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A Fast Strategy to determine the Physical and Electrical Parameters of Photovoltaic Silicon Cell

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ABSTRACT

This paper proposes a fast strategy to extract and exploit the electrical parameters of photovoltaic cell using the double-diode model. The polycrystalline silicon (poly-Si) junction is chosen in this work due to the importance of its proprieties in industrial and economic fields. The proposed method to extract the solar cell electrical parameters contains two steps. The first is based on the graphical adjustments to choose the initial values of these parameters, and the second is numerical, using Modified Newton-Raphson's algorithm. The obtained parameters extractions values are compared to the others methods and give a considerable agreement. Furthermore, we have developed a complementary analytical method to deduce both the minority's carrier's lifetime and the diffusion lengths through the diffusion and recombination current densities. The found values of these parameters are precisely comparable with theoretical models, and give very useful informations on the intrinsic quality of the studied cell.

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1. INTRODUCTION

In recent years, the Photovoltaic Cells (PVC) based on semiconductor junction, in particular on polycrystalline silicon (poly-Si), know a great focus because they have several proprieties as the low cost and simplicities during manufacturing stages. Many research works in the PVC fields allow to ameliorate the photovoltaic conversion efficiencies to exceed the range between 19.8% and 23% [1], [2]. To better understand of the physical mechanisms inside the solar cell, we must to precisely determine these electrical parameters values. The real model of PVC contains both the series and parallel resistances, and two ideal diodes [3], [4]. A good handling of this model requires precise determination of its electrical parameters. The values of the latter are not given by the data sheet of the manufacturer of these PVC. Moreover, they are not directly measurable by the experimental set-ups. Several numerical techniques have been used for the identification of these parameters such as the least square method [5], the Newton's method [6], and the Levenberg Marquardt's method [7].

In this work, the used model of PVC depends on seven electrical parameters (photocurrent I_{ph}, diffusion saturation current I_{s_1}, ideality factor n_1 of diode 1, recombination saturation current I_{s_2}, ideality factor n_2 of the second diode, series resistance R_s and shunt resistance R_{sh}). The proposed method in this work is based on the Newton's algorithm. One of the problems in using this last is the choice of the initial values; a poor choice of these parameters can produce a divergence of this method. This is why it is interesting to initialize the Newton's method with values given by other complementary methods, such as the graphical one [8].

Nowadays, a better determination of the minority carrier's lifetime permits judging the quality of the PVC material [9]. A high value of lifetime indicates a good material, while a low lifetime can inform the inadequate technical problems of PVC construction as a dislocations or high impurity concentrations in this material [10], [11]. The objective of this paper, in one hand, is to determine the seven electrical parameters of the pn Si-poly using the developed algorithm. In the other hand, the exploitation of the found electrical parameters make it possible to deduce both the minority carrier's lifetime and diffusion lengths using the analytical method.

2. SOLAR CELL MODELING

2.1. Electrical model of double diode

The photovoltaic cells can be represented by the Shockley double diode model and his equivalent electrical circuit is described by the diagram of Figure 1 [12]. The analytical relationship between the current I and the voltage V of this model is:

$$I = I_{ph} - I_{s_1}(exp((V + IR_s)/n_1V_{th}) - 1) - I_{s_2}(exp((V + IR_s)/n_2V_{th}) - 1) - (V + IR_s)/R_{sh} \quad (1)$$

The electrical terms of this equation are the photocurrentI_{ph}, the diffusion reverse saturation currentI_{s_1}, the recombination reverse saturation currentI_{s_2}, the ideality factors of the two diodes(n_1, n_2), the series resistanceR_s, the parallel resistance (or shunt) R_{sh}. The thermal voltage ($V_{th} = KT/q$) of the PVC is equal approximately to $26\,\text{mV}$ at$25\,°C$, (q) is the elementary electron charge, (K) is the Boltzmann's constant, and (T) is the absolute cell temperature.

