An approach to identify and characterize a solar panel using five parameters

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Zoubir Chelli
PhD in Electrical Engineering
Institution: University of Mohamed-Cherif Messaadia of Souk Ahras; Laboratory of Electrical Engineering and Renewable Energy (LEER)
Address: P.O.B. 1553, Souk Ahras, Algeria
E-mail: zoubir.chelli@univ-soukahras.dz

Tarek Khoualdia
PhD in Mechanical Engineering
Institution: University of Mohamed- Cherif Messaadia of Souk Ahras
Address: P.O.B. 1553, Souk Ahras, Algeria
E-mail: t.khoualdia@univ-soukahras.dz

Taher Bouadjila
PhD in Electrical Engineering
Institution: University of Mohamed- Cherif Messaadia of Souk Ahras, Laboratory of Electrical Engineering and Renewable Energy (LEER)
Address: P.O.B. 1553, Souk Ahras, Algeria
E-mail: t.bouadjila@univ-soukahras.dz

Djamel Nekkar
PhD Student in Electrical Engineering
Institution: University of Echahid Hamma Lakhdar of El Oued
Address: P.O.B. 789, El Oued, Algeria
E-mail: nekkar.djamel@outlook.com

ABSTRACT
The efficiency and accuracy of the method used in modeling the ET-M53695 photovoltaic panel (PV) is necessary to predict the performance of photovoltaic systems. This article presents and analyzes three cases used (manufacturer, simulink model and the proposed model) to estimate the unknown parameters of photovoltaic devices for the five-parameter diode model. The study has two main objectives: (i) extract the unknown parameters by the iterative method of the f solve function from Matlab, the simulink and manufacturer model under standard test conditions (STC), (ii) verify the efficiency and accuracy of the proposed method, at each data point of the current-voltage curve (category 1), and the error relative to each point of short circuit current (Isc), open circuit voltage (Voc) and maximum power (Pmax) (category 2). The convergence of the proposed method was very fast and the differences between the different parameters of the three models under the STC conditions are almost minimal and the error is always well below 0.01%. We also note that the manufacturers' curves and the curves of the method used are almost identical. The results show that the most accurate method is obtained by the proposed model. It was shown that there is good agreement with all important points of the I-V characteristics; especially at the points Isc, Voc and Pmax, and with the energy supplied by the PV system.

Keywords: Photovoltaic Panel (PV), Five-Parameter, f Solve Function, I-V Characteristics.
1 INTRODUCTION

Electricity is today the easiest form of energy to exploit, but before consuming it it will have to be produced. The production of photovoltaic electricity has seen an increase in interest in recent years with production exceeding 1800 MW throughout the world. This increase was accompanied by an increase in research aimed at optimizing the energy provided by solar cells. Modeling the latter is a crucial step and has led to a diversification in the models proposed by different researchers. Their differences are mainly in the number of diodes, the finite or infinite shunt resistance, the constant or non-constant ideality factor, as well as the numerical methods used for the determination of the different unknown parameters (Bencherif, 2022; El Marghichi, 2023; Alhousni, 2022; Cárdenas, 2017).

We encounter several models in the literature whose precision remains dependent on the mathematical modeling of the different intrinsic physical phenomena involved in the electricity production process. In most works in the literature, we mainly find the equivalent five-parameter model based on the mathematical modeling of the I-V current-voltage characteristics (Ismaeel, 2021). In this model, the effect of the shunt resistance is neglected because its value is important and more particularly for crystalline Si modules (Saive, 2019; Abdulrazzaq, 2020).

The five-parameter model involves five parameters, namely: Iph (the photocurrent), Is (the saturation current), n (the ideality factor) and Rs (the series resistance), Rsh (the shunt resistance). These parameters are not generally measurable quantities or included in manufacturing data. Consequently, they must be determined from the systems of the I–V equations at various operating points given by the manufacturer or taken from experimental tests (Hali, 2024; Aoun, 2019).

The principle of our work is to find and apply an efficient and optimal algorithm or method to extract the maximum available power and compare this model with the Matlab Simulink model and the manufacturer's model.

2 MODELING OF THE PHOTOVOLTAIC MODULE

The modeling of photovoltaic modules necessarily involves a judicious choice of equivalent electrical circuits, taking more or less detail. Numerous mathematical models are developed to represent a strongly nonlinear behavior, resulting from that of the semiconductor junctions which are the basis of their achievements (Rhouma, 2017).

