Design, implementation and testing of a characterization photovoltaic panels system

Álvaro Jaramillo
Bonie Restrepo
Jorge Arango
Alfonso Berrio
Instituto Tecnológico Metropolitano – Colombia

1 Introduction

To understand the operation of an array of photovoltaic (PV) panels, it is necessary to consider the individual behavior of a panel and each of the cells that compose it [1, 2]. To characterize a PV panel, it is only considered direct mode of operation (as a generator). However reverse mode operation of a PV panel (as a load), must be consider, although it is a less common analysis [3, 4]. In a panel, the reverse mode operation can occur for a damaged cell, or because the electrical characteristics of some cells are not the same, or if some of the modules are exposed to partial or total shading. As a result, these affected cells do not generate electricity and otherwise behave as a load, consuming energy coming from rest of the array. Consequently these cells dissipate energy as heat, resulting in some cases in permanent damage to the panel [5-7].

In order to evaluate the performance of the photovoltaic module, in direct and reverse mode of operation, it is necessary to make an electrical and thermal characterization thereof. For electrical characterization, experimental measurements must be made of Current-Voltage (I/V) and Power-Voltage (P/V) curves. As a first step, it was proposed to develop a system for characterization of photovoltaic panels for direct mode operation (as a generator). The second stage of this project, which is not reported in the article seeks to characterize and obtain the curves of a PV panel in the reverse mode of operation (as a load).

To obtain the characteristic curve in direct mode operation of a PV panel, it is possible to use different methods described in the literature [8]. However, the cost of the necessary equipment, the time required to make the test, the accuracy and reliability of the results, are factors that must be considered to choose the most appropriate alternative. The procedure to obtain the characterization curves, consist in connect an element, active or passive, to the panel terminals and measure the voltage and current signals. Ideally, this type of testing have to be made when the panel is exposed to constant radiation and temperature. Below are define some of the methods described in the literature:

- Variable Resistance: The resistance value is changed in incremental steps, starting at zero ohm and until the current is approximately zero amps. This method is only applicable to low-capacity PV panels due to the need of a high power resistors to dissipate energy coming from the panel [9].
- Capacitive Load: When the capacitor is connected to the panel, its charge increases, current drops and voltage rise. When the capacitor is fully charged, the current supplied by the photovoltaic panel becomes zero. To obtain reliable curves, a good quality capacitor is required, this means that it has a low equivalent series resistance [8].

- Electronic Load: Uses a transistor (usually a MOSFET) as a load. When this method is used to trace I/V curve of the PV panel, the MOSFET must operate in three modes: cut-off, active, and in the Ohmic region. During the process, most of the power delivered by the PV panel must be dissipated by the MOSFET, limiting its application to medium power panels [10].
- Bipolar Amplifier Power: It is based on a class B amplifier, which use two transistors BJT as a load. Bipolar transistors must operate in three modes: cut, active and saturation region. Therefore, as in the method of electronic load, most of the power supplied by the PV panel must be dissipated by the transistors. This restrict its application to medium power panels [8].
- Four Quadrants Power Supply: A power supply whose output can be varied by a reference input signal or programmed to perform sweeps on a specific range of values. These types of power supplies are relatively expensive but offer the most reliable results [11].

To characterize different PV panels, it has been proposed to solve the problem in several steps. The first stage, presented in this paper, shows the development and implementation of a test system for the reconstruction of electrical characteristics curves of PV panels in the first quadrant (direct mode), using the method of the electronic load. The electronic load method was chosen over the other mentioned methods above, as it is an available element in the institute labs. This device can be programmed and operated remotely. Thus, it possible to perform the characterization automatically, over different conditions. The capacity of the device available, fits the maximum power of the PV panel available.

2 Methodology

The development environment included in Matlab® was used to implement the prototype and its graphical user interface. This environment was chosen because of its versatility and ability to interact with hardware, in this case, the electronic load. The configuration, operation and reading data of electronic load was done through serial communication using the protocol of electronic load [12]. The program, created in Matlab® development environment, communicates with the electronic load, adjusting its parameters and sending a series of instructions for performing the test. Additionally, the electronic load takes record of voltage, current and power and sends it to the program. The program is designed to store the readings made by the load and once the test is complete, the program displays the results graphically. The operation of the prototype was tested first with a simulator of photovoltaic panels and finally with some panels exposed to the midday sun, in the city of Medellín, Colombia. In both cases, the panel and the simulator, were connected directly to the electronic charge, which was controlled by software. The prototype development was divided into three phases as described below.

