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PV CHARACTERIZATION USING CAPACITIVE LOAD

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Abstract. *This work has as objective to carry out the construction of a simple and efficient I–V curve tracer, which measure voltage and current simultaneously from a photovoltaic device to obtain the operational characteristic curve of it. The I–V curve tracer is based in capacitive load, for this we use a RC circuit, previously designed. Hence, the construction process of the device is easy assembly and less expensive than the commercial devices. It was proved, that the curve tracer device ready and in full operation can provide a simple, reliable, quickly and accurately data collection of a characteristic curve, since the greatest error of the experimental results was 7.37% while the lowest error was only 0.13%.*

Keywords: *Photovoltaic, RC, I-V Curve, Module, Curve tracer*

1. INTRODUCTION

The characterization of a photovoltaic module is a tool that helps in proving the generation power capacity of the device, as well as detecting manufacturing defects and demonstrating the module's ability, over its useful life, to withstand prolonged exposure to certain conditions without significant degradation of their characteristics (Prieb, 2002). In general, the complete characterization of a photovoltaic module consists of electrical, mechanical and environmental tests, but it is from the analysis of the I-V characteristic curve that the main parameters that define the behavior of a module are obtained. The knowledge of the electrical characteristics of a photovoltaic module is one of the most important topics, in order to get the maximum use of the energy that the module can provide to the system in which it will be used, for that reason when purchasing a commercial module, most suppliers provide such data.

The main reason to perform the evaluation of the electric behavior of a module in the standard conditions is to perform the characteristic curve IV, since it allows to compare qualitatively different types of modules, since it is expected that a module that presents better performance under standard conditions, continue being best when these conditions vary in the field.

The different standards define several procedures for obtaining the I-V curve, mostly in laboratory or indoor using a solar simulator, and also in field or outdoor, using natural sunlight. All the procedures have in common the use of a pre-calibrated standard device (reference cell) that must have the same spectral response as the test sample. In this way, the problem of spectral distribution is minimized, leaving only the question of irradiance and cell temperature (Ramos, 2006). Basically, the procedure is based on the recording of curve IV and sample temperature and recording of the short-circuit current and temperature of the standard device, concomitantly, and then on the correction of the values obtained, for the desired conditions. The schematic of the test, with the appropriate connections, is shown in figure 1.

It can be used an electronic load (Kuai and Yuvarajan, 2015) (Gaiotto, et al., 2016) (Taciuc, 2016), resistive load (Willoughby, et al. 2014) or capacitive load (Muñoz and Lorenzo, 2006) (Spertino, et al., 2015) in place of the block "variable load" in Fig. 1, as method for a curve tracer. Moreover, the curve tracer based on capacitive loads is simpler, cheaper and scalable from module level to array level. However, it is required an assertive sizing of the capacitive load to optimize the duration and the accuracy of the measurements (Spertino, et al., 2013). Thus, the calculation and implementation of a small size I–V curve tracer based in capacitive load are discussed in this paper.