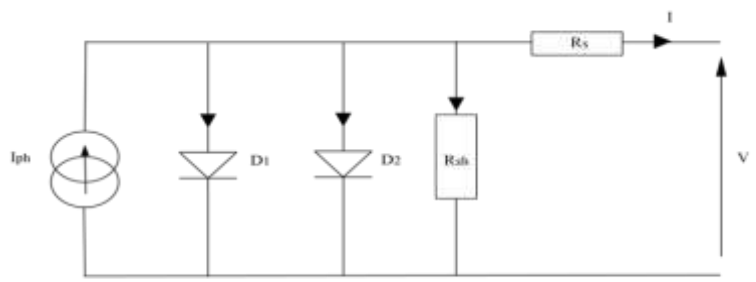

Figure 1. The double-diode equivalent circuit model

2.2. Minoity carrier lifetime measurement

As cited previously, the minority carrier recombination is quantified by their lifetimes. The dominant type of recombination in the silicon is the Shockley–Read–Hall (SRH) mechanism. In this last, the recombination of the electron doesn't follow a direct transition from the conduction to the valence bands, but it follows an indirect transition via the recombination zones which his energy level is located in forbidden band gap. Also, the bulk recombination lifetime of minority carriers τ_{SRH} is highly depending on the density and the position of these traps. The (τ_{SRH}) is identified by the following equation [13]:

$$\tau_{SRH} = \Delta n/U_{SRH} \quad (2)$$

Where (Δn)the excess of the charge carriers is related to the equilibrium, and (U_{SRH}) is the recombination rate SRH in the PVC. This lifetime in the junction can identify the diffusion length of the minority carrier. This last represents the average distance that a photo-generated carrier can cross before it is recombined. The relationship between τ_{SRH} and (L) is defined by the following formula [13]:

$$L = \sqrt{D.\tau_{SRH}} \quad (3)$$

With (D) is the diffusion coefficient, and the lifetime τ_{SRH} depends on the defects level in the junction.

3. PROPOSED METHOD OF ELECTRICAL PARAMETERS EXTRACTION

The extraction of photovoltaic parameters necessitates the resolution of nonlinear Equation (1), which is difficult to obtain analytically accurate values of these parameters with analytical methods. In this study, an accurate numerical method to extract these parameters is presented using two steps.

The best choice of initial parameters can accelerate the algorithm convergence. Contrary, poor initial values increase the iterations number and can affect on the optimization algorithm. In literature many techniques can determine the initial parameters of PVC used to start the Newton Raphson's method [14], [15].

3.1. Resistances values of R_s and R_{sh}

The initial estimation of these resistances R_{s0} and R_{sh0}, can be calculated by graphical method [16]. In the small voltage values, the I=f (V) curve is linear:

$$I = I_{ph} - (V + R_s I)/R_{sh} \tag{4}$$

This equation can be written:

$$I = I_{pA} - G_a V \tag{5}$$

With $I_{pA} = I_{ph}/(1 + G_{sh} R_s)$ and $G_a = G_{sh}/(1 + G_{sh} R_s)$

Thus, G_a is the right slope with a value $G_a \approx \frac{1}{R_{sh}}$. Knowing that $(G_{sh} R_s \gg 1)$, the shunt resistance R_{sh}, is the inverse tangent of the line at the point $(V = 0, I = I_{sc})$ which is expressed as :

$$1/R_{sh0} = (dI/dV)_{I=I_{sc}} = tg(\beta) \tag{6}$$

- In the high voltage values of the curve I=f (V), the current through the cell is given by:

$$I_c = I_{ph} - I_0 exp(\beta(V + R_s I)/n) \tag{7}$$

To determine the R_s series resistance, the voltage V is written as independent variable in Equation (7) to give the following equation:

$$V = \frac{n}{\beta} ln\left(I_{pA}/I_0\right) - R_s I + \frac{n}{\beta} ln\left(1 - I_c/I_{pa}\right) \tag{8}$$

The $(-R_s)$ is the slope of this equation and the $\tan(\alpha)$ at the point $(V = V_{oc}, I = 0)$, can be written as:

$$tan(\alpha) = (dI/dV)_{V=V_{oc}} = -1/R_{s0} \tag{9}$$

The initial value of photocurrent I_{ph}^0 can be deduced from R_{s0} , R_{sh0} and I_{sc} as:

$$I_{ph}^0 = I_{sc}\,(R_{s0} + R_{sh0})/R_{sh0} \tag{10}$$

3.2. Diode ideality factors

In equation (1), the first diode (D_1) represents a diffusion process of load carriers, while the second diode (D_2) represents the carrier's recombination in the space charge region. Several authors use the ideality factors ($n_1 = 1$ and $n_2 = 1$) in ideal cell but these values become unsuitable for a real diode [17], [18]. To initialize these factors (n_1^0, n_2^0) we choose the initial values of ideality factors equal to (1, 2) respectively.

