A five parameter extraction of PV module based on outdoor measurements using Labview

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Abstract— **Manufacturers of photovoltaic modules typically provide electrical parameters at only one operating condition called Standard Test Condition (STC) which is not sufficient to determine their overall performances in real condition of work. This paper presents a five parameters extraction mainly based on outdoor measurements. The model is able to describe the I-V and P-V characteristics of a photovoltaic module for any operating condition of temperature and solar irradiance. A series of experimental I-V curves obtained in various real conditions of temperature and irradiance conducted at the Centre of development of renewable energies in Algiers (CDER). From the experimental data, some specific key points are used to extract the model parameters. The predicted I-V and P-V curves are compared with experimental data to conclude on the validity of the model and the followed procedure.**

Keywords-Photovoltaic modules; Analytic method; Five-parameter model; One-diode equivalent circuit; Solar energy; I-V characteristics; P-V caracteristics.

I. INTRODUCTION

Renewable energy is expected to be an important source of energy in the future because it have made a successful transition from small stand-alone sites to large grid connected systems, avoiding transport losses and contribute to CO_2 emission reduction in urban areas. In particular, photovoltaic (PV) power systems, which converts solar irradiance to electrical power, could be a suitable solution to meet local energy demand in isolated areas and strengthening the electrical network at the common point of connection (CPC) and reduction of electrical consumption bill of owners [1]-[4]. The model of the photovoltaic device that is studied in the present work is the so called "One Diode Equivalent Circuit Model" [5],[6]. Thus, the main task assigned to the present work is to develop a simple and practical method, to extract the five parameters related to the model of PV module under study with a sufficient degree of precision. The method presented in this paper is based on experimentally known values, such as short circuit current, open circuit voltage and current and voltage at maximum power point, which are key points allowing the characterization of PV modules behavior [1]-[8]. So, when a particular PV module or PV generator has to be modeled to predict its performance in real conditions of irradiance and temperature, it is necessary to perform I-V measurement of the targeted PV module in order to get the its key points for the extraction of the main parameters. Moreover, only considering manufacturing tolerances, when similar modules are tested differences appear between them. So, their parameter values will be different. Even if the same module is tested under different conditions, different values are obtained [6], [7].

II. PV SYSTEM MODELING

Mathematical description of the I-V characteristic of PV cell is derived from the physic of the p-n semiconductor junction [3],[9]. Fig.1 shows the equivalent circuit of the five-parameter model [7].

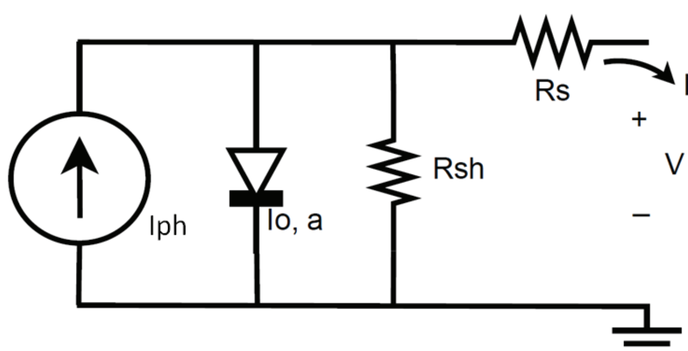

Figure 1. One diode equivalent circuit

This circuit includes a series resistance and a diode in parallel with a shunt resistance. This circuit can be used either for an individual cell, for a module consisting a several cells or for an array consisting of several modules [10]. The current-voltage relationship of a photovoltaic cell is given by:

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$$I = I_{ph} - I_0 \left(e^{\left(\frac{V + IR_S}{a}\right)} - 1 \right) - \frac{V + IR_S}{R_{sh}} \quad (1)$$

Where I_{ph} is the photocurrent in (A), I_0 is the diode saturation current in (A), a = nkT/q modified ideality factor, n the diode ideality factor, k the Boltzmann constant (JK^{-1}), q the electronic charge (C), T the cell temperature (K), V_t the thermal voltage (V_t = kT/q, V), R_s the series resistance (Ω) and R_{sh} is the shunt resistance (Ω) [11].

