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MODELLING OF A PHOTOVOLTAIC PANEL BASED ON THEIR ACTUAL MEASUREMENTS

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Abstract- The objective of this paper is the realization of a computer model that simulates the behavior of a photovoltaic module for any value of irradiance and temperature. This will allow us to work with the photovoltaic module regardless of weather conditions. For its implementation we use two computer programs, Excel and Matlab. In Excel, we will adapt our data and Matlab will make the model itself. The model will be made from experimental and technical data of the commercial panel Mitsubishi PV-TD185MF5. The data are taken randomly during a year. We have tried to collect as many combinations of irradiance and temperature as possible. The validity of this model is demonstrated by means of the implementation of IV and PV curves of the photovoltaic panel. The precise knowledge of these curves provides insight into the module operation and adequacy of model.

Keywords: Photovoltaic Cell, PV-IV Curves, Modeling, Simulation, Matlab.

I. INTRODUCTION

Photovoltaic solar energy is a clean and renewable energy, with a long life and high reliability. Because of its high cost and low efficiency its energy production is lower than other energy sources. The ideal solar cell, theoretically, can be modeled as a current source in anti-parallel with a diode, as Figure 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 shunt resistance and another one in series. The use of simple models provides sufficient accuracy to analyze the behavior of the solar cell, and has proven been effective in most cases.

According to [1-11] and based on the equivalent circuit of a photovoltaic panel, in Figure 1, the relationship between the voltage (V) and current (I) provided by a module, as shown in Equation (1).

$$I = I_L - I_S \cdot \left(e^{\frac{(V+IR_S)q}{akTN_S}} - 1 \right) - \frac{(V + IR_S)}{R_p} \tag{1}$$

In this case composed of N_s cells in series. Although this equation could also be used to represent a single cell (N_s = 1).

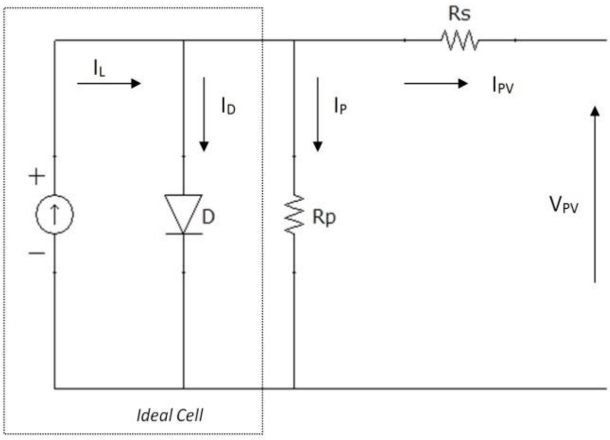

Figure 1. Equivalent circuit for PV modules

To determine the behavior of the solar panels it is necessary to know the voltage and amperage provided by different operating states in which they may be encountered.

For this we have developed the IV and PV curves, Figure 2, from Equation (1). The characteristic curve is called to the relationship between the electrical current (power) that provides the cell and the potential difference between its ends, for a given radiation intensity, when the load is been changing. These curves also depend on the temperature at which the cell is.

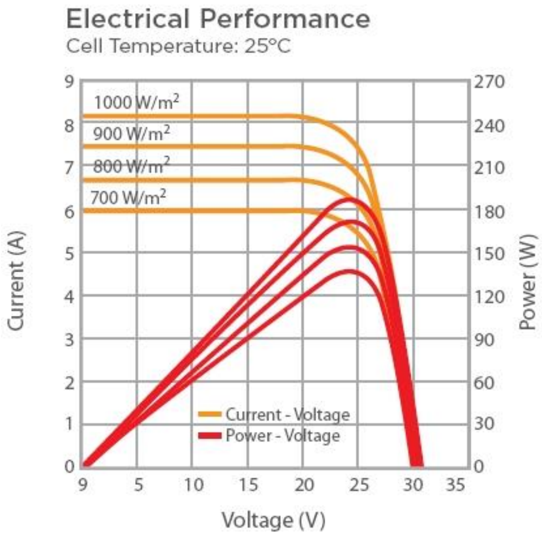

Figure 2. Curves *I-V* and *P-V* for constant *Tª*

A. Photovoltaic Panel to Be Developed

In order to apply these concepts to developments of a solar cell model, the Mitsubishi PV-TD1185MF5 PV module has been chosen for modelling. This module has 50 series connected polycrystalline cells. The key specifications are shown in Table 1.