3.3. Saturation current Is_1 and Is_2

The saturation currents I_{s_1} and I_{s_2} are determined from the Equation (1) at points $A_1(0, I_{sc})$ and $A_2(V_{co}, 0)$. A system of two equations was obtained and solved with Cramer's method [19].

$$I_{s_1}[\exp(V_{co}/(n_1 V_t)) - 1] + I_{s_2}[\exp(V_{co}/(n_2 V_t)) - 1] = I_{ph} - V_{co}/R_{sh} \tag{11}$$

$$I_{s_1}[\exp((I_{sc} R_s)/(n_1 V_t)) - 1] + I_{s_2}[\exp((I_{sc} R_s)/(n_2 V_t)) - 1] = I_{ph} - I_{sc} - (I_{sc} R_s)/R_{sh} \tag{12}$$

Using the matrix notation, this equation system can be written as:

$$I_{s_1} A_{11} + A_{12} I_{s_2} = I_{ph} - I_{sc} - (I_{sc} R_s)/R_{sh} \tag{13}$$

$$A_{21}I_{s_1} + A_{22}I_{s_2} = I_{ph} - V_{co}/R_{sh} \quad (14)$$

With, $A_{11} = [exp((I_{sc}R_s)/(n_1V_t)) - 1]$, $A_{12} = [\exp(I_{sc}R_s)/(n_2V_t)) - 1]$, $A_{21} = [\exp((V_{co})/(n_1V_t)) - 1]$, $A_{22} = [exp((V_{co})/(n_2V_t))) - 1]$, $B_1 = I_{ph} - I_{sc} - (I_{sc}R_s)/R_{sh}$, $B_2 = I_{ph} - V_{co}/R_{sh}$
The system solution formed by the Eq. (13) and Eq. (14) is given as follows [20]:

$$I_{s_1}^0 = (B_2A_{12} - B_1A_{22})/det \quad (15)$$

$$I_{s_2}^0 = (B_2A_{11} - B_1A_{21})/det \quad (16)$$

Where (*det*) is the matrix determinant: $\det = (A_{22}A_{12} - A_{12}A_{21})$

4. DEVELOPED METHOD

Our approach is based on the Newton-Raphson's method to solve the nonlinear equation of (f(x)=0). The algorithm of this method use the Taylor development at the order 1 in initial value x0 of solution. The root approximation of the equation (f(x)=0) is given as:

$$x_{i+1} = x_i - f(x_i)/f'(x_i) \quad (17)$$

Where (i) is the iteration number and f'(x) is the derivative of the function f(x). After each iteration, the developed software program is stopped when $|f(x_{i+1})| < \varepsilon$, ($\varepsilon$: stopping tolerance). In this condition, the equation (1) becomes as:

$$F(I,V) = -I_{s_1}(\exp((V + IR_s)/(n_1V_{th})) - 1) - I_{s_2}(\exp((V + IR_s)/(n_2V_{th})) - 1) - (V + IR_s)/(R_{sh}) - I = 0 \quad (18)$$

In this study, the function variables are $x_1, x_2, , \ldots, x_M$. these latter represent seven electrical parameters of PVC. These variables are the elements of the vector X ($X = [x_1, x_2, \ldots, x_M]$) and the problem is presented by (N) equations as the following compacted form $F_i(x_1, x_2, \ldots, x_M) = 0$ with$(i = 1,2, \ldots, N)$. The obtained system contains a equations number greater than the seven parameters. In this case, the obtained Jacobian matrix (J) is not a square matrix, so we must use the pseudo inverse of the Jacobian(J^+). Thus, the parameters vector (X) to be identified are updated at each iteration of the modified Newton-Raphson's method (MNR) [21]:

$$X_{i+1} = X_i - [J^+]_i . [\underline{F}]_i \quad (19)$$

Where X_i is the vector containing the resulting parameters at iteration(i), F_i is the elements of vector F and $(i = 1, \ldots, N)$ and (N) is the number of values in a set of data). The row vector elements (J_i) is given by: $J_i = [\partial F_i/\partial x_1, \partial F_i/\partial x_2, \ldots, \partial F_i/\partial x_M]$, and the iterative process will stop, when the error $\|X_{i+1} - X_i\| \le \varepsilon$. The main steps of computational algorithm to estimate the PV parameters are shown in Figure 2.

