International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 1, January - 2014

Evaluation of a PV Model Based on a Novel Parameter Estimation Procedure for Different Manufacturers Modules

Mohamed Abd-El-Hakeem Mohamed,
Faculty of Engineering, Electric Eng.,
Al-Azhar University, Qena, Egypt.

Mohamed.H.Osman,
Faculty of Engineering, Electric Eng.,
Al-Azhar University, Qena, Egypt.

Abstract

This paper presents the evolution of the single diode five parameters model for different manufacturer's modules. Also a novel procedure is improved to estimate the parameters of a PV model. The proposed procedure proposes an easy and accurate alternative approach to predict the current-voltage characteristics of a photovoltaic (PV) system. The proposed procedure is used the Newton-Raphson method based on simplified method to calculate the parameters of a PV system .The initial values of these parameters are estimated by using the simplified method to prevent a bad starting point which can compromise the convergence of the Newton-Raphson's method. Also the proposed equations which are used to calculate these parameters of a PV system, allow one to calculate it's without relying on the experimental I-V curve to determine the parameters of a PV system as usually reported in literature. The proposed procedure takes the temperature dependence of the cell dark saturation current into consideration. The proposed procedure is used to calculate the parameter of different manufacturer panel models, which is able to predict the panel behaviour in different temperature and irradiance conditions, is built and tested.

Nomenclature

STC- Standard Test Conditions (E_{ref} =1000 W/m², T_{ref}=25 °C, spectrum AM1.5).
Io - Dark saturation current in STC.
Rsh- Panel parallel (shunt) resistance.
Isc - Short-circuit current in STC.
Vmpp - Voltage at the Maximum Power Point (MPP) in STC.
Pmpp - Power at the MPP in STC.
Kv - Temperature coefficient of the open-circuit voltage.
q- Electron charge.
ns - Number of cells in series.
Iph - the photo-generated current in STC.
Rs - Panel series resistance.
A - Diode quality (ideality) factor.
Voc -Open-circuit voltage in STC.
Impp - Current at the MPP in STC.
K_i- Temperature coefficient of the short-circuit current.
Vt - Junction thermal voltage.
T- Cell Temperature, in Kelvin.
V- The voltage appearing at the cell terminals.

1. Introduction

Nowadays the worldwide installed Photovoltaic power capacity shows a nearly exponential increase, despite of their still relatively high cost[1] .This, along with the research for lower cost and higher efficiency devices, motivates the research also in the control of photovoltaic inverters, to achieve higher efficiency and reliability[2,3,4]. The possibility of predicting a photovoltaic plant's behavior in various irradiance, temperature and load conditions is very important for sizing the photovoltaic plant and converter, as well as for the design of the Maximum Power Point Tracking (MPPT) and control strategy. There are numerous methods for extracting the panel parameters. The majority of the methods are based on measurements of the I-V curve or other characteristic of the panel [5-8]. Charles et al. [5] have suggested a method that analyzes the practical I-V measurements. The different mathematical methods have been presented in order to estimate the parameters of the four parameters PV model and to simulate its current-voltage and power-voltage characteristics [6]. A new approach for modeling the temperature dependence of the dark saturation current and the equation parameters can be evaluated by using five data points obtained from an experimental I-V curve is presented in paper [7]. El Tayyan [8] has proposed the new equation is that one doesn't rely on the experimental I-V curve to determine Rsh.

Many investigations were reported above, about estimation for a model of photovoltaic panels using the Newton-Raphson method but no attention was paid to the initial estimation of PV system parameters. The initial estimation of these parameters is critical because a bad starting point can compromise the convergence of the Newton-Raphson's method. On other hand, single exponential models that neglect the shunt resistance is used in [6]. However, this assumption is not generally valid for amorphous PV systems. And also, the problems of relying on the experimental I-V curve to determine of PV system parameters still unsolved. This motivates the authors to investigate the new method in order to estimate the Parameters of PV panels by using Newton-Raphson based on simplified method.

In this paper the construction of a model for a PV panel using the single-diode five-parameter model, based exclusively on data-sheet parameters. The parameters of a PV system are calculated by using the Newton-Raphson method. The initial values of these parameters are estimated by using the simplified method. Also the proposed method, allows one to calculate the parameters PV system without relying on the experimental I-V curve to determine Rsh. In this work the temperature dependence of the cell dark saturation current is taken into consideration.

