STUDY OF DEGRADATION OF PV MODULES AFTER 20 YEARS OF OUTDOOR

José Bione M. F.
University of Pernambuco
Escola Politécnica
Rua Benfica, nº 455, Madalena,
Recife-PE, Brazil CEP 51020-231
e-mail: jbionef@poli.br

M.C. Alonso Garcia
CIEMAT – Centro de Investigaciones
Energéticas, Medio Ambientales y Tecnológicas
Av. Complutense, 22, 28040, Madrid Spain.
e-mail: carmen.alonso@ciemat.es

B. Asenjo
CIEMAT – Centro de Investigaciones
Energéticas, Medio Ambientales y Tecnológicas
Av. Complutense, 22, 28040, Madrid Spain.
e-mail: mbegona.asenjo@ciemat.es

ABSTRACT

This paper presents the results of the characterization of photovoltaic modules after 20 years of outdoor exposure, and 10 years of operation in Brazil. Several samples of the installed modules were sent to CIEMAT laboratories in Madrid (Spain), where visual inspection, IR characterization, analysis of the chemical composition of the modules, and electrical characterization was performed. I-V curves were measured indoors with solar simulator, and main curve parameters were compared to those obtained from an equivalent module without external exposure. The effect of dust and dirt was evaluated. The comparison between measurements made before and after cleaning of the modules showed that, on average, I_{SC} and P_{MAX} values were an average growth of around 1.9% to 4.03%, respectively.

There was also a decrease in average short-circuit current clean module, approximately 4.75% over the reference value and 8.6% over the standard value. Series and shunt resistance were calculated, relating these values with the power losses and the visual defects found.

1. INTRODUCTION

At the beginning of the decade of the 80, the Chesf (Hydro Electric Company of San Francisco) created a working group to study alternative energy sources not derived from petroleum. In 1982, was signed a cooperation agreement in the field of renewable energies between Germany and Brazil, with the aim of developing a hybrid pilot plant, which will provide solar energy, wind energy and diesel. This was installed in 1986 in Natal-RN, and had 11 kWp PV system with the ability to operate in isolation or connected to the grid. The rest of the plant consisted of a wind turbine of 14 kW, diesel generator of 50kW and one battery bank of 50 kVAh. The experimental activities were completed in December 1989, with the deactivation of Natal-RN plant, the Chesf decide to install a PV field test at its headquarters in Recife, consisting of 528 modules 10/20/01 AEG PQ type, with a power 11kWp. This system was integrated into the conventional power grid, going into operation in 1996. In 1998 a problem in the power conditioning system and the difficulties for service because the equipment was imported forced the shutdown of the system as a producer of energy, but photovoltaic modules remained in their structures to the current date.

2. METHODOLOGY

Five samples of randomly selected modules to represent the photovoltaic solar power plant were sent to Ciemat laboratories. The kind of the modules is the PQ 10/20/01 AEG, and consist of 20 polycrystalline silicon cells connected in series.

These modules were compared with equivalent modules at CIEMAT, which were never exposed to the sunlight, and with nominal data. Characterization was performed by means of visual inspection, I-V curve measurement in solar simulator, infrared and electroluminescence measurements, and the analysis of the chemical composition and the morphology of different layers by Energy Dispersive X-ray analysis (EDX) and Scanning Electron Microscope (SEM).

2.1 Visual Inspection

The first activity carried out was visual inspection, which involves a thorough review of critical issues and existing defects in the modules. These serve as reference points for potential problems to be registered in the tests. Major findings can be summarized as follows:

- encapsulant browning (cells area and/or the whole module front surface);
- delamination and bubbles formation in the encapsulant,
- back sheet polymer cracks;
- front surface soiling/frosting (ingrained dirt which was not possible to remove);
- blackening at the bottom edge of the module;
- junction box connections corrosion;
- oxidation and discoloration;
- junction cables insulation degradation (modules without junction boxes);
- glass breakage (front and back of the module).

2.2 IxV curve measurements

I-V curves were measured by means of a large area pulsed solar simulator. First measurements were performed with the modules as they came from the plant, and after that they were cleaned. The comparison between measurements made before and after cleaning (Figure 1) of the modules showed that, on average, the values of short circuit current (I_{sc}) and maximum power (P_{max}) had a variation of about 5% and 4% respectively. Changes in open circuit voltage (V_{oc}) are less than 1%. It can be said that the dust has not introduced major distortions in the shape of the module (IxV) curves, even taking into account that the deposition of dirt was not uniform. The main effect results in a decrease in peak power and short circuit current, which makes clear the need for periodic cleaning of the modules in order to avoid loss of power and the consequent drop in overall system performance .