Table 1. Key specifications of the Mitsubishi PV Panel

Model	PV-TD185MF5
Cell type	Polycrystalline Silicon 156 x 156 mm
Maximum Power [W]	185
Open Circuit Voltage V_{oc} [V]	30.60
Short circuit Current I_{sc} [A]	8.13
Voltage, max power V_{mpp} [V]	24.40
Current, max power I_{mpp} [A]	7.58
Normal operating cell temperature (*NOCT*)	47.5 ºC

The performance of solar cell is normally evaluated under the standard test condition (STC), where an average solar spectrum at AM 1.5 is used, the irradiance is normalized to 1000 W/m^2, and the cell temperature is defined as 25 ºC.

II. DEVELOPED MODEL

To make this model, experimental values of voltage and current of solar modules are need. These values have been obtained from measurements in the solar module Mitsubishi PV-TD1185MF5. Data were obtained from the schema shown in Figure 3 since August, 2013 until the present day. For the configuration of the elements Sineax CAM and TV809 two programs (CB-Manager and TV800 plus) have been needed. In these programs are chosen the magnitudes to be measured and the conversion to perform.

A. Experimental Data

The scheme of Figure shows the manner of connecting the elements for the acquisition of experimental data, Figures 3 and 4.

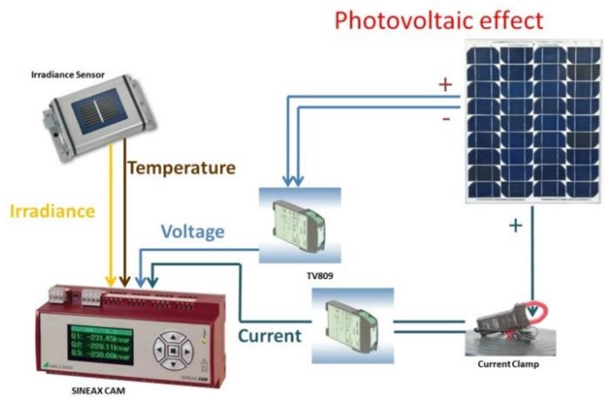

Figure 3. Arrangement of the elements.

CB-Manager integrates all the functions necessary for configuring the SINEAX CAM and for displaying the measured values.

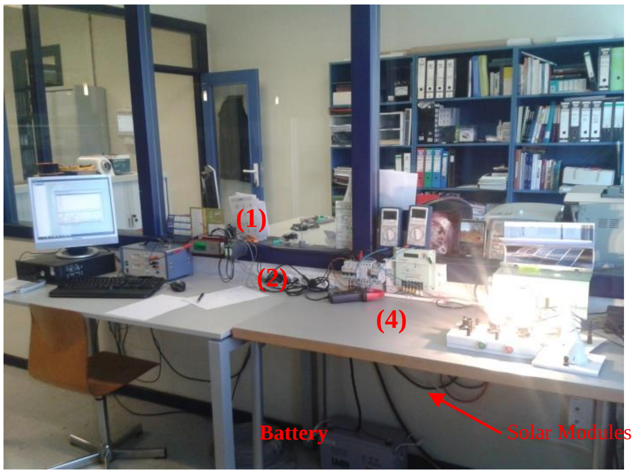

Figure 4. Disposition of the physical devices.

The elements used are:

1. Sineax CAM: It is designed for long-term measurements in industrial installations or electrical distribution networks. It allows a continuous measurement and recording of measurement data. The interface I/O can be configured according to the requirements. The selected parameters to register are irradiance, temperature, voltage and current. With its unique combination of hardware and software modules this measuring device provides a solution for each measurement task. The adaption to this task is performed quick and easy by means of the CB-Manager software.
2. TV809: Its functions are, to isolate electrically the input and output signals, amplifying and/or converting the signal level or type (current or voltage) of the input DC signals. Measured variables and measuring ranges are programmed with the help of a PC. The functions of the two elements in our scheme are, to convert the voltage and current of the module in a 4-20 mA current proportional to the input of SINEAX CAM.
3. Irradiance sensor (Si-420TC-T-K): It is a pattern cell. This element will provide irradiance and temperature of the system throughout the duration of the measurement. The measurement time for this test will not be long. When

the sensor adquires working temperature, these two values will have very little variation, therefore they will be assumed constant for the realization of the IV and PV characteristic curves.

4. Current clamps: Chauvin Arnoux PAC12: The PAC12 can measure direct currents provided by the solar module. Providing a voltage proportional to the measured current. Later another TV809 will be needed to convert this tension in another proportional current, which is measured with the SINEAX CAM.

