STUDY OF A 20-YEAR OLD PV PLANT (MTBF PROJECT)

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The aim of the collaboration between the LEEE-TISO and the ESTI laboratory (JRC, Ispra), is to determine the Mean Time Before Failure (MTBF) of the first PV plant connected to the public electrical grid in Europe (1982). This entails investigation of the physical degradation mechanisms in action and to correlate field reliability with accelerated lifetime tests (IEC/CEI 61215).
The combination of systematic monitoring and laboratory measurements provide a unique opportunity to study the system. The main work of the collaboration has entailed, detailed visual inspections and Infra Red analysis, performance measurements of strings and individual modules, analysis of the evolution of the system Performance Ratio over time, repeated accelerated lifetime tests and correlation of all these data.
First results obtained on this study, evidence the good condition of the plant and the remarkable resistance of its modules.
Keywords: Lifetime – 1: PV Array – 2: Degradation – 3

1. INTRODUCTION

The 10kW PV plant, installed in 1982 on the roof of the University of Applied Science of Southern Switzerland, in Lugano, was the first grid-connected system in Europe.

It consists of 252 Arco Solar, ASI 16-2300, sc-Si modules, using PVB encapsulant and tedlar / aluminium / tedlar backsheet. The field is currently organised in 12 strings of 21 series connected modules, following the substitution of the inverters (1992) [1]. The original and current configuration of the plant is given in Table 1 [2].

MODULES		
Type of modules: Arco Solar, ASI 16-2300 sc-Si		
Module power @STC: 37Wp		
PLANT, connection to the grid: 13 May 1982		
Configuration	Initial	Present, since 92
Nominal power	10.656 kWp	9.324 kWp
N° of modules	288	252
Strings, modules	24 str of 12 mod	12 str of 21 mod
Working voltage	200 V	± 350 V
Array tilt / No field	65° / 3	55° / 3
Inverter	Abacus, 10kW	Ecopower, 15kW

Table 1: initial and current plant configuration.

The primary objective of this plant was to provide a technologically advanced facility of medium size giving practical information for the planning of future larger photovoltaic plants.

Due to the proximity of the plant to its 20-year design life, a collaboration between the LEEE-TISO and the ESTI laboratory (JRC, Ispra) has been started. Its objectives are to determine the Mean Time Before Failure (MTBF) of the system, to investigate the physical degradation mechanisms in action and to correlate field reliability with accelerated lifetime tests (IEC/CEI 61215).

To reach these goals, detailed visual inspections and Infra Red (IR) analysis has been performed on the whole installation. Performance measurements of strings and individual modules have been executed together with the analysis of the evolution of the system Performance Ratio over time. Repeated accelerated lifetime tests have been undertaken in an effort to estimate the residual lifetime. The correlation of all these data forms the aim of this collaboration.

2. VISUAL INSPECTION

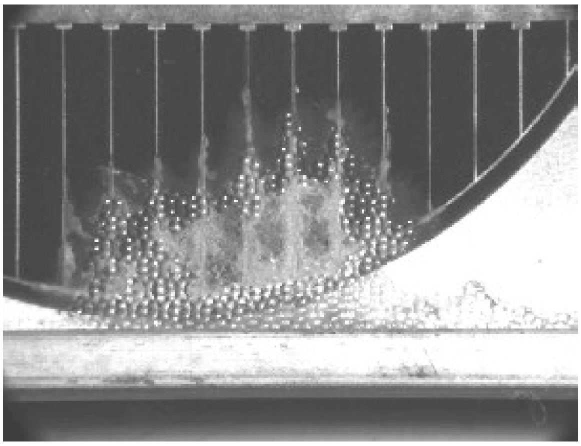
2.1 Colours changes

Yellowing of modules' represents the most evident visual defect. It appears on 98% of the plant modules (double the percentage from 1985 [3]) and, for the 63% of panels, it strongly covers their entire background tedlar.

In order to see if this yellowing effects the output of the modules the spectral response of both a non-yellowed and heavily yellowed module were measured. The results indicate that the yellowing has little effect on their performance, with the mismatch factors being practically identical (0.9994 non-yellowed and 0.9993 heavily yellowed).

2.2 Encapsulant delamination

Examination of the installed modules indicated that 92% of the modules exhibited some form of delamination (an increase of 15% in the last four years [4]). In about one third of these panels (27%), the delamination represents a major defect as defined by the International Standard IEC/CEI 61215, as it forms a continuous path between the frame and a part of the circuit (Picture 1).



Picture 1: encapsulant delamination (major defect)

Insulation tests have been performed on both dry and wet (after immersion in water) conditions on the worst delaminated modules. No failure in the insulation was observed, indicating a good level of insulation despite the obvious major defects present.

Possible effects of delamination on module efficiency depend on several aspects, in particular when the delamination affects the active cell area.

One module with some cells variously affected by delamination has been analysed. After the execution of performance measurements on individual cells, the power degradation of each damaged cell has been calculated and then compared to the corresponding delaminated area. The results, shown in Table 2, show that cell performance losses are proportional to their damaged area.

