ANALYSIS OF THE DEGRADATION OF 735 COMMERCIAL CRYSTALLINE SILICON MODULES AFTER FIRST OPERATION YEAR

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ABSTRACT: This article intends to spread the results obtained in the degradation analysis of 735 crystalline silicon modules after first operation year. Degradation analysis carried out in this work consists of modules characterization in laboratory before field installation and after one year in operation in real conditions. This characterization includes peak power measurement according to IEC 61215 and additional indoor infrared thermographic inspection. Analyzed modules belong to two large PV plants located in the South of Spain. Analysis shows a general decreasing of electrical parameters values in the range between -1.0% to -3.5% in all modules. Measurements indicate that main power losses are due to short circuit current degradation. Furthermore, no new thermographic defects were detected after first operation year, but higher electrical losses have been observed in defective modules.
Keywords: PV Modules, Quality Control, Testing and Characterization

1 INTRODUCTION

One of the most important aspects of the financiall modelling for the profitability of a PV plant resides in the forecast of the PV module performances throughout the predicted 25 year life. The performance guarantee of the photovoltaic module offered by manufacturers is typically 90% performance during first 10 years and then 80% performance until 25 years. Nevertheless, such a warranty can hide serious dangers from the economical point of view for the end-user: it becomes every day more clear and important, to gain a deeper knowledge of the annual degradation of PV modules, in order to results in more precise modelling. The importance it is clear: if a batch of modules is not in agreement with the typically offered warranty from a determined moment, the energy (and consequently, the money) production of the PV plant will suffer a heavy and sudden drop. To control and minimize these technical risks, in most of PV plants there are a certain number of modules which are tested every year to tailor degradation. This is a fundamental approach used to check the expected productivity of PV plants.

Degradation is considered as the termination of the ability of a PV module to perform its primary function which is to provide useful electric power. Normally, degradation of modules is not caused by one isolated factor, but that is dependent on multiple factors, some of which interact causing degradation that may be not reproducible in the laboratory degradation tests as, for instance, climate chamber tests between others. For this reason it is necessary to tailor PV module degradation during its useful lifetime.

Exhaustive studies of PV modules degradation have been reported in the past. For example, studies carried out by the NREL show module performance losses of 1-2% per year in systems tested over ten-year period [1] and the LEEE-TISO has measured losses ranging from -0.7 and -8.2% respect nominal power after first 15 month of exposure [2].

In general, these of investigations have been carried out with short amount of samples. LEEE-TISO, for instance, have measured power degradation on 98 c-Si modules between -0% and -5% after first exposure (initial degradation) with respect to the initial power and -1.2% during the first year [3].

Thank to the large experience acquired by ENERTIS SOLAR in the quality control of PV modules, we possess now a remarkable database of measurements performed on modules operating in several PV plants. In particular, in this work, we focused our attention on a sample of 735 modules from 6 different manufacturers operating in only to large PV plants located in southern Spain. Among the different tests we are able to conduct in our laboratory, we limited our analysis only to those we consider more reliable in determining the modules performance degradation. Modules here analyzed are 6 of the most important manufacturers, so this work provides varied information about photovoltaic PV Industry state of the art. As far as we know, this work is the first systematic massive study carried out on such a large amount of modules.

Tests used for the analysis are included in the quality control of PV modules which was exposed in a previous work [4]. Tests are: peak power measurement and infrared thermographic inspection (see Fig. 1). Peak power measurement gives information regarding electrical performance of the modules and thermographic inspection regarding concerning hot-spots, broken cells and non active areas in cells. All tests were carried out in the ENERTIS SOLAR laboratory which is accredited for PV modules characterization in following the IEC 17025 standard.

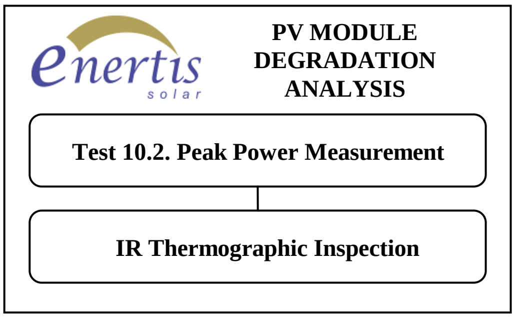

Figure 1: Tests included in the degradation analysis

2 SAMPLING PROCEDURES

To avoid breaking confidential agreements with our clients, the name of the manufacturers are concealed in this work.

735 modules were extracted from two large PV plants located in the South of Spain, one of 19 MWp and the other of 13 MWp. A total of six manufacturers have been analyzed. This investigation has been started as part of the quality control procedure during modules supply of the plants at the beginning of the projects. These initial results, corresponding to analysis before modules installation, were published in a previous work [5]. Tests performed after one operation year are included in the Annual Quality Program of the PV plants.