B. Data Processing

The measured data are saved in TXT files. After some minor modifications, all these files are opened as a single file in Excel as Figure 5.

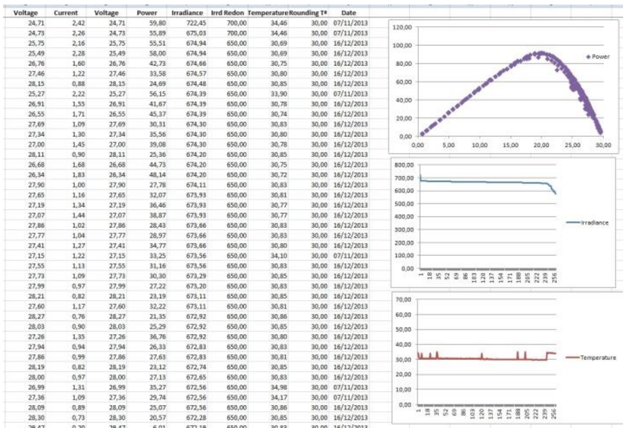

Figure 5. Data processed in Excel

In Excel the values of temperature and irradiance are rounded as follows:

=REDOND.MULT(Temperature;10)

=REDOND.MULT(Irradiance;50)

With the temperature data are formed five data groups: Curves 50º, 40º, 30º, 20º and 10º C. Subsequently, each of these groups are arranged, depending on the irradiance. Forming other subgroups: 1000, 900, 800, 700, 600, 500, 400, 300, 200 and 100 W/m^2.

With this, we have groups of curves for different values of irradiance to different types of temperature as Figure 6.

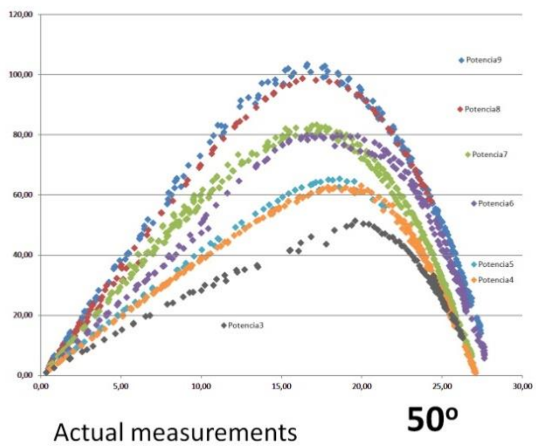

Figure 6. *P-V* curves for a temp of 50º

III. EXPERIMENTAL DESIGN

Experimental data pairs (V, P) are loaded in Matlab

```
>> A=load('dates.txt');
>> voltage=A(:,1);
>> power=A(:,2);
```

Open the Curve Fitting Tool (cftool). Select X data (Voltage) and Y data (Power). There are different fit options. For example, polynomial, a cubic polynomial, ... A polynomial curve 5º degree will be chosen. This is done for all the curves. Thereby, polynomial equations 5º degree will be obtained from the experimental data

In Excel, it apply to these equations, values of voltage from 0 to 30 (from 0.5 to 0.5) yielding the curves as shown in Figure 7.

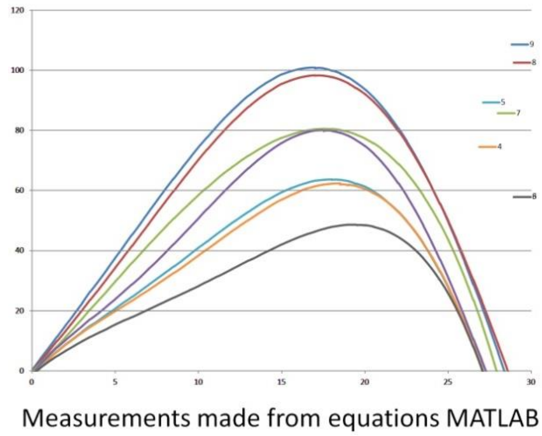

Figure 7. *P-V* curves for a temp of 50º from Matlab in Excel

IV. SIMULATION RESULTS

With these same equations, is generated in Matlab a file able to show the desired PV curve, from values of temperature and irradiance previously chosen as Figure 8.

