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Obtaining the characteristics curves of a photocell by different methods

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Abstract. The objective of this paper is to show different models that simulate the behavior of a photovoltaic cell. The study of photovoltaic systems, in an effective way, requires a precise knowledge of the IV and PV characteristic curves of those photovoltaic elements. This paper shows the results of the implementation of various methods of simulation of a photovoltaic cell, the representation of their IV and PV characteristic curves. The knowledge of the curves allows to know the functioning of the cell and the adequacy of the model. The models are implemented in Matlab/Simulink and in Excel. To carry out mathematical models or experimental data will be needed.

Key words

Photovoltaic Cells, PV-IV Curves, Modeling, Simulation, Matlab/Simulink.

1. Introduction

The high interest aroused by distributed generation due to the opening of electricity markets and the need for alternatives to conventional electric power generation, fossil fuel based, has fostered a renewed interest in renewable systems. Among these renewable systems, photovoltaic systems are expected to play an important role in the generation of electrical energy in the future.

Photovoltaic energy is a clean energy, with a long service life and high reliability. Thus, it can be considered as one of the most sustainable renewable energies. These systems may be located at the points of consumption or near them, avoiding transmission losses. And, in addition, contributing to the reduction of CO_2 emissions in urban centers.

An ideal solar cell, theoretically, can be modeled as a current source in anti-parallel with a diode (Fig. 1). The direct current generated, when the cell is exposed to light, varies linearly with solar radiation. An improvement of the model includes the effects of a series resistor and other one in shunt. [1]

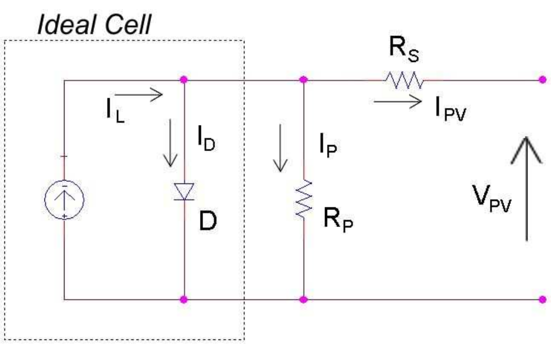

Fig. 1. Equivalent circuit of a photovoltaic cell

The equation describing the relationship between voltage (V) and current (I) provided by a module is as follows:

$$I = I_L - I_D - I_P \qquad (1)$$

Being the net current of the cell, the difference of the photocurrent I_L, (the current generated by the incident light, directly proportional to the sun irradiation), I_D (the normal diode current) and I_P the current through the shunt resistor. If each term is replaced by its value is obtained:

$$I = I_L - \underbrace{I_0.(e^{\frac{q.(V+I R_S)}{aKT}} - 1)}_{I_D} - \underbrace{\frac{(V+I R_S)}{R_P}}_{I_P} \qquad (2)$$

Where, I_0 is a saturation current of the diode (A), V is a cell voltage (V), q is the charge of an electron, equal to $1'6.10^{-19}$ (C), a is the diode ideality constant, K is the Boltzan's constant, $1'38.10^{-23}$ (j/K) and T is the cell temperature. [2-7]

The typical representation of the output characteristic of a photovoltaic device (cell, module, or photovoltaic system) is called characteristic curve, and indicates their behaviour. The IV curve indicates the relationship between the current and voltage *according to the level of incident radiation and temperature*. The PV curve indicates the same relationship but for power and voltage. These curves can be obtained in several ways. Mainly, they can be calculated from (2) or can be obtained experimentally from the photovoltaic system. This way could be expensive and complicated.

It is, therefore, extremely interesting to have computer models that simulate the behavior of the solar cell. The validity of these models will depend on the similarity of the relationship between the current and voltage, compared to the physical model. The result of this simulation has to be a graph or curve similar to that provided by the manufacturer. (Fig. 2)

