DEVELOPMENT OF A CLIMATIC CHAMBER FOR PHOTOVOLTAIC MODULES TESTING

Alexandre José Bühler, purpleblind@yahoo.com.br
Fabiano Perin Gasparin, gasparin.fabiano@gmail.com
Giuliano Arns Rampinelli, giuliano.rampinelli@ufrgs.br
Arno Krenzinger, arno.krenzinger@ufrgs.br

UFRGS – Universidade Federal do Rio Grande do Sul
Av. Bento Gonçalves, 9500 Porto Alegre – RS. CEP 91501-970

Abstract. *The electrical characterization of photovoltaic modules is necessary to evaluate the device's quality and to estimate conversion of solar energy into electrical energy. The measurement of the characteristic I-V (current versus voltage) curve is fundamental to complete module characterization. The standard test conditions (STC) correspond to solar irradiance of 1000 W/m², module cell temperature of 25 °C and spectral radiation distribution AM 1,5 (air mass 1,5). Obtaining the I-V curve with the module temperature of 25 °C is usually a difficult task under natural sunlight, mainly in summer months. In order to make easier the control of module temperature, it was built a metallic climatic chamber in the facilities of the Solar Energy Laboratory of the Universidade Federal do Rio Grande do Sul. The internal temperature is controlled by an air conditioning system. The climatic chamber is made with trapezoidal profile metallic panels, filled with polyurethane for insulating purposes. The chamber has a window to expose the modules to sunlight. It stands on a rotatory basis which allows the azimuthal angle adjustment. Therefore the modules can be exposed to the direct radiation along the whole day. In this work it is presented the chamber building stages and its main characteristics. Likewise, the methodology for measurement the current voltage characteristics according to international standards is also discussed. The chamber has been used to test photovoltaic modules under different conditions. It is also possible measurement of photovoltaic devices with temperatures lower than the environmental air temperature.*

Keywords: *Solar Energy, Photovoltaic Module, Characterization of Photovoltaic Modules, Thermal Measurements*

1. INTRODUCTION

The world energy demand has been increasing continually in the last few years and this demand could be supplied through new thermal and nuclear power plants installations. However, in a time when the idea of sustainability has taking place, renewable energy sources appear as a feasible and promising alternative for the world energy demands.

In this context, the photovoltaic (PV) solar energy has increased its role around the world in the last years. The solar cells industry has been growing about 25% per year in the last years, enlarging also for stand alone systems but mainly for grid connected power plant (Tolmasquim, 2004). In countries such as German and Spain the governments have been investing in PV installation systems, research and dissemination of this technology. In the case of Spain, for example, the Renewable Energies Incentive Plan had established as a target installing 400 MW PV systems until 2012. However, due to the governmental incentives, Spain reached at the end May of 2008 almost 780 MW of PV installed systems.

In Brazil, the photovoltaic solar energy is still far from the European status, but its future is promising. Brazil has a solar potential larger than Spain and has already research and development institutes regarding this technology. In fact Brazil has all conditions to disseminate PV technology in the future.

Regarding this increasing of PV installation systems, a reliable and efficient PV module characterization is important in order to verify installed systems and design new ones. Mechanical, thermal and electrical tests are very important to foresee the PV generator behavior under different operation conditions.

2. ELECTRICAL CHARACTERISTICS OF A PHOTOVOLTAIC MODULE

In order to determine the electrical performance of a photovoltaic module, it is indispensable to determine the current-voltage (*I-V*) curve, known as characteristic curve. From *I-V* curve it is possible to obtain important information about the electrical characteristics of a PV generator such as the short circuit current (I_{SC}), the open circuit voltage (V_{OC}) and the maximum power point (P_M). The determination of an *I-V* curve, according to the standard NBR-12136 (ABNT, 1991a) shall be done in specific conditions of incident irradiance (G), module temperature (T_C), and solar spectral radiance distribution (G = 1000 W/m², T_C = 25 °C and AM = 1.5).

Figure 1 shows an *I-V* curve and a *P-V* curve (power *versus* voltage) of a monocrystalline silicon PV module with 130 W nominal power rating.