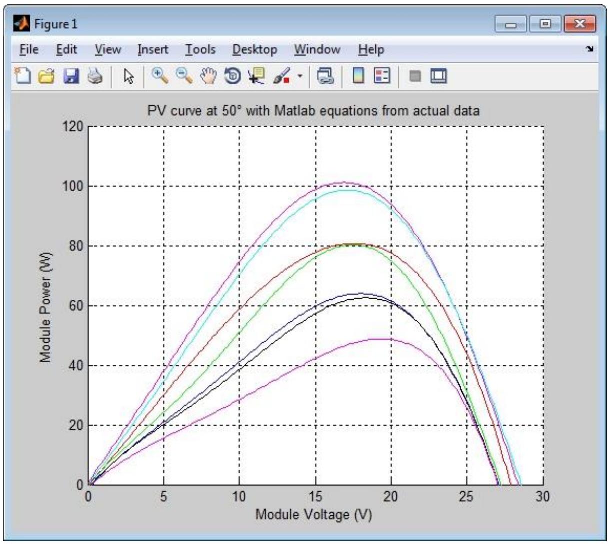

Figure 8. P-V curves for a temp of 50º in Matlab

It have also been made other models in Matlab. For example, one is able to provide a characteristic curve and not the full range of curves. Also based on the same data there is another model in Simulink.

V. CONCLUSIONS

The main advantage is that this model has been developed from actual experimental data from the solar module. In the results are included all losses.

However it is not always possible to obtain this information because it may be expensive or because you cannot have means or time to get them. It is therefore very interesting to have simulation models to work in any weather condition.

The main disadvantage of this model is that it is very difficult to obtain all the necessary values. The data obtained are dependent on the weather and are only valid for a particular panel. For each panel, you have to repeat all measures.

For example, in this model the curves are widespread only five temperatures, instead of having the whole temperature range.

Another disadvantage is that it takes a long time to take the experimental data.

NOMENCLATURES

I_{sc}: Short-circuit current
I_{mpp}: Current at the maximum-power point
I_L: Light-generated current
I_D: Diode current
I_S: Diode reverse saturation current
I_p: Current through the shunt resistance
I_r: Irradiation
V_{OC}: Open-circuit voltage
V_{mpp}: Voltage at the maximum-power point
P_{mpp}: Power at the maximum-power point
R_S: Series resistance
R_P: Shunt resistance
q: Electron Charge constant, $1.6\ 10^{-19}$ C
n: emission coefficient, ideality factor. (Si = 1.2)
a: Diode ideality constant.
k: Boltzmann's constant
T: Cell temperature
N_S: Number of cells in series

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REFERENCES

[1] J.A. Gow, C.D. Manning "Develoment of a Photovoltaic Array Model for Use in Power Electronics Simulation Studies", IEE Proceedings on Electric Power Applications, Vol. 146, No. 2, pp. 193-200, March 1999.
[2] J.A. Ramos, I. Zamora, J.J. Campayo, "Modelling of Photovoltaic Module", International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada, Spain, 23-25 March 2010.
[3] M.G. Villalva, J.R. Gazoli, E. Ruppert, "Modeling and Circuit Based Simulation of Photovoltaic Arrays", Brazilian Journal of Power Electronics, Vol. 14, No. 1, pp. 35-45, 2009.
[4] Widalys, DeSoto, "Improvement and Validation of a Model for Photovoltaic ArrayPerformance", M.Sc. Thesis, Mechanical Engineering, University of Wisconsin-Madison, 2004.
[5] C. Osorio, "Matlab-Simulink Models", Mathworks.
[6] G. Walker, "Evaluating MPPT Converter Topologies Using a Matlab PV Model", Journal of Electrical & Electronics Engineering, Australia, Vol. 21, No. 1, pp. 49-56, 2001.
[7] F. Gonzalez Longatt, "Model of Photovoltaic in Matlab", 2nd Latin American Congress of Students of Electrical Engineering, Electronics and Computer Science (II CIBELEC 2005), Puerto la Cruz, Venezuela, April 2006.
[8] A. Oi, "Design and Simulation of Photovoltaic Water Pumping System, Master's Thesis, California Polytechnic State University, Sn Luis Obispo, USA, 2005.
[9] http://ecee.colorado.edu/~ecen2060/matlab.html.
[10] A. Luque, S. Hegedus, "Handbook of Photovoltaic Science and Engineering", John Wiley & Sons Ltd, 2003.
[11] A.S. Golder, "Photovoltaic Generator Modeling for Large Scale Distribution System Studies", Master's Thesis, Drexel University, USA, January 2007.

BIOGRAPHIES

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