2.1 Remote configuration and control of the electronic load

The remote configuration and control of the electronic load were achieved through serial communications using the libraries available in Matlab and according to the communication protocol of the electronic load [12]. All code was written from scratch. The configuration and operation of the load was included in the main function of the program, which is represented in the block diagram shown in Fig. 1. Each instruction of the main function, corresponding to sub-functions that perform a simple task, as the adjustment of a certain configuration parameter, reading of the variable or the operation mode of the load. The objective was to develop a modular program to facilitate debugging and code reuse in other sub-functions.

As can be seen in Figure 1, the initial part of the program defines the parameters for serial communication with the electronic load. Then, setting for maximum values of voltage, current and power are made, these values are associated with the nominal operating of the PV panel to be characterized.

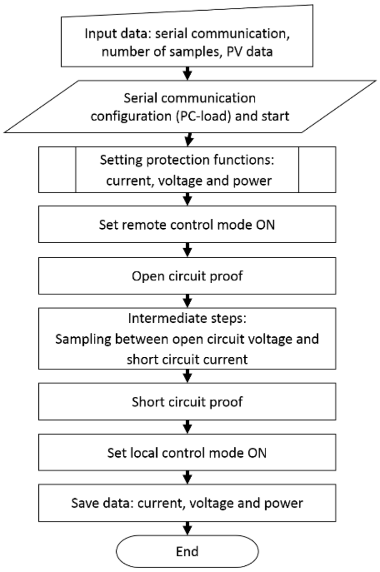

Figure 1: Block diagram of the main function

For the characterization of any panel, was proposed a reconstruction point to point of the IV and PV curves. The test starts measuring the open circuit voltage, then a sweep, point to point, between the open circuit voltages to the nearest value to zero volts is performed by the program. The number of steps to rebuild the graphs is chosen by the user in the GUI (Graphical User Interface). In each stage the operation mode of the load, including current, voltage or constant impedance is changed as is need. For the open-circuit voltage, for example, the constant current mode is set to a value of zero amps. For the intermediate steps, the load mode is set to constant voltage and varying the voltage going in decreasing values. Finally the load is adjusted in constant impedance mode, with a value of zero for short circuit testing.

2.2 Design and development of the prototype

For GUI prototype input parameters, according to their origin were grouped as below; Serial communication: speed of data transmission and communication port; Test characteristics: number of samples per curve; Characteristics of PV panel: Nominal operating voltage and maximum power output. For data input, we designed and developed a graphical interface that offers an experience simple and intuitive user, additionally prevents the entry of invalid data, as can be seen in Figure 2. The application includes an option allows exporting data, IV and PV curves, to an Excel and Matlab (.mat) format; additionally export an image of the curves in png format.

2.3 Prototype testing

Two tests were developed to test the prototype: the first using a programmable DC source, which allows the simulation of a photovoltaic panel; and the second, with a photovoltaic panel outdoors. In both cases feeding the electronic load controlled by the software prototype developed.

Figure 2: Graphical interface user

3 Results

PV panels simulator Chroma 62000H was used in the first stage of tests [12]. The **Figure 3**Figure 3 shows a schematic of the communication between the PC running the program and the electronic load; further the electrical connection between the load and the simulator panels. Some tests were performed using the characteristics of PV panels HYBRITEC-QM5-85/12, HYBRITEC-M5 30/12 and HYBRITEC 10/12 with standard test conditions (Irradiance: 1000W/m2, cell temperature: 25°C and a spectral distribution of the incident radiation of 1.5). Initially linearly spaced measures, with respect to the voltage, were taken, but to obtain a more reliable behavior of the panel, we chose a denser spacing in the nonlinear region of the curve, which is one of the most important characteristic of the panel, called Maximum Power Point (MPP).

Photovoltaic panel HYBRITEC-QM5-85/12, exposed to irradiation noon on a sunny day was used for the second stage of testing. Irradiation and temperature measurements were taken manually using the MacSolar device [14].

