International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

An Improved Numerical Approach for Photovoltaic Module Parameters Acquisition Based on Single-Diode Model

Dominique Bonkoungou[†‡*], Zacharie Koalaga[†], Donatien Njomo[‡] and François Zougmore[†]

[†]Laboratory of Materials and Environment (LAME) / Faculty of Sciences/ University of Ouagadougou / P.O.Box 7021 Ouagadougou / Burkina-Faso
[†‡]Environmental Energy Technologies Laboratory (EETL) /Faculty of Sciences /University of Yaoundé 1/ P.O.Box 812 Yaoundé /Cameroon

Accepted 18 Dec 2015, Available online 20 Dec 2015, **Vol.5, No.6 (Dec 2015)**

Abstract

This paper presents an easy and an improved numerical approach of modeling photovoltaic (PV) modules. An accurate current-voltage (I-V) model of PV modules is inherently implicit and non-linear and calls for iterative computations to obtain an analytical expression of current as a function of voltage. In this paper, a numerical approach is proposed to forecast the PV module performance for engineering applications. The proposed approach was implemented in a Matlab script and the results have been compared with the datasheet values provided by manufacturers and other approaches in standard test conditions (STC). This approach permits to extract five unknown parameters and also allows quantifying the effects of panel temperature and irradiance on key cells parameters. The model is validated by covering a wade of operation conditions using only information provided by the manufacturer's datasheet. The various equations of the model are presented in details in this paper. Unlike other cell modeling techniques, this proposed approach enables computation of model parameters at any environmental conditions. The advantage of this model is its ability to compute simultaneously all the model parameters. A modification is also reported in the Newton-Raphson's solving to attain the best convergence.

Keywords: *Photovoltaic, simulation, Matlab software, Newton-Raphson approach.*

1. Introduction

Solar energy conversion has various advantages such as short time response of installation and long life of exploitation, circuit simplicity, no need of moving part and realizes a salient, safe, a renewable source of electricity (H. Meekhi, *et al*, 2007). Many research have been done regarding for increasing the efficiency of a solar cell (L. Castaner and S. Silvestre, 2002). But the main problems of this source of energy are low energy conversion efficiency and high installation cost. Consequently, different kinds of solar cells have been designed and introduced. Knowing that, a solar panel is one of the essential parts of a photovoltaic system which converts solar energy to electrical energy and it has also nonlinear current-voltage (I-V) characteristic curves. Therefore, modeling of a photovoltaic system predicts the system's electrical behavior in various environmental and load conditions (L. Castaner and S. Silvestre, 2002). In order to accurately predict the system's electrical behavior, it is necessary to have comprehensive and precise models for all parts of the system especially their solar panels. An accurate knowledge of solar cell parameters from experimental data is of vital importance for the design of solar cells and for the estimates of their performance. Over the years, several methods have been suggested for extracting the values of solar cell parameters from current-voltage characteristics with series and shunt parasitic resistances. Some of these methods use the illuminated current-voltage data and the subsequently calculated conductance of the devices (M. Chegaar, *et al*, 2001, 2004, 2006). Other methods are based on the Co-content function from the exact explicit analytical solutions of the illuminated current-voltage characteristics (A. Ortiz-conde*, et al,* 2006). Jain and Kapoor (A. Jain and A. Kapoor, 2004, 2005) have proposed a simple analytical method using Lambert W-function to express the transcendental illuminated current-voltage characteristics of a real solar cell containing parasitic power consuming series and shunt resistance.

The non-linear and implicit relationships that exist between the current–voltage curves, however necessitate using tedious iterative numerical calculation (M. De Blas, *et al*, 2002), (F. Ghani*, et al*, 2013), (M. Villalva, *et al,* 2009). Furthermore most of these parameters depend on both the cell temperature and the irradiance. Thus, the knowledge of their behavior is crucial to correctly predict the performance

*Correspondinh author: **Dominique Bonkoungou**

of PV cells and modules. The choice of a model that closely emulates the characteristics of solar modules is very important. A PV module is known to be accurate if it fits the measured current-voltage data at all operating conditions. Several modules are introduced among the more popular ones are the circuit based on the single diode model (K. Ishaque, *et al,* 2009) and the two diode model. In literature, analytical and numerical approaches are generally used to extract the solar modules parameters. The former requires information on several key points of the current-voltage characteristic curve. It has to be noted that the current-voltage curve is highly non-linear and any wrongly selected points may result in significant errors in the computed parameters. The numerical extraction approach is based on certain mathematical algorithm to fit all the points on the current-voltage curve. More accurate result can be obtained because all the points on the current-voltage curve are simultaneously utilized. Deviation of several data points may not severely affect the accuracy of the parameters as in the case of analytical method.

In this paper we propose an improved numerical approach to extract the PV module parameters. The performance of the model is investigated and compared to other method: the simplified model developed by the authors (E. Saloux, *et al*, 2011) and the model described by Walker (G. Walker, 2001) namely: explicit model and Rs-approach respectively. Furthermore, to ensure its practicality the proposed approach is validated using six solar modules of different types from various manufacturers. Root mean square error (RMSE) accuracy of these methods is also obtained to verify the effectiveness of the proposed model. Finally, the results obtained have been deeply examined by using the fill factor, due to its simultaneous dependence on solar cell parameters to forecast the performance of the proposed approach.