A. Resolution flowchart

A closed-form exact solution of equation (1) for the unknown current I is not available. Thus numerical methods should be used to solve it. In this work the Newton-Raphson iterative method is used [3],[8],[11].

In Fig.2 is shown the steps of Newton-Raphson method to resolve a non linear equation. We take equation (1) equal to f(I, V), and X = (I, V).

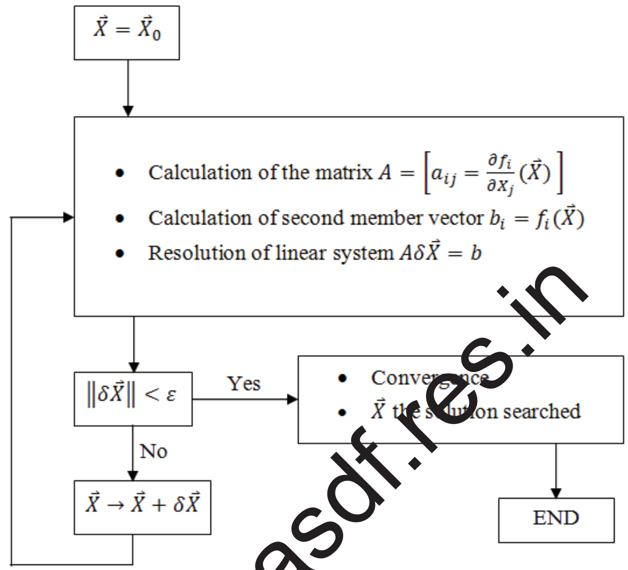

Figure 2. Newton-Raphson resolution flowchart

B. Labview code

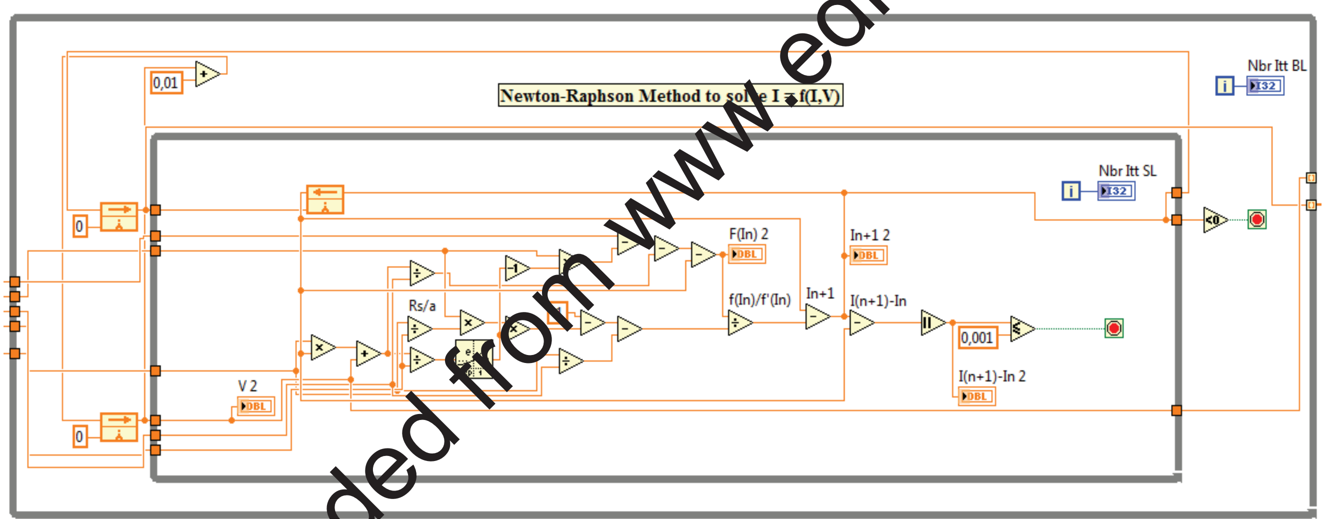

Figure 3. Newton-Raphson program in Labview to solve I = f(I,V)

Labview is used to program the Newton-Raphson method to solve the I = f(I,V) equation. Fig.3 present the Labview program to solve the I = f(I,V) equation based on the flowchart given as above.

