power compared to the experimental values and at the manufacturers issued values. To prove what was claimed, the characteristic of the panels were drawn on the basis of the results obtained by the method described here. The simulated curves pass almost by all the experimental points for all the modules tested. In other words, the simulated and measured characteristics current-voltage are practically confused, this means that the currents and the voltages provided by the standard diode model by using the extracted parameters with the help of the suggested method in relation to the measured values are really similar with an insignificant difference (see Table V and VI).

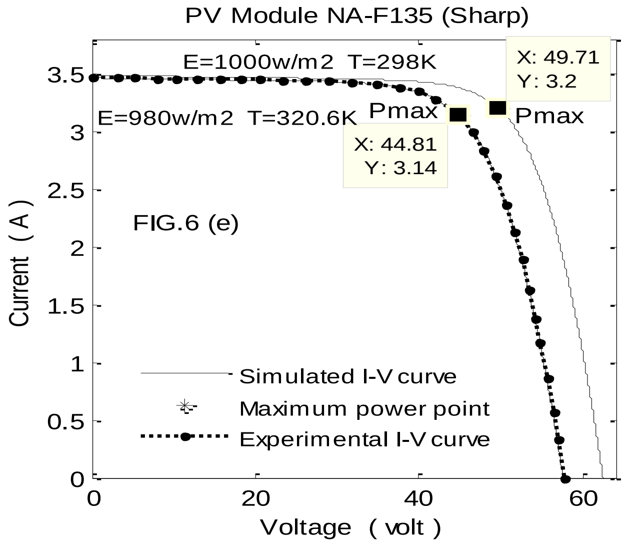


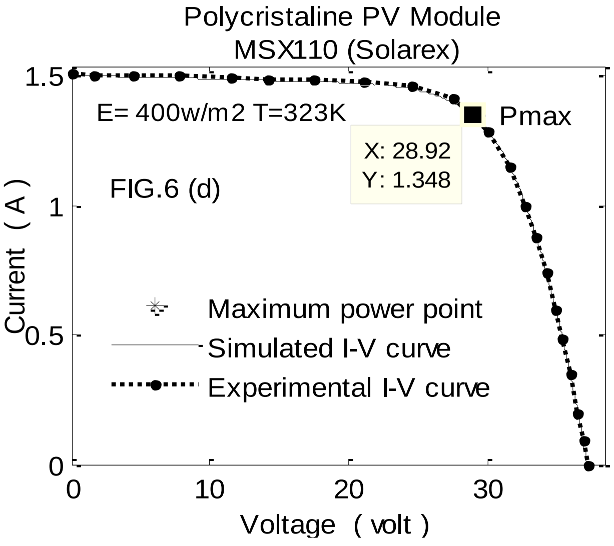
Comparison between the simulated and experimental I-V curves at (980 and 1000W/m^2, 48.8, 50 and 25^{o}C, Panel HR-185 and MSX110)





Comparison between the simulated and experimental I-V curve at (400 and 250W/m², 45°C and 50°C, Panel MSX110)





Comparison between the simulated and experimental I-V curve at (200, 980 and 1000W/m², 47.6and 25°C Panel NA-F135) FIGS.6. Comparison between the simulated and experimental I-V curves

Tables II and IV show the results achieved through the use of the proposed equations did not show any significant differences with respect to those obtained with other more complete equations, as can be easily seen. It can be seen that the voltage errors are always less than 0.04% and that the current errors are even less than 0.2% for all the modules tested that is in the standard test condition (See Table II) or at the experimental conditions of irradiation and cells temperature (See Table IV). It can be seen that the difference for the maximum power coordinates (Vm, Im) is very far of the ceiling of 1%. In all the cases of the module tested, its power lies near the lower specified limit. These results prove the validity of the proposed equations (19), (33), (37), (38) and (40) for finding loss resistances and the other parameters that let the I-V curves in the vicinity of the point of maximum power, which is reproduced with a high degree of approximation.

To note that series resistance Rs affects much the maximum power voltage, if the difference between the experimental voltage and the simulated voltage is weaker this proves than the value of the series resistance simulated is more accurate. While the shunt resistance control also the current of the maximum power, if the difference between the experimental current and the simulated current is broader, consequently the error made on Rsh is significant, which is not in this study.