2. Equivalent circuit of the solar cell

Mathematical descriptions of the I-V characteristics of PV cells are available since many years and are derived from the physics of the p-n semiconductor junction.A crystalline solar cell is, in principle, a large-area silicon diode. In the dark state, the I-V characteristic curve of this diode corresponds to the one of a normal p-n junction diode and it produces neither a voltage nor a current. Illumination of the PV cell creates free charge carriers, which allow current to flow through a connected load. The so called photocurrent I_{ph} is proportional to irradiance [9]. If the circuit is open the photocurrent is shunted internally by the p-n junction diode. The simplest equivalent circuit of a PV cell (Fig. 1) is a current source whose intensity is proportional to the incident radiation, in parallel with a diode D and a shunt resistance Rsh. This resistance represents the leakage current to the ground. The internal losses due to current flow and the connection between cells are modeled as a small series resistance Rs [9].

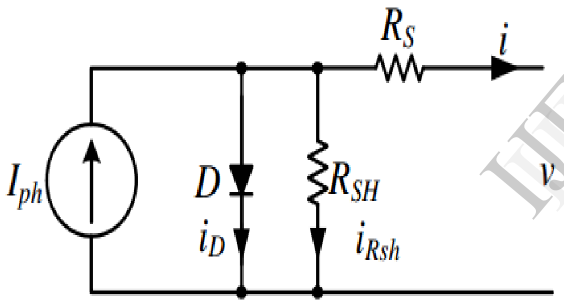

Figure.1. Equivalent circuit of a photovoltaic cell using the single exponential module

The general current-voltage characteristic of a PV panel based on the single exponential model is:

$$I = I_{ph} - I_o\left(e^{\frac{V+IR_s}{n_sV_t}} - 1\right) - \frac{V+IR_s}{R_{sh}} \quad (1)$$

In the above equation, V_t is the junction thermal voltage:-

$$V_t = \frac{AKT}{q} \quad (2)$$

It is a common practice to neglect the term '−1'in (1), as in silicon devices, the dark saturation current is very small compared to the exponential term.

3. Single diode model of PV sell

In order to construct a model of the PV panel, which exhibits the specifications described in the datasheet, using the above-mentioned single-diode model, there are five parameters to be determined: Iph, Io, A, Rs, and Rsh. The goal is to find all these parameters without any measurement, using only the data from the product data-sheet.

3.1. Starting equations

Equation (1) can be written for the three key-points of the V-I characteristic: the short-circuit point, the maximum power point and the open-circuit point.

$$I_{sc}=I_{ph} - I_o e^{\frac{I_{sc}R_s}{n_sV_t}} - \frac{I_{sc}R_s}{R_{sh}} \quad (3)$$

$$I_{mpp} = I_{ph} - I_o e^{\frac{V_{mpp}+I_{mpp}R_s}{n_sV_t}} - \frac{V_{mpp}+I_{mpp}R_s}{R_{sh}} \quad (4)$$

$$I_{oc} = 0 = I_{ph} - I_o e^{\frac{V_{oc}}{n_sV_t}} - \frac{V_{oc}}{R_{sh}} \quad (5)$$

The above parameters are normally provided by the data-sheet of the panel. An additional equation can be derived using the fact that is on the P-V characteristic of the panel, at the MPP, the derivative of power with voltage is zero.

$$\left.\frac{dP}{dV}\right|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = 0 \quad (6)$$

So far there are four equations available, but there are five parameters to find, therefore a fifth equation can be derived using the fact that is on the P-I characteristics of a PV system at the maximum power point, the derivative of power with respect to current is zero [8].

$$\left.\frac{dP}{dI}\right|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = 0 \quad (7)$$

3.2. Parameter extraction

From the expression of the current at short-circuit and open-circuit conditions, the photo-generated current Iph and the dark saturation current Io can be expressed:

$$I_{ph} = I_o e^{\frac{V_{oc}}{n_sV_t}} + \frac{V_{oc}}{R_{sh}} \quad (8)$$

By inserting Eq. (8) into Eq. (3), it takes the form:

$$I_{sc} = I_o\left(e^{\frac{V_{oc}}{n_sV_t}} - e^{\frac{I_{sc}R_s}{n_sV_t}}\right) + \frac{V_{oc}-I_{sc}R_s}{R_{sh}} \quad (9)$$