2. Photovoltaic module modeling

The implemented PV generator model is based on the one proposed by the authors (M. Chegaar, *et al*, 2001), (A. Jain and A. Kapoor, 2004, 2006). Based on the single diode equivalent circuit model (A. Jain and A. Kapoor, 2004), the characteristic equation of I-V curve for cell is given by:

$$\mathrm{I} = \mathrm{I_{PV}} - \mathrm{I_0}\left[\exp\left(\frac{\mathrm{V} + \mathrm{I} * \mathrm{R_S}}{\mathrm{A} * \mathrm{V_T}}\right) - 1\right] - \left(\frac{\mathrm{V} + \mathrm{I} * \mathrm{R_S}}{\mathrm{R_{SH}}}\right) \quad (1)$$

where I_{PV} is the current generated by the incidence of light; I_0 is the diode reverse bias saturation current; R_S represents the equivalent series resistance and R_{SH} the parallel resistance; $V_T = \frac{K*T}{q}$ is the thermal voltage of the cell; q is the electron charge; K is the Boltzmann constant; T is the temperature of the p-n junction and A the diode ideality factor. Based on the equivalent circuit of a PV module, its characteristic equation is given as follows (F. Ghani, *et al*, 2013), (M. Villalva, *et al*, 2009):

$$\mathrm{I} = \mathrm{N_P I_{PV}} - \mathrm{N_P I_0}\left[\exp\left(\frac{\mathrm{V} + \left(\mathrm{N_S}/\mathrm{N_P}\right) * \mathrm{I} * \mathrm{R_S}}{\mathrm{A} * \mathrm{N_S} * \mathrm{V_T}}\right) - 1\right] - \left(\frac{\mathrm{V} + \left(\mathrm{N_S}/\mathrm{N_P}\right) * \mathrm{I} * \mathrm{R_S}}{\mathrm{R_{SH}} * \mathrm{N_S}/\mathrm{N_P}}\right) \quad (2)$$

where N_S is the number of series cells; N_P is the number of parallel cells.

This model yields more accurate result than the PV model with series resistances R_S but at the expense of longer computational time. The PV module temperature is computed from the ambient temperature using equation (3):

$$\mathrm{T_m} = \mathrm{T_{amb}} + \frac{(\mathrm{NOCT} - 20) * \mathrm{G}}{800} \quad (3)$$

where $\mathrm{T_{amb}}$: ambient temperature; NOCT: nominal operating module temperature at standard conditions; G : solar irradiation.

2.1 Improved method to compute PV module parameters

The equation for PV current as a function of temperature and irradiance can be written as:

$$I_{PV} = I_{SC,n} * \frac{G}{G_n}\left(1 + K_i\left(T_m - T_n\right)\right) \quad (4)$$

Where $\mathrm{I_{SC,n}}$: short circuit current at reference temperature and solar radiation. Reference conditions are given by the manufacturers as 25°C solar irradiation level of 1000 W/m^2.

G_n : Reference solar radiation; K_i short circuit current temperature coefficient and T_n is the reference temperature. The open circuit voltage $\mathrm{V_{OC}}$ can be written as:

$$V_{OC} = V_{OC,n} + K_V\left(T_m - T_n\right) \quad (5)$$

where $\mathrm{V_{OC,n}}$: open circuit voltage at Standard Test Conditions (STC) and $\mathrm{K_V}$ open circuit voltage temperature coefficient.

The diode saturation current $\mathrm{I_0}$ dependence on temperature can be expressed by (M. Villalva, *et al*, 2009):

$$I_0 = I_{0,n} * \left(\frac{T_n}{T}\right)^3 * \exp\left[\frac{q * E_g}{A * K}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (6)$$

Where E_g is the band-gap energy of the semiconductor ($E_g = 1.12$ eV for the polycrystalline Silicon at 25°C) (H. Meekhi, *et al,* 2007), (A. Jain and A. Kapoor, 2005), (G. Walker, 2001) and $\mathrm{I_{0,n}}$ the nominal saturation current expressed by equation (6) at STC.

$$I_{0,n} = \frac{I_{SC,n}}{\left[\exp\left(\frac{V_{OC,n}}{A*V_{T,n}}\right)-1\right]} \quad (7)$$

Now, the single diode model of PV device can be improved by modifying the above equations

$$I_{0,n} = \frac{I_{SC,n} + K_i * \Delta T}{\left[\exp\left(\frac{V_{OC,n} + K_v * \Delta T}{A * V_{T,n}}\right)-1\right]} \quad (8)$$

where $V_{T,n}$ the thermal voltage; $\Delta T = T - T_n$ with T the temperature at real conditions and T_n the temperature at Standard Test Conditions.

Since the saturation current has strong temperature dependence; equation (8) results in a linear variation of $I_{0,n}$ with respect to temperature T. The validity of the model with the new equation has been tested through computer simulation and through comparison with experimental data (M. Vilalva, *et al*, 2009).