III. PARAMETER EXTRACTION

To evaluate the five parameters in (1), five independent pieces of information are needed. This five parameters depend on the incident solar irradiance, cell temperature, and on their reference values [10]-[12]. These reference values are generally provided by manufacturers of PV modules for specified operating condition such as STC (Standard Test Conditions) for which the irradiance is 1000 W/m² and the cell temperature is 25°C [9]-[11].

A. Reference parameters

For calculate the five reference parameters we need an equation system with five equations. At this work we use:

- Short circuit condition: I = I_{sc}, V = 0
- Open circuit condition: I = 0, V = V_{oc}
- The maximum power point: I = I_m, V = V_m
- The derivative dV/dI of (1) at V = V_{ocref}, gives -R_{s0}
- The derivative dV/dI of (1) at I = I_{scref}, gives -R_{sh0}

Where R_{S0} and R_{sh0} are respectively the slops of I-V curve in open circuit and short circuit points. In this work, R_{S0} and R_{sh0} are taken from manufacturer's data.

The simultaneous solution of the equations system was performed by means of a nonlinear equation solver [2]. The Newton Raphson method is used to solve systems of nonlinear equations. It find the roots of a non linear function by computing the Jacobian linearization of the function around an initial guess point, and using this linearization to move closer the nearest zero [12], [13]. Where I_{scref}, V_{ocref}, I_{pmref}, V_{mpref} are given by a mathematical translation in the measure instrument PVPM in outdoor measurements of several I-V curves on a Isofoton (106/12) PV module [14].

1) Resolution of non linear equation system flowchart:

We used in this part Matlab, Mathcad, and Labview in Labview environment for the program. Fig.4 shows the flowchart steps for solving an equation system.

Fig.4 shows the flowchart of resolution of non linear system of five equations, for extracting the five parameters.

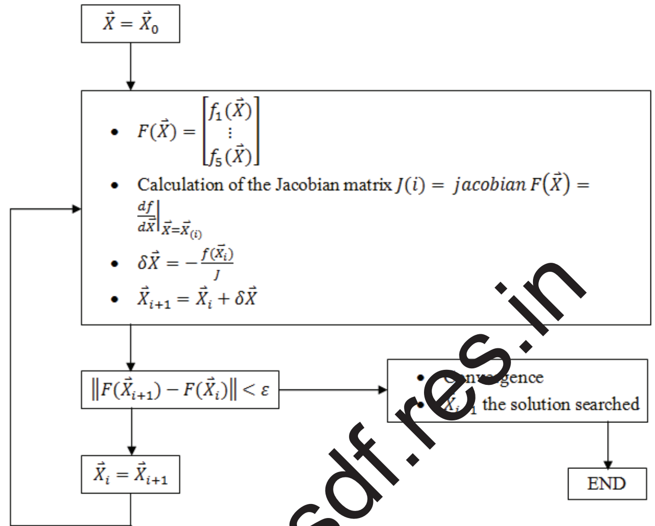

Figure 4. Flowchart of resolution of non linear system equation

2) Labview code:

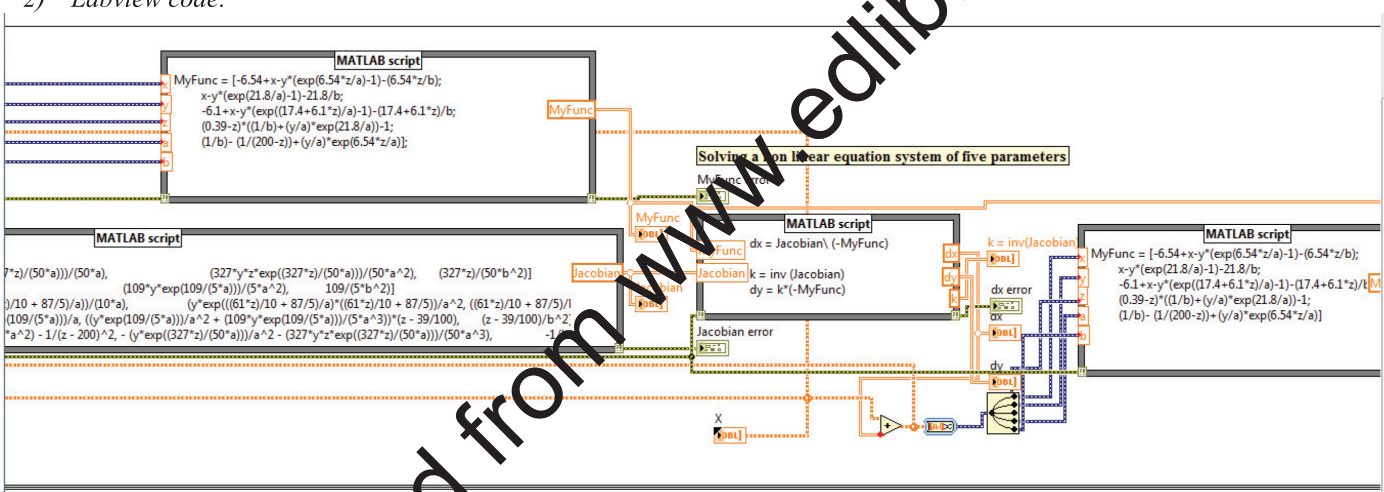

Figure 5. Program Labview to solve the non linear system equations for extract five parameters

Fig.5 shows Labview code for solving the non linear system of five equations. At last we get the X vector with five reference parameters I_{phref}, I_{0ref}, R_{sref}, a_{ref} and R_{shref}.

B. Real parameters

Now after determined the five main parameters at reference conditions. their values at any condition of temperature and irradiance are given by, [6]-[15]:

- Modified ideal factor

$$a = a_{ref}\left(\frac{T}{T_{ref}}\right) \tag{2}$$

- Saturation current of the diode

$$I_0 = I_{0ref}\left(\frac{T}{T_{ref}}\right)^3 e^{\left(\frac{N_s E_g}{a_{ref}}\left(1-\frac{T_{ref}}{T}\right)\right)} \tag{3}$$

- Photocurrent

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{phref} + \alpha(T - T_{ref})\right) \tag{4}$$

- Series resistance R_s=R_{sd}

$$R_s = R_{sref} - \left(\frac{a}{I_0} e^{\left(-\frac{V_{oc}}{a}\right)}\right) \tag{5}$$

- Shunt resistance R_{sh}

$$R_{sh} = R_{shref}\left(\frac{G_{ref}}{G}\right) \tag{6}$$

Where T_{ref} and T are the reference and measured temperature, N_s is the number of solar cells serially forming the PV module, E_g is the band gap energy of the semiconductor and α the temperature coefficient of the short circuit current.

IV. Model Validation

In order to validate the model given above for PV modules, the model output and experimental measurement are compared for commercial mono-crystalline PV module from Isofoton (106/12), composed of two parallel strings of 36 solar cells.

Ten measures files are used to validate this model, with different conditions. The aim of this tests is to extract the five parameters for the real conditions for each measure with the couple (T, G) and use them after in the model. At last we compare the simulation results with those obtained by measures.

A. Five parameter extraction

Table I shows the five PV module parameters evaluated at both reference and real conditions.

TABLE I. Five Parameters For Reference And Real Conditions

	Conditions			Five parameter	
	Manufacturer	***Measure***		***Manufacturer***	***Measure***
Isc 0: (A)	6,54	6,68	**Iph_{ref}: (A)**	6,548	6.69
Voc 0: (V)	21,8	21,3	**$I0_{ref}$: (A)**	$4,44^{-9}$	1.097^{-5}
Imp0: (A)	6,1	5,95	**Rs_{ref}: (Ω)**	0,23	0.157
Vmp0: (V)	17,4	16,68	**a_{ref}**	1,033	1.60[illegible]
MPPT: (Wp)	106,14	99,275	**Rsh_{ref}: (Ω)**	199,771	200.371

The real parameters values at any condition of temperature and irradiance are given by (2)-(6) and modeled in Labview for given the adequate parameters at each temperature and irradiance for the different measures files.