TABLE V: Absolute relative errors between issued and calculated at STC

Panels	E W/m²	T °C	issued maximum power	Calculated maximum power	Absolute relative error ΔPmax %	Absolute relative error ΔIm %	Absolute relative error ΔVm %
HR-185	1000	25	185.0136	185.0136	0.0000	0.0000	0.0000
MSX 110	1000	25	109.8860	109.8865	0.0455	0.0300	0.0304
NA-F135	1000	25	159.0400	159.070	0.0188	0.0937	0.0201

TABLE VI: Absolute relative errors between measured and calculated at different illuminations and temperature

Panels	E W/m²	T °C	Measured maximum power	Computed maximum power	Absolute relative error ΔPmax %	Absolute relative error ΔIm %	Absolute relative error ΔVm %
HR-185	980	48.8	177.537	177.537	0.0000	0.0000	0.0000
MSX 110	980	50.0	96.9240	96.8649	0.0610	0.0610	0.0000
	400	50.0	38.9793	38.9842	0.0126	0.0003	0.0200
	400	45.0	39.6808	39.6749	0.0149	0.0200	0.0000
	250	45.0	23.4773	23.4804	0.0132	0.0313	0.0353
NA-F135	980	47.6	140.672	140.7034	0.0223	0.0000	0.0223
	200	25.0	26.7194	26.7047	0.0550	0.0313	0.0238

The greatest absolute relative error values at standard test conditions for the chosen modules are around 0.0%, 0.03% and 0.094 % for the current Im and 0.0%, 0.03% and 0.02% for the voltage Vm respectively for the Monocrystalline HR-185, polycrystalline MSX110, thin film PV modules NA-F135. But in the test conditions the error made on the current Im for the three modules taken in the tables order of 980 w/m2 and the cells temperatures is 0.0%, 0.06%, and 0.00%, the error made on the voltage Vm is 0.0%, 0.035%, and 0.023%.

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Modules	Im (A)	Vm (V)	Rs (Ω)	Rsh (Ω)	a (V)
STP185S-24	5.202	36.62	0.4521	586.46	2.2138
MEPV220	7.520	29.29	0.2624	550.33	1.9745
MF165EB3	6.834	24.21	0.2412	2616.5	1.7089
FE110-TF-3E	1.069	102.9	6.6965	377.00	6.7550

The method shows a little underestimation or overestimation of the maximum power current and voltage and Power (Table V and VI), which will lead to more moderate results and wiser predictions when the model is used to simulate the behaviour of a PV system and to evaluate the benefit of the economic investments.

For the analysed panels, Table V provides the absolute relative errors of current and power between the issued, and the computed data, while Table VI lists the absolute relative error of the current Im, the voltage Vm and of maximum power between measured and calculated data. The maximum absolute relative errors for the current Im, the voltage Vm and for the power do not exceed 0.1%.

Since At short circuit conditions, the diode current is very small and the light current Iph is approximately equal to the short circuit current, if we take this condition in consideration in the Eq.(1), the error made on the current Im of the maximum power by using these suggested models, the error is almost null.

			Slop method	Proposed method
Module	E W/m^2	T ^{o}C	Rs (Ω)	Rs (Ω)
HR-185	980	48.8	0.4813	0.4855
MSX110	980	50.0	0.7040	0.7027
	400	50.0	1.7082	1.7016
	400	45.0	1.7202	1.7100
	250	45.0	2.7952	2.7700
NA-F135	980	47.6	1.1125	1.1038
	200	25.0	5.1078	5.0409

The computed values of the series resistance are compared with the experimental values determined by using the slope method at different irradiance and temperatures, which are contained in Table VII.

TABLEVII: Experimental and calculated results of Rs

The results obtained by the proposed method are in good consensus with the experimental values (slope method).

The proposed equations have the added advantage of requiring only the values of Isc, Voc, Vm and Im. These values can be catalogue data (STC), or those obtained under other conditions or through testing.