In this work, equation (8) is obtained from equation (7) by including in the equation the current coefficient K_i, the voltage coefficient K_v and apply it to the single diode model. This modification aims to match the open circuit voltages of the model with the experimental data for a very large range of temperatures. Equation (8) proposes a different approach to express the dependence of I_O on the temperature so that the net effect of the temperature is the linear variation of the open circuit voltage according to the practical voltage/ temperature coefficient (M. Vilalva, *et al*, 2009), (K. Ishaque, *et al,* 2009), (E. Saloux, *et al*, 2011), (G. Walker, 2001). Using equation (4), (6) and (8), three parameters (I_{PV} ; I_O ; A) of this model can be readily determined.

2.2 Numerical approach to determine the parallel resistance and the series resistance values

The two parameters R_S and R_{SH} in equation (1), are computed through iteration. Several researchers have evaluated these parameters independently, but the results are unsatisfactory (M. Bashahu, *et al,* 1995), (D. Chan, *et al,* 1986). In other works for example (E. Saloux, *et al*, 2011), (G. Walker, 2001), the parallel resistance is neglected. In the present work, a concept of simultaneously varying both the values is shown. These remaining parameters can be obtained from voltage derivative equation at short circuit, open circuit and maximum power points of datasheet of PV module as follow:

$R_{SH0} = -\frac{dV}{dI}$ at the short circuit point ($I = I_{SC}$ and $V = 0$);

$R_{SH0} = -\frac{dV}{dI}$ at the open circuit point ($I = 0$ and $V = V_{OC}$);

$\frac{I_{mpp}}{V_{mpp}} = -\frac{dI}{dV}$ at the maximum power point ($I = I_{mpp}$ and $V = V_{mpp}$).

From equation (1) at the maximum power point condition, the expression for R_{SH} can be arranged and rewritten as:

$$R_{SH} = \frac{V_{mpp}\left(V_{mpp} + I_{mpp} * R_S\right)}{V_{mpp}\left\{I_{PV} - I_0 * \left[\exp\left(\frac{V_{mpp} + I_{mpp} * R_S}{A*V_T}\right)-1\right] - P_{\max}\right\}} \quad (9)$$

This equation means that for any value of R_S there will be a value of R_{SH} that makes the mathematical I-V curve cross the experimental (V_{mpp}; I_{mpp}) point (M. Vilalva, *et al*, 2009). To start the iteration process, the suitable initial data for R_{SH} and R_S are fixed. The initial conditions for both resistances are given below:

$$R_{S,initial} = 0 \quad (10)$$

$$R_{SH,initial} = \frac{V_{mpp}}{I_{SC}(T_{ref}) - I_{mpp}} - \frac{V_{OC}(T_{ref}) - V_{mpp}}{I_{mpp}} \quad (11)$$

In the iterative process R_S must be slowly incremented. For every iteration, the value of R_{SH} is obtained simultaneously using equation (9). Furthermore, we can compute the output current value of the cell using the Newton-Raphson approach that we have developed in a Matlab script. The flowchart of the proposed approach is shown in fig. 1.

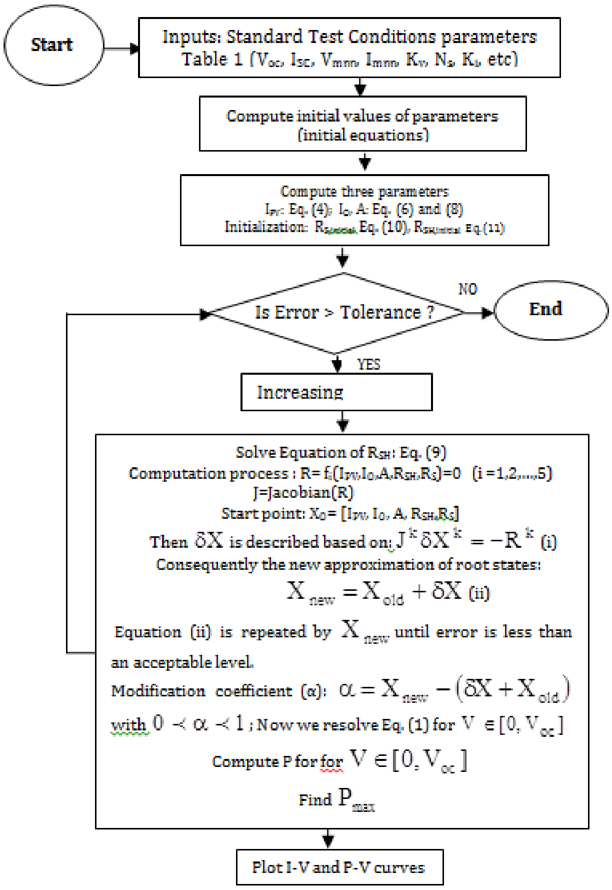


Fig.1 Flowchart of the parameter extraction approach

Table 1 Selected solar modules specifications in the experiments at STC

	Crystalline modules			Thin film modules		Amorphous module
Parameters	SM55	MSX-60	KC200GT	FS-277	SPV80-TF	QS60DU
Types	Si-mono	Si-poly	Si-poly	CdTe	Cis	a-Si: H single
Efficiencies (%)	12.89	10.75	14.20	10.84	10.11	5.46
P_{mpp}(W)	55	60	200	77.50	80	60
I_{SC}(A)	3.45	3.80	8.21	1.22	2.26	1.30
I_{mpp}(A)	3.15	3.50	7.61	1.11	1.95	1.00
V_{OC}(V)	21.70	21.10	32.90	90.50	56.5	77
V_{mpp}(V)	17.40	17.10	26.30	70.10	41	60.30
K_V(mV/°C)	-74	-80	-123	-184	-189	-343
K_i(mA/°C)	2.3	3	0.90	0.50	0.90	0.90
N_S	36	36	24	116	99	100