B. Labview interface

The layout of the developed virtual instrument can be viewed in front panel format for an interactive user interface, including the model parameters, different curves of I-V and P-V and errors.

- Model parameters.

In Fig.6, is shown the interface dedicated to the description of the sane five parameter model and its configuration on one hand. In other hand indicators displaying all real parameters in real time are displayed in Fig.7.

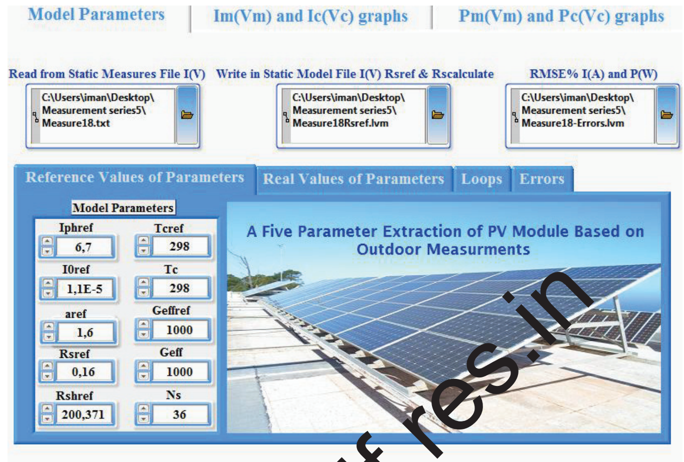

Figure 6. Parameters configuration

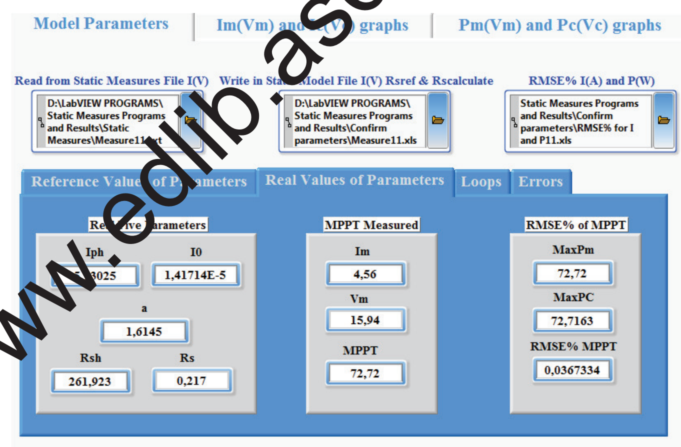

Figure 7. Real values of parameters

- Curves.

In the 10 file measures we have different conditions of work. In this part we examine the sane five parameter model for different couple of (T, G), and we compare with measures data.

Plots of I-V and P-V simulate with $R_s = R_{sref}$ and $R_s = R_{sd}$ and measured for different cases are shown below.

a) Case 1: Fig.8 shows the experimental I-V curve and those obtained by simulation. In this case the couple (T, G) = (27.7 °C, 765 W/m²), whene Fig.9 shows the plot of the power versus voltage (P-V), obtained in simulation results and measured results.

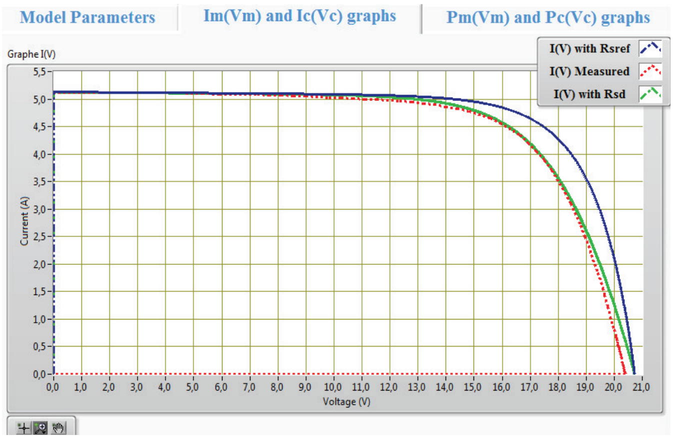

Figure 8. I-V measured curve and I-V simulated curves for (T, G) = (27.7 C, 765 W/m²).