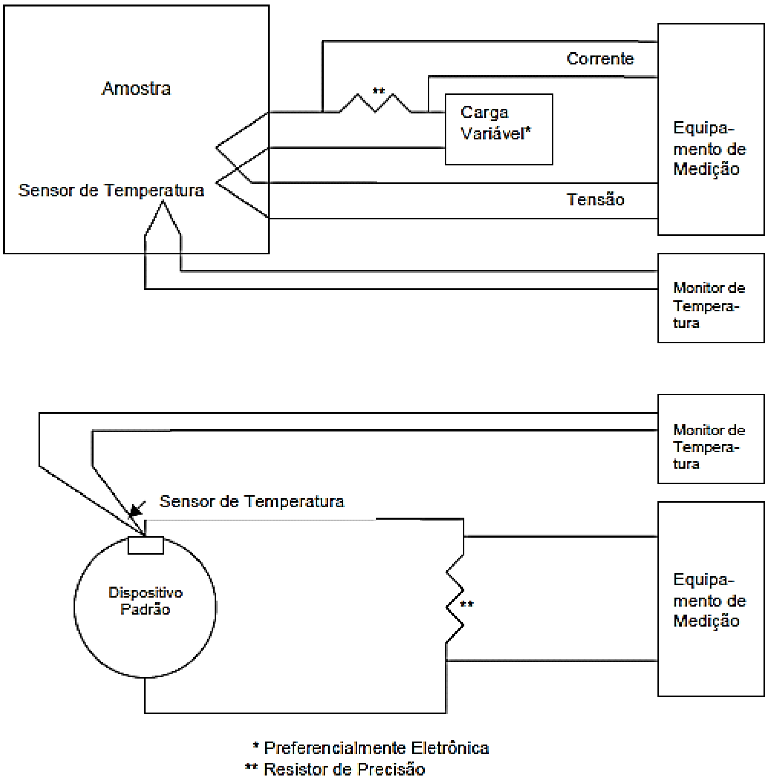

Figure 1. Schematic of characterization test setup

2. EXPERIMENTAL PROCEDURE

2.1 Capacitive Load calculation

As can be seen in Fig. 2, by the process of charging a capacitor through a photovoltaic module, it is possible to obtain all points of the I-V. Starting with the short-circuit current (Isc), passing through the point of maximum power (Imp and Vmp), to the open circuit voltage (Voc) where the current is zero.

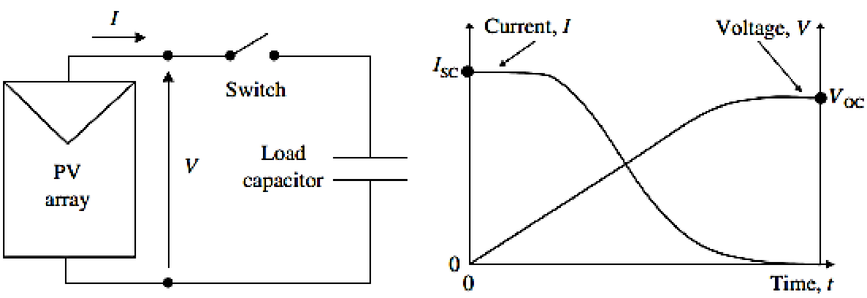

Figure 2. Charging process of a capacitor connected to a PV device

Determine the optimum capacitance value to support the current and voltage of the PV module and made more efficient the measurement processes it is necessary. For this, it is possible to use the characteristic equation of a capacitor:

$$I_c(t) = C\frac{dV}{dt} \quad (1)$$

Solving this differential equation, it is possible to find an expression that defines the capacitance value in function of the characteristics of the photovoltaic module as follows:

$$C = \frac{I_{sc}}{V_{oc}} \cdot t \qquad (2)$$

where t is the charge time of the capacitor which is usually between 100 µs and 2 s. Thus, taking as a reference a charge time of 2ms and knowing that the Voc and Isc of the PV module used in this work are 37,1V and 8,2A respectively, the capacitance value must be 9677 µf. A close value can be achieved using two capacitors of 4700 µf in parallel. Consequently, Fig. 3 shows the circuit for measuring the characteristics of a photovoltaic module using capacitive load.

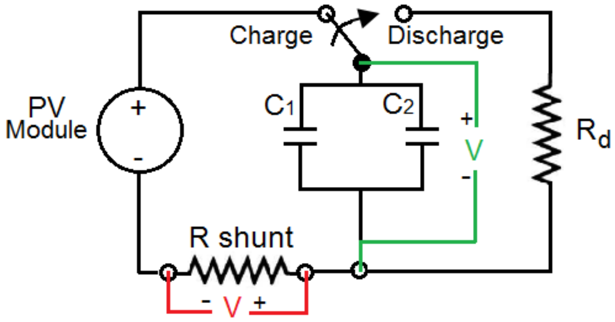

Figure 3. Schematic circuit for measuring the I-V curve of a PV module

2.2 Metodology

During the charging process, in order have an accurate measure of the current, a shunt resistor of 0.001 Ω was used in parallel with a voltmeter, ie for each ampere of current in the circuit in the voltmeter it will be increased by 1mV. For the voltage measurement, a voltmeter was used in parallel with the capacitors. All measurements are during the charging process of the circuit of Fig. 3, noting that the discharge process shown is only to reduce the stored voltage in the capacitors to zero, however the discharge resistance (Rd) must withstand the total stored power. In this case, a 50 Ω and 250 W resistor was used for discharge. Measurements were made using two Agilent 34411A multimeters on parallel bus using IEEE488 protocol connected to a PC by USB.

The communication of the multimeters with the PC and the processing of data was done using LabVIEW as shown in Fig. 4 and 5. For measure the temperature of the module, a pre-calibrated T-type thermocouple connected to a National Instruments NI9213 acquisition module was used, and for the radiation, the Amprove Solar-100 device was used.