The second term in the parenthesis from the above equation can be omitted, as it has insignificant size compared to the first term. Than Eq. (9) becomes:

$$I_{sc} = I_o e^{\frac{V_{oc}}{n_sV_t}} + \frac{V_{oc}-I_{sc}R_s}{R_{sh}} \quad (10)$$

Solving the above equation for Io, results in:

$$I_o = \left(I_{sc} - \frac{V_{oc}-I_{sc}R_s}{R_{sh}}\right) e^{-\frac{V_{oc}}{n_sV_t}} \quad (11)$$

Eqs. (8) And (11) can be inserted into Eq. (4), which will take the form

$$I_{mpp} - I_{sc} + \frac{V_{mpp}+I_{mpp}R_s - I_{sc}R_s}{R_{sh}} + \left(I_{sc} - \frac{V_{oc}-I_{sc}R_s}{R_{sh}}\right) e^{\frac{V_{mpp}+I_{mpp}R_s-V_{oc}}{n_sV_t}} = f_1 \quad (12)$$

The above expression still contains three unknown parameters: Rs, Rsh, and A. The derivative of the power with voltage at MPP can be written as:

$$\frac{dP}{dV}\bigg|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = \frac{d(IV)}{dV} = I + \frac{dI}{dV}V \qquad (13)$$

Thereby, to obtain the derivative of the power at MPP, the derivative of Eq. (12) with voltage should be found. However, Eq. (12) is a transcendent equation, and it needs numerical methods to express Impp. Eq. (12) can be written in the following form:

$$I = f(I,V) \qquad (14)$$

Where $f(I,V)$is the right side of Eq. (12) .By differentiating Eq. (14):

$$dI = dI\frac{\partial f(I,V)}{\partial I} + dV\frac{\partial f(I,V)}{\partial V} \qquad (15)$$

The derivative of the current with voltage results in:

$$\frac{dI}{dV} = \frac{\frac{\partial}{\partial V}f(I,V)}{1-\frac{\partial}{\partial I}f(I,V)} \qquad (16)$$

From Eqs. (16) And (13) results:

$$\frac{dP}{dV} = I_{mpp} + \frac{V_{mpp}\frac{\partial}{\partial V}f(I,V)}{1-\frac{\partial}{\partial I}f(I,V)} \qquad (17)$$

From the above:

$$\frac{dP}{dV}\bigg|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = I_{mpp} - V_{mpp}\frac{-\frac{(I_{sc}R_s+V_{oc}-I_{sc}R_{sh})e^{\frac{V_{mpp}+I_{mpp}R_s-V_{oc}}{n_sV_t}}}{n_sV_tR_{sh}}+\frac{1}{R_{sh}}}{1-\frac{(I_{sc}R_s+V_{oc}-I_{sc}R_{sh})R_se^{\frac{V_{mpp}+I_{mpp}R_s-V_{oc}}{n_sV_t}}}{n_sV_tR_{sh}}+\frac{R_s}{R_{sh}}} = f_2 \qquad (18)$$

here are two equations now, Eqs .(12) and (18), with three unknowns. Eq. (7) can be the used as the third equation.

$$\frac{dP}{dI}\bigg|_{\substack{V=V_{mpp}\\ I=I_{mmp}}} = V_{mpp} - I_{mpp}\frac{1-\frac{(I_{sc}R_s+V_{oc}-I_{sc}R_{sh})R_se^{\frac{V_{mpp}+I_{mpp}R_s-V_{oc}}{n_sV_t}}}{n_sV_tR_{sh}}+\frac{R_s}{R_{sh}}}{-\frac{(I_{sc}R_s+V_{oc}-I_{sc}R_{sh})e^{\frac{V_{mpp}+I_{mpp}R_s-V_{oc}}{n_sV_t}}}{n_sV_tR_{sh}}+\frac{1}{R_{sh}}} = f_3 \qquad (19)$$

It is possible now to determine all the three unknown parameters, the Rs, A, and Rsh using Eqs. (12), (18) and (19). As these equations do not allow separating the unknowns and solving them analytically, they are solved using Newton Raphson iterative method is exploited because it converges remarkably quickly, especially if the iteration begin sufficiently near the desired root.