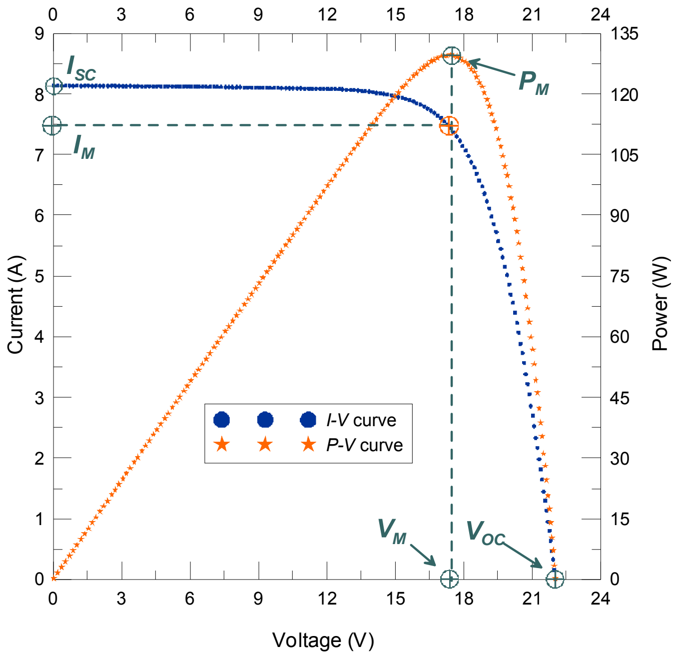

Figure 1. Characteristic curve (*I-V*) and power *versus* voltage curve (*P-V*) of a 130 W nominal power rating monocrystalline silicon module.

The temperature of a PV cell has a significant influence on the performance of a PV device as well on the shape of the characteristic curve. Short circuit current increases slightly with the increase of temperature according to coefficient (α) which represents values around 0.06%°C^{-1} or 0.03 mA°C^{-1} cm^{-2} for crystalline silicon technologies. In the case of amorphous silicon, such coefficient has values about 0.08%°C^{-1}. Temperature coefficient of short circuit current is defined by Eq. (1).

$$\alpha = \frac{\partial I_{SC}}{\partial T} \tag{1}$$

where I_{SC} is the short circuit current and T is the module temperature.

Open circuit voltage decreases linearly with increasing of the cell temperature due to exponential increase of the reverse saturation current. This current arises due to the creation of minority carriers by thermal excitation. Crystalline silicon modules have an open-circuit voltage temperature coefficient (β) about -2.3 mV/ °C per cell, approximately. This coefficient is defined by Eq. (2).

$$\beta = \frac{\partial V_{OC}}{\partial T} \tag{2}$$

The maximum power point of a PV device is also affected by cell temperature. The maximum available power decreases with increasing of temperature in a rate depending on the module electrical properties. Crystalline silicon modules have a power temperature coefficient between -0.30% °C^{-1} and -0.50% °C^{-1} (Lasnier, 1990). In the case of amorphous silicon the coefficient is normally around -0.30% °C^{-1}. The decreasing on the available power of a *PV* device causes a decreasing in device's efficiency.

3. CLIMATIC CHAMBER FOR PHOTOVOLTAIC MODULES TESTING

The determination of an *I-V* curve in a standard temperature of 25 °C is often a difficult task under natural illumination, mainly in the summer, where the environmental temperature can be easily greater than 30 °C. In order to facilitate module temperature control during characterization tests under natural illumination, a climatic chamber with metallic structure was built in the facilities of the Solar Energy Laboratory (LES) of the Universidade Federal do Rio Grande do Sul (UFRGS). Figure 2 presents the climatic chamber already installed and in use at the facilities of the LES. In Fig. 2 the window is open and it is possible to see two different PV modules stood on a metallic device with adjustable tilt angle.

Figure 2. Climatic chamber in a PV module characterization test.

This chamber has approximately 17 m^3 of internal space where the temperature is controlled by means of an air conditioning system with heating and cooling functions. This air conditioning system is a split one with 12000 BTU/h, equivalent to 3500 W thermal power.

Walls and internal roof of the chamber are made with trapezoidal profile metallic panels, filled with polyurethane for insulating purposes. Panels are 50 mm thick and have good mechanical resistance due to the trapezoidal shape. The climatic chamber has a window aperture, 3.0 m width and 1.4 m height (without glass), in order to expose the modules to sunlight. This window is 30° tilted to horizontal position. The chamber stands on a rotatory basis which allows the azimuthal angle adjustment between ±180°, allowing module exposure to direct radiation along the whole day. Figure 3 presents some details of the rotatory basis of the chamber at the time of its construction.