Table 2 Extracted parameters for six (06) solar modules at T=25° and G = 1000 W/m^2

	Crystalline modules			Thin film modules		Amorphous module
Parameters	SM55	MSX-60	KC200GT	FS-277	SPV80-TF	QS60DU
I_O(10^{-9}A)	49	180	985	3	809	9
I_{PV}(A)	3.452	3.811	8.213	1.21	2.259	1.30
A	1.30	1.35	1.35	1.55	1.50	1.65
R_S(Ω)	0.36	0.180	0.221	5.10	3.70	2.39
R_{SH}(Ω)	300	360.00	415.3	800	650	600
I_{SC}(A)	3.450	3.80	8.21	1.22	2.26	1.30
I_{mpp}(A)	3.150	3.501	7.610	1.11	1.950	1.06
V_{mpp}(V)	17.40	17.14	26.30	70.1	41	60
V_{OC}(V)	21.70	21.10	32.90	90.5	56.50	77
P_{mpp}(W)	55	60	200	7.50	80	60

Table 3 Extracted parameters for solar modules at different conditions

Types of modules	G(W/m^2) T(°C)	200 25	400 25	600 25	800 25	1000 25	1000 50	1000 75
SM55	I_{SC}(A)	0.69	1.38	2.07	2.76	3.45	3.51	3.56
	V_{OC}(V)	19.7	20.6	21.1	21.4	21.7	19.8	18
	I_{mpp}(A)	0.62	1.25	1.89	2.54	3.15	3.18	3.17
	V_{mpp}(V)	16.2	16.8	17.1	17.2	17.4	15.14	13.6
	P_{mpp}(W)	10.1	21.1	32.3	43.7	55	49	43.1
MSX-60	I_{SC}(A)	0.76	1.52	2.28	3.04	3.8	3.87	3.95
	V_{OC}(V)	19.1	19.9	20.5	20.8	21.1	19.20	17.3
	I_{mpp}(A)	0.68	1.38	2.8	2.78	3.49	3.51	3.51
	V_{mpp}(V)	15.6	16.4	16.1	17	17.2	15.2	13.3
	P_{mpp}(W)	10.7	22.5	34.3	47.3	60.0	53.4	46.8
KC200GT	I_{SC}(A)	1.64	3.28	4.93	6.57	8.21	8.29	8.37
	V_{OC}(V)	29.8	31.2	31.9	32.5	32.9	30.1	27.3
	I_{mpp}(A)	1.40	2.99	4.5	6.02	7.55	7.52	7.46
	V_{mpp}(V)	24.5	25.6	26.1	26.4	56.5	23.7	20.9
	P_{mpp}(W)	36.3	76.3	117	159	200	178	156
FS-277	I_{SC}(A)	0.24	0.49	0.73	0.98	1.22	1.23	1.24
	V_{OC}(V)	83.3	86.4	88.2	89.5	90.5	86.1	81.9
	I_{mpp}(A)	0.22	0.44	0.66	0.88	1.09	1.10	1.10
	V_{mpp}(V)	68.8	70.8	71.5	71.6	71.6	66.7	62.2
	P_{mpp}(W)	15.2	31.2	47.1	62.7	78.1	73.1	68.2
SPV-80 TF	I_{SC}(A)	0.45	0.91	1.36	1.81	2.26	2.28	2.30
	V_{OC}(V)	50.2	52.9	54.5	55.6	56.5	51.7	46.9
	I_{mpp}(A)	0.38	0.78	1.18	1.58	1.98	1.96	1.92
	V_{mpp}(V)	39.4	40.7	40.9	40.8	40.4	35.9	31.5
	P_{mpp}(W)	15.2	31.8	48.5	64.6	80	70.10	60.3
QS60DU	I_{SC}(A)	0.26	0.52	0.78	1.04	1.30	1.32	1.34
	V_{OC}(V)	71.1	73.7	75.1	76.2	77	67.3	58.7
	I_{mpp}(A)	0.20	0.40	0.59	0.79	1.00	1.05	1.05
	V_{mpp}(V)	57.3	58	59.5	60	60.3	52.3	44.6
	P_{mpp}(W)	11.7	23.6	35.3	47.4	60.3	55	48.4

3. Analysis and Discussion

The single diode model presented and described in the paper is applied by measured parameters of PV modules. Six commercials modules are selected and used in the model verification. The experimental data is extracted from the manufacturer's datasheet. Six modules of different types are utilized. These include the mono-crystalline (SM55), poly-crystalline (MSX60, KC200GT), Thin-film types (SPV80-TF, FS-277) and amorphous silicon type (QS60DU). The specifications of these modules are summarized in table 1. The calculated results are compared with the explicit model (E. Saloux, *et al*, 2011) and the Rs-approach (G. Walker, 2001). The Table 2 and 3 give the extracted parameters for the different selected modules at STC (T= 25°C, G = 1000W/m^2) and different operating conditions respectively.