Table I shows details of selected modules and sampling percentage respect of total modules per manufacturer. The sampling procedure has been carried out following ISO 2859-1 rule.

Table I: Sampling details

Manufacturer	Total modules	Selected modules	Percentage (%)
A	14133	50	0.35
B	48634	257	0.53
C	19350	82	0.42
D	7611	32	0.42
E	37943	200	0.53
F	33025	114	0.35
TOTAL	160696	735	0.46

3 RESULTS

3.1 Peak power measurement

I-V curves of the modules have been obtained by means of a Class AAA solar simulator according to IEC 60904-9. Temperature and irradiance corrections have been performed according to IEC 60891. Test area of the simulator is 2×2 m^2 and it is situated in a black tunnel with a distance between xenon flash lamp and test plane of 6 meters. This equipment has a flash plateau of 10 milliseconds. Ambient temperature in the black tunnel is always kept to a value of 25±2 ºC in order to minimize errors that can be introduced by extrapolations. Estimated uncertainties, for a 95% level of confidence, are: peak power measurement ±1.6%, open circuit voltage ±0.46% and short circuit current ±1.53%. Table II shows the electrical parameters losses expressed as absolute percentages. These losses correspond to difference between values in the initial test and test performed after one year under operation. Reported values have been obtained averaging the results of each batch of modules.

Table II: Difference of electrical parameters after one operation year.

Manufacturer	ΔI_{SC} (%)	ΔV_{OC} (%)	ΔP_m (%)
A	-1.0	-1.4	-1.7
B	-1.3	-1.4	-1.0
C	-2.7	-2.0	-2.6
D	-3.4	-1.7	-3.0
E	-3.0	-0.7	-3.5
F	-1.9	-1.0	-1.5

Table II show decreased electrical parameters in all manufacturers. Power losses from 1.0% to 3.5% are observed. These results are especially worrying in the case of manufacturers D and E. Furthermore, for these two manufacturers it is clear that power losses are mainly due to short circuit current losses.

Figs. 2-3 show the degradation trend of Isc and Voc as a function of power in samples of Manufacturer D; Figs.4-5 show degradation of same parameter in samples of Manufacturer E. Figs.2 and 4 indicate different degradation patterns for Isc for manufacturers D and E. Higher dispersion of Isc losses in modules from Manufacturer E has been observed.

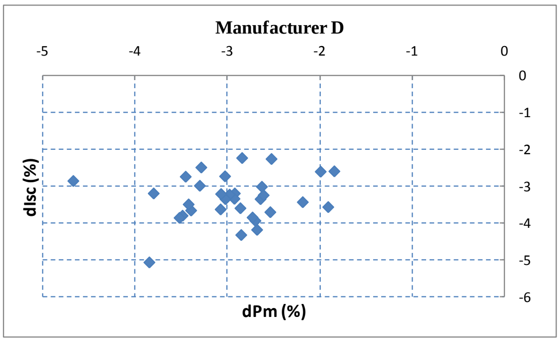

Figure 2: Degradation of Isc vs. degradation of Pm after one operation year in samples of Manufacturer D.

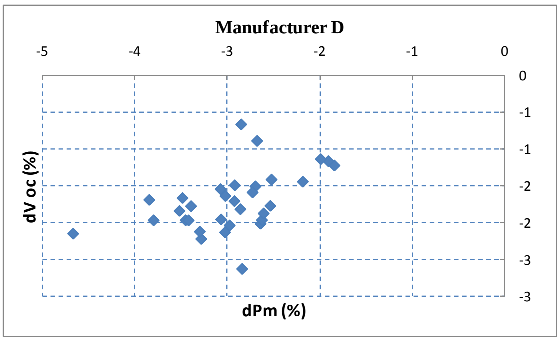

Figure 3: Degradation of Voc vs. degradation of Pm after one operation year in samples of Manufacturer D.

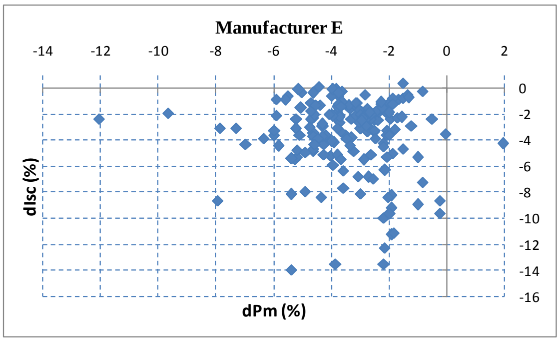

Figure 4: Degradation of Isc vs. degradation of Pm after one operation year in samples of Manufacturer E.

