Analytical Identification Method for the Single Diode Model Parameters of a Photovoltaic Panel using Datashet 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 previously. Moreover, this method correctly reproduces the PV curves under various temperatures and irradiation levels.

Keywords: PV panel, Single diode model, Datashet, 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-Yong 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 ($R_o$), and a parallel parasitic resistance ($R_p$).

![Fig. 1 – Equivalent electrical circuit for single diode model](image)

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

$$I = I_s - I_s \left( \frac{V + R_s I}{nN_s V_{th}} \right) - \frac{V + R_s I}{R_p},$$

(1)

where $I_s$ 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:

$$I(V) = \frac{I_s + I_{ph} - V}{1 + R_s G_p} - \frac{nV_{th}}{R_s} \times$$

$$W \left( \frac{I_o R_p}{nV_{th} (1 + R_s G_p)} \exp \left( \frac{V + R_s \left( I_s + I_{ph} \right)}{nV_{th} (1 + R_s G_p)} \right) \right).$$

(2)

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

$$P(V) = \frac{I_o + I_{ph} - V}{1 + R_s G_p} \times$$

$$W \left( \frac{I_o R_p}{nV_{th} (1 + R_s G_p)} \exp \left( \frac{V + R_s \left( I_s + I_{ph} \right)}{nV_{th} (1 + R_s G_p)} \right) \right).$$

(3)

2.2 Extraction Method

The aim of this method is the find the five PV mod-
ule parameters: \( I_ph, I_o, n, R_o \) 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 \( V_{oc} \);
- The nominal short-circuit current \( I_{sc} \);
- 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 sheet information, we will define a five analytical equations to extract the five module parameters without any approximation.

### 2.2.1 Identities 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:

\[
n = \frac{K_v}{N V_{zh}} \left( \frac{K_i}{T_{zh}} \frac{3}{T_{ref}} \frac{E_p}{k_BT_{ref}} \right),
\]

where \( T_{ref} \) is the temperature at STC conditions (reference conditions) and \( E_p \) 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 a 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:**

\[
0 = I_{ph} - I_o \left( \exp \left( \frac{V_{oc}}{nN_vV_{zh}} \right) - 1 \right) \frac{V_{oc}}{R_p}.
\]

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

\[
I_{sc} = I_{ph} - I_o \left( \exp \left( \frac{R I_{sc}}{nN_vV_{zh}} \right) - 1 \right) \frac{R I_{sc}}{R_p}.
\]

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

\[
I_{mp} = I_{ph} - I_o \left( \exp \left( \frac{V_{mp} + R I_{mp}}{nN_vV_{zh}} \right) - 1 \right) \frac{V_{mp} + R I_{mp}}{R_p}.
\]

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

\[
\frac{-I_{mp}}{V_{mp}} = \frac{I_o}{nN_vV_{zh}} \left( \frac{I_o}{V_{mp} R_s} \left( \exp \left( \frac{V_{mp} + R I_{mp}}{nN_vV_{zh}} \right) \right) \right)
\]

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

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

where:

\[
f = \frac{nN_vV_{lh}}{I_{mp}},
\]

\[
g = \frac{V_{mp} (2I_{mp} - I_{sc})}{V_{mp} I_{sc} + V_{oc} (I_{mp} - I_{sc})},
\]

\[
h = \frac{2V_{mp} - V_{oc} + V_{mp} I_{sc} - V_{oc} I_{mp}}{nN_vV_{lh}}.
\]

### 2.2.3 Parallel Resistance \( R_p \), Photo Current \( I_{ph} \) and Saturation Current \( I_o \)

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

\[
G_p = \frac{\gamma (I_{mp} - I_{sc}) + \beta I_{sc} - \alpha I_{mp}}{A\alpha + B\beta + C\gamma},
\]

\[
I_o = \frac{V_{oc} (-I_{sc} + I_{mp}) - V_{mp} I_{sc}}{A\alpha + B\beta + C\gamma},
\]

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

where \( G_p = 1/R_p \).

The parameters \( \alpha, \beta \) and \( \gamma \) are given by:

\[
\alpha = \exp \left( \frac{R I_{sc}}{nN_vV_{zh}} \right); \beta = \exp \left( \frac{V_{mp} + R I_{mp}}{nN_vV_{zh}} \right);
\]

\[
\gamma = \exp \left( \frac{V_{oc}}{nN_vV_{zh}} \right).
\]

The expressions of \( A, B \) and \( C \) are:

\[
A = V_{mp} + R I_{mp} - V_{oc},
\]

\[
B = V_{oc} - R I_{sc},
\]

\[
C = R I_{sc} - R I_{mp} - V_{mp}.
\]

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 \( I_o \) 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.
To calculate the five parameters values for various temperatures and irradiation levels, we use the following expressions [13, 17, 18]:

\[ n = n_{\text{ref}}, \]
(18)

\[ R_n = R_{n,\text{ref}}, \]  
(19)

\[ R_p = R_{p,\text{ref}}, \]
(20)

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

\[ I_s = \frac{I_{sc,\text{ref}} + K_s(T - T_{\text{ref}})}{nN_sV_{th} \exp \left( \frac{V_{oc,\text{ref}} + K_v(T - T_{\text{ref}})}{nN_sV_{th}} \right)} - 1. \]
(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>
<thead>
<tr>
<th>Parameters</th>
<th>KC200GT</th>
<th>SQ80</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{sc} ) (A)</td>
<td>8.21</td>
<td>8.06</td>
</tr>
<tr>
<td>( V_{oc} ) (V)</td>
<td>32.9</td>
<td>33.6</td>
</tr>
<tr>
<td>( I_{mp} ) (A)</td>
<td>7.61</td>
<td>7.56</td>
</tr>
<tr>
<td>( V_{mp} ) (V)</td>
<td>26.3</td>
<td>26.4</td>
</tr>
<tr>
<td>( K_v ) (mV/°C)</td>
<td>-123</td>
<td>-123</td>
</tr>
<tr>
<td>( K_i ) (mA/°C)</td>
<td>3.18</td>
<td>3.21</td>
</tr>
<tr>
<td>( N_s )</td>
<td>54</td>
<td>56</td>
</tr>
</tbody>
</table>

Table 2 shows 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 mean squared error (RMSE) for the current is calculated in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present method</th>
<th>Nassareddine et al. [17]</th>
<th>Shongwe et al. [7]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n )</td>
<td>1.0758</td>
<td>1.0758</td>
<td>1.343</td>
</tr>
<tr>
<td>( R_n ) (Ω)</td>
<td>0.269</td>
<td>0.284</td>
<td>0.2163</td>
</tr>
<tr>
<td>( R_p ) (Ω)</td>
<td>118.345</td>
<td>157.853</td>
<td>993</td>
</tr>
<tr>
<td>( I_0 ) (A)</td>
<td>2.16710⁻⁹</td>
<td>2.19510⁻¹⁰</td>
<td>1.77210⁻⁹</td>
</tr>
<tr>
<td>( I_{ph} ) (A)</td>
<td>8.228</td>
<td>8.210</td>
<td>8.212</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.1442</td>
<td>0.1844</td>
<td>0.1564</td>
</tr>
</tbody>
</table>

To evaluate the validity of the proposed technique,
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.

REFERENCES