Figure 3. Details of the chamber metallic structure and its rotatory basis at the time of its construction.

In order to minimize thermal energy exchanges between the inside and outside of the chamber by means of convection, there are two air curtains located on the bottom of the window. Such curtains provide a maximum air flows around 14 m/s. Besides, to minimize thermal energy exchanges, the curtains can also be used to reduce the cooling time of modules by means of forced convection. This is important in some testing procedures where is necessary heating and cooling a module several times in sequence, such as in the Brazilian standard procedure (ABNT, 1991b) to determinate series resistance of a PV module.

4. MEASUREMENTS OF THE CLIMATIC CHAMBER THERMAL BEHAVIOUR

In order to analyze the climatic chamber internal thermal behavior and its influence in the module heating and cooling regimes, it was performed an experiment which is described as follow.

Three temperature sensors Pt100 class A were used, in order to measure the internal average temperature of the chamber, external environmental temperature and module temperature. In the case of the module, its temperature was measured on its back side, on a central cell. Other two important quantities, the solar irradiance and relative humidity of the air (RH) were also measured. The RH was simultaneously measured with the temperatures. The arrangement of the used sensors is presented in Fig. 4 and Fig. 5.

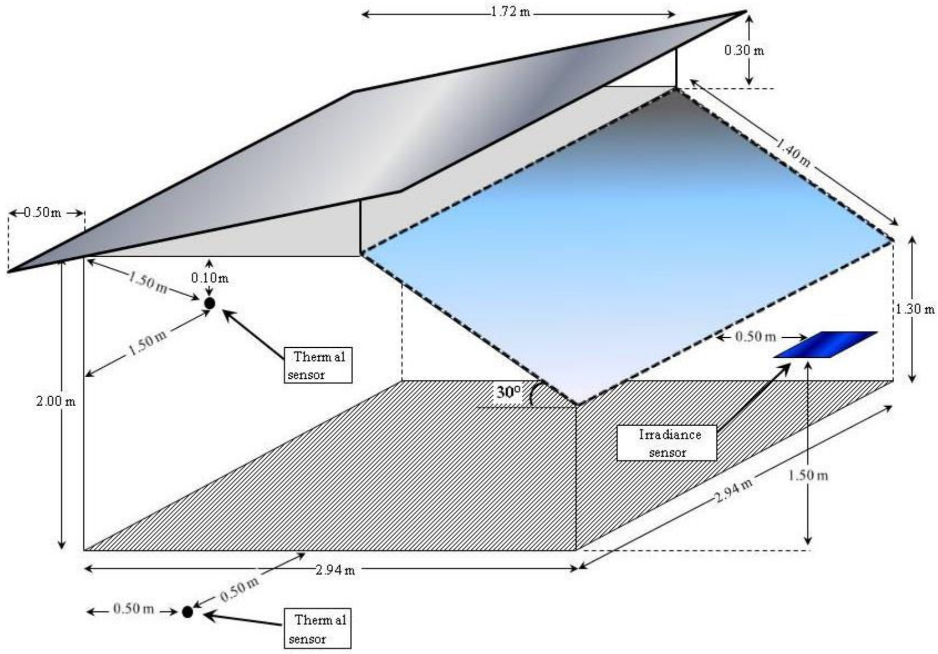

Figure 4. Arrangement of temperature and irradiance sensors for the thermal tests, perspective view of the climatic chamber.

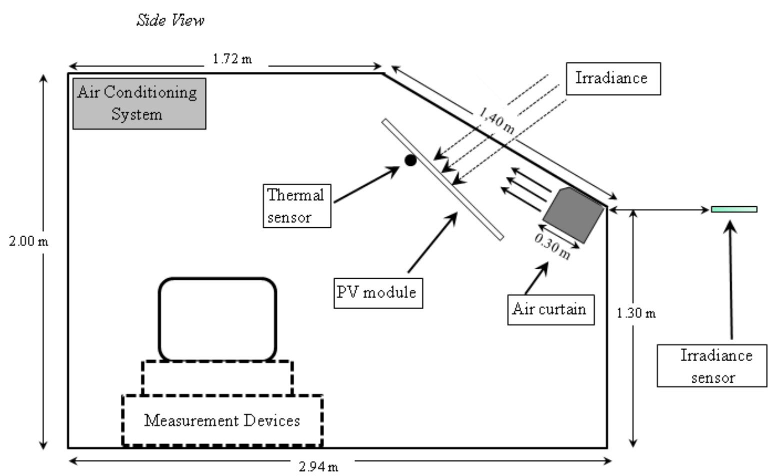

Figure 5. Details of the inside of the chamber and arrangement of the temperature and irradiance sensors, side view.