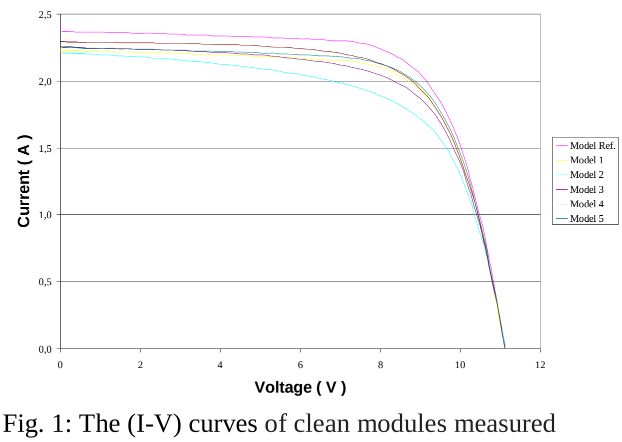


Fig. 1: The (I-V) curves of clean modules measured after long-term outdoor exposure.

As the modules do not have by-pass diodes, the typical steps indicating the working point of by-pass diodes [1] are not found in these curves. The effect of dirt is then smoothed in the I-V curve.

The comparison between measurements made after twenty years of operation showed that one of the causes of the maximum power reduction is the change in the slope of the curve near V_{OC}, a behavior that may be associated with an increase in R_S. Also there was a considerable decrease in short circuit current. In order to relate changes in the curves with the parameters of the device, equations (1) and (2), were used to calculate series and shunt resistance [6].

$$R_S = \frac{-1}{\left(\frac{\partial I}{\partial V}\right)_{V=V_{OC}}} - \frac{1}{\frac{\gamma}{n_S m} I_{SC}} \tag{1}$$

$$R_{sh} = \frac{-1}{\left(\frac{\partial I}{\partial V}\right)_{V=0}} \tag{2}$$

$$\gamma = \frac{e}{K \cdot T} \tag{3}$$

Where: I_{SC} is the experimental short-circuit current; n_S is the number of cells in series of the module; m is the ideality factor of the diode (between 1 and 1.2); K is the Boltzmann constant, e the electron charge and T the temperature in Kelvin. Series and shunt resistance were calculated (Table I), together with main I-V curve parameters.

Module 2 had the highest series resistance and lower shunt resistance, confirming its worst performance among the modules of the test. In addition, Module 4 presented the best result, coinciding with the highest resistance in parallel.

TABLE I: Values of series and shunt resistances of the ample modules

	Module 1	Module 2	Module 3	Module 4	Module 5
Rs(Ω)	0,5704	0,6456	0,6199	0,5887	0,5593
Rsh(Ω)	126,58	44,05	103,09	178,57	120,48

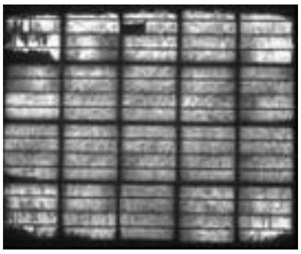
Table II summarizes the results of main parameters for both clean and uncleaned module 4. The comparison with the reference module (ModRef), that is a same type module not exposed to sunlight, and nominal module data (Standard Module, STD) is also presented

Table II: Variation of the characteristic parameters of the curve IxV Module 4 (the best). Var ModRef and Var ModSTD indicate differences in percentage of the measured values with respect to the reference module and the standard data respectively.

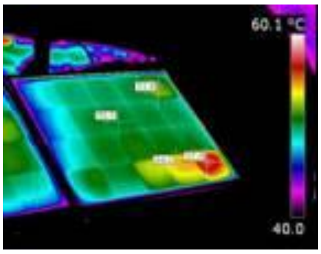
Parameter	Module 4						Module Reference	Module STD
	Dirty			Clean				
	Value	Var ModRef (%)	Var ModSTD (%)	Value	Var ModRef (%)	Var ModSTD (%)		
I_{SC} (A)	2,25	-5,06	-8,9	2,29	-3,38	-7,28	2,37	2,47
I_{MP} (A)	1,97	-6,64	-7,08	2,01	-4,74	-5,19	2,11	2,12
P_{MAX} (W)	17,2	-7,03	-12,16	17,6	-4,86	-10,11	18,5	19,58
Ef_cell (%)	8,6	-7,53	-	8,8	-5,38	-	9,3	-
V_{OC} (V)	11,1	-0,36	-0,45	11,11	-0,27	-0,36	11,14	11,15
V_{MP} (V)	8,76	-0,34	-1,57	8,73	-0,68	-1,91	8,79	8,9
FF (%)	69	-1,85	-13,53	69	-1,85	-13,53	70,3	79,8
Ef_mod (%)	6,68	-7,03	-12,16	6,84	-4,86	-10,11	7,19	7,61

2.3 <u>Infrared, electroluminiscence and SEM characterisation</u>

Following are shown some examples of the infrared (IR), electroluminescence (EL) and SEM characterization. IR images were taken outdoors with the module in short circuit conditions. EL images were taken indoors in dark conditions, with the module forward biased to current equivalent to short circuit current.

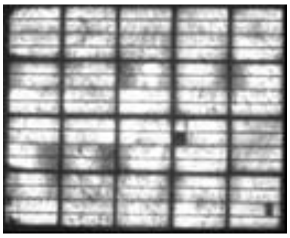


(a)

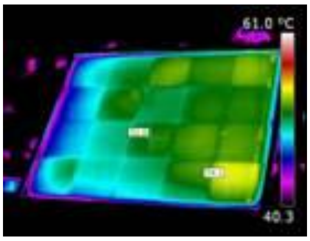


(b)

Figure 2: electroluminescence image (a) and IR image (b) of module 2.