3.3. Expression of photo current Iph and dark saturation current Io

The first equations when constructing the model are the expressions of I_o from Eq. (3) and I_{ph} from Eq. (5), in STC.

$$I_o = (I_{sc} - \frac{V_{oc}-I_{sc}R_s}{R_{sh}})e^{-\frac{V_{oc}}{n_sV_t}} \qquad (20)$$

$$I_{ph} = I_o e^{\frac{V_{oc}}{n_sV_t}} + \frac{V_{oc}}{R_{sh}} \qquad (21)$$

4. Initial estimation of PV parameters by using simplified explicit method

The initial estimation of PV parameters is critical because a bad starting point can compromise the convergence of the Newton-Raphson's method. The initial values of these parameters are estimated by using the simplified method. In this method some of approximations are applied as (I_{sc}=I_{ph}, and Rsh=∞),after simplification of equations (3), (4) and (5) we obtain [6].

$$I_o = I_{sc}(e^{-\frac{V_{oc}}{n_sV_t}}) \qquad (22)$$

The equation at the point of maximum power at is turned becomes:

$$I_{mpp} = I_{sc}\left(1 - e^{\left(\frac{V_{mpp}-V_{oc}+I_{mpp}R_s}{n_sV_t}\right)}\right) \qquad (23)$$

From this equation, we can deduce the initial value of series resistance:

$$R_{so} = \frac{n_sV_t\ln\left(1-\frac{I_{mpp}}{I_{sc}}\right)+V_{oc}-V_{mpp}}{I_{mpp}} \qquad (24)$$

By exploiting the fact that the derivative of the maximum power is zero:

$$\frac{dP}{dV} = 0 = I + \frac{\partial I}{\partial V}V \qquad (25)$$

And using equation (20) one can find:

$$A_o = \frac{q(2V_{mpp}-V_{oc})}{n_sKT\left(\frac{I_{sc}}{I_{sc}-I_{mpp}}+\ln(1-\frac{I_{mpp}}{I_{sc}})\right)} \qquad (26)$$

The last parameter to be determined is the shunt resistance Rsho, from equation 5:

$$R_{sho} = \frac{(V_{oc})}{(I_{ph}-\left(I_oe^{\left(\frac{I_{sc}R_s}{n_sV_t}\right)}\right))} \qquad (27)$$

5. Parameters estimation procedure of PV panel model

This section describes the Newton-Raphson based on simplified in order to calculate the three unknown parameters (Rs, A, and Rsh) of PV panel model. Then, the other parameters $(I_o, and\ Iph)$ are calculated directly from Eqs. (21, 22) respectively. The determination of all unknown parameters (A, R_s, R_{sh}, I_{ph}, and I_o) at various temperature and irradiance conditions, are described in the following steps:-

Step1:-The parameters (A, Rs, and Rsh) are determined by using Newton-Raphson method. To apply the Newton-Raphson method for obtaining these parameters, the values of (Isc, Voc, Impp, and Vmpp) are obtained from the datasheet for different manufacturers modules (SP75 solar [10] module sand KC200GT solar module [11]) at 25 ◦C, AM1.5, and 1000 W/m2 as shown in the table1.

Table1. Shows the data obtained from the datasheet for KC200GT solar module sand SP75 solar module at 25 °C, AM1.5, and 1000 W/m^2.