The complete configuration for synchronize the NI software with the Agilent devices for the appropriate data acquisition of the IV curve is shown in Fig. 5, where is possible to see that the main problem with this configuration is to ensure the parity between the communication trigger and the charge/discharge switch. Hence, to avoid to loss part of the IV curve data it was used 5 trigger counts with 500 samples for each one, completing 2500 samples.

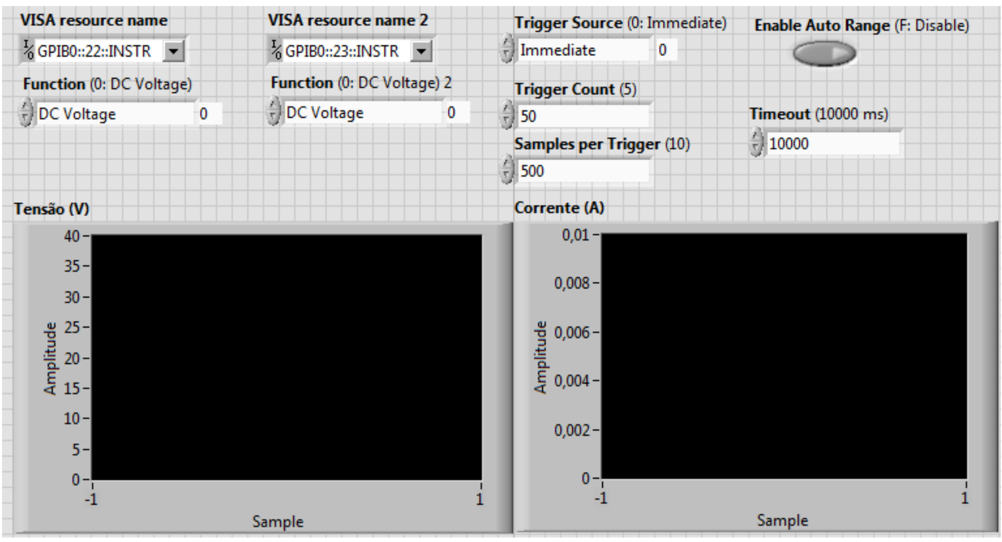

Figure 4. LabVIEW VI for IV curve measuring (front panel)

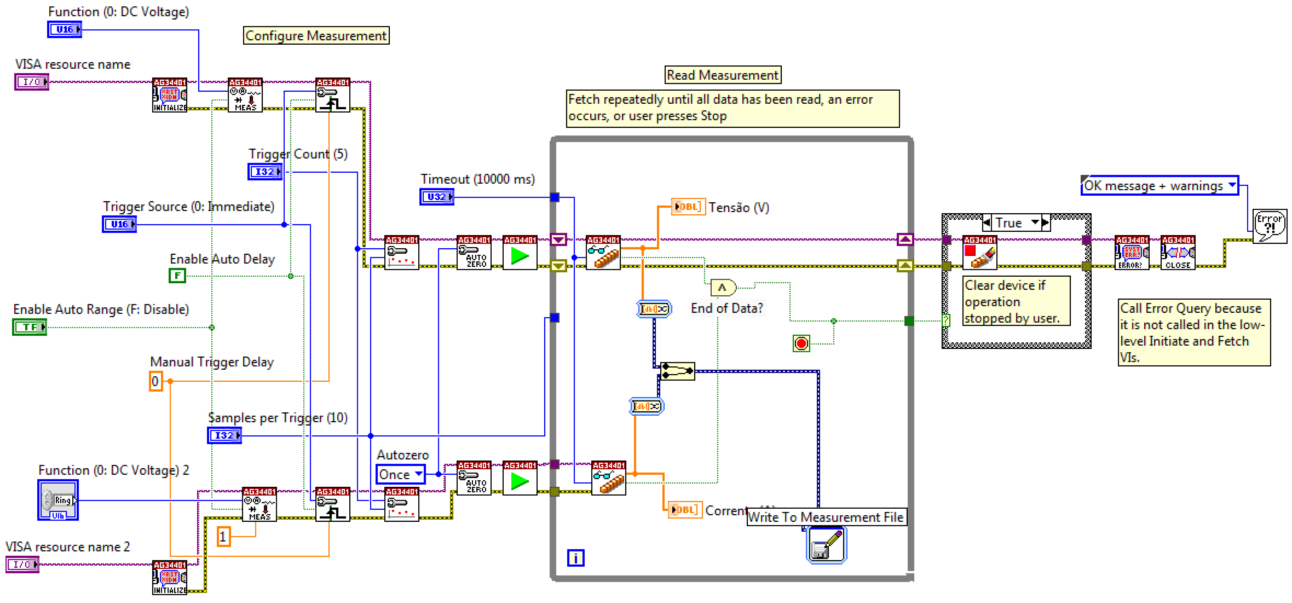

Figure 5. LabVIEW VI for IV curve measuring (configuration panel)