(a)



(b)

Figure 3: electroluminescence image (a) and infrared image (b) module 2.

Electroluminicence images showed some dark areas indicating non active parts of the cells. IR images showed some cells with higher temperatures thant the rest, but this temperature increase (about 10°C) was not indicative of a hot spot or a major defect.

The chemical composition of different module layers was determined by Energy Dispersive X-ray analysis (EDX) and the morphology by Scanning Electron Microscope (SEM).

SEM images (Figure 4 and 5) show the surface morphology changes of Brazil photovoltaic modules.

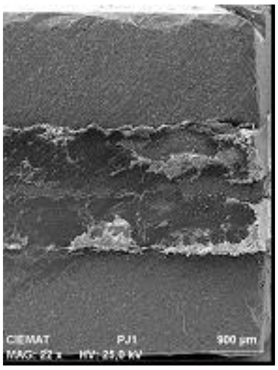
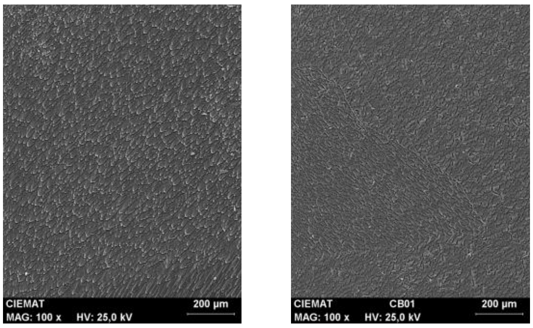


Figure 4: SEM image of cross-section Brazil module.

In the cross-sectional image shows the different parts of the module: glass, (ethylene-vinyl acetate) EVA, polycrystalline silicon film, EVA and glass

In Figure 5, the grains in the of Brazil module appear less elongated than those that can be seen on a SiO_2 films that has not experienced the process of encapsulation or over time.



(a) (b)

Figure 5: SEM image of SiO_2 films. (a) Brazil module and (b).

The other hand, the EVA polymer (Figure.6) has undergone degradation and contamination of adjacent fims as Na (1.52 %), Si (2.58 %), Ca (0.16 %),etc..

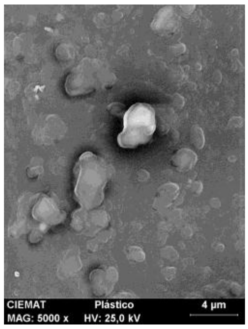


Figure 6: SEM image of EVA films

3. CONCLUSIONS

The comparison between measurements made before and after cleaning of the modules showed that, on average, I_{SC} and P_{MAX} values were an average growth of around 1.9% to 4.03%, respectively. The variation of V_{oc} less than 1%.

With respect to the variations with respect to the reference module and the standard module, the main effects are also observed in I_{sc} y P_{max}. The mean change in V_{OC} has been small, and does not lead to a conclusive analysis, since variations are within the uncertainties of the measurements. The drop in maximum power seems to reflect, among other things, changes in the slope of the curve near V_{oc}, a behavior that may be associated with an increase in R_s. There was also a decrease in average short-circuit current in clean modules, approximately 4.75% over the reference value and 8.6% over the standard value. In some cases, a decrease in shunt resistance was also observed.

Observed visual degradation factors, such as changing the colour, opacity of the encapsulant, moisture ingress or air inside the modules, etc., did not introduce significant variations in performance.

It can be concluded that the variation of maximum power output of the modules, after twenty years of operation had an average of 5.81% to 11.01% for the clean modules when compared to reference modules and STD, respectively. If we consider the effect of dust accumulation, the average reduction in power would extend to the order of 9.84% to 12.92% for dirty modules when compared to reference modules and STD.

The SEM images show a morphology change in the modules due to degradation and interaction between the layers that form the module.

4. REFERENCES

[1] Alonso-García M.C., Ruiz J.M., Herrmann W. (2006). Computer simulation of shading effects in photovoltaic arrays. Renewable Energy 31, 1986-1993
[2]ASIF-2010. Informe anual de la Asociación Española de Energía Solar Fotovoltaica (ASIF) 2010. Hacia la implantación internacional de la fotovoltaica española.
[3]Norma CEI 60904-9:1995. Dispositivos fotovoltaicos. Parte 9. Requisitos de los simuladores solares.
[4] Kengo, M., Hiroshi, K., Izumi, T., Yoshihiro, H. (2003). Degradation Factor Analysis of Crystalline-Si PV Modules Through Long-Term Field Exposure Test. 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan.
[5] Montero, M; Acosta, D; Fernández, G; Cadena (2002). Deterioro del Eva de Paneles Fotovoltaicos. Avances en Energías Renovables y Medio Ambiente 6, 1, 4.43 – 4.48
[6] Polman A., Van Sark W. G. J. H. M., Sinke W. and Saris F. W. (1986). A new method for the evaluation of solar cell parameters. Solar cells 17, pp. 241-245. M. Smith, A.