Modules	Manufacturer	Isc (A)	Voc (V)	Im (A)	Vm (V)
Monocrystalline PV modules					
STP185S-24	Suntech	5.6	45.2	5.20	36.6
MEPV220	eurener	8.12	36.6	7.52	29.27
Polycristalline PV module					
MF165EB3	MITSUBISHI	7.36	30.40	6.83	24.2
Thin film PV module					
FE110-TF-3E	French energy	1.42	130	1.07	102.7

By supplementing this study, we gather some different modules; the Table VIII groups their data at standard test conditions.

TABLE VIII: STC data of the gathered modules

The Table IX contains the losses parameters Rs and Rsh and thermal voltage a, and the coordinates of the maximum power points determined by the Eqs. (19), (33) and (40), except the French energy module its series resistance is calculated by the Eq. (34).

TABLE IX: Calculated results (proposed method)

See in Table VIII and IX the greatest value of the difference between the obtained values of the points of the maximum power to the values given by the manufacturers is of 0.004 A on Im of MF165EB3 module and 0.02V on Vm of the two modules STP185S-24 and FE110-TF-3E. These differences are very small, with committed error equal to 0.058% on Im of MF165EB3 and 0.0546% on Vm and 0.0195% of the both modules STP185S-24 and FE110-TF-3E respectively.

To achieve this work, we compare the values of the losses parameters Rs and Rsh and the thermal voltage a of some modules, whose the values of the parameters and the specified points of the modules are published by Mr. Villalva et al. [20, 21] for the panel KC200GT, Frans Nieuwenhout and Nico van der Borg [22] for the module MSX53 and T Ikegami, T Maezono [23] for the module GT136. The published values of these modules are recorded in the Table X and XI. Table XII contains the calculated values by using the proposed method.

TABLE X: Published data at STC

Panel s	Isc (A)	Vco (V)	Im (A)	Vm (V)	Rs Ω	Rsh Ω	a (V)
KC200 GT	8.21	32.90	7.61	26.30	0.221	415.4	1.4049
MSX 53	3.40	20.60	3.20	16.70	0.480	200	0.9006

TABLE XI: Published data at 747.1 W/m2 and 48.3 ^{0}C of T$_{cell}$

Panel	Isc (A)	Vco (V)	Im (A)	Vm (V)	Rs (Ω)	Rsh(Ω)	a (V)
GT136	3.60	18.80	3.18	14.70	0.3464	193.7	1.4744

TABLE XII: Computed values of the parameters (proposed method)

Modules	Rs (Ω)	Rsh (Ω)	a (V)
KC200GT	0.2328	602	1.7940
MSX53	0.3580	infinity	0.9721
GT136	0.3576	88.64	1.1388

TABLE XIII: Absolute differences between issued and calculated Im and Vm

	Published				Calculated			
Panels	Im (A)	Vm (V)	ΔIm	ΔVm	Im (A)	Vm (V)	ΔIm	ΔVm
KC200 GT	7.732	27.0	0.1217	0.70	7.61	26.3	0.001	0.00
MSX 53	3.131	16.5	0.2650	0.21	3.19	16.7	0.009	0.00
GT 136	3.175	14.3	0.005	0.41	3.18	14.7	0.001	0.00

The maximum power current and voltage computed with the values of the losses parameters and the thermal voltage a mentioned in Table XII obtained by the proposed method are in good agreement with the published data of the current Im and the voltage Vm of the maximum power (Table XIII) for all the modules better than those calculated with the values given by the authors. The absolute error committed on the maximum power Pmax obtained by the published values is 4.30%, 3.26% and 2.86% for the modules KC200GT, MSX53 and GT136 respectively.

While the absolute relative error performed with the proposed method is of 0.026%, 0.00% and 0.099% for the same modules taken in the preceding order. By examining these results this proves that this method is more correct and much more accurate.

FIGS. 7 (a), (b) and (c) show the difference between the current-voltage characteristics of the panels evaluated by the published data (TABLE X and XI) and with the extracted parameters by means of the proposed method (TABLE XII) as well as the maximum power points are marked on each curve of each panel.