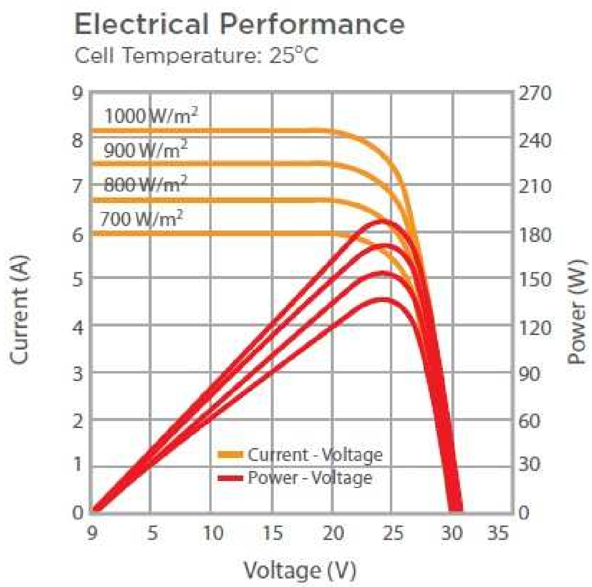

Fig. 2. Characteristic curves provided by the manufacturer

In this case the graphics provided by the manufacturer are at constant temperature and for different values of irradiance (1000 W/m^2, 900 W/m^2, 800 W/m^2 y 700 W/m^2). Graphs can also be obtained at constant irradiance and different temperature values.

2. Characteristic Curves

The current-voltage curve (IV) shows the possible combinations of pairs of current-voltage of the photovoltaic device. Conceptually, the curve represents the combinations of current and voltage at which the cell can operate, if the irradiance and cell temperature could be kept constant. The evaluation of the performance of solar cells and the design of photovoltaic systems must be based on the electrical characteristics, that is, in the current-voltage relationships of the cells subjected to various levels of irradiation and temperature.

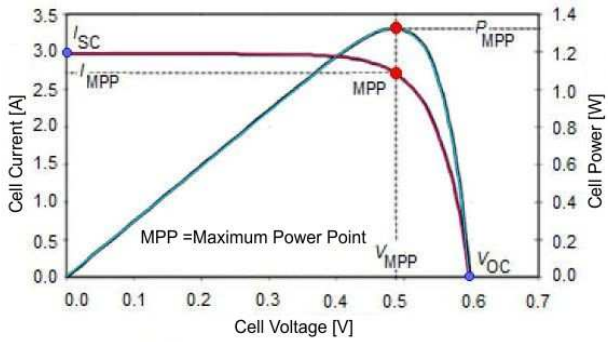

Fig. 3. Characteristic curves of a solar cell

Figure 3 shows the IV characteristic curves (red) and PV (blue), for a cell working at temperature and radiation will be obtained known; depending on these factors a curve or another. The horizontal axis represents the working cell voltage (V) and the vertical axis the current (A). It shows the energy produced by the cell or photovoltaic module at a point, called operating point, in any part of the IV curve. The coordinates of the point of operation are the operating voltage and current.

Analyzing the graph, there are several characteristic points. The cell will produce the maximum intensity when the resistance between the terminals of the output circuit is minimal; this is when there is short circuit. The operating voltage is zero and this value is called "Short Circuit Current" (I_{SC}). The maximum voltage is reached in the case that the resistance is infinite and then the current is zero, the circuit is open, that is, there is "Open Circuit Voltage" (V_{OC}). Another point to consider is the maximum of the PV curve, called maximum power point (MPP), which corresponds to the point on the IV curve, wherein the area of the rectangle formed by the points (V,I) is maximum. This is the point at which the module operates with maximum efficiency and produces the maximum output power. It is the point of maximum power (V_{mpp}, I_{mpp}). In a photovoltaic system operating, one of the functions of the inverter is to constantly adjust the load. The available power of a photovoltaic device at any point along the curve is simply the product of current and voltage at that point and is expressed in Watts.

3. Simulation Types

The models presented in this paper are the result of the search for different computer simulation models of solar cells or photovoltaic panels. The models differ depending on whether they were modeled with Excel, Matlab, Simulink, or with the support of some of their toolbox. Following is a brief overview of each of the types of simulation discussed in this paper.

A. Matlab Programming

This model is made only in Matlab, based on mathematical equations that define the photovoltaic cell. From the work of Walker [6], Gonzalez [7] and Ahikiro [8] a function in Matlab [2] has been developed which calculates the current module from data of voltage, solar radiation and temperature. Setting the constant temperature or radiation, curves IV and PV will be obtained. From another script also calculates the maximum power point.