These models differ from each other by the mathematical procedures and the number of parameters involved in the calculation of the voltage and current of the photovoltaic module, using Matlab as a simulation tool and the ET-M53695 module as a test module Table 1:
Table 1. Electrical characteristics of the ET-M53695 photovoltaic module in standard test conditions

<table>
<thead>
<tr>
<th>Sizes</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard irradiance, E</td>
<td>1000 W/m²</td>
</tr>
<tr>
<td>Standard temperature, T</td>
<td>25 °C</td>
</tr>
<tr>
<td>Maximum power, Pmax</td>
<td>95 W</td>
</tr>
<tr>
<td>Maximum voltage, Vmp</td>
<td>18.52 V</td>
</tr>
<tr>
<td>Maximum current, Imp</td>
<td>5.13 A</td>
</tr>
<tr>
<td>Open circuit voltage Voc</td>
<td>22.5 V</td>
</tr>
<tr>
<td>Short circuit current Isc</td>
<td>5.57 A</td>
</tr>
<tr>
<td>Number of cells ns</td>
<td>36</td>
</tr>
</tbody>
</table>

Source: Authors.

The photovoltaic module is represented by an equivalent electrical circuit and shown by Fig. 1. Which is made up of five parameters, namely: a current source $I_{ph}$, the losses are modeled by two resistors, a shunt resistance $R_{sh}$, a series resistance $R_s$, and a diode current $I_d$ for the polarization of the cell and the phenomenon of the recombination of minority carriers and $n$ the ideality factor (Saive, 2019; Toledo, 2016).

The equation characterizing the current-voltage variation curve $I$-$V$ is given by:

$$I = I_{PH} - I_s \left[ \exp \left( \frac{V + I \times R_s}{n_s V_{th}} \right) - 1 \right] - \frac{V + I \times R_s}{R_{sh}}$$  \hspace{1cm} (1)

Figure 1. Equivalent circuit of a single solar cell

These parameters are not generally measurable quantities or included in manufacturing data. Consequently, they must be determined from the systems of the $I$-$V$ equations at various operating points given by the manufacturer or from direct measurement on the module. In this context, we will below study the methods for identifying the different parameters of the current-voltage characteristic of a photovoltaic module.
3 METHODS FOR IDENTIFYING THE DIFFERENT PV PARAMETERS

The five unknown parameters in this model are Iph (the photocurrent), Is (the saturation current), n (the ideality factor) and Rs (the series resistance) and Rsh (the shunt resistance). These parameters are determined from the measurement of the characteristic (I–V) for a pair of irradiance and reference temperature (Eref, Tref) given to the STC ("Standard Test Conditions", 1000 W/m2, 25 °C) by the manufacturer, or from direct measurement on the module (Saive, 2019 ; Di Piazza, 2017). These measurements are essential in order to specify the basic data necessary for the characterization of the different parameters of the model (the 4 values Voc open circuit voltage, Isc short circuit current of the module, Imp, Vmp voltage and current at the maximum power point). Three remarkable points of the characteristic (0, Isc), (Vco, 0) and (Vmp, Imp) (Jain, 2004), can be used to determine the five unknown parameters (Iph, Id, Rs, Rsh, n) where:

\[ I_{sc} = I_{ph} - I_s \exp \left( \frac{I_s R_s}{n_s V_{th}} \right) - \frac{I_{sc} R_s}{R_{sh}} \] (2)

\[ I_{mp} = I_{ph} - I_s \exp \left( \frac{V_{mp} + I_{mp} R_s}{n_s V_{th}} \right) - \frac{V_{mp} + I_{mp} R_s}{R_{sh}} \] (3)

\[ I_{OC} = I_{PH} - I_s \exp \left( \frac{V_{OC}}{n_s V_{th}} \right) - \frac{V_{OC}}{R_{sh}} = 0 \] (4)

\[ \frac{dI}{dV} = I_{mp} + V_{mp} \frac{\left( I_{sc} R_{sh} - V_{OC} + I_{sc} R_s \right) \exp \left( \frac{V_{mp} + I_{mp} R_s - V_{OC}}{n_s V_{th}} \right)}{n_s V_{th} R_{sh}} \frac{1}{R_{sh}} = 0 \] (5)

\[ \frac{dI}{dV} = -\frac{1}{R_{sh}} \frac{\left( I_{sc} R_{sh} - V_{OC} + I_{sc} R_s \right) \exp \left( \frac{I_{sc} + R_s - V_{OC}}{n_s V_{th}} \right)}{n_s V_{th} R_{sh}} \frac{1}{R_{sh}} = 0 \] (6)