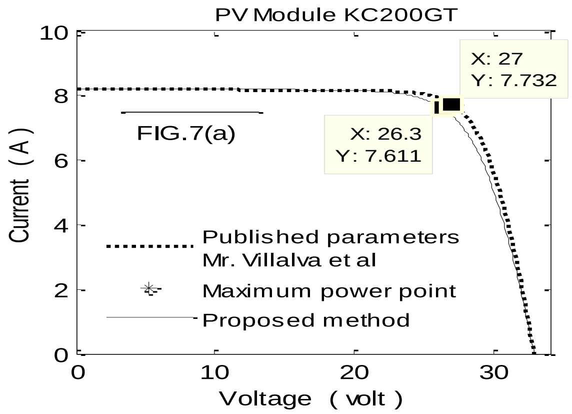

FIG.7 (a)

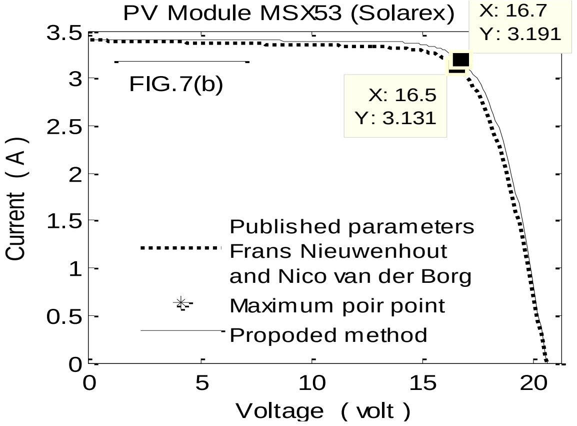

FIG.7 (b)

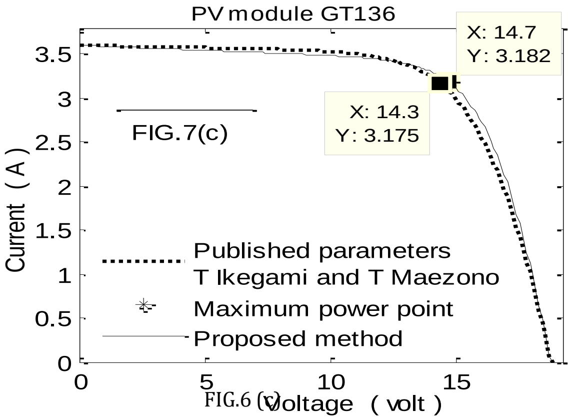

FIG.6 (c)

FIG.7. Comparison between the curves evaluated with the issued and calculated data.

The calculated curves by the suggested method pass through the same points Isc, Vco and the maximum power point with a inconsiderable absolute difference compared with the data issued in the STC of the panels KC200GT, MSX53 and GT136 at the edited conditions, but the curves plotted by the published data by the authors are so far from the maximum power point with a considerable difference (TABLE XIII).

The analysis made it possible to observe that the calculated values of both series and shunt resistance seem to vary slightly with temperature and in almost inverse linear mode with the solar irradiance. From this observation, the series and shunt resistance can be estimated by:

$$Rs = \frac{Rsref}{\theta(E)} \quad (42)$$

$$Rsh = \frac{Rshref}{\theta(E)} \quad (43)$$

Where :

$$\theta(E) = \frac{E}{Eref} \quad (44)$$

E: irradiance

Eref: reference irradiance 1000 W/m^2, AM 1.5

Rshref: series resistance obtained at standard test conditions

Rshref: shunt resistance obtained at standard test conditions

In order to verify again the Eqs (42) and (43) we use the experimental data of the module Kyocera KC200GT at different temperatures at the standard irradiance 1000 W/m^2, AM 1.5 (its data at STC are reported in TABLE X) and various irradiances at a fixed temperature 25°C edited by Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho [24] and the calculated parameters at STC mentioned in TABLE XII. The comparisons between issued and calculated data are presented on the curves of FiG.8 and FiG.9.