Parameter	KC200GT solar module	SP75 solar module
Maximum Power (Pmpp)	200 W	75 W
Maximum Power Voltage (Vmpp)	26.3 V	17 V
Maximum Power Current (Impp)	7.61 A	4.4 A
Open Circuit Voltage (Voc)	32.9 V	21.7 V
Short Circuit Current (Isc)	8.21 A	4.8 A
Temperature Coefficient of Voc(Kv)	- 0.123V/°C	- 76 mV/°C
Temperature Coefficient of Isc (Ki)	+ 3.18 mA/°C	+ 2 mA/°C
number of cells (ns)	54	36

Step2:- The elements of the resulting Jacobian matrix (J) are obtained by differentiating equations (12), (18) and (19) with respect to the diode quality (ideality) factor (A), panel series resistance (Rs) and panel parallel (shunt) resistance (Rsh), and are collected into portioned vector matrix forms, as:

$$\underbrace{\begin{bmatrix} \frac{\partial f1}{\partial A} & \frac{\partial f1}{\partial Rs} & \frac{\partial f1}{\partial Rsh} \\ \frac{\partial f2}{\partial A} & \frac{\partial f2}{\partial Rs} & \frac{\partial f2}{\partial Rsh} \\ \frac{\partial f3}{\partial A} & \frac{\partial f3}{\partial Rs} & \frac{\partial f3}{\partial Rsh} \end{bmatrix}}_{Jacobian} \underbrace{\begin{bmatrix} \Delta A \\ \Delta Rs \\ \Delta Rsh \end{bmatrix}}_{correction} = \underbrace{\begin{bmatrix} \Delta f_1 \\ \Delta f_2 \\ \Delta f_3 \end{bmatrix}}_{mismatches}$$

Step 3:- The initial mismatch vector and the inverse of Jacobian matrix are calculated corresponding to the initial values of A, Rs, and Rsh which are calculated in Eqs. (24, 26, 27) and are used for obtaining initial correction vector as follows:

$$\begin{bmatrix} \Delta A^{(0)} \\ \Delta R_s^{(0)} \\ \Delta Rsh^{(0)} \end{bmatrix} = \begin{bmatrix} \left.\frac{\partial f_1}{\partial A}\right|^{(0)} & \left.\frac{\partial f_1}{\partial R_s}\right|^{(0)} & \left.\frac{\partial f_1}{\partial Rsh}\right|^{(0)} \\ \left.\frac{\partial f_2}{\partial A}\right|^{(0)} & \left.\frac{\partial f_2}{\partial R_s}\right|^{(0)} & \left.\frac{\partial f_2}{\partial Rsh}\right|^{(0)} \\ \left.\frac{\partial f_3}{\partial A}\right|^{(0)} & \left.\frac{\partial f_3}{\partial R_s}\right|^{(0)} & \left.\frac{\partial f_3}{\partial Rsh}\right|^{(0)} \end{bmatrix}^{-1} \begin{bmatrix} \Delta f_1^{(0)} \\ \Delta f_2^{(0)} \\ \Delta f_3^{(0)} \end{bmatrix}$$

Step 4:- The initial corrections (Δ A, , Δ Rs and Δ Rsh) are added to initial estimated values of A, , Rs and Rsh to obtain their new values first iteration, the general form can be written as:

$$A^{(k+1)} = A^{(k)} + \Delta A^{(k)}$$

$$R_s^{(k+1)} = R_s^{(k)} + \Delta R_s^{(k)}$$

$$R_{sh}^{(k+1)} = R_{sh}^{(k)} + \Delta R_{sh}^{(k)}$$

Step 5: The process of iteration is repeated until the values of these correction are minimized.

Step 6: the last two parameters (I_o, and Iph) of five PV parameters model are calculated directly from Eqs. (21, 22) respectively.

Step 7:-The above steps are considered in STC. To include the effects of the environment, e.g. temperature and irradiance, these equations has to be completed with the corresponding terms.

For the short circuit current and open circuit voltage:

$$I_{sc} = I_{sc,ref} \frac{G}{G_{ref}} + K_i(T - T_{ref}) \quad (28)$$

$$V_{oc} = V_{oc,ref} + V_t \ln\left(\frac{G}{G_{ref}}\right) + K_v(T - T_{ref}) \quad (29)$$

At the last the variations of the current and voltage at the maximum power point are described by:

$$I_{mpp} = I_{mpp,ref} \frac{G}{G_{ref}} + K_i(T - T_{ref}) \quad (30)$$

$$V_{mpp} = V_{mpp,ref} + V_t \ln\left(\frac{G}{G_{ref}}\right) + K_v(T - T_{ref}) \quad (31)$$

Step 8:- The above steps are repeated at different manufacturer data sheets in table1.