The iterative resolution of the five nonlinear equations Eq. (2), Eq. (3), Eq. (4) and Eq. (5), Eq. (6) can be ensured by the function “solve” of the environment Matlab.
3.1 ITERATIVE METHOD

3.1.1 Function f solve

f solve is a function available in the Matlab software library. It is designed to solve a system of nonlinear equations comprising several real variables. These functions are often given in vector form F(X)=0, where F and X can be real vectors or matrices.

The standard formalism of this function is given by Eq. (7):

\[ X = \text{fsolve}(\text{FUN}, 0) \]  

(7)

First of all, the algorithm for this function of Matlab is initialized by the vector (or matrix) X0. Then, solving the imposed equations in FUN is performed iteratively to provide an update of X0 (i.e., X) and values of FUN evaluated in X. Finally, a stopping criterion is examined at each iteration and according to the values of F obtained. This allows you to accept or reject the solution update obtained and stop the resolution algorithm.

Knowing that this Matlab function uses two resolution algorithms: local and global. Indeed, for the local algorithm, f solve requires a first estimate to start its iterations. Consequently, the solution obtained is strongly dependent on this initial estimate. On the other hand, the global algorithm starts with random vectors (matrices) and continues to update them until reaching the vector of the desired solution ensuring the lowest cost (Yoon, 2015).

In general, the Matlab function f solve can be applied in several variants in which the user has the possibility of choosing the appropriate version among which allows solving the nonlinear equation given by Equation. 1. The different versions of this function existing in the Matleb software are as follows:

- \( X= \text{fsolve} (\text{FUN}, \text{X0}, \text{options}) \);
- \( X= \text{fsolve} (\text{problem}) \);
- \([X, \text{fval}]= \text{fsolve} (*)\);
- \([X, \text{fval}, \text{existflag}, \text{output}]= \text{fsolve} (*)\);
- \([X, \text{fval}, \text{existflag}, \text{output}, \text{jacobian}]= \text{fsolve} (*)\).

3.1.2 Description

In this paragraph, we will give some essential details to properly carry out each variation of this function of Matlab. We will therefore have:
X= f solve (FUN, X0, options):

The resolution is ensured with specific optimization options which are available in the optimotions file.

X= f solve (problem):

The system of nonlinear equations must be described beforehand in the form of a problem in which the user must specify the initialization of the solution, the option adopted during the optimization process, etc.

[X, f val]= f solve (*):

Regardless of the syntax imposed by the user, this formalism solves the system of nonlinear equations and returns the values of FUN to the solution X.

[X, f val, existflag, output, jacobian]= f solve (*):

In this case, the stopping criterion ensuring the desired solution is conditioned by the sign of the sufficient condition described by the Jacobian matrix (Available at: Mathworks.fsolve. https://www.mathworks.com/help/optim/ug/fsolve.html).

4 RESULTS AND DISCUSSION

The equations of the previous section for the different methods of calculating the parameters of the current-voltage and power-voltage characteristics were simulated in the Matlab environment for the ET-M53695 solar module. The results of the method used were compared with those provided by the manufacturer.

The simulation study was carried out on an ET-M53695 type solar panel. Its typical electrical characteristics are summarized in Table 2 below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power Pmax</td>
<td>95 W</td>
</tr>
<tr>
<td>Optimal voltage Vmp</td>
<td>18.52 V</td>
</tr>
<tr>
<td>Optimal current Imp</td>
<td>5.13 A</td>
</tr>
<tr>
<td>Number of cells ns</td>
<td>36</td>
</tr>
</tbody>
</table>

Source: Authors

Table 3 represents the results of the five photovoltaic parameters obtained using the fsolve and Matlab Simulink method:

<table>
<thead>
<tr>
<th>parameter</th>
<th>Is</th>
<th>Rs</th>
<th>Rsh</th>
<th>Iph</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method fsolve</td>
<td>1.023e-8</td>
<td>0.216</td>
<td>1.8051e+3</td>
<td>5.569</td>
<td>1.195</td>
</tr>
<tr>
<td>PV Simulink</td>
<td>7.664e-11</td>
<td>0.243</td>
<td>101.596</td>
<td>5.583</td>
<td>0.974</td>
</tr>
</tbody>
</table>

Source: Authors
Figure 2 shows the I(V) and P(V) characteristics of the ET-M53695 module given by the manufacturer:

Figure 2. Effect of irradiance on the manufacturer’s characteristic I=f(V) and P=f(V)

Source: https://www.solairedesign.com/Catalogue/Panneauxsolaires/ET/ET_85.pdf

See the two Figures 3 and 4 extracted from the PV module by Matlab Simulink:

Figure 3. Effect of irradiance on the characteristic I=f(V) by Matlab Simulink

Source: Authors
Figure 4. Effect of irradiance on the characteristic $P=f(V)$ by Matlab Simulink

Source: Authors

The Figure 5 and Figure 6 extracted from the PV module by the method used

Figure 5. Effect of irradiance on the characteristic $I=f(V)$ by the proposed method

Source: Authors
4.1 INTERPRETATION

Table 4 represents the parameters (Voc, Isc, Pmax, Vmp, Imp) of the panels under the conditions STC 1000 w/m² and 25 °C. We can notice that the results obtained by the iterative method and that given by the constructor are almost similar.

<table>
<thead>
<tr>
<th>Constructor</th>
<th>Proposed method</th>
<th>Simulink model</th>
<th>Absolute error between constructor and proposed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voc</td>
<td>22.5</td>
<td>22.48</td>
<td>0.02</td>
</tr>
<tr>
<td>Isc</td>
<td>5.57</td>
<td>5.56</td>
<td>0.01</td>
</tr>
<tr>
<td>Pmax</td>
<td>95</td>
<td>95.43</td>
<td>0.43</td>
</tr>
<tr>
<td>Vmp</td>
<td>18.52</td>
<td>18.2</td>
<td>0.32</td>
</tr>
<tr>
<td>Imp</td>
<td>5.13</td>
<td>5.217</td>
<td>0.087</td>
</tr>
</tbody>
</table>

Table 5 illustrates The power obtained for several sunsets of the three models we find that the powers are almost identical.

<table>
<thead>
<tr>
<th>Pmax (w)E(w/m²)</th>
<th>Manufacturer model</th>
<th>Matlab Simulink Model</th>
<th>Model by the iterative method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>95</td>
<td>95.01</td>
<td>95.43</td>
</tr>
<tr>
<td>800</td>
<td>75.2</td>
<td>76.23</td>
<td>76.22</td>
</tr>
<tr>
<td>600</td>
<td>55.4</td>
<td>57.17</td>
<td>56.84</td>
</tr>
<tr>
<td>400</td>
<td>35.8</td>
<td>37.9</td>
<td>37.37</td>
</tr>
<tr>
<td>200</td>
<td>16.6</td>
<td>18.59</td>
<td>18.04</td>
</tr>
</tbody>
</table>

Source: Authors
5 CONCLUSION

The permanently random behavior of PV highlights the need for an adapted model to respond much more to the required precision, therefore we want to study the behavior of PV by extracting unknown electrical parameters from the model. Several models have been proposed in the literature to simulate PV. Equivalent electrical models are the most widespread. In order to validate this type of model, it is often convenient to implement it on a simulation tool such as: Matlab Simulink. The most popular and popular model is that based on an equivalent circuit with a single diode. This model, characterized by five unknown parameters, provides an acceptable prediction of energy efficiency.

From then on, we use a technique to combine the speed of convergence and the precision of the result. This technique demonstrated an interesting result which subsequently allowed us to use it to build our model. After an exposition of the generalities on the photovoltaic phenomenon and the different characteristics of the quantities linked to the panel, a simple iterative technique based on the resolution of a system of five non-linear equations modeling the solar panel studied is proposed in the third part. We calculated the five parameters of the model: Iph, Is, Rs, Rsh, n under STC conditions, with very rapid convergence and minimal differences between the different calculated parameters and that of the manufacturers. the three models studied are exposed to STC conditions. We also notice that the manufacturers' curves and the curves of the PV model used are almost identical.

We conclude that the modeling technique used turns out to be very satisfactory.
REFERENCES