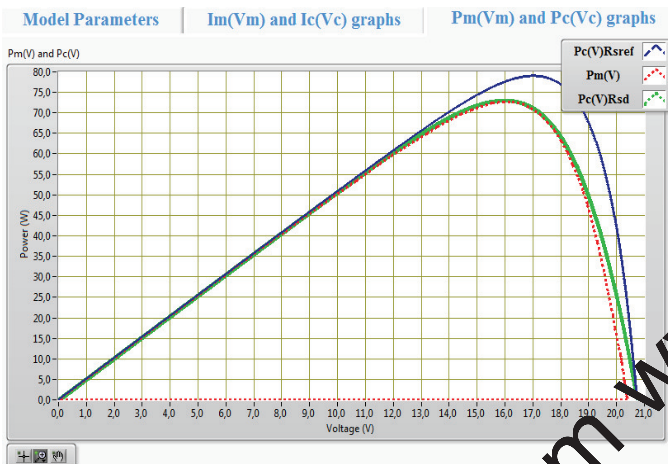

Figure 9. P-V measured curve and P-V simulated curves for (T, G) = (27.7 C, 765 W/m²)

b) Case 2: Fig.10 shows the experimental I-V curve and those obtained by simulation. In this case the couple (T, G) = (27.9 °C, 752 W/m²), where Fig.11 shows the plot of the power versus voltage (P-V), obtained in simulation results and measured results.

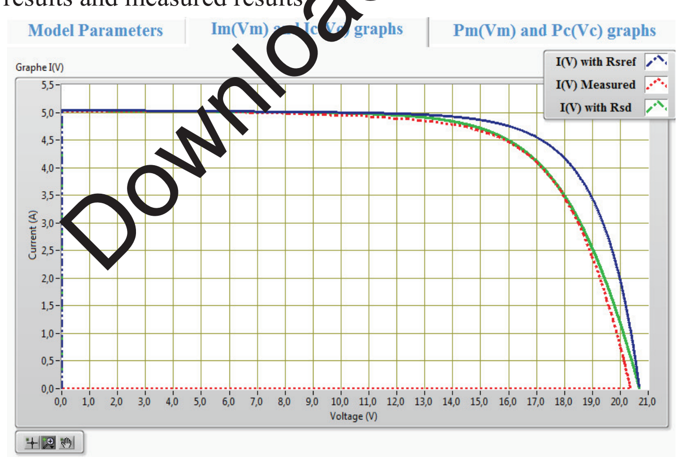

Figure 10. I-V measured curve and I-V simulated curves for (T, G) = (27.9 C, 752 W/m²).

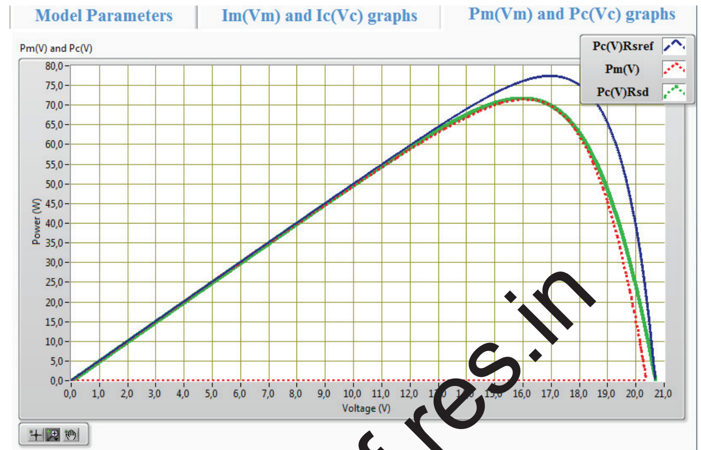

Figure 11. I-V measured curve and I-V simulated curves for (T, G) = (27.1 C, 809 W/m²).

It can be seen the high correlation shown by the model mainly by the model with dynamic resistance R_{sd}.