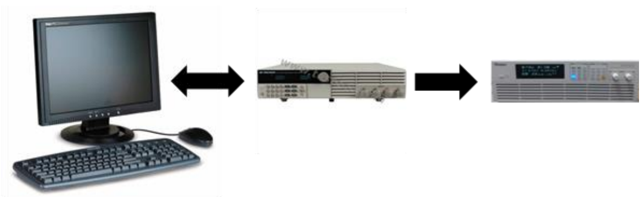

Figure 3: Communication between the computer and the electronic load, and connection between the electronic load and panel simulator

3.1 Test based on a PV panels simulator device

In Figure 4, the results of the simulation of Hybrytec 10/12 PV panel are shown, using the Chroma 62000H PV device. To simulate the behaviour of Hybrytec 10/12 PV panel, Chroma 62000H [11] device requires as input the maximum power: 10 W, maximum peak current: 0.58 A, maximum peak voltage: 17.40 V, open circuit voltage: 21.80 V and short circuit current: 0.63 A.

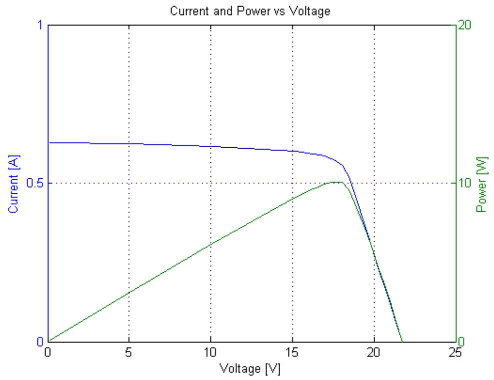

Figure 4: Characteristic curves of the simulated panel Hybrytec 10/12

3.2 Test using the PV panel Hybrytec QM5-85/12

For performed outdoors testing, we used the PV panel Hybrytec QM5-85/12, with the following characteristics: maximum power: 85W, maximum peak current: 4.83 A, maximum peak voltage: 18.02 V, open circuit voltage: 21.85 V and short circuit current: 5.22 A. Curves I/V and P/V presented in Figure 5, were obtained at 13.00 with a temperature of 47°C and an irradiation of 1037 W/m2.

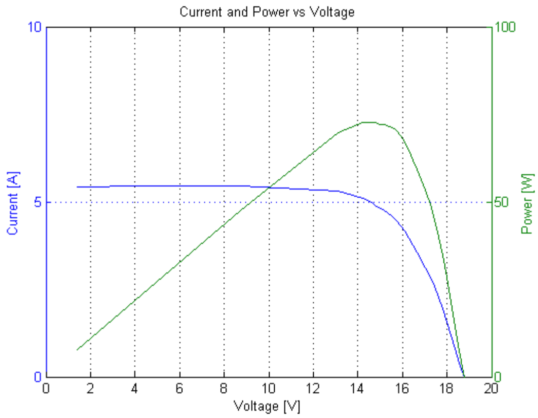

Figure 5: Characteristic curves of the simulated panel Hybrytec-QM5-85/12

Figure 6 shows the variations in the characteristic curves irradiation due to changes caused by the passage of a cloud.

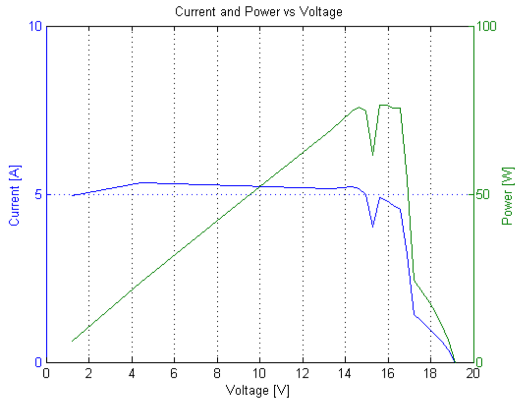

Figure 6: Characteristic curves of the PV panel Hybrytec-QM5-85/12

4 Conclusions

A program with graphical user interface was developed using the Matlab® development environment, which allows the reconstruction of the characteristic curves of a photovoltaic panel automatically. The method of programmable electronic load was used in the test system, demonstrating its good performance and reliability in the results

The performance of the program, considering every features in the internal functions and the GUI, was tested with the panel simulator Chroma 62000H. At this stage of testing, it was determined that it was not necessary to make a uniform sample measurement base on voltage. There are two main reasons to do a dynamic sampling during the test, reduce the time of the measures and obtain a more reliable curves in non-linear regions, where a denser sampling was made.

