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Analytical Identification Method for the Single Diode Model Parameters of a Photovoltaic Panel using Datasheet Values

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An analytical identification method is presented in this paper to estimate the five parameters of photovoltaic panel using only the datasheet values and the single diode model. The proposed technique is based on calculating analytically the different parameters using the remarkable points in datasheet at standard test conditions (STC). The obtained results have a good agreement between the simulated current-voltage and power-voltage curves and the experimental data extracted from datasheet for KC200GT PV module. The accuracy of the proposed method is compared with other work published previously. Moreover, this method correctly reproduces the PV curves under various temperatures and irradiation levels.

Keywords: PV panel, Single diode model, Datasheet, Parameter estimation, Lambert function.

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1. INTRODUCTION

The identification of the five photovoltaic panel or solar cell parameters using experimental data or using only datasheet values and the single diode model have been widely investigated and discussed by many researchers [1-18].

In recent years, three approaches for estimation of the different parameters have been discussed: analytical, iterative and numerical approaches. Javier Cubas [10] has developed an analytical method based on a reduced amount of information, consisting in the normal manufacturer data and formulating a four coupled equations to determine series resistance R_s, shunt resistance R_p, saturation current I_s and photo current I_{ph},. Villalva and all [11] have proposed an iterative method to obtain the five parameters, the aim of this method is to find the value of R_s (and hence R_p) that adjust the peak of the theoretical power-voltage curve and the experimental peak power at the maximum point extracted from datasheet. For the both previously methods, the ideality factor are supposed equal to 1.3 for crystalline technology. Jung-Young Park and al. [15] have presented effective parameters extraction based on pattern search algorithm in order to enhance the model accuracy for the maximum power region, the objective function used in this work is based only on the MPP conditions, the solution in this technique is very sensitive to the choice of the initial guesses.

In this work, we propose an analytical method to estimate the five parameters of PV module using the single diode model and the datasheet information.

2. MATHEMATICAL MODELING AND THE EXTRACTION METHOD

2.1 The Single Diode Model

The photovoltaic module can be described by an equivalent circuit model based on single ideal diode, a constant photo-generated current source I_{ph}, a series parasitic resistance (R_s), and a parallel parasitic resistance (R_p).

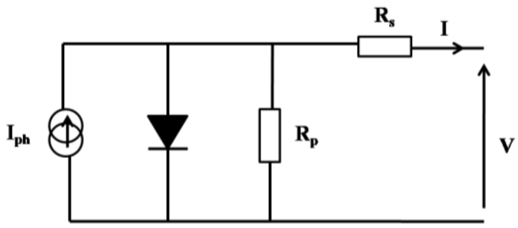

Fig. 1 – Equivalent electrical circuit for single diode model

This equivalent circuit can be modeled by the following equation of the current I and voltage V:

$$I = I_{ph} - I_0\left(\exp\left(\frac{V+R_sI}{n.N_s.V_{th}}\right)-1\right)-\frac{V+R_sI}{R_p}, \quad (1)$$

where I_0 is the saturation current, I_{ph} is N_s is the number of cells connected in series and $V_{th} = kBT/q$ is the thermal voltage.

The expression (1) is a transcendental equation. We can give an explicit solution $I = f(V)$ based on Lambert function:

$$I(V) = \frac{I_0+I_{ph}-V}{1+R_sG_p} - \frac{nV_{th}}{R_s}\times W\left(\frac{I_0R_s}{nV_{th}\left(1+R_sG_p\right)}\exp\left(\frac{V+R_s\left(I_0+I_{ph}\right)}{nV_{th}\left(1+R_sG_p\right)}\right)\right). \quad (2)$$

By multiplying the equation (2) by V, the power P can be written as:

$$P(V) = \frac{\left(I_0+I_{ph}-V\right).V}{1+R_sG_p} - \frac{nV_{th}}{R_s}.V\times W\left(\frac{I_0R_s}{nV_{th}\left(1+R_sG_p\right)}\exp\left(\frac{V+R_s\left(I_0+I_{ph}\right)}{nV_{th}\left(1+R_sG_p\right)}\right)\right) \quad (3)$$

2.2 Extraction Method

The aim of this method is the find the five PV module parameters: I_{ph}, I_0, n, R_s and R_p using only the datasheet information without any experimental data. The PV modules datasheets give the following information under standard test conditions (STC):

– The nominal open-circuit voltage V_{ocn};
– The nominal short-circuit current I_{scn};
– The voltage at the maximum power point V_{mp};
– The current at the maximum power point I_{mp};
– The open-circuit voltage/temperature coefficient K_V;
– The short-circuit current/temperature coefficient K_I;

Exploiting these six datasheet information, we will define a five analytical equations to extract the five module parameters without any approximation.