5. RESULTS AND DISCUSSIONS

5.1. Determination of electrical parameters of PVC

The used database in this study consists of 26 points (N=26) of I-V measurements. These experimental values are ranging from (-0.2V, 0.764A) to (0.59V, -0.21A) [22], [23].

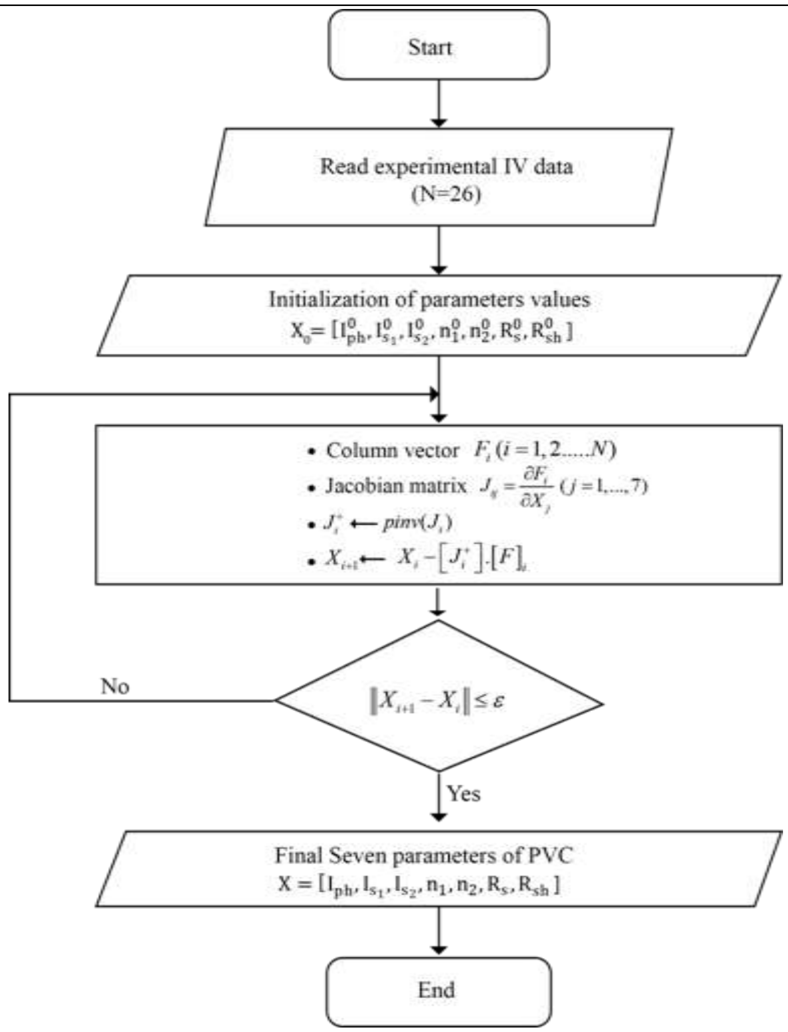

Figure 2. The flowchart of proposed algorithm for solar cell parameters estimation.

An experimental investigation of PVC is defined in the standard test condition (STC) which is the Air Mass 1.5 spectrum, an incident power density $P_i$of $1000\ W.m^{-2}$ and a temperature of 25 ºC. Using the proposed method, the obtained current (I), power (P), and absolute current error (E) versus the voltage (V) are presented in the Figure 3. This error is defined as:

$$E = \sum_{i=1}^{N}(I_i^m - I(V_i, X))^2 \quad (20)$$

Where I_i^m, V_i^m are the measured current and voltage respectively. $I(V_i^m, X)$ is the calculated current by Equation (1) and (X) is electrical parameters vector defined in Equation (29). As it is observed in Figure 3(a) and Figure 3(b), satisfactory agreement is remarkable between the obtained results and the experimental data. To confirm this observation, the deviation between the measured and the calculated current is relatively small; it does not exceed 7 mA as shown in Figure 3(c). By analyzing the error variation in this curve, the output voltage increases significantly with error (E). This result obliges us to take into account the step voltage (δV) which is variable during the measurement process. Therefore, for the high voltage measurement, the values of step voltage must be small.