C. Accuracy of model

In order to quantify the goodness of the modeling procedure for the I-V and P-V characteristics of a commercial PV module, the following indexes of error are calculated:

The mean relative error E_x of calculated parameters I_{sc}, V_{oc}, I_{mp}, V_{mp} and MPPT given by the following expression.

$$E_X = 100\frac{X_c - X_m}{X_m}\ (\%) \quad (7)$$

Where X_c is the calculated data and X_m is the experimental data.

Fig.12, Fig.13, and Fig.14 respectively shows the I_{sc}, V_{oc}, and MPPT errors for the 10 measures. As can be seen, the deviation obtained between simulation results and real measures data is almost negligible at short circuit current and at the maximum point power. Furthermore errors below 1.4% max obtained for at open circuit voltage for the 10 measures.

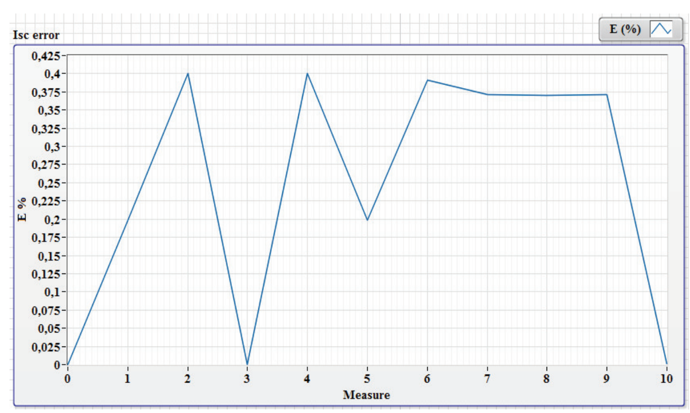

Figure 12. Isc error E(%) for the 10 measures.

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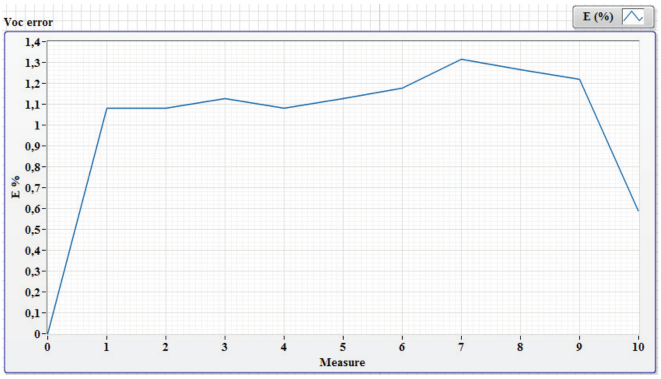

Figure 13. Voc errors E(%) for the 10 measures.

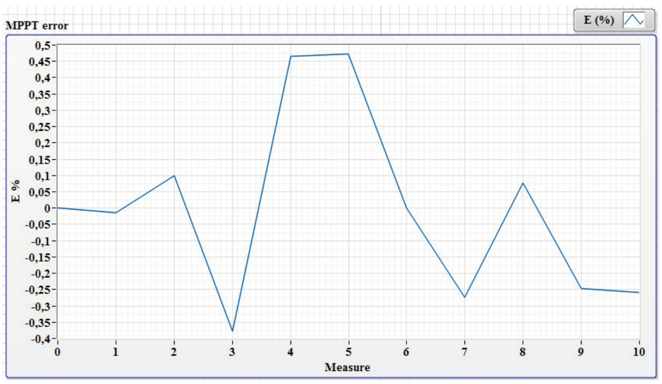

Figure 14. MPPT error E(%) for the 10 measures.

- Root Mean Square Error in percent (RMSE (%)); it is given by:

$$\mathrm{RMSE}\ (\%) = 100\,\frac{\sqrt{\frac{\sum_{i=1}^{N}(X_{ical}-X_{iexp})}{N}}}{X_{exp}} \quad (8)$$

X = [I_{sc}, V_{oc}, I_{mp}, V_{mp} and MPPT], calculation of RMSE is obtained for the 10 measures.