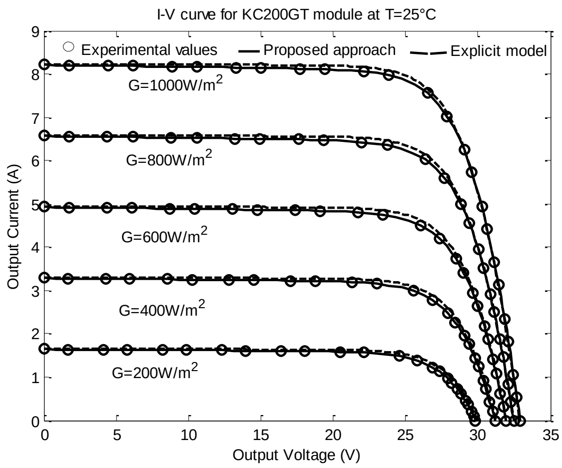


Fig.2 Current-voltage curves of proposed approach and explicit model of the KC200GT module for various irradiances

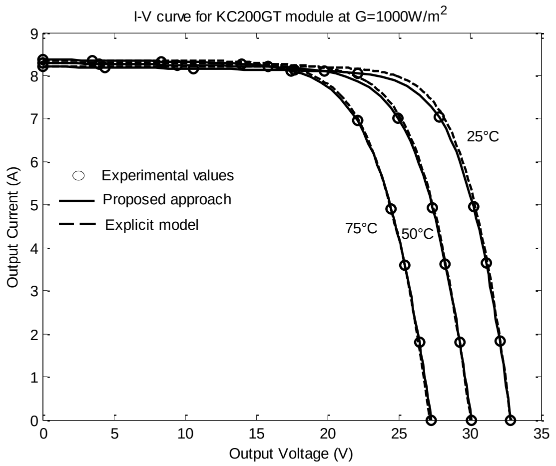


Fig.3 Current-voltage curves of proposed approach and explicit model of the KC200GT module for various temperatures

The characteristic I-V curves obtained by using the explicit model as well as the proposed approach for the KC200GT are plotted in figs.2 and 3. It can be seen that I-V curves obtained by the proposed approach strongly agrees to the experimental data. The current-voltage curves for the Rs-approach are not included to avoid the overcrowding of plots. However, a comparison between the proposed approach and the Rs-approach will be later undertaken in the performance evaluation. The performance of the proposed approach when subjected to temperature variation is shown in fig.3. The accuracy of the model was tested at different temperature levels (25°C, 50°C and 75°C). Fig.3 shows that the proposed approach accurately matches to the experimental values for all three temperature situations.

In the vicinity of the maximum point M_{mpp}, the explicit model shows deviation from the experimental values. The proposed approach and the explicit model don't exhibit similar results at this point. This is to be expected because in the proposed approach we use a maximum power matching algorithm while the explicit model doesn't use any maximum power algorithm at standard test condition.

In order to assess the accuracy of the proposed approach over current-voltage curves, a mean square error (MSE) and root mean square error (RMSE) analysis was carried out. The mean square error and root mean square error values were computed using the following equations:

$$MSE\left(I_{\exp}, I_{approach}\right) = \frac{1}{N}\sum_{i=1}^{N}\left(I_{\exp} - I_{approach}\right)^2 \qquad (11)$$

$$RMSE = \left(MSE\right)^{1/2} \qquad (12)$$

Where N is the number of samples; $I_{approach}$ the proposed approach current value and $I_{\exp}$ the experimental current values. For a comprehensive comparison the errors between our approach and the explicit model are calculated. Figs.4- 7 analyze the root means square error of V_{mpp} and P_{mpp} for KC200GT module at different irradiance and temperature levels. It can be seen that the proposed approach presents very lower errors for all operating conditions. In most cases, these maximum errors occur near the vicinity of M_{mpp} (K. Ishaque, *et al*, 2009). This is to be expected because the value of the resistance plays an important role in determining the curvature of the I-V curve. For the explicit model the series resistance is neglected for all environmental conditions. The lack of consideration of R_S will result an inaccurate current-voltage curve near M_{mpp} when the irradiance or temperature changes. Therefore R_S is calculated appropriately for every irradiance and temperature value. This justifies these low errors.

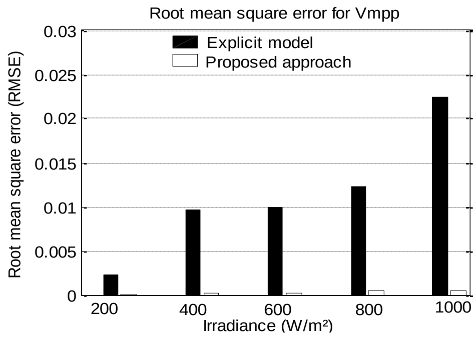
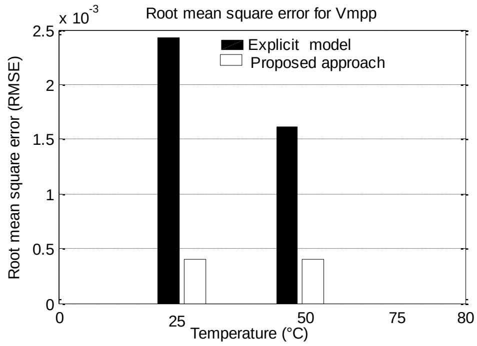