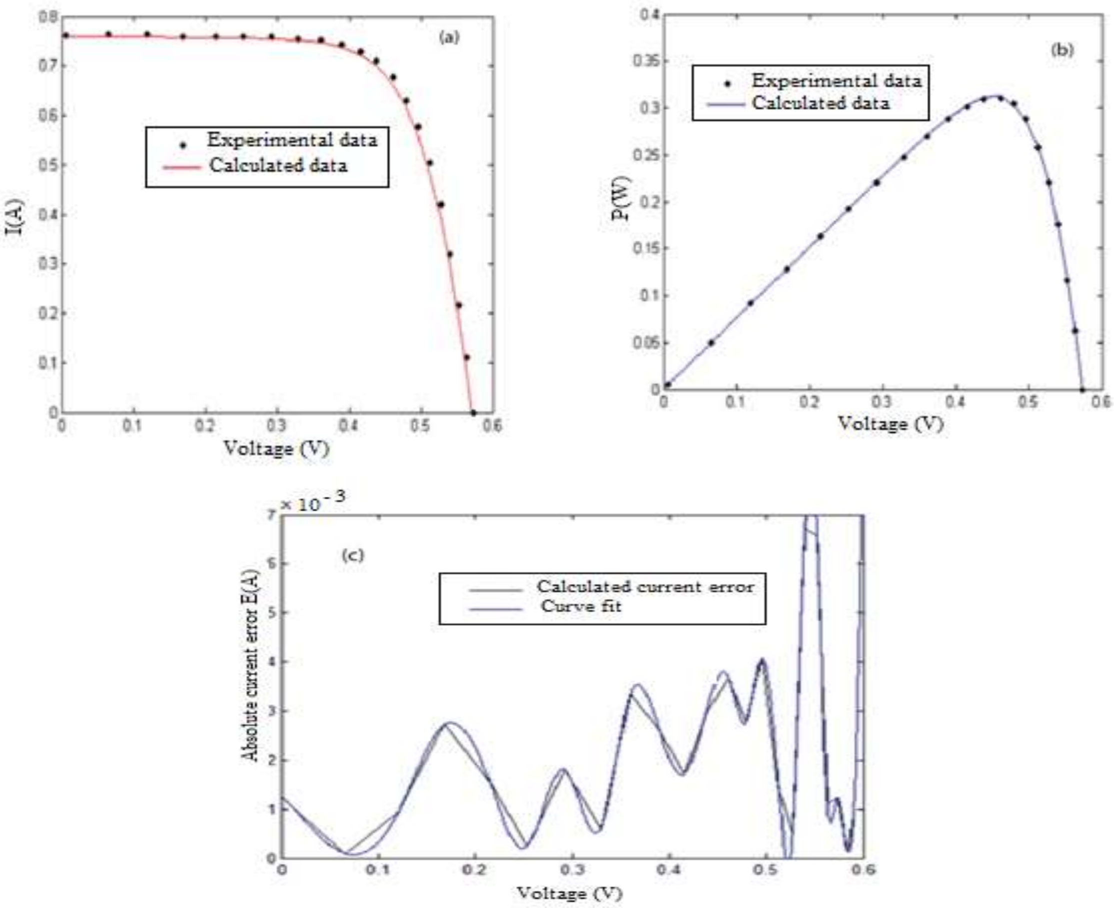

Figure 3. (a) *I-V* characteristics, (b) *P-V* characteristics of calculated and experimental measurements and (c) the variation of absolute current error with voltage

Using developed method, the initial values of seven electrical parameters and their optimal final values are listed in Table 1. In this table, some reference values are presented to be compared with the final ones [24]. It's noted that the initial and final values are closer but they show significant variations. Also, the found optimal values by the developed method are very similar to those given in the reference. These results show the importance of initialization stage because they permit a fast convergence of developed algorithm. To analyze the performance of the proposed technique, many statistical errors are calculated and interpreted. These indicators are the standard deviation (SD), the root mean square error (RMSE), the mean bias error (MBE), and the "t-statistics". Their analytical expressions are defined as follows [8, 24]:

$$SD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(I_i - I_i^m)^2},\ RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(I_i - I_i^m)^2},\ MBE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(I_i - I_i^m)},$$
$$t = \sqrt{(N-1)MBE^2/(RMSE^2 - MBE^2)} \quad (21)$$