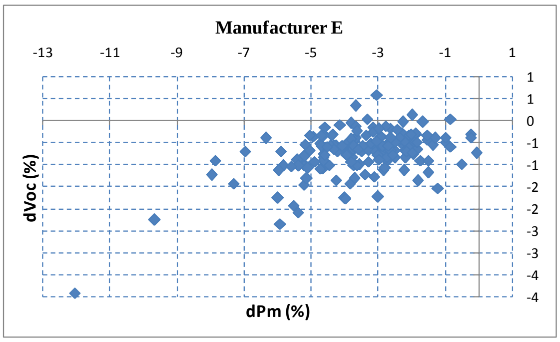

Figure 5: Degradation of Voc vs. degradation of Pm after one operation year in samples of Manufacturer D.

3.2 IR Thermographic Inspection

This inspection permits to detect defects which are not visible with a naked eye: cracked or broken cells, hot-spot in cells or their connections and soldering, non active cells or region which do not contribute to photogeneration. Test was performed in indoor conditions with module forward-biased. The inspection after one year under operation was focused on the determination of new thermographic defects and analysis of possible relation between thermal defects and power degradation.

Actually, no new thermographic defects have been detected after one operation year. Table III shows percentage of defects per manufacturer after test.

Table III: Percentage of thermographic defects per manufacturer

Manufacturer	Percentage of thermographic defects
A	2,0%
B	18,7%
C	9,8%
D	3,1%
E	34,5%
F	13,0%
AVERAGE	16,22%

Figures 6 and 7 show examples of modules with hot spots in soldering and broken cells respectively detected during test.

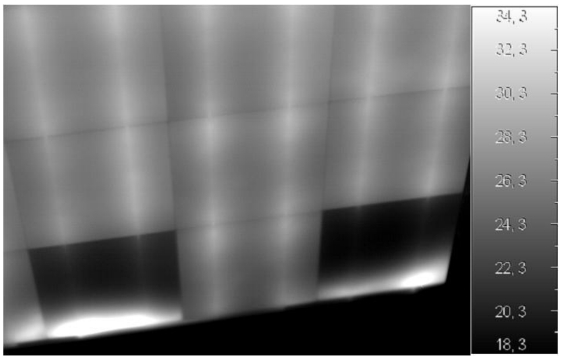

Figure 6: Modules with hot spots in soldering.

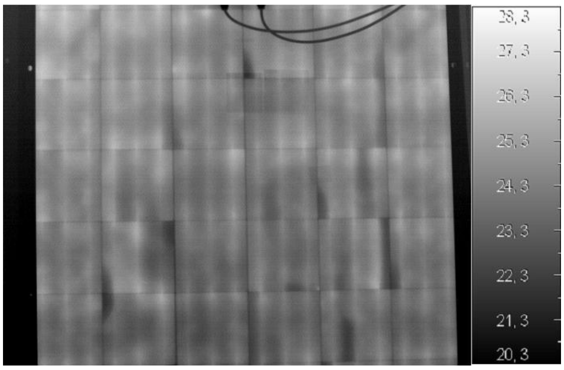

Figure 7: Module with multiple broken cells

A study related to the possible correlation between of power degradation and thermographic defects has been conducted. In order to perform the analysis on the most homogenous sample, this analysis has been carried out with the modules from those manufacturers with the higher percentage of thermal defects (see table III). Table IV summarizes the results: in this table we calculate the increase in the losses of the electrical parameters of defective modules respect to the rest of the modules without defects. Exposed values correspond to absolute percentages.

Table IV: Averaged variation of electrical losses in defectives modules

Manufacturer	$\Delta I_{SC\ losses}$ (%)	$\Delta V_{OC\ losses}$ (%)	$\Delta P_{m\ losses}$ (%)
B	+0,5	+0,4	+0,2
C	+0,9	+0,2	+1,1
E	+0,7	+0,2	+1,0
F	+0,2	+0,1	+0,6
AVERAGE	+0,6	+0,2	+0,7

Higher degradation is observed in all analyzed manufacturers. After one operation year, the degradation increase is not worrying yet but periodical analysis of power degradation and thermographic inspection of PV modules should be performed in order to verify the compliance with performance warranty conditions.

4 CONCLUSIONS

735 photovoltaic modules from two large PV plants have been characterized to quantify power degradation after one operation year under real conditions. Analyzed modules belong to 6 different manufacturers. Characterization consists in two tests: peak power measurement with Class AAA solar simulator and infrared thermographic inspection.

Peak power measurements show averaged power degradation in all the analyzed manufacturers with absolute decreases from 1.0% to 3.5. Analysis of averaged electrical parameters indicates that the degradation is mainly due to Isc drop. This is clearer in the case of modules with higher averaged power degradation.

No new thermographic defects have been detected in the modules after one operation year. Furthermore, a first evidence of larger power degradation in modules with defects than those without ones has been found out. Analysis shows that modules with thermographic defects present higher power degradation, a clear indication of the needs to perform periodical quality control of PV modules in order to verify the compliance with performance warranty conditions and reach the prospected energetic and economic profitability of the PV plant.

5 REFERENCES

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