2.2.1 Ideality Factor *n*

According to [17], the ideality factor n for the PV module can be expressed using the different remarkable points at STC by the following expression:

$$n = \frac{K_v - \dfrac{V_{oc}}{T_{ref}}}{N_s V_{th}\left(\dfrac{K_I}{I_{sc}} - \dfrac{3}{T_{ref}} - \dfrac{E_g}{k_B T_{ref}^2}\right)}, \quad (4)$$

where T_{ref} is the temperature at STC conditions (reference conditions) and E_g is the band gap energy.

2.2.2 Series Resistance R_s

The second equation in this method is based on expressing the series resistance as function of ideality factor n. To find this expression we use the three remarkable points in datasheet: open-circuit point, short-circuit point and maximum power point:

Equation at open circuit:

$$0 = I_{ph} - I_0\left(\exp\left(\frac{V_{oc}}{n.N_s.V_{th}}\right) - 1\right) - \frac{V_{oc}}{R_p}. \quad (5)$$

Equation at short circuit point (I_{sc},0):

$$I_{sc} = I_{ph} - I_0\left(\exp\left(\frac{R_s I_{sc}}{n.N_s.V_{th}}\right) - 1\right) - \frac{R_s I_{sc}}{R_p}. \quad (6)$$

Equation at the maximum power point (I_{mp}, V_{mp}) :

$$I_{mp} = I_{ph} - I_0\left(\exp\left(\frac{V_{mp} + R_s I_{mp}}{n.N_s.V_{th}}\right) - 1\right) - \frac{V_{mp} + R_s I_{mp}}{R_p}. \quad (7)$$

The derivative of the power at the maximum point gives the following expression:

$$\frac{-I_{mp}}{V_{mp}} = -\frac{I_0}{nN_s V_{th}}\left(1 - \frac{I_{mp}}{V_{mp}} R_s\right)\left(\exp\left(\frac{V_{mp} + R_s I_{mp}}{n.N_s.V_{th}}\right)\right) - \frac{1}{R_p}\left(1 - \frac{I_{mp}}{V_{mp}} R_s\right). \quad (8)$$

Using the negative branch of the Lambert function, we can write the resistances R_s as follow [5]:

$$R_s = f\left[W_{-1}\left(g\exp(h)\right) - (j+h)\right]\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}, \quad (9)$$

where:

$$f = \frac{nN_s V_{th}}{I_{mp}}$$
$$g = -\frac{V_{mp}\left(2I_{mp} - I_{sc}\right)}{\left(V_{mp} I_{sc} + V_{oc}\left(I_{mp} - I_{sc}\right)\right)}$$
$$h = -\frac{2V_{mp} - V_{oc}}{nN_s V_{th}} + \frac{V_{mp} I_{sc} - V_{oc} I_{mp}}{\left(V_{mp} I_{sc} + V_{oc}\left(I_{mp} - I_{sc}\right)\right)} \quad (10)$$
$$j = \frac{V_{mp} - V_{oc}}{nN_s V_{th}}.$$

2.2.3 Parallel Resistance R_p, Photo Current I_{ph} and Saturation Current I_0

To extract the parallel resistance, the photo current and the saturation current, we find three equations as function of series resistance R_s and ideality factor n. Exploiting the equations (5), (6) and (7), R_p, I_{ph} and I_0 can be written as [12]:

$$G_p = \frac{\gamma\left(I_{mp} - I_{sc}\right) + \beta I_{sc} - \alpha I_{mp}}{A\alpha + B\beta + C\gamma}, \quad (11)$$

$$I_0 = \frac{V_{oc}\left(-I_{mp} + I_{sc}\right) - V_{mp} I_{sc}}{A\alpha + B\beta + C\gamma}, \quad (12)$$

$$I_{ph} = \frac{I_{sc} V_{oc}(\beta - 1) - I_{sc} V_{mp}(1-\gamma) + I_{mp} V_{oc}(1-\alpha)}{A\alpha + B\beta + C\gamma}, \quad (13)$$

where $G_p = 1/R_p$

The parameters α, β and γ are given by:

$$\alpha = \exp\left(\frac{R_s I_{sc}}{nN_s V_{th}}\right); \beta = \exp\left(\frac{V_{mp} + R_s I_{mp}}{nN_s V_{th}}\right); \gamma = \exp\left(\frac{V_{oc}}{nN_s V_{th}}\right). \quad (14)$$