The steps of the experiment are described as follow:

a) The window aperture is set toward the direct sun radiation, the metallic curtain is open and the module temperature is monitored until the maximum value has been reached.
b) The RH is measured.
c) The metallic curtain is closed and the chamber is set on a position which does not expose the front side to direct sun radiation. This is done in order to avoid that direct sun radiation reaches the metallic curtain, because there is not any kind of thermal insulation on it. This procedure guarantees the smaller possible radiation absorption and therefore an increasing in the module cooling rate.
d) The environmental outside temperature, the chamber inside temperature, the module temperature and the horizontal global solar irradiance are measured each 20 seconds. The monitoring begins in this step and is maintained until the end of the experiment.
e) The module temperature is measured until a minimum value is reached, then the window is once again set toward the direction of sun radiation.
f) The metallic curtain is open, the temperature of the module and the inside of the chamber are measured until the module temperature reaches a maximum value.
g) The RH is measured again.
h) The steps b) to g) are performed again, however with the air curtains on. This procedure is done in order to evaluate how air curtains influence the heating and cooling module regime.

This experiment was carry out in a day with stable irradiance (clear sky) in a period between 10.30am and 01.30pm, when the effect of irradiance variation in the heating module regime can be ignored. The wind speed during the tests was considerably low and therefore its effect in the heating and cooling module regime was not considered.

The module tested was an amorphous silicon technology which main characteristics are shown in Tab. 1.

Table 1. Characteristics of the tested module.

Manufacturer	Model	Nominal power rating	Area	Absorption coefficient	Specific heat capacity
BP solar	MST45MVHS	45 W	0.81 m^2	70%	920 J kg^{-1}°C^{-1}

Figure 6 and Fig 7. show the cooling and heating regime of the module and the inside of the chamber, as well the variation of the environmental temperature and the horizontal global solar irradiance along the tests. In Fig. 6 the test was performed with the air curtains off and in Fig. 7 the test was performed with the air curtains on.

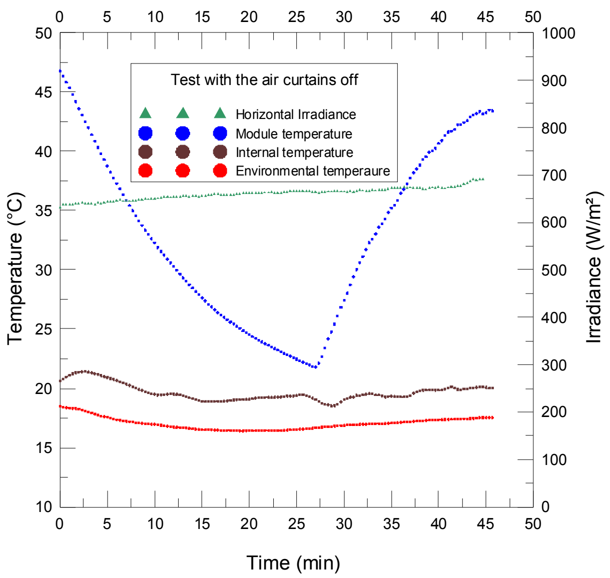

Figure 6. Thermal regime of the module and inside of the chamber with the air curtains off.