To evaluate the characterization system for different PV technologies and different power rating of photovoltaics modules, it was used the three PV modules shown in Tab. 1. Finally, intending to obtain more accurate in the measuring process, it was defined that the characterization procedure will be repeated five times for each module, always trying to keep the same conditions of radiation and temperature in all the tests.

Table 1. Reference data of the PV modules used in characterization test of the device

N°	PV Module Type	Isc Ref (A)	Voc Ref (V)	Imp Ref (A)	Vmp Ref (V)
1	Multi crystalline Si	0,66	21,52	0,60	17.56
2	Mono crystalline Si	8,20	37,10	7,69	29,90
3	Multi junction	4,85	28.7	4.46	23,00

3. RESULTS AND DISCUSSION

Fig. 6 shows an example of the collected data for the current and voltage curves from module number one. Due that this module power is smaller than the projected module, the charging time of the capacitor at the test was approximately 150µs. However, for the other modules the charging time of the capacitor was

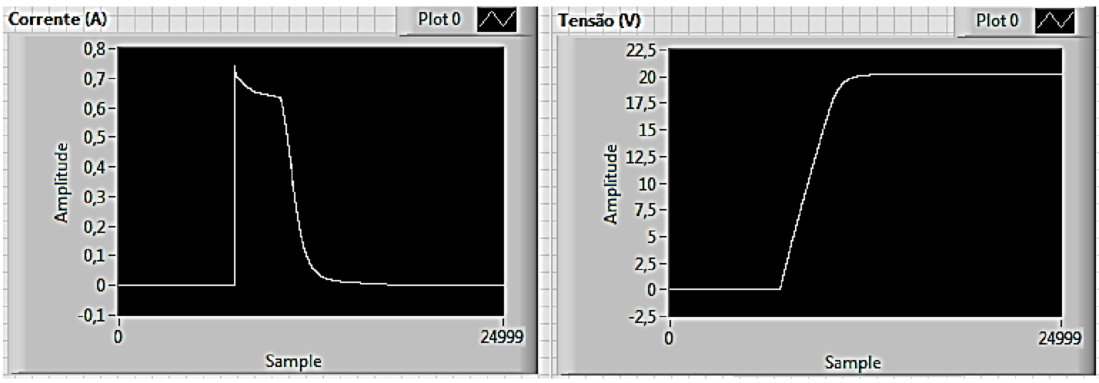

Figure 6. Current and voltage curves obtained for the first PV module

During the measurement of the curves shown in Fig. 6, the measured radiation and temperature were 1108 W/m^2 and 24.6 °C respectively.

Further, Fig. 7 shown the IV curve obtained from all the tested modules after filtering. Fig. 7, allows to observe the different shapes of the IV curve obtained from characterization device even for the same module, as shows Fig. 7b and c. This behavior can be explained by several reasons like fast changes in temperature, wrong chose of acquisition rate, and electrical noises due to the capacitive nature of the device, and as seen from Fig. 7b and c these apparently little errors represent a significant difference in the main operational points of the IV curve.