6. Results and discussion

The previous section describes the construction of a PV panel model. This model has been implemented in Matlab, in order to verify it in different temperature and irradiance conditions. The proposed model was tested using different manufacturer data sheets in table.

The results have been compared to the characteristics and values provided by the product data-sheet. The temperature dependencies of the model's V-I curve have been verified by plotting the characteristics for three different temperatures.

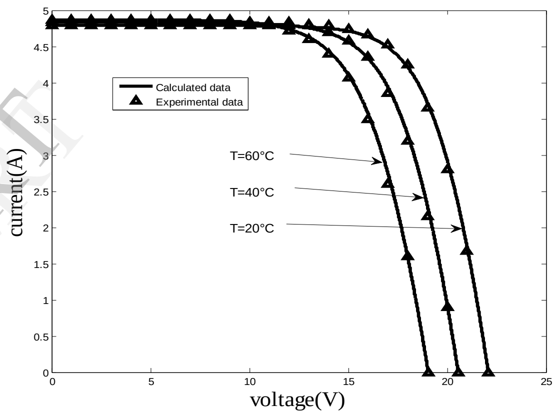

Figure.2. Voltage-Current characteristics of the shell SP75 model (mono-crystalline silicon)at three different temperatures and standard irradiation.

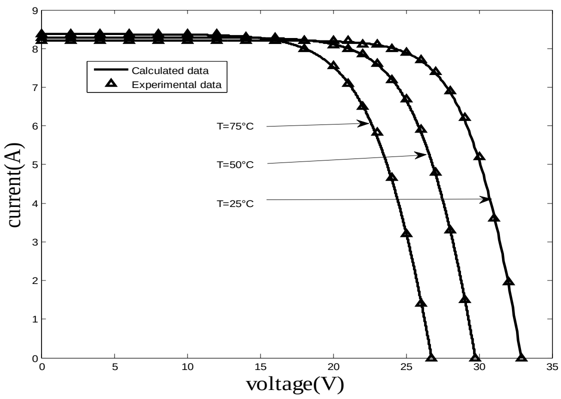

Figure.3. Voltage-Current characteristics of the KC200GT model (multicrystal) at three different temperatures and standard irradiation.

It can be seen on the above figures (2, 3) that the short-circuit current, and the open-circuit voltage are in very good agreement with the data-sheet values for SP75 (mono-crystalline silicon) solar module and KC200GT (multicrystal) solar module. The change in the open-circuit voltage and short-circuit current are in accordance with the temperature coefficients given in the data-sheet.

The calculated and experimental variations of power with voltage for the shell SP75 model and the KC200GT model, at three different temperatures and standard irradiation are illustrated in figures (4, 5).

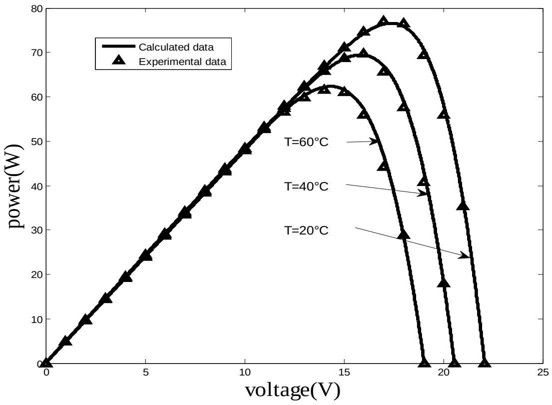

Figure. 4. Voltage Power characteristics of the shell SP75 model (mono-crystalline silicon) at three different temperatures and standard irradiation.

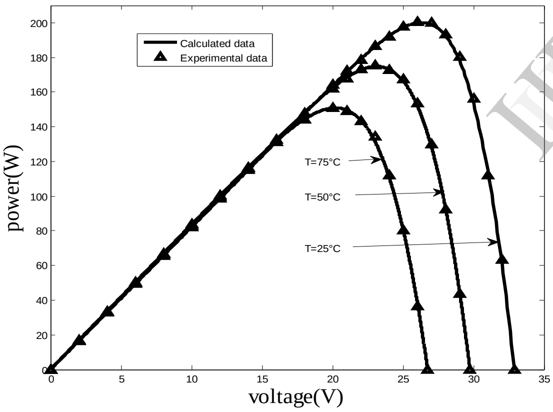

Figure.5. Voltage-Power characteristics of the KC200GT model (multicrystal) at three different temperatures and standard irradiation.