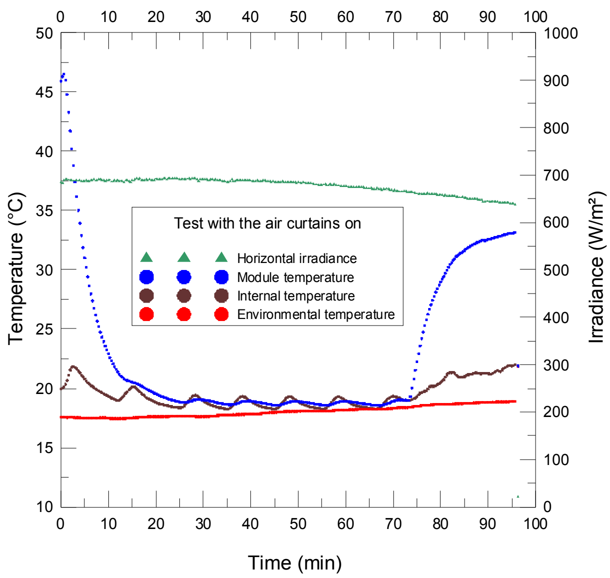

Figure 7. Thermal regime of the module and inside of the chamber with the air curtains on.

The performed tests allowed estimating the time constants for the module cooling and heating regime. This determination was done for the two different analyzed situations, air curtains on and air curtains off. The results are shown in Tab. 2 and the measurement conditions are shown in Tab. 3.

Table 2. Time constants for the cooling and heating regime, determinate with the air curtains off and on.

Air curtain off	τ(min)	Air curtain on	τ(min)
Heating	6	Heating	7
Cooling	14.3	Cooling	6

Table 3. Module temperature and measurement conditions for the cooling and heating regime
with the air curtains off and on.

	Initial temperature (°C)	Final temperature (°C)	Average environmental temperature (°C)	Average irradiance (W/m²)	RH (%)
			- Air curtains off -		
Heating	21	43.5	20	680	45
Cooling	47	17	21	670	45
			- Air curtains on -		
Heating	19	33,5	18.5	650	45
Cooling	46	19	17.5	680	45

Analyzing the results it is possible to see that the module heating time was slightly longer when the air curtains were on, on the other hand the cooling time was shorter. This result would be different according to the module properties and the measurement conditions, such as environmental temperature and incident solar irradiance. One important fact, which shall be taken into account, is that during the performed tests the environmental temperature was lower than the minimum temperature of the inside of the chamber. Certainly, if the environmental temperature were higher during the thermal test, the effects of air curtains would be more important.

5. METHODOLOGY FOR PHOTOVOLTAIC MODULES TESTING USING THE CLIMATIC CHAMBER

To determinate a characteristic curve of a PV device using the climatic chamber it is performed a procedure described as follow:

1) With the chamber closed, the air temperature inside the chamber is set approximately 2 °C lower than the temperature which is intended to measure the *I-V* curve. Such procedure provides measurements of *I-V* curves in temperatures around 20°C at the minimum, once the air conditioning system has minimum temperature setting of 18°C.
2) The module temperature is measured by a sensor attached in the back side of the PV module.
3) Once stabilized the module temperature, the metallic curtain is open, however the module is kept covered with an opaque material.
4) In this step it is possible to switch on the air curtains if the external environmental temperature is higher than internal chamber temperature. It provides a slower heating regime of the module.
5) The opaque material is removed and the module temperature is monitored until the desired value is reached, when the *I-V* curve is measured by means of an *I-V* tracer.
6) If it is necessary to vary the incident irradiation on the module, the azimuthal angle of the chamber can be modified. However, the azimuthal angle is kept in a range which avoids reflection mismatches between the module and reference cell (used to measure the incident irradiance) surfaces. The azimuthal angle should not be higher than 30°.

6. CHARACTERISTIC CURVE MEASUREMENTS

After the construction of the climatic chamber, the determination of *PV* modules *I-V* curves in the standard temperature, became easier than before. Moreover, tests to determinate module temperature coefficients (α, β e γ), became also easier, providing good results. Such coefficients are important to translate an *I-V* curve from the measured condition to another one and therefore, to foresee the available power in a specific operation condition, (Bühler and Krenzinger, 2008). Figure 8 shows *I-V* curves and Fig. 9 shows *P-V* curves measured at same irradiance, but different temperatures for an amorphous silicon module. These curves were obtained by an *I-V* curve tracer developed on the LES - UFRGS by Gasparin, (2009).