Table 1. Extracted Electrical Parameters for Poly-Si solar Cell in Reference [24] and in this Work

Electrical parameters	Initial values	Final values	In reference [24]
I_{ph} (A)	0.7675	0.7643	0.7602
Is_1(A)	2.77×10^{-10}	1.7432×10^{-10}	10-10
Is_2(A)	8.13×10^{-10}	5.3975×10^{-6}	9.889×10^{-7}
N_1	1	0.99	1.6
N_2	2	2.00	1.192
R_s(Ω)	0.045	0.0450	0.032
R_{sh}(Ω)	61.549	61.5495	81.3

The obtained statistical errors provide information on the over or under-estimation of the calculated values related to the experimental data. Indeed, a higher value of RMSE indicates that there is an inappropriate adopted model. A positive value of MBE implies an overestimation of the fitting curve compared to the data base. A small value of 't-statistical' error indicates that the used model is correctly specified.

The found values of these statistical indicators are presented in Table 2, and compared with reference values [24]. This table shows that developed method is powerful and accurate, and indicates that extracted PVC parameters are more precise than those found by another works [24]. Indeed, the errors (SD, RMSE and NRMSE) are ameliorated about 10 times, while the other errors (MBE and t) are ameliorated 10^5 times.

Table 2. Statistical Indicators Results of Electrical Model.

Indicateurs statistiques	Our method	In reference [24]
$S_D(10^{-3})$	2.79	20.32
RMSE (10^{-3})	2.73	19.92
MBE (10^{-3})	5.1×10^{-5}	-14.10
t (10^{-5})	9.3×10^{-5}	5.01

5.2. Determination of lifetime and diffusion length carrier minorities

In order to link the electrical with the physical parameters the Shockley–Read–Hall (SRH) theory is used. The studied parameters in this relationship are the minority carrier lifetimes (τ_n, τ_p) and length diffusion (L_n, L_p) in regions P and N respectively. In this work, a surface (S=2 cm^2) of p-n Silicon is chosen with other physical parameters listed in Table 3.

In literature, the current densities (J_{01}, J_{02}) of diode 1 and 2 respectively are defined as [25], [26]:

$$J_{01} = q\frac{n_i^2}{N_a}\sqrt{D_n/\tau_n} + q\frac{n_i^2}{N_d}\sqrt{D_p/\tau_p} \quad (22)$$

$$J_{02} \approx \pi\, qWn_i/\sqrt{\tau_n\tau_p} \quad (23)$$

Where (n_i) is the intrinsic carrier density, (W) is depletion layer width, (N_a) and (N_d) are acceptor and donor densities, (D_n) and (D_p) are the diffusion coefficients of minority carriers, (τ_n) and (τ_p) are lifetimes of minority carriers in P and N regions respectively. In equation (23) the expression (W) is given as:

$$W = \sqrt{\frac{2\epsilon}{q}(1/N_a + 1/N_d)V_{bi}} \quad (24)$$

Table 3. Device and material parameters of *np* poly-Si solar cell used in calculation

Physical parameters	Parameters values
$N_i(cm^{-3})$	1.5×10^{10}
$E_g(eV)$	1.12
$N_a(cm^{-3})$	10^{15}
$N_d(cm^{-3})$	5×10^{18}
$D_n(cm^2/s)$	34.49
$D_p(cm^2/s)$	11.75
W(μm)	1.01
$V_{bi}(V)$	0.795

Where ϵ is the absolute dielectric constant of the semiconductor, and V_{bi} is the built-in voltage across the p-n junction expressed as:

$$V_{bi} = V_t\ln((N_aN_d)/n_i^2) \quad (25)$$

The preceding equations are simplified and written as:

$$a\sqrt{\tau_p} + b\sqrt{\tau_n} = c\,J_{01}/J_{02} \text{ and } \sqrt{\tau_n\tau_p} = c/J_{02} \quad (26)$$

With $a = q\sqrt{D_n}\, n_i^2/N_a,\ b = q\sqrt{D_p}\ n_i^2/N_d,\ c = \pi q W n_i$

Equation (26) gives a following second order equation:

$$a(\sqrt{\tau_p})^2 - (c\,J_{01}/J_{02})\sqrt{\tau_p} + bc/J_{02} = 0 \qquad (27)$$