Figures (4, 5) provide a clear view on how the curves vary with temperature. There is significant reduction in the power output of the photovoltaic system as cell temperature increases. And also, the calculated (P-V) curves at different temperatures are in good agreement with the experimental data for different models (SP75 and KC200GT).

To show the effect of irradiance on the performance of a module the temperature is kept fixed at25 °C and the values of irradiance are changed to different values. The variation of the current-voltage characteristics with irradiance are shown in Figure (6, 7).

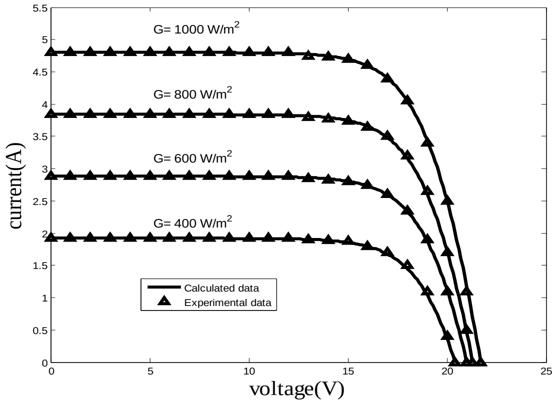

Figure. 6. Voltage-Current characteristics of the shell SP75 model (mono-crystalline silicon) at different irradiation and standard temperature.

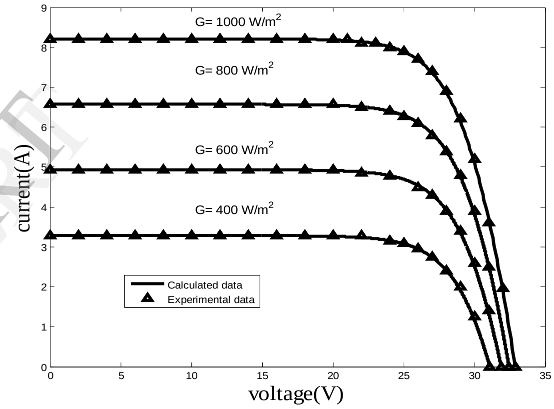

Figure. 7. Voltage-Current characteristics of the KC200GT model (multicrystal) at different irradiation and standard temperature.

From the figures (6, 7) it can be noted that, according to the theory, the short circuit current shows a linear dependence with the irradiation, unlike the open-circuit voltage, which increases logarithmically with the irradiation. Figures (6, 7) show that, the calculated (I-V) curves at different irradiation are in good agreement with the experimental data for different models (SP75 and KC200GT).

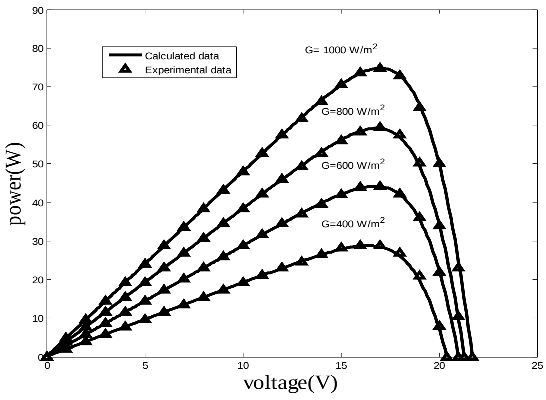

Figure. 8. Voltage Power characteristics of the shell SP75 model (mono-crystalline silicon) at different irradiation and standard temperature.

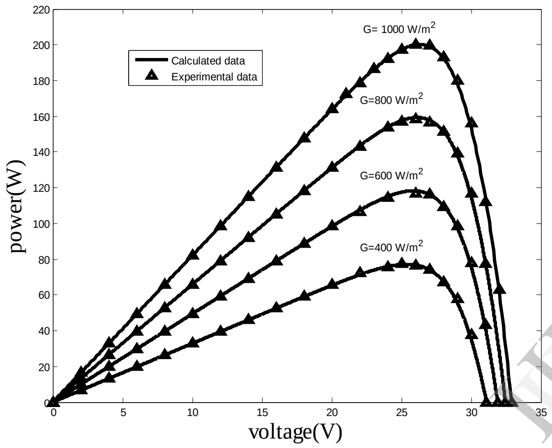

Figure. 9. Voltage-Power characteristics of the KC200GT model (multicrystal) at different irradiation and standard temperature.