Fig.4. Root means square error for V_{mpp} for the proposed approach and the explicit model for KC200GT module for various irradiances



(b)

Fig.5. Root means square error for V_{mpp} for the proposed approach and the explicit model for KC200GT module for various temperatures

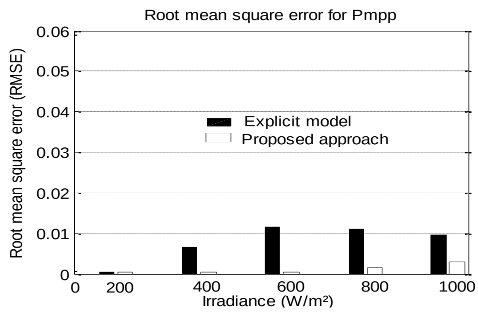


Fig.6. Root means square error for P_{mpp} for the proposed approach and the explicit model for KC200GT module for various irradiances

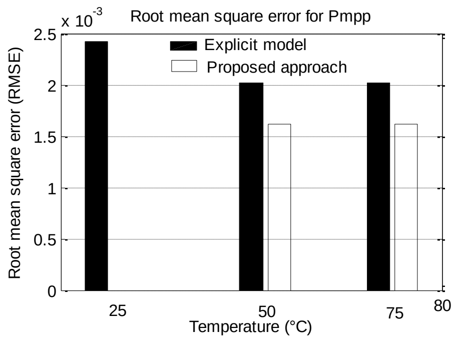


Fig.7. Root means square error for P_{mpp} for the proposed approach and the explicit model for KC200GT module for various temperatures

4. Performance evaluation of the proposed approach

In order to assess the effectiveness of the proposed approach, others technologies are carried out. RMSE accuracy has also been calculated. Figs.8 and 9 show computed I-V curves of MSX-60 module as compared with the Rs-approach (G. Walker, 2001). It can be seen that the proposed approach matches very well with the experimental values at different irradiance and temperature levels. Nevertheless, the Rs-approach exhibits deviation near the vicinity of M_{mpp} as mentioned previously. Figs.6 and 7 show the RMSE for V_{mpp} and P_{mpp} respectively computed with the proposed model and the Rs-approach for MSX-60 module. In figs.10-13, the RMSE of the proposed approach and Rs-approach is computed and exhibits very low errors for our model. Figs.14-17 show the I-V curves for FS-277 and QS60DU modules at different irradiance and temperature levels. These figures show good I-V curves of thin-film and amorphous solar module for the proposed approach. We observe that the proposed approach current-voltage curve agrees accurately to the experimental values for both types of modules. Estimated errors for both amorphous and thin film solar modules are given in table 4. The results obtained, when compared with the explicit model, indicate the viability of the proposed approach in reducing significantly the error in the extracted parameters for solar cells.

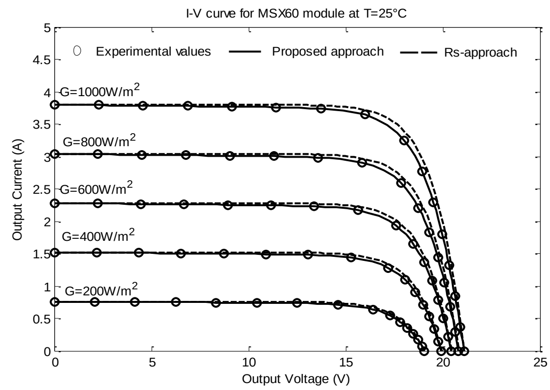


Fig.8. I-V curves of proposed approach and explicit model of the MSX60 module for various irradiances

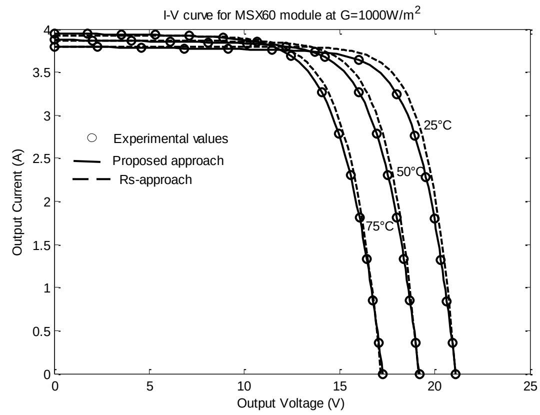


Fig.9. I-V curves of proposed approach and explicit model of the MSX60 module for various temperatures

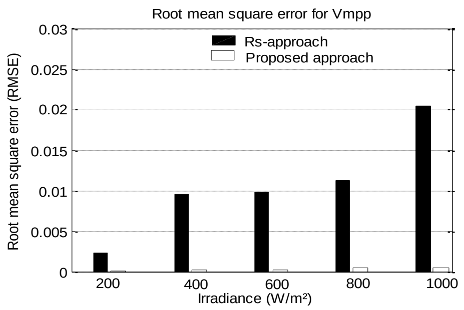


Fig.10. Root means square error for V_{mpp} for the proposed approach and the Rs-approach for MSX60 module for various irradiances