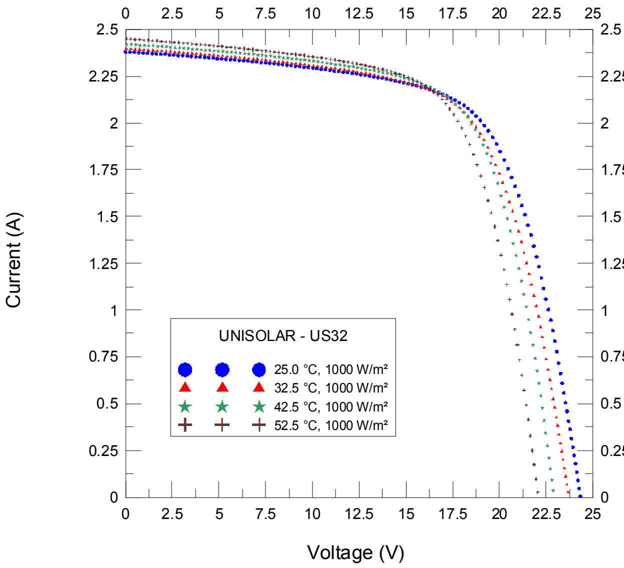

Figure 8. *I-V* curves measured at same irradiance but different temperatures for an amorphous silicon module (Unisolar – US32).

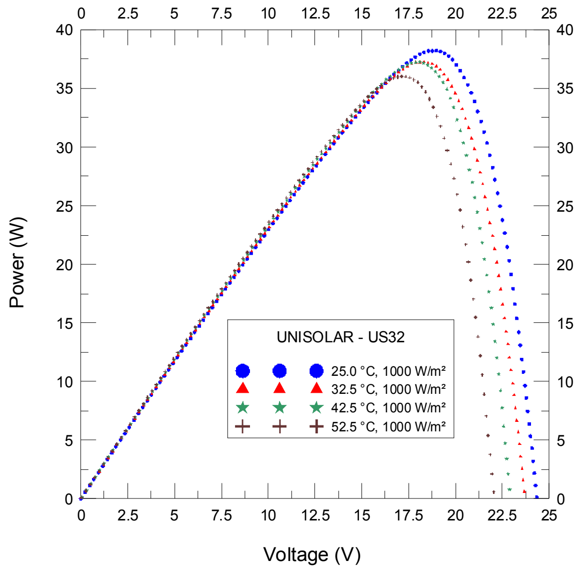

Figure 9. *P-V* curves measured at same irradiance but different temperatures for an amorphous silicon module (Unisolar – US32).

7. CONCLUSIONS

A climatic chamber for photovoltaic modules testing was built. Thermal tests have been performed since the construction of the chamber, providing very good results. With such climatic chamber, tests to determine module temperature coefficients became easier, mainly in the summer months. Tests using the air curtains shown that the module heating time became slower while module cooling time became faster. This is important when a large number of tests have to be performed.

8. ACKNOWLEDGEMENTS

The authors wish to acknowledge the CNPq and FINEP by the financial support.

9. REFERENCES

ABNT, Associação Brasileira de Normas Técnicas, 1991a. “NBR12136 Módulos fotovoltaicos – Determinação de características fotoelétricas”, Rio de Janeiro.

ABNT, Associação Brasileira de Normas Técnicas 1991b. “NBR12302 Módulos fotovoltaicos – Correção das curvas características corrente versus tensão (I x V), em função da temperatura e radiação”, Rio de Janeiro.

Bühler, A.J. and Krenzinger, A., 2008. “Comparação entre diferentes métodos de translação de curvas I-V de módulos fotovoltaicos”. In: Congresso Brasileiro de Energia Solar e III Conferencia Latinoamericana de la ISES, 2008, Florianópolis. Anais do II CBENS & III ISES-CLA. Recife : ABENS, 2008.

Gasparin, F. P., 2009, “**Desenvolvimento de um traçador de curvas características de Módulos Fotovoltaicos**”. Dissertação de Mestrado, PROMEC/UFRGS, Porto Alegre RS.

Lasnier, F. and Ang, T. G., 1990. “**Photovoltaic Enginnering Handbook**”.Adam Hilger, New York. 568p.

Tomasquim, M. T., 2004. “**Alternativas Energéticas Sustentáveis no Brasil**”, Relume-Dumará, Rio de Janeiro.

10. RESPONSABILITY NOTE

The authors are the only responsible for the printed material included in this paper.