The expressions of A, B and C are:

$$A = V_{mp} + R_s I_{mp} - V_{oc},$$
$$B = V_{oc} - R_s I_{sc}, \quad (15)$$
$$C = R_s I_{sc} - R_s I_{mp} - V_{mp}.$$

The proposed extraction method of the five parameters from datasheet can be summarized for three steps:

– Find the ideality factor n from equation (4).
– Find the series resistance R_s from equation (9) by injecting the value of n.
– Find the parallel resistance R_p, the saturation current I_0 and the photocurrent I_{ph} from equation (11), (12) and (13) respectively by injecting the values of n and R_s.

2.3 Temperature and Irradiation Dependence

The information cited in datasheet such as I_{sc}, V_{oc}, I_{mp} and V_{mp} are measured in standard test conditions (reference conditions). To calculate the five parameters values for various temperatures and irradiation levels, we use the following expressions [13, 17, 18]:

$$n = n_{ref}, \tag{18}$$

$$R_s = R_{s,ref}, \tag{19}$$

$$R_p = R_{p,ref}, \tag{20}$$

$$I_{ph} = \left(I_{ph,ref} - K_i\left(T - T_{ref}\right)\right)\frac{G}{G_{ref}}, \tag{21}$$

$$I_s = \frac{I_{sc,ref} + K_i\left(T - T_{ref}\right)}{\exp\left(\frac{V_{oc,ref} + K_v\left(T - T_{ref}\right)}{nN_sV_{th}}\right) - 1}. \tag{22}$$

According the previously expressions, the presented method is using to extract the new parameters under different temperatures and irradiation levels.

3. RESULTS AND DISCUSSION

3.1 Method Validation

In order to validate the proposed extraction method from datasheet information, the multi-crystal module KC200GT from Kyocera has been used in this study. The manufacturer's datasheets information of these two PV modules operating under STC conditions (measured at 25°C and A.M1.5 (1000 W/m²)) are summarized in Table 1 [17].

Table 1 – Manufacturers datasheet of KC200GT and SQ80

Parameters	KC200GT
I_{sc} (A)	8.21
V_{oc} (V)	32.9
I_{mp} (A)	7.61
V_{mp} (V)	26.3
K_V (mV/°C)	– 123
K_I (mA/°C)	3.18
N_s	54

Table 2 show the five parameters extracted for KC200GT PV module using the proposed method. The results are compared with the recently published parameters related to the same modules by using only datasheet values. It can be seen that the obtained parameters have a good agreement with the values published in the literature. We note that this estimation method has the advantage that it is fast and it needs any initial guesses or approximations. Furthermore, to check the accuracy of this method, the root men squared error (RMSE) for the current is calculated in Table 2. To evaluate the validity of the proposed technique,

Table 2 – Estimation parameters for KC200GT

Parameter	Present method	Nassareddine et al. [17]	Shongwe et al. [7]
n	1.0758	1.0758	1.343
R_s (Ω)	0.269	0.284	0.2163
R_p (Ω)	118.345	157.853	993
I_0 (A)	2.16710^{-9}	2.19510^{-10}	$1.772.10^{-7}$
I_{ph} (A)	8.228	8.210	8.212
RMSE	0.1442	0.1844	0.1564

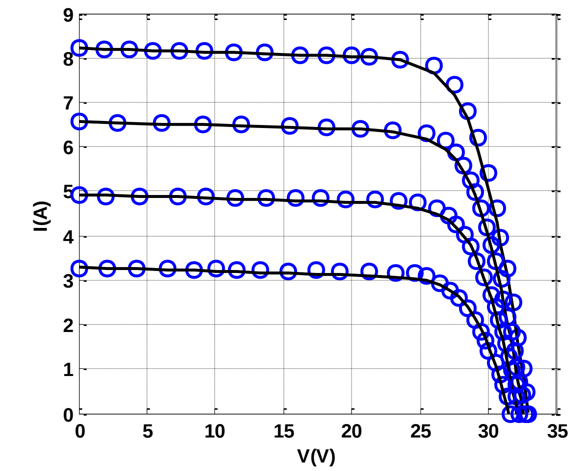

Fig. 2 – Experimental (dot) and simulated (line) *I-V* curve for various irradiation levels for KC200GT module at 25°C