In the same way, Figs.(8,9) shows the comparison between the calculated P-V characteristic, and the experimental characteristic . Also, it can be seen that the calculated (P-V) curves at different irradiation are in good agreement with the experimental data for different models (SP75 and KC200GT).

8. Conclusion

A model for photovoltaic panels, based exclusively on datasheet parameters has been developed and implemented. The method for extracting the panel parameters from datasheet values has been presented, and the obtained values have been used in the implemented model. The parameters of a PV system are calculated by using the Newton-Raphson method. The initial values of these parameters are estimated by using the simplified method, Also A new equation dP/dI=0 at the maximum power point is introduced. This new equation replaces the equation, usually used in literature, determined from the slope of the I-V curve at the short circuit current, namely, dI/dV=-1/Rsh. In this work the temperature dependence of the cell dark saturation current is taken into consideration. From the present analysis, one can draw the following main conclusions:-

1- By using the simplified method to estimate the parameters of a PV system the iteration begins sufficiently near the desired and the Newton-Raphson iterative method converges remarkably quickly.

2- The proposed equations which are expressed in a PV system, allow one to calculate the parameters PV system without relying on the experimental I-V curve to determine Rsh.

3- The temperature dependence of the cell dark saturation current is expressed with an alternative formula, which gives better correlation with the datasheet values of the power temperature dependence.

4- The calculated (I-V, P-V) curves based on proposed model are in good agreement with the experimental data at different manufacturer models shell SP75 model (mono-crystalline silicon and shell KC200GT model multicrystal).

5- The calculated (I-V, P-V) curves based on proposed model are in good agreement with the experimental data for different effects of the environment (temperature and irradiance).

Reference

[1] [s.n.], "Trends in photovoltaic applications. Survey report of selected iea countries between 1992 and 2005", International Energy Agency, Report IEA-PVPS Task 1 IEA PVPS T1-15:2006, 2006.

[2] Baifeng Chen, Jih-Sheng Lai, Chien-Liang Chen, Wensong Yu, Kees N, Cong Zheng, "Design and optimization of 99% CEC efficiency soft-switching photovoltaic inverter", Applied Power Electronics Conference and Exposition (APEC), 2013, PP. 946 – 951.

[3] Kapoor D., Sodhi P., Deb D., "Solar panel simulation using adaptive control", Control Applications (CCA), IEEE International Conferenceon, 2012, PP.1124 – 1130.

[4] Luigi G., de Brito, M.A.G, Sampaio L.P, Canesin C.A, "Integrated inverter topologies for low power photovoltaic systems", Industry Applications (INDUSCON), IEEE/IAS International Conference, 2010, PP.1-5.

[5] J.P. Charles, M. Abdelkrim, "A practical method of analysis of the current voltage characteristics of solar cells", Solar Cells, Solar Cells,1981, PP. 169-178.

[6] RKhezzar, M Zereg, "Comparative Study of Mathematical Methods for Parameters Calculation of Current-Voltage Characteristic of Photovoltaic Module", in Proc. Int. Conf. Elect. Electron. Eng., Nov. 2009, pp. I-24–I-28.

[7] D. Sera, R. Teodorescu, and P. Rodriguez, "PV panel model based on datasheet values", Industrial Electronics, ISIE. IEEE International Symposium , 2007,pp. 2392–2396,.

[8] Ahmed A. El Tayyan, "PV system behaviour based on datasheet", Journal of Electron Devices, Vol. 9, 2011, pp. 335-341.

[9] A. Goetzberger, V.U. Hoffmann, "Photovoltaic Solar Energy Generation", Springer, Berlin, 2005.

[10] Shell SP75 photovoltaic solar module; http://www.shell.com/solar.

[11] KC200GT photovoltaic solar module; http://www.kyocera.com.