An analytical method for parameter identification based on datasheet values

Hao Lu\textsuperscript{1,a}, Yunpeng Zhang\textsuperscript{1,b}, Peng Hao\textsuperscript{1,c}

\textsuperscript{1} School of Electrical Engineering, Shandong University, Jinan, China
\textsuperscript{a}email: 202034686@mail.sdu.edu.cn, \textsuperscript{b}email: zhangyp@sdu.edu.cn,
\textsuperscript{c}email: 201934280@mail.sdu.edu.cn

*Corrsponding Author: \textsuperscript{b}email: zhangyp@sdu.edu.cn

Abstract: A new method for extracting five parameters of single diode is presented in this paper. Through the further derivation and simplification of the formula, five parameters under a single condition can be obtained analytically by using only three key operating points (open circuit voltage point (OC), short circuit current point (SC), maximum power point (MPP)) and datasheet values, which can achieve high accuracy in only two iterations. The accuracy and effectiveness of proposed method have been validated by experimental data under different environmental conditions.

1. Introduction

The modeling of photovoltaic (PV) system is very important to evaluate its efficiency and performance under various operating conditions. In general, PV modeling is based on appropriate electrical equivalent circuits, using a set of parameters that represent the properties of PV modules and operating conditions.

In the actual solar cell, the energy is dissipated in the contact resistance and the leakage current at the edge of the solar cell. The effect is equivalent to the series resistance $R_s$ and parallel resistance $R_{sh}$ in the model. $R_s$ is mainly due to the resistance of the material itself, contact resistance, and additional equivalent to resistance, $R_{sh}$ is mainly equivalent to the leakage of the edge of the battery and the leakage of the metal bridge formed by the microcracks, scratches, etc. of the battery when the metallized electrode is made. The photo-generated current $I_{ph}$ does not change with the change of the working state under constant working conditions, and can be equivalent to a constant current source. The photo-generated current flows through the load, and the voltage across the load acts on the diode at the same time, causing the diode to be forward biased. The current flowing through the diode is called the dark current $I_0$. Therefore, each single diode model’s (SDM) parameter have its physical meaning. However these parameters cannot be measured directly and do not provided by manufacturer [1-4]. Instead, the characteristic parameters short circuit current $I_{sc}$, open circuit voltage $V_{oc}$, maximum power current $I_{mp}$ and voltage $V_{mp}$, and temperature coefficients of $I_{sc}$ ($\alpha_{I_{sc}}$) and $V_{oc}$ ($\beta_{V_{oc}}$) are provided in datasheet values, which can be used for parameters identification.

The purpose of this study is to introduce an analytical method which only uses the datasheet information to accurately and directly determine the five parameters of the PV module. The proposed equations constitute an improvement on the method described in [5] and maintain the same level of accuracy, but the formula is obviously simpler and more cost-effective. The calculation of proposed
method is simple and can be completed by using a calculator within only two iterations. The performance of proposed method was validated by experimental data under different irradiance (G) and temperature (T) conditions.

2. Extraction of SDM’s parameters

The equivalent circuit of the SDM is shown in Fig. 1. In SDM, the PV module output I-V characteristic is represented by five physical parameters (n, Ip, Io, Rs, and Rsh). The I-V characteristic of SDM can be represented by Eq. (1) [6].

\[
I = I_p - I_s \left( e^{\frac{V_{oc} + I_s R_s}{a}} - 1 \right) - \frac{V + I_s R_s}{R_{sh}} \tag{1}
\]

In order to calculate the five parameters, five independent equations have to be formulated. The three standard equations adopted in most studies are derived by evaluating Eq. (1) at the SC, OC and MPP operating points at STC [7]:

At SC (0, Isc):

\[
SC : I_{sc} = I_p - I_s \left( e^{\frac{I_s R_s}{a}} - 1 \right) - \frac{I_{sc} R_s}{R_{sh}} \tag{2}
\]

At OC (Voc, 0):

\[
OC : 0 = I_p - I_s \left( e^{\frac{V_{oc}}{a}} - 1 \right) - \frac{V_{oc}}{R_{sh}} \tag{3}
\]

At MPP (Vm, Ip):

\[
MPP : I_{mp} = I_p - I_s \left( e^{\frac{V_{mp} + I_{mp} R_s}{a}} - 1 \right) - \frac{V_{mp} + I_{mp} R_s}{R_{sh}} \tag{4}
\]

Where \( a = nV_{th}N_s \). In addition, the slope of the P-V curve at MPP is zero, which is used in this study and the equation can be simplified as [8]:

\[
\frac{V_{mp}}{I_{mp}} = \frac{a}{I_p + I_s - I_{mp} - \frac{V_{mp} + I_{mp} R_s - a}{R_{sh}}} \tag{5}
\]

The fifth equation can be deduced from the temperature coefficients \( \alpha_{sc} \) and \( \beta_{voc} \), which has been used in the literature [9]:

\[
\delta = \frac{a}{V_{oc}} = \frac{1 - 298.15 \beta_{voc}}{50.1 - 298.15 \alpha_{sc}} \tag{6}
\]

By using Eqs. (2)-(5), the explicit analytical expression of the five parameters can be expressed as:

\[
I_s = \frac{I_p - \frac{V_{oc}}{R_{sh}}}{e^{\frac{V_{oc}}{a}} - 1} \tag{7}
\]
\[ a = \delta V_{oc} \]

\[ R_{sh} = \frac{a}{V_{mp} + I_{mp}R_s - a} \]

\[ I_{ph} = I_s - I_{mp} \]

\[ R_s = \frac{R_{sh}I_{mp}}{I_{mp}} \]

\[ I_{ph} = I_{sc} + I_s \left( e^{\frac{l_{sc}R_s}{a}} - 1 \right) + \frac{I_{sc}R_s}{R_{sh}} \]

3. Results and discussions

3.1. Comparison of Absolute Error under varying irradiance conditions

To visualize the calculation accuracy, the absolute error index under a specific irradiance and temperature is calculated as follows:[10]

\[ \text{Absolute Error} = |I_{exp} - I_{cal}| \]

where \( I_{exp} \) and \( I_{cal} \) are the measured and calculated current, respectively.