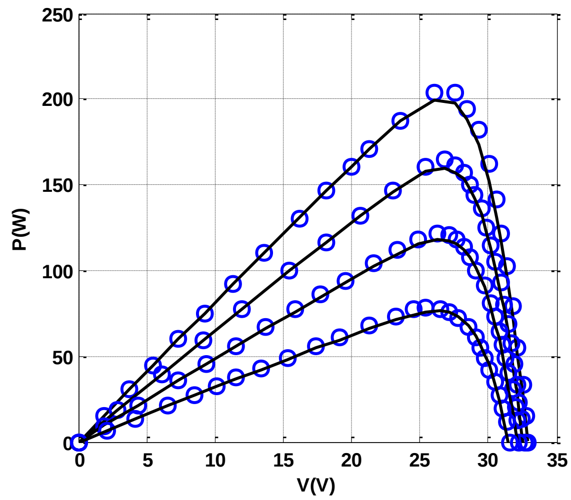

Fig. 3 – Experimental and simulated *P-V* curve for various irradiation levels for KC200GT module at 25°C

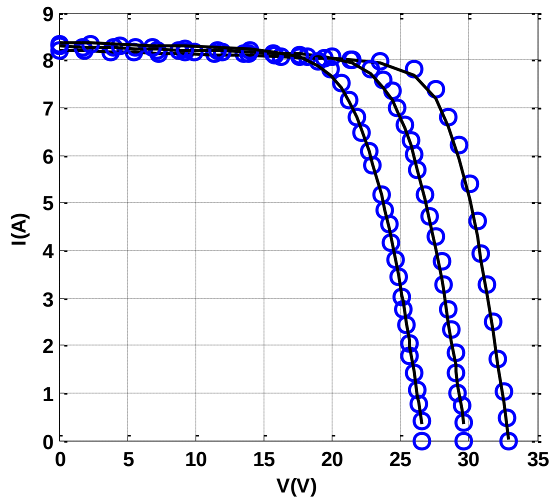

Fig. 4 – Experimental (dot) and simulated (line) *I-V* curve for various temperatures KC200GT module at 1000W/m²

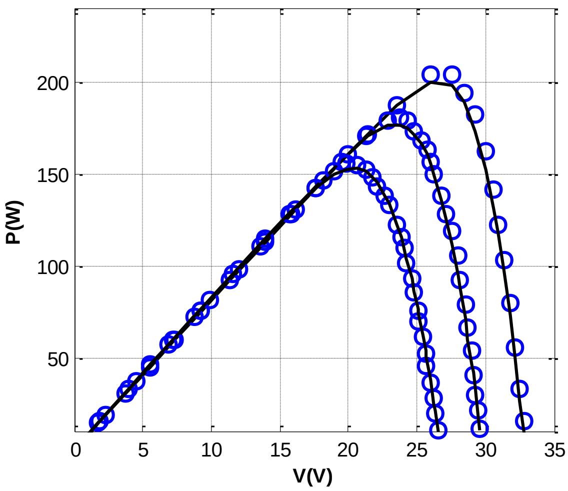

Fig. 5 – Experimental (dot) and simulated (line) *P-V* curve for various temperatures KC200GT module at 1000W/m²

a comparison with experimental characteristics is very useful. Figures 2 and 3 show the simulated *I-V* and *P-V* curves plotted using equation (2) and (3) respectively under various irradiation levels at 25°C and compared with experimental data extracted from datasheet. It can be seen that this technique successfully describes the *PV* characteristics.

Figures 4 and 5 show the experimental and the simulated *I-V* and *P-V* curves under various temperatures at 1000W/m². It can be seen, the proposed technique successfully describes the PV characteristics.

4. CONCLUSION

In this work, an analytical method to identify the five PV modules parameters using only datasheet values has been proposed. It is based on five analytical expressions to extract the parameters at standard test conditions. The results obtained for the KC200GT under different temperatures and irradiation levels indicate a good agreement between experimental and simulated data.

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