TABLE II. DIFFERENT DATA MEASURES MEAN RELATIVE ERRORS AND RMSE (%) AT MPPT

	I_{SC} (A)	V_{OC} (V)	I_{MP} (A)	V_{MP} (V)	MPPT (WP)
RMSE (%)	0.161	1.161	0.405	0.486	0.1684

Table II shows the different cases with measured data and calculated data. The RMSE (%) is calculated for all cases. As can be seen, a good agreement has been obtained between simulation results and real measures data.

V. CONCLUSION

This paper indicates how the five parameters of a single diode model are determined and gives their values at reference end real conditions. These values are then used within the model to calculate the five parameters for any other conditions. A sane five parameter model is programmed in combination between Matlab, Mathcad and Labview given the PV module characteristic at any conditions, and determination of characteristic parameters such as the short circuit current, the open circuit voltage, the current and voltage at maximum power point.

The results obtained by the simulation were validated using measured data performed at photovoltaic laboratory of the centre of development renewable energy, the comparison has shown a good agreement approving then that the single one diode model can be an accurate tool for the prediction of energy production.

REFERENCES

[1] I. Kashif, S. Zainal, M. Saad, and S. Amir, "Parameter extraction of solar photovoltaic modules using penalty-based differential evaluation," Appl Energy 2012; 99, pp. 297-308.

[2] V. L. Brano, A. Orioli, G. Ciulla, A. Di Gangi, " An improved five parameters model for photovoltaic modules," Solar Energy Materials & Solar Cells, 2010; 94, pp. 1358-1370.

[3] F. Adamo, F. Attirissimo, A. Di Nisio, A. M. L. Lanzolla, M. Spadavecchia, "Parameters estimation for model of photovoltaic panels," 15 IME KO World Congress Fundametal and Applied Metrology, September 6-11, 2009, Lisbon, Portugal.

[4] A. Elkholy, F. H. Fahmy, A. Abu Elela, "A new technique for photovoltaic module performance mathematical model," International Conference on Chemistry and Chemical Engineering (ICCCE 2010)...

[5] G. Farivar, B. Asaei, "Photovoltaic module single diode model parameters extraction based on manufactorer datasheet parameters," IEEE International Conference On Power ond Energy (PE Con 2010), Malaysia .

[6] M. A. De Blas, J. L. Torres, E. Prieto, A. Garcia, "Selecting a suitable model for characterizing photovoltaic devices," Renewable Energy, 2002; 25, pp. 371-380.

[7] C. Carrero, O. Ramirez, I. Rodrigez, C. A. Platero, "Accurate and fast convergence method for parameter estimation of PV generators based on three main points of the I-V curve,"Renewable Energy 2011; 36, pp. 2972-2977.

[8] L. Rahmani, A. Kessal, A. Chouder, "Parameters extraction of photovoltaic module at reference and real conditions," 46th International Universities Power Engineering Conference, 5-8th Septembre 2011, Soest, Germany.

[9] J. Wang, J. Shieh, Y. Su, K, Kuo, Y. Chang, Y. Liang, J. Chou, K. Liao, J. Jiang, "A novel method for the determination of dynamic resistance for photovoltaic modules," Energy, 2011; 36, pp. 5968-5974.

[10] W. De Soto, S. A. Klein, W. A. Beckman, "Improvement and validation of a model for photovoltaic array performence," Solar Energy, 2006; 80, pp. 78-88.

[11] A. Couder, S. Silvestre, N. Seddaoui, L. Rahmani, "Modeling and simulation of a grid connected PV system based on the evaluation of main PV module parameters," Simulation Modelling Practice and Theory, 2012; 20, pp.46-58.

[12] A. Orioli, A. Di Gangi, "A procedure to calculate the five-parameter model of crystalline silicon photovoltaic modules on the basic of the tabular performance data," Applied Energy 2013; 102, pp. 1160-1177.

[13] G. Dzimano, "Modeling of photovoltaic systems," A Thesis, Presented in Partial Fulfillment of the Requirements for the Degree Master of Science in the Graduate School of The Ohio State University, The Ohio State University, 2008..

[14] http://www.pvpmc.org/.

[15] W. De Soto, "Improvement and validation of a model for photovoltaic array performence," M.S Thesis, Mechanical Engineering University of Wisconsin-Madison, 2004.