The solution of this equation is:

$$\sqrt{\tau_p} = ((c\,J_{01}/J_{02}) \pm \sqrt{\Delta})/ \qquad (28)$$

The discriminant of this equation is: $\Delta = cJ_{01}(cJ_{01} - 4ab)/(J_{02})^2$
For silicon semiconductor, the density (n_i) as a function of the temperature (T) can be written as [27]:

$$n_i = 4.34 \times 10^{15} \times T^{3/2} \exp(-6493/T) \qquad (29)$$

The Table 3 can be exploited to determine the physical parameters (τ_n, τ_p, L_n, and L_p) using Equation. (22-29). These parameters are presented in Table 4 and compared with those found by other research [28]. They show a small difference between τ_n in the Equation (28) and their references. However, the difference of (τ_p) is important which

Table 4. Comparison of the Physical Parameters Calculation and the Data Reported

Physical parameters	Proposed method	Reference method [28]
τ_n(s)	2.35×10^{-5}	1.17×10^{-5}
τ_p(s)	1.36×10^{-8}	1.18×10^{-7}
L_n(μm)	285	201
L_p(μm)	4	12

Approximately equal to 10%; the calculated (τ_p) is greater about 10 times than in reference [28]. This difference due to existing of recombination mechanism in the depletion region. Generally, these mechanisms are neglected in standard J_{02} formula [13]. The analytical expression of J_{02} must be corrected by an effective coefficient (α) as ($J_{02} = \alpha\, qWn_i/\sqrt{\tau_n\tau_p}$). In this case, the values of these parameters are $\tau_p = 1.22 \times 10^{-7}$ s, $L_p = 12$ μm, and α=3π.

6. CONCLUSION

This paper proposes a fast method for electrical parameters extraction of poly-Si solar cell with two diodes model. The advantages of this model are the real representation of the intrinsic material phenomena. Also it can give information about the recombination of charge carriers due to the inevitable defects in the material. The proposed method is based on the initialization values of seven electrical parameters with graphical method and the development of new algorithm. This later is based on the Newton Raphson's method to determine the optimal values of these parameters. The obtained results compared with theory and some previously published work show a good agreement with I-V experimental data. This method is very simple to use in real times measurements, and can determine easily many physical parameters like the minority carrier lifetime, diffusion length though recombination current densities. The determined values comparing with the theoretical models show an excellent agreement in level of physical and electrical parameters extraction.

REFERENCES

[1] J. Zhao, A. Wang, P. Campbell, M. A. Green, "A 19.8% efficient honeycomb multicrystalline silicon solar cell with improved light trapping," *IEEE.Transactions on Electron Devices*, vol. 46, pp. 1978–1983, 1999.
[2] N. M. A. Green, K. Emery, Y. Hishikawa, W. Warta, E. D. Dunlop, "Solar cell efficiency tables (version 37)," Progress in Photovoltaics: Research and Applications, vol. 23, pp. 3-11, 2016.
[3] E. Chahid, O.Idali, M. Fedaoui, M. Eritali and A. Malaoui, "Effect of measurement factors on photovoltaic cell parameters extracting," *International Journal of Electrical and Computer Engineering*, vol. 7, pp.50-57, 2017.
[4] M. A. Abdourraziq and M. Maaroufi, "Experimental Verification of the Main MPPT Techniques for Photovoltaic System," *International Journal of Power Electronics and Drive System*, Vol. 8, pp. 384 – 391, 2017.

[5] WH. Press, WT. Vettering, SA. Teukolsky, *Numerical Recipes in C: The Art of Scientific Computing*, 2nd Ed., Cambridge University Press, UK, 1992.

[6] T. Easwarakhanthan, J. Bottin, I. Bouhouch, C. Boutrit, "Nonlinear Minimization Algorithm for Determining the Solar Cell Parameter with Microcomputers," *Int. J. Sustain. Energ* , vol. 4, pp. 1-12, 1986.

[7] D. Marquardt," An Algorithm for Least Squares Estimation of Non Linear Parameters," *J. Soc. Indust. Appl. Math*, vol. 11, pp. 431-441, 1963.

[8] A. Malaoui, E. Barrah, J. Antari, "Implementation a new approach for modeling and determining the electrical parameters of solar cells," *Int. J. Innov. Appl. Stud*, vol. 15, pp. 329–338, 2016.