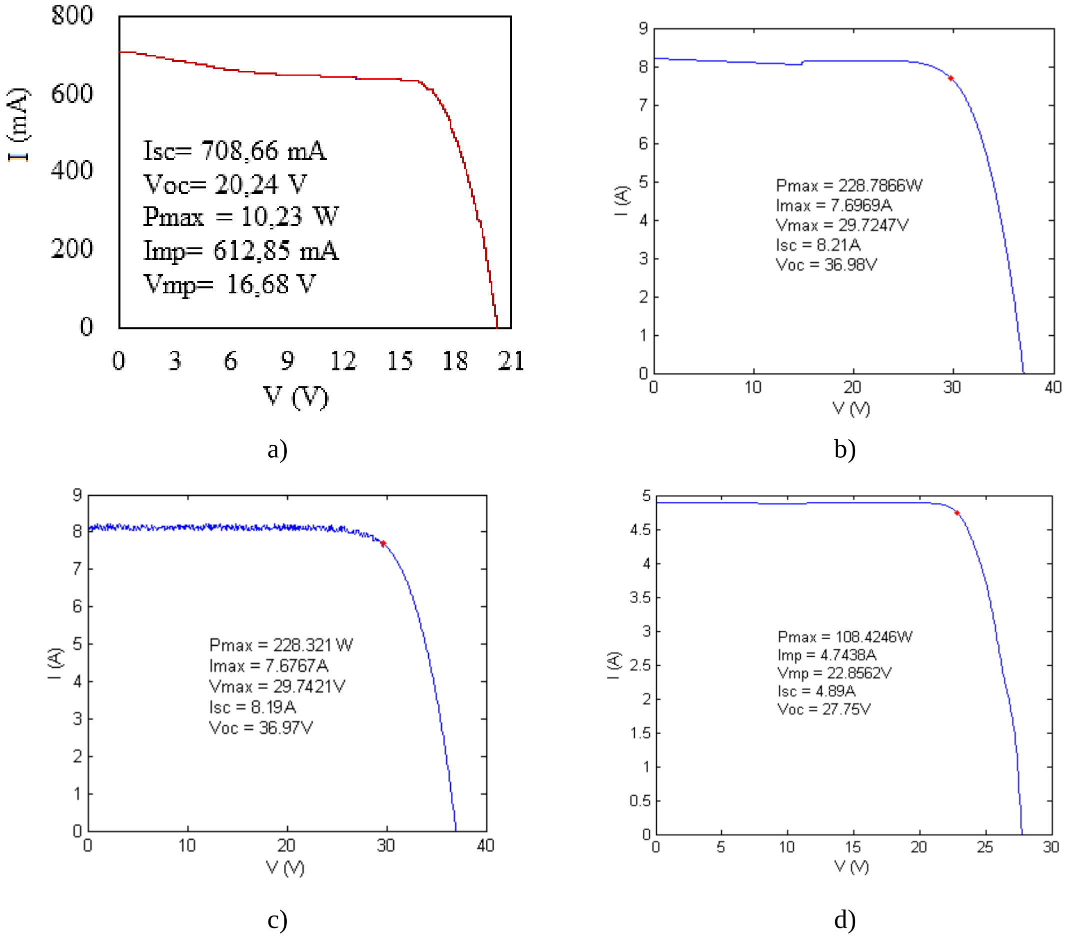

Figure 7. IV from the characterization procedure: a) Module 1 (multi crystalline Silicon), b) Module 2 (monocrystalline Silicon), c) Module 2 (monocrystalline Silicon), d) Module 3 (Multijunction)

Comparing the data in Fig. 7 with the reference data in Tab. 1, it can be seen that the only module that presents significant differences between them is the multijunction module (Module 3). This difference is mainly due to the difficulty in controlling the temperature of the module throughout the test, because it is a high concentration module with passive heat dissipation. Thus, the only way to bring the temperature of the module to the one specified by the standard is by perform an indoor test with controlled environment temperature, or by using active heat dissipation that allows to set the temperature condition in the module.

The relative errors (ε) of the characterization procedure at the main characteristic points of the IV curve, are summarized in Tab. 2, where is observed that as expected module 3 was exclude of this analysis.

Table 2. Relative error of the characterization procedure for modules 1 and 2

Module 1		**Module 2**
ε_{Isc} (%)	7.37	0.13
ε_{Voc} (%)	5.94	0.32
ε_{Imp} (%)	2.14	0.09
ε_{Vmp} (%)	5.01	0.58
Mean(ε)	5.11	0.28

From Tab. 2 it is possible to note that the characterization device has a better performance for module 2. This behavior can be attributed to the fact that it was used the data of the module 2 to sizing the capacitors of the device and the considerable power difference among module 1 and 2.

4. CONCLUSIONS

From Tab. 2, it can be concluded that the proposed characterization device presents good reliability, since the greatest error of the calculated characteristics compared to the manufacturer was 7.37% for the short circuit current of module 1, while the lowest error was only 0.13% also for the short circuit current but of module 2.

Even when the characterization device has shown be effective for performed the IV curve of different PV modules, it is necessary to ensure that the environment conditions to be the closest possible to the conditions established by the standards.

Aiming to reduce remaining errors, some adjust are needing in the acquisition rate of the characterization device.

5. ACKNOWLEDGMENTS

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7. RESPONSIBILITY NOTICE