B. Matlab Tools

This section has taken into account two ways to represent the IV and PV curves. In the first form of representation, the graphic interface for curve fitting Cftool (Curve Fitting Toolbox) has been used. The starting point of this model is the manufacturer's datasheet, in which the IV and PV curves of the panel are represented. In this curve at least three coordinates (V, I) are known, (0, I_{SC}), (V_{mpp}, I_{mpp}) and (V_{OC}, 0). Manually more coordinates can be approximated to facilitate the representation. With these coordinates, the tool will provide an equation of a similar curve to the original one.
In the second form, the model consists of two Matlab programs. The first serves for the presentation and data capture and calculations are made in the second one. These calculations are based on three functions of MATLAB: fsolve, fzero and lsqnonlin. In this case the data used were obtained experimentally from the panels analyzed. Data can be exchanged from one form of representation to another.

C. Basic model in Simulink

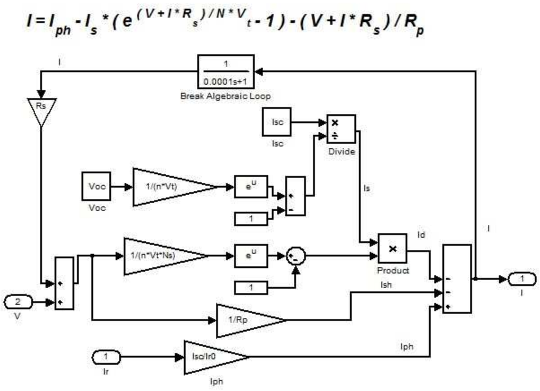

Fig. 4. Basic model in Simulink

This model is made based on [5] and [9]. It is a model like the one shown in section D, also based on mathematical equations (1) but made with elements of Simulink. It is a basic model in which the values of R_S (0.001 Ω) and R_P (1000 Ω) are assumed to be known

D. Simulink model with tags

This is the usual way to model a PV cell that has been developed among other authors, by Villava [3]. It starts from the same equations as in section A, but it is developed in Simulink. Based on this kind of programming could also simulate the basic model of the previous section in this way.

E. Model of physical component

This model is made from physical elements using Simscape. With those elements, electrical equivalent circuit diagram of the cell is performed.

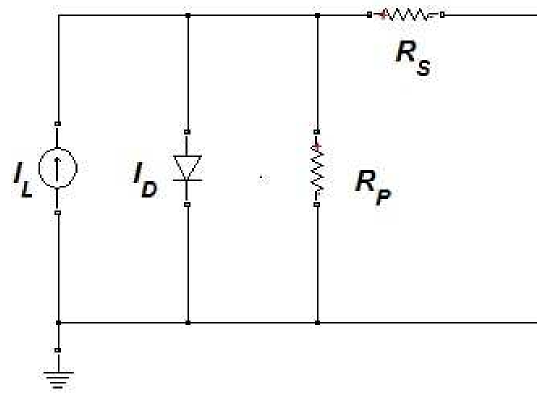

Fig. 5. Model of physical component in Simulink

F. Model of advanced component library

This is the simplest model. It works with an element of SimElectronics, that is a toolbox dependent of Simscape. The element to model, Solar Cell, appears in the Source Library. Only, it is needed to enter the parameters that define the cell, provided by the manufacturer's data sheet.

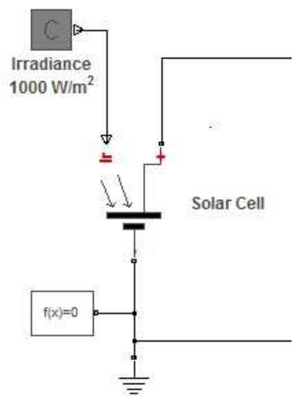

Fig. 6. Characteristic curves obtained with the A-model

4. Results

One can say that, fotocurrent depends on the irradiation of the moment, for a fixed temperature (in these cases, 25° C). The higher the irradiation, the greater the current. On the other hand, voltage is going to maintain almost constant and it is not going to vary much, although increases or diminishes the irradiation.