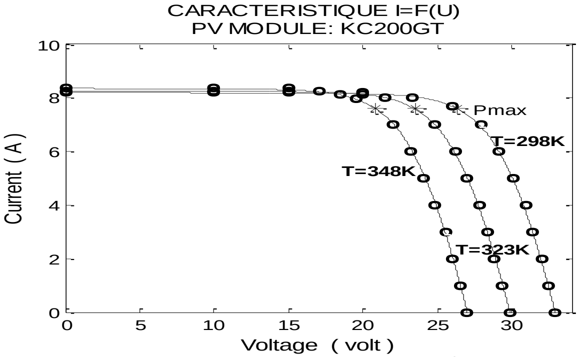

FIG. 8. I–V curves and experimental data of the KC200GT panel at different temperatures, 1000 W/m^2 .

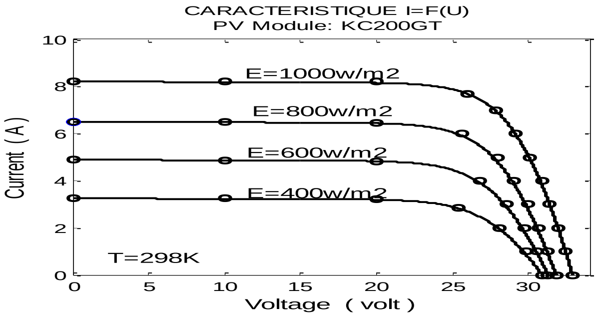

FIG. 9. I–V curves and experimental data of the KC200GT panel at different irradiations.

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FIG. 8 shows the I–V curves at different irradiations at a fixed temperature. The circular markers in the graphs represent experimental (V, I) points. Most of these points are matched with the simulated curve. Therefore, the relations mentioned in the Eq (42) and (43) can be used to estimate the shunt resistance.

VI. CONCLUSION

In this work, a simple, effective and fast method is presented in order to determine the five parameters of photovoltaic panels of various technologies (Monocrystalline silicon, Polycrystalline silicon, and the thin film) by using the standard diode model. This method is based on two main axes, the equation binding only the two parameters Rs and Rsh and the series resistance model. This method requires only the information currently provided by the manufacturers, which is sufficient to determine the five parameters of the single diode model. Obtaining the four other parameters depends only on the values of Rs. The models of the series resistance according to the obtained results given at the Tables IV and XIII offer a high degree of accuracy by using a normal scientific calculator, Hence, the programming and computational cost of the suggested equations of the models of the proposed method are minimal. With the series resistance values so calculated and the remainder of the parameters, the characteristics I-V of the photovoltaic modules can be traced with a high degree of reliability. In all the cases analyzed in this study the results showed that the errors made on current Im and Vm, they are absolutely negligible likewise for the maximal power.

The error observed of the maximal power of the tested modules was never higher than 0.1% (see TABLE V, VI, X and XIIII) for the Monocrystalline and Polycrystalline PV modules and 0.3% (see TABLE V and X) for thin film technology.

REFERENCE

[1] M. Haouari-Merbaha, M. Belhamel, I. Tobías, J. M. Ruiz, “Extraction and analysis of solar cell parameters from the illuminated current–voltage curve”, Sol. Energy Mater. Sol. Cells, Vol. 87, pp. 225-233 (2005).

[2] Adelmo Ortiz-Conde, Francisco J. García Sánchez and Juan Muci. “New method to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I–V characteristics”, Sol. Energy Mater. Sol. Cells, Vol. 90 pp. 352–361 (2006).

[3] Priyanka, Mohan Lal and S.N. Singh, “A new method of determination of series and shunt resistances of silicon solar cells”, Sol. Energy Mater. Sol. Cells, Vol. 91, pp. 137-142 (2007).

[4] Z. Ouennoughi and M. Chegaar, “A simpler method for extracting solar cell parameters using the conductance method”, Solid-State Electron., Vol. 43, pp. 1985-1988 (1999).

[5] M. Tivanov, A. Patryn, N. Drozdov, A. Fedotov and A. Mazanik, “Determination of solar cell parameters from its current–voltage and spectral characteristics”, Sol. Energy Mater. Sol. Cells,Vol. 87, pp. 457-465 (2005).

[6] J. Thongpron, K. Kirtikaraa, C. Jivacate, “A method for the determination of dynamic resistance of photovoltaic modules under illumination”, Sol. Energy Mater. Sol. Cells, Vol. 90, pp. 3078-3084 (2006).