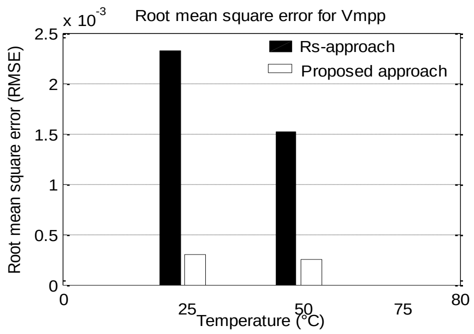


Fig.11. Root means square error for V_{mpp} for the proposed approach and the Rs-approach for MSX60 module for various temperatures

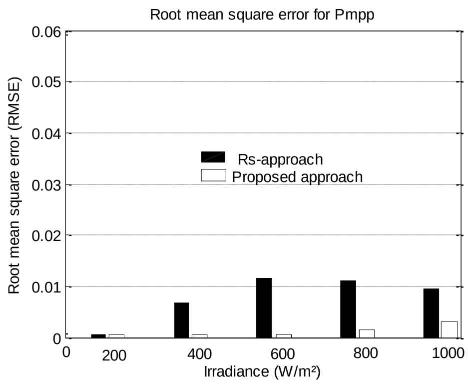


Fig.12. Root means square error for P_{mpp} for the proposed approach and the Rs-approach for MSX60 module for various irradiances

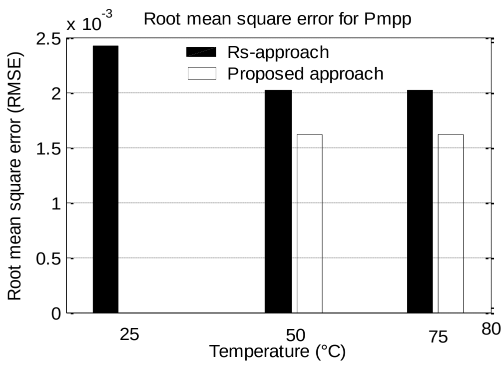


Fig.13. Root means square error for P_{mpp} for the proposed approach and the Rs-approach for MSX60 module for various temperatures

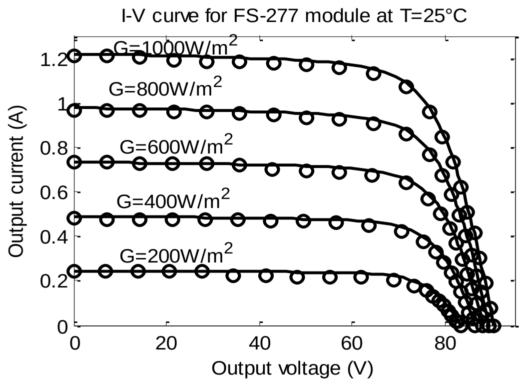


Fig.14. I-V curves of proposed approach and experimental values of the FS-277 module for various irradiances

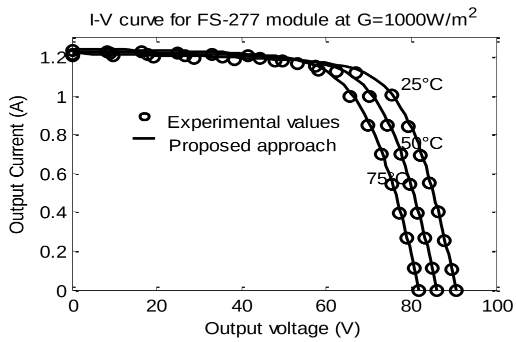


Fig.15. I-V curves of proposed approach and experimental values of the FS-277 module for various temperatures

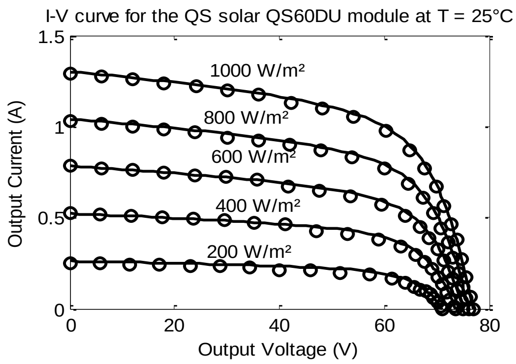


Fig.16. I-V curves of proposed approach and experimental values of the QS60DU module for irradiances

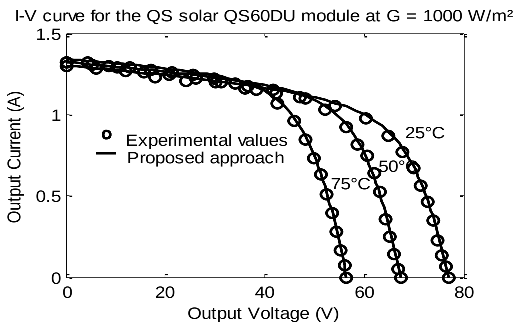


Fig.17. I-V curves of proposed approach and experimental values of the QS60DU module for temperatures

Table 4 Comparison of the proposed approach and explicit model [13] (T= 25°C and G = 1000W/m^2)