A real tests was made with PV module Hybrytec-QM5-85/12 where the correct performance of the test system was proved, software developed and electronic load.

5 Further work

For the presentation of the data in the graph, it is possible to use curve fitting techniques, such as least squares or kernel regression, in cases where there are unexpected changes of radiation and temperature by the temporal passage of clouds, ensuring a curve that represents the real behavior of the panel.

For outdoor testing, the data must be taken in the shortest time to avoid unexpected changes in radiation and temperature. A new version of the system will be implemented with a separate step of acquiring data, to obtain the values of voltage, current, plus temperature and irradiation in a faster procedure. With this additional subsystem is expected to obtain more detailed and reliable information from the PV panels.

For the second stage of the system, is intended to obtain the characteristic curves in the reverse mode of operation of a PV panel. In order to perform the complete characterization of the electrical behavior of the PV panels. These data will be used for the design of electronic devices that integrate the panels in the most appropriate manner, for isolated and plugged systems. Additionally, these data will be used for energy evaluation of PV solar generation projects.

Acknowledgements

This article was supported by Instituto Tecnológico Metropolitano under the project PM14105. Equipment used belong to the Group of Automation and Electronics Research - GIAE, of Instituto Tecnológico Metropolitano.

Referencias

[1] Salmi, T. et al. (2012). MATLAB/Simulink Based Modeling of Photovoltaic Cell. International Journal of Renewable Energy Research (IJRER) 2(2), pp. 213–218.

[2] Liu, J. (2014). Solar Cell Simulation Model for Photovoltaic Power Generation System. International Journal of Renewable Energy Research (IJRER) 4(1), pp. 49–53.

[3] Sidawi, J. et al. (2011). The effect of reverse current on the dark properties of photovoltaic solar modules. Energy Procedia 6, pp. 743–749.

[4] Zegaoui, A. et al. (2011). Photovoltaic Cell/Panel/Array Characterizations and Modeling Considering Both Reverse and Direct Modes. Energy Procedia 6, pp. 695–703.

[5] Bishop, J. (1988). Computer simulation of the effects of electrical mismatches in photovoltaic cell interconnection circuits. Solar Cells 25, pp. 73–89.

[6] Wang, Y. & Lin, S. (2011). Analysis of a partially shaded PV array considering different module connection schemes and effects of bypass diodes. Proceedings International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (pp. 1–7). September 28-30, Pattaya City, Thailand.

[7] Restrepo, B., Trejos, A. & Ramos, C. (2013). Modeling of PV Systems Based on Inflection Points Technique Considering Reverse Mode. TecnoLogicas edición especial octubre, pp. 237-248.

[8] Durán, E. et al. (2008). Different methods to obtain the I–V curve of PV modules: A review. Proceedings 33rd IEEE Photovolatic Specialists Conference (pp. 1-6). My 11-16, San Diego, USA.

[9] Andújar, J. et al. (2004). Sıstema para la Generacıón Automátıca de Curvas I-V , P-V Y Monıtorızacıón de Módulos Fotovoltaıcos. Memorias XXV Jornadas de Automática (pp. 1-6). September 8-10, Ciudad Real, Spain.

[10] Durán, E. et al. (2012). Determination of PV Generator I-V/P-V Characteristic Curves Using a DC-DC Converter Controlled by a Virtual Instrument. International Journal of Photoenergy 2012, pp. 1–13.

[11] Adamo, F. et al. (2011). Characterization and Testing of a Tool for Photovoltaic Panel Modeling. IEEE Transactions on Instrumentation and Measurement 60(5), pp. 1613–1622.

[12] BK PRECISION. 300W Programmable DC Electronic Load. Online [July 2014].

[13] © Chroma ATE Inc. (2013). Model 62000H series Programmable DC Power Supply. Online [July 2014].

[14] SOLARC. Dispositivo de medición portátil de radiación solar y temperatura (con kit de fijación/orientación). Online [July 2014].