[7] Erees Q.B. Macabebe and E. Ernest van Dyk. “Parameter extraction from dark current–voltage characteristics of solar cells ”, S.Afr. J. Sci., Vol. 104, pp. 401-404 (2008). Electronic document available in: http://www.scielo.org.za/pdf/sajs/v104n9-10/a1710410.pdf. Accessed in August 18, 2010.

[8] J. Salinger, « Measurement of Solar Cell Parameters with Dark Forward I-V Characteristics ». Acta Polyt., Vol. 46 No. 4, pp. 25-27 (2006).

[9] Ewa Radziemska. “Dark I–U–T measurements of single crystalline silicon solar cells ”, Energy Convers. Manage., Vol. 46, pp. 1485-1494 (2005).

[10] R. Hussein, D. Borchert, G. Grabosch and W.R. Fahrner. "Dark I–V–T measurements and characteristics of (n) a-Si/(p) c- Si heterojunction solar cells”, Sol. Energy Mater. Sol. Cells, Vol. 69, pp. 123-129 (2001).

[11] E. Q. B. Macabebe and E. E. Van Dyk. “Parameter extraction from dark current–voltage characteristics of solar cells ”, S.Afr. J. Sci., Vol. 104, September/October, pp. 401-404 (2008).

[12] C. Carrero, J. Rodrıguez, D. Ramırez, C. Platero. “Simple estimation of PV modules loss resistances for low error modelling”, Renewable Energy 35 (2010) 1103–1108.

[13] S. Dib, M. De La Bardonnie, A. Khoury, F. Pelanchon and P. Mialhe. “A new method for the extraction of diode parameters using a single exponential model”, Act. Passive Electron. Compon, Vol. 22, pp. 157-163 (1999).

[14] M. Bashahu, A. Habyarimana, Renewable Energy, vol 6, 1995, pp. 129-138.

[15] A. Vishnoi, R. Gopal, R. Dwivedi and S. K, Srivastava, “Distributed parameter analysis of dark I-V characteristics of the solar cell - estimation of equivalent lumped series resistance and diode quality factor”, Circuits, Devices and Systems, IEE Proceedings G, Vol. 140, No. 3, pp. 155-164 (1993).

[16] John A. Duffie and William A. Beckman “Solar engineering of thermal processes”, second ed 1991.New York. John Wiley , pp 770-772

[17] Soteris Kalogirou “Solar energy engineering: processes and systems », Elsevier (2009), pp. 477 – 486.

[18] J.A. Gow, and C.D. Manning, “ Development of a photovoltaic array model for use in power electronic simulation studies”, IEE Proceeding Electric power Application, vol. 146, No. 2, March 1999, pp. 193-200.

[19] The Bogdan, S.B., Salameh, Z.M., 1996. “ Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system”, IEEE Transactions on Energy Conversion 11 (2), 367–375.

[20] M. G. Villalva, J. R. Gazoli, and E. R. Filho, “Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays”, IEEE Trans. Power Electronics, 24, no. 5, pp. 1198-1208, 2009.

[21] M. G. Villalva, J. R. Gazoli, and E. R. Filho, “Modeling and circuit-based simulation of photovoltaic arrays”, Brazilian Journal of Power Electronics,14, no. 1, pp. 35-45, 2009.

[22] Frans Nieuwenhout, Nico van der Borg, Wilfried van Sark and Wim Turkenburg, “A New Method for Estimating Insolation Based on PV- Module Currents in Cluster of Stand-Alone solar systems”, progress in photovoltaics: research and applications Prog. Photovolt. Res. Appl. 2007; 15; 29 January 2007 in Wiley ; pp 387–404

[23] T. Ikegami, T. Maezono, F. Nakanishi!, Y. Yamagata,K. Ebihara, “Estimation of equivalent circuit parameters of PV module and its application to optimal operation of PV system”, Solar Energy Materials & Solar Cells 67 (2001), pp 389-395

[24] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho, “ Comprehensive Approach to Modelling and Simulation of Photovoltaic Arrays”, IEEE TRANSACTIONS ON POWER electronics, vol. 24, no. 5, may 2009, pp 1204.