[9] J. R. Haynes, W. Shockley, "The Mobility and Life of Injected Holes and Electrons in Germanium," Phys. Rev, vol. 81, pp. 835–843, 1951.

[10] A. I. Elani Ussama, "The effective carrier lifetime measurement in silicon: The conductivity modulation method," *J. King. Saud. Univ. Sci*, vol. 22, pp. 9–13, 2010

[11] J. W. Corbett, J. C.´ Bourgoin," Les défauts ponctuels dans les semiconducteurs," *J. Phys. Colloques* , vol. 39, pp. 17-21, 1978.

[12] H. Sharma, N. Pal, Y. Singh, P. K. Sadhu, "Development and Simulation of Stand Alone Photovoltaic Model Using Matlab/Simulink, "*International Journal of Power Electronics and Drive System*, vol. 6, pp. 703-711, 2015.

[13] H. J. Hovel, *Semiconductors and Semimetals*, vol. 11, Academic, New York, 1979

[14] A. Laudani, F. Riganti-Fulginei, A. Salvini, "High performing extraction procedure for the one-diode model of a photovoltaic panel from experimental I–V curves by using reduced forms, "*Sol. Energy,* vol. 103, pp. 316–326, 2014.

[15] F. Ghani, M. Duke, J. Carson, "Numerical calculation of series and shunt resistance of a photovoltaic cell using the Lambert W-function: experimental evaluation, "*Sol. Energy*, vol. 87, pp. 246–253, 2013

[16] K. Bouzidi, M. Chegaar, A. Bouhemadou, "E interface, "*Sol. Energy. Mater. Sol. Cells*, vol. 91, pp. 1647–1651, 2007

[17] M. G. Villalva, J. R. Gazoli and E. R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," in *IEEE Transactions on Power Electronics*, vol. 24, no. 5, pp. 1198-1208, May 2009.

[18] K. Ishaque, Z. Salam, H. Taheri, "Simple, fast and accurate two diode model for photovoltaic modules, "*Solar Energy Materials and Solar Cells*, vol. 95, pp. 586–594, 2011b.

[19] J. Appelbaum, A. Peled, "Parameters extraction of solar cells – A comparative examination of three methods, "*Solar Energy Materials and Solar Cells*, vol. 122, pp. 164-173, 2014.

[20] A. Adel, A. Hamdi, A. Montaser, "Deduction of two diode model parameters for photovoltaic system, "*In: 3rd International Conference on Energy Systems and Technologies*, Cairo, pp. 121-135, 2015.

[21] A. Ben-Isael, "A Newton-Raphson method for the solution of systems of equations, " *Journal of Mathematical Analysis and Applications*, vol. 15, no. 2, pp. 243-252, August 1966.

[22] T. Easwarakhanthan, J. Bottin, I. Bouhouch, C. Boutrit, "Nonlinear Minimization Algorithm for Determining the Solar Cell Parameters with Microcomputers, " *International Journal of Solar Energy*, vol. 4, pp. 1-12, 1986.

[23] M. A. Green, A. W. Blakers, J. Q. Shi, E. M. Keller, S. R. Wenham, "High efficiency silicon solar cells, "*IEEE. Trans. Electron. Dev*, vol. 31, pp. 679-683, 1984.

[24] M. R. Al Rashidi, K. M. El-Naggar, M. F. Al Hajri, "Parameters Estimation of Double Diode Solar Cell Model, "In. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, vol. 7, pp. 118- 121, 2013.

[25] E. Simoen, J. Vantellmont, C. Layes, "Effective generation-recombination parameters in high-energy proton irradiated silicon diodes, " *Applied Physics Letters*, vol. 69, pp. 2858, 1996.

[26] K. Taretto, U. Rau, J. H. Werner, "Method to extract diffusion length from solar cell parameters—Application to polycrystalline silicon, "*Journal of Applied Physics*, vol. 93, pp. 5447-5455, 2003.

[27] Y. P. Varshni, "Temperature dependence of the energy gap in semiconductors, "*Physica*, vol. 34, pp. 149–154, 1967.

[28] J. Liou, W.W. Wong, "Comparison and optimization of the performance of Si and GaAs solar cells, "*Solar Energy Materials and Solar Cells*, vol. 28, pp. 9-28, 1992.

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