The absolute error of proposed method with respect to the voltage under different irradiance conditions is shown in Fig. 2. In Fig. 2, the maximum absolute error of the proposed method appears in 1040.3 W/m², and the maximum absolute error is 0.08 A. The absolute error of the proposed method fluctuates to a certain extent in the high voltage area and high irradiance, and other positions are relatively stable. The results show that the method has better accuracy at different working points under different irradiance intervals.
Fig. 2. Absolute error under various irradiance intervals

3.2. Comparison with Laudani’s and methods

In order to study the accuracy of our model, root-mean-square error (RMSE) between the estimated and the measured current in I–V curves is calculated, where RMSE is defined as follow:

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (I_i - I_{(V_i,I_i)})^2}
\]

where \(N\) denotes the number of empirical points of an I-V curve, \(I_i\) is the measured current, and \(I_{(V_i,I_i)}\) is the estimated value of current.

Table 2 RMSE OF I–V CURVES FOR THE LAUDANI’S AND PROPOSED MODELING

| Method    | Time (ms) | RMSE (A) |
|-----------|-----------|----------|
|           |           | C1       | C2       | C3       | C4       | C5       |
| Laudani   | 8.143     | 0.0128   | 0.0229   | 0.0288   | 0.0313   | 0.0382   |
| Proposed  | 0.644     | 0.0117   | 0.0223   | 0.0282   | 0.0314   | 0.0425   |

Table 2 shows the calculating time and RMSE under different conditions for different methods. It can be seen from the table that the proposed method decreases the calculating time by about 13 times of Laudani’s method, but the accuracy of the predicted curve for both methods are almost the same. The similarity in accuracy can also be seen from Fig. 3. The I-V and P-V curves of the proposed and Laudani’s methods almost overlap, and they have good agreement at different irradiance intervals with the experimental data.
4. Conclusion
On the basis of the SDM, five independent equations are obtained through the equations at three key operating points, the derivative equation at the maximum power point and the equation deduced from temperature coefficients [9]. The initial values of the proposed method can be obtained by collating and approximating the five equations, and the accurate results can be obtained by substituting the five initial values into the first five exact equations. The calculation of this method is simple and can be completed by using a calculator within only two iterations. Compared with Laudani's method, on the premise of keeping the accuracy basically unchanged, the computing time of proposed method is greatly reduced, which indicates the great performance of proposed method in the estimation of I–V characteristic.

Acknowledgment
We would like to thank NREL and especially Mr. Marion for providing the experimental data.

References
[1] C. Zhang, Y. Zhang, J. Su, T. Gu, and M. Yang, "Modeling and Prediction of PV Module Performance Under Different Operating Conditions Based on Power-Law I–V Model," *IEEE Journal of Photovoltaics*, vol. 10, no. 6, pp. 1816-1827, 2020.
[2] F. Ghani, G. Rosengarten, M. Duke, and J. K. Carson, "On the influence of temperature on crystalline silicon solar cell characterisation parameters," *Solar Energy*, vol. 112, pp. 437-445, 2015.
[3] J.-Y. Park and S.-J. Choi, "A novel datasheet-based parameter extraction method for a single-diode photovoltaic array model," *Solar Energy*, vol. 122, pp. 1235-1244, 2015.
[4] A. M. Humada et al., "Modeling of PV system and parameter extraction based on experimental data: Review and investigation," *Solar Energy*, vol. 199, pp. 742-760, 2020.
[5] A. Laudani F. Riganti Fulginei, and A. Salvini, "Identification of the one-diode model for photovoltaic modules from datasheet values," *Solar Energy*, vol. 108, pp. 432-446, 2014.
[6] S. Li, Q. Gu, W. Gong, and B. Ning, "An enhanced adaptive differential evolution algorithm for parameter extraction of photovoltaic models," *Energy Conversion and Management*, vol. 205, 2020.
[7] A. Laudani, F. Riganti Fulginei, and A. Salvini, "High performing extraction procedure for the one-diode model of a photovoltaic panel from experimental I–V curves by using reduced forms," *Solar Energy*, vol. 103, pp. 316-326, 2014.

Fig. 3. Comparison of (a) I–V, (b) P-V characteristic under a wide range of irradiance intervals
[8] D. M. Fëbba, R. M. Rubinger, A. F. Oliveira, and E. C. Bortoni, "Impacts of temperature and irradiance on polycrystalline silicon solar cells parameters," *Solar Energy*, vol. 174, pp. 628-639, 2018.

[9] E. I. Batzelis and S. A. Papathanassiou, "A Method for the Analytical Extraction of the Single-Diode PV Model Parameters," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 504-512, 2016.

[10] F. Bradaschia, M. C. Cavalcanti, A. J. do Nascimento, E. A. da Silva, and G. M. de Souza Azevedo, "Parameter Identification for PV Modules Based on an Environment-Dependent Double-Diode Model," *IEEE Journal of Photovoltaics*, vol. 9, no. 5, pp. 1388-1397, 2019.