Below are the graphs (Fig. 7-13) showing the results of this study:

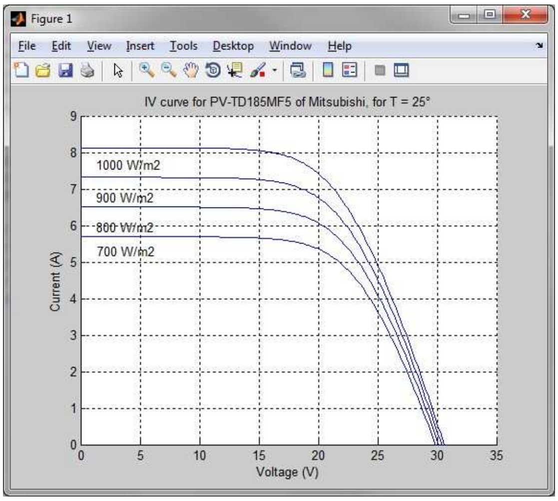

Fig. 7. Characteristic curves obtained with the A-model

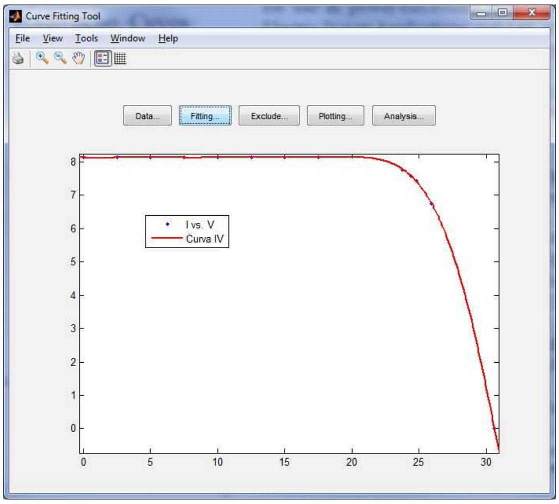

Fig. 8. Characteristic curves obtained with the B1-model

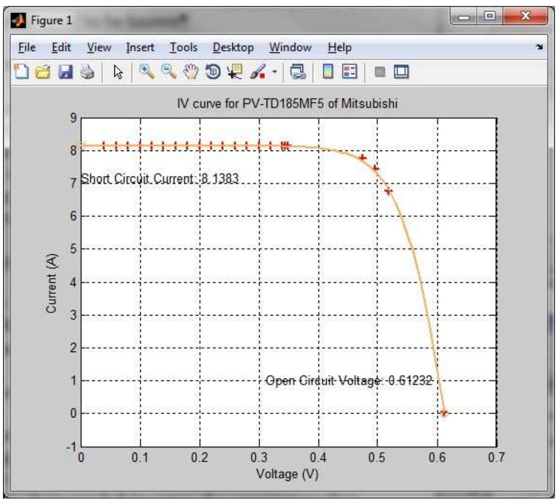

Fig. 9. Characteristic curves obtained with the B2-model

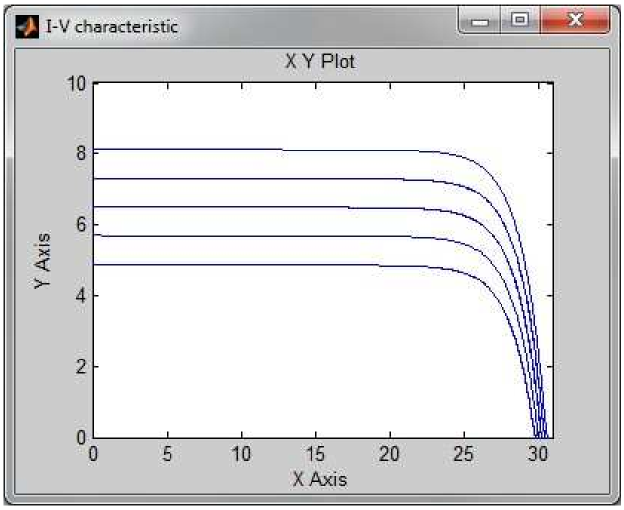

Fig. 10. Characteristic curves obtained with the C-model

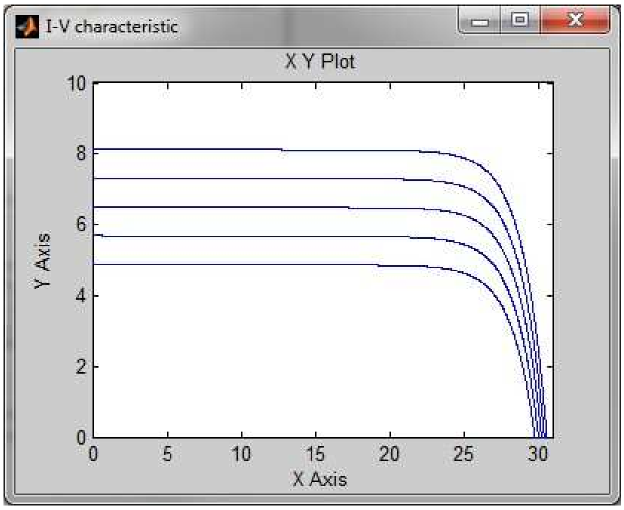

Fig. 11. Characteristic curves obtained with the D-model

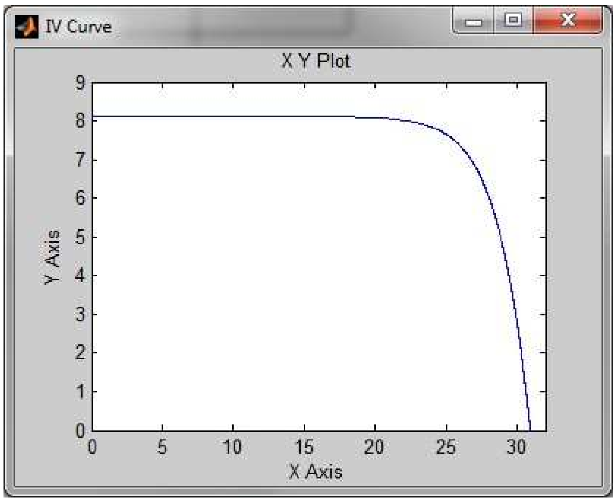

Fig. 12. Characteristic curves obtained with the E-model

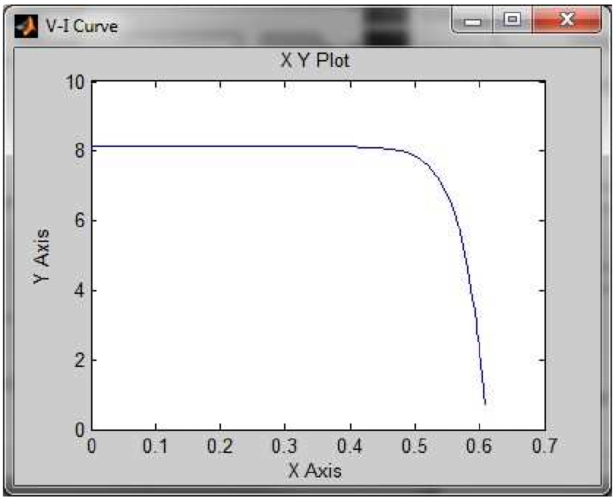

Fig. 13. Characteristic curves obtained with the F-model

5. Conclusions

As already mentioned, to get experimental data can be expensive and will depend primarily on weather conditions, so it is very useful to have simulation models to be able to work at any time. For this reason, in this paper, several methods of modeling photovoltaic panels have been developed.

The objective of the models is to achieve similar IV and PV characteristics curves to the graphs that are in the data sheet of the manufacturer of the different solar panels.

The most similar will be the best model, or the one that behaves more like the physical model. In the made models, the results are similar and they resemble the desired results, although they are simple models, and it is possible to study the behavior and performance of photovoltaic cells in the time domain.

The developed model A, with electrics main parameters, is valid for I-V characteristics measured and can work with few parameters of input demonstrate to graph and numerically the operation of a solar model. Unfortunately, the manufacturers do not provide the values of the resistance in series nor in parallel of the cell. That would make easier the simulation.

The set of experiments with different models designed in Matlab/Simulink (model B) provide the ability to analyze easily the study of the photovoltaic cell, based on few data pairs (V, I) that are known. It can be said that the results obtained with those models are quite similar. The models made in this section "Matlab Tools" are models for a fixed irradiance and cannot be generalized for any irradiance. For each irradiance must be, recalculated the pairs (V, I) for the corresponding curve.

The models C and D are more likely to work than those developed in model A. These three models are very similar, because they start from the same equation, but the Simulink models, being in a graphical environment, are easier to see and to analyze the performance of the model. Models C and D are almost the same model. Because, they are the result of the same equation. But defined with different elements.

In the models A, C, D and F, it is easier to make adjustments than in the model E. Because in the first models are used data supplied by the manufacturer. And in the model E, you need to know the values of R_S and R_P that are not normally provided by the manufacturer.

The easiest model to work with and to configure is the model E. This model is provided and developed by Matlab, Solar Cell Block. The block represents a single solar cell as a resistance R_S that is connected in series with a parallel combination of the following elements: Current source, two exponential diodes and parallel resistor R_P.

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