Parameters		I_{SC}(%)	V_{oc}(%)	I_{mpp}(%)	V_{mpp}(%)
Amorphous module (QS60DU)					
Explicit model	*RMSE*	**1.2**	**0.0016**	**0.5**	**0.81**
Proposed model	*RMSE*	0.303	0.000	0.00608	0.0038
Thin film module (FS-277)					
Explicit model	*RMSE*	**0.007**	**1.77**	**0.76**	**0.048**
Proposed model	*RMSE*	0.000	0.0378	0.0259	0.018

Conclusions

This paper proposed an improved numerical approach modeling for I-V characteristics of PV modules. The performance of the PV module in dependence of irradiance and temperature was investigated. The parameters used in the testing procedures to describe the performance of a PV module are based on the single diode model of a PV cell. The five parameters (I_{PV}, I_o, A, R_S and R_{SH}) are obtained by imposing on both the computed I-V characteristics and I-V characteristics measured by manufacturers. The thermal performance of the proposed approach is improved by means of a coefficient that is computed using the maximum power temperature coefficient which is a data usually provide by manufacturers. The capacity of the proposed approach to computed I-V characteristics was tested by comparing the results with the explicit model and Rs-approach was made and exhibits very lower errors. The differences between the computed and the measured values are always less than the values tolerance declared by the manufacturers. In most cases the proposed approach resulted more precise than the explicit model and the Rs-approach.

The results of the application of the proposed approach confirm the reliability of the proposed procedure. In general it was found that the proposed approach is very accurate and converges to the solution very rapidly with high consistency.

Acknowledgments

This work was supported by a fellowship from Pimaso, a program financed by the European Union (E.U)

References

H. Meekki, A. Mellit, H. Sall, and Belhout (2007), Modeling and simulation of photovoltaic panel based on artificial neural networks and VHDL-language, 4th inter. Conference on Computer integrated Manufacturing CIP'.

L. Castaner, S. Silvestre (2002), Modeling photovoltaic system using Pspice, John Wiley & Sons.

M. Chegaar, G. Azzouzi, P. Mialhe (2006). Simple parameter extraction method for illuminated Solar cells,Solid-State Electronics 50, 1234-1237.

M. Chegaar, Z. Ouennoughi, F. Guechi (2004), extraction dc parameters of solar cells under illumination, Vacuum 75, 367-372.

M.Chegaar,Z.Ouennoughi, A.Hoffman (2001), A new method for evaluating illuminated solar cell parameters, Solid-State Electronics 45, 293-296.

A Ortiz-Conde, Francisco J, G. Sánchez, J. Muci (2006), New method to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I–V characteristics, Solar Energy Materials and Solar Cells ;vol. 90, 352–361.

A. Jain, A. Kapoor (2005). A new method to determine the diode ideality factor of real solar cell using Lambert W-function, Solar Energy Materials & Solar cells 85, 391-396.

A. Jain, A. Kapoor (2004). Exact analytical solution of the parameters of real solar cells using Lambert W-function, Solar Energy Materials & Solar cells 81, pp. 269-277.

M. A. De Blas, J. L. Torres, E. Prieto, A. Garcia (2002). Selecting a suitable model for characterizing PV devices, Renewable energy 25, pp. 371-380.

F. Ghani, M. Duke, J. Garson (2013). Numerical calculation of series and shunt resistances and diode quality factor of a photovoltaic cell using the Lambert W-function, Solar Energy 91, pp. 422-431.

M. G Villalva, J. R. Gazoli and E. R. Filho (2009). Modeling and circuit based simulation of photovoltaic arrays. Brazilian Journal of Power Elctronics 14, NO.1, pp.35-45.

K. Ishaque, Z. Salam, S. Mekhilef and A. Shamsudin (2012), "Parameter extraction of solar photovoltaic modules using penalty-based differential evolution", Applied Energy, vol. 99, pp.297-308.

E. Saloux, A. Teyssedou, M. Sorin (2011). explicit model of photvoltaic panels to determine voltages and currents at the maximum power point. Solar Energy, pp. 713-722.

Geoff Walker (2001), Evaluating MPPT converter topologies using a MATLAB PV model. J. Elect. Electron. Eng. Australia, vol. 21, pp. 49–56.

M. Bashahu and A. Habyarimana (1995). Review and test of methods for determination of the solar cell series resistance. Renewable Energy ,Vol.6, No.2, pp. 129-138.

D .S .H .Chan, J. R. Phillips and J. C. H. Phang (1986). A comparative study of extraction methods for solar cell model parameters. Solid-State Electronics, Vol. 29, No.3, pp. 329-337.

SM55. Siemens solar module datasheet [online] available http:// www.siemenssolarpv.com>

Solarex MSX-60 solar arrays datasheet [online] available http:/www.californiasolarcenter.org

KC200GT. Efficiency multi-crystalline photovoltaic module datasheet Kyocera [online] available http:// www.kyocera.com.sg/products/solar

SPV80-TF: Schueco Module Datasheet [online] available http:// www.schueco.de

FS-277: First Solar Module Datasheet [online] available http:// www.firstsolar.com

QS60DU: QS Solar Module Datasheet [online] available http:// www.qssolar.com