Cell (n)	Del. area (%)	Pm [W]	ΔPm (%)	Isc [A]	ΔIsc (%)
1	0.0	0.93	-	2.27	-
2	3.0	0.87	-6.5	2.20	-3.4
3	8.3	0.76	-18.3	2.00	-11.7

Table 2: cells performance degradation compared to the cells corresponding delaminated area.

However, in this case the module efficiency does not show any measurable degradation in power, having a maximum of 33 W (actual mean modules maximum power), similar to other non-delaminated panels. This means that bad looking modules are, not necessarily, also bad working ones.

2.3 Other defects

Other defects frequently detected are:

- sealant infiltration detected on 76% of modules, usually observed along upper and lower module edges;
- cracked cells, on 15% of panels (usually one cell per module). Surprisingly, no measurable effects on module performance have been detected for those modules with cracked cells;
- cell gridline browning, present, in particular, on the cell in front of the junction box and on those close to module edges;
- bad seal of the junction box on the tedlar backsheet with the consequent risk of detachment when opening, so leading to a loss in insulation resistance.
- oxidation of the terminal connections leading to higher electrical resistance. Severe oxidation can, in worst cases, cause detachment when wiring.

3. IR ANALYSYS

In all modules of the plant, the cell in front of the junction box always shows an increase of about 4°C, in respect to the other cells of the module.

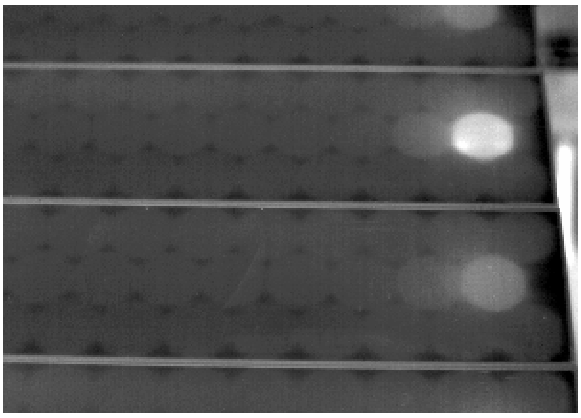
Infrared analysis of the plant detected the presence of hot-spots on 24% of modules (22% in 1999), over and above the 4°C value normally found for the cell in front of the junction box.

The hot spot cells are likewise always found on the cell in front of the junction box and show an overheating of about 10°C (under real operating condition) with respect to the rest of the module surface, whose temperature distribution is very regular.

Hot-spots represent the principal cause of power degradation, for example the least efficient module of the plant, with a maximum power of 26.2 W (-29% with respect to the nominal value) has a hot-spot.

An example of a hot-spot cell is given by the module whose IR image is shown in Picture 2 (the hot-spot also corresponds to a delaminated cell).

The IR image of three modules clearly shows two modules exhibiting slightly raised temperatures for the cell in front of the j-box, while the center module exhibits a noticeable hot spot. The current-voltage characteristics of this module are shown in Figure 1, which clearly shows the loss in performance (-24% with respect to the nominal value).



Picture 2: IR image showing the higher cell temperatures and a hot-spot on cell in front of the junction-box ($\Delta T_{cell\_module} \cong 10°C$).

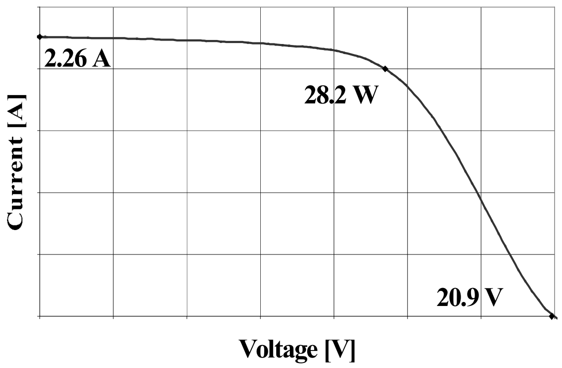


Figure 1: IV curve of the module with a hot-spot (shown in Picture 2).

4. INDOOR PERFORMANCE MEASUREMENTS

4.1 Reference modules

Since 1982, eighteen reference modules were periodically measured at ESTI. Thirteen of them have remained quite stable, while the other five show a loss in power of about 9% with respect to the mean power measured in 1982. Two of the degraded modules have a hot-spot, another one has damaged cell.

4.2 All plant modules

To correlate visual defects with module electrical characteristics and to accurately estimate their power degradation, indoor performance measurements of all of the plant modules were made. Having no initial measured maximum power value for all of the modules, the data have been compared to the manufacturers nominal power (37 W). Results show that, after about twenty years, 59% of the modules exhibited a variation of less than -10% to the stated nominal power, 35% of modules exhibited a variation of between -10% and -20%, and only for the 6% of modules showed a variation loss greater than -20%.

The maximum power distribution of all plant modules (mean maximum power = 33.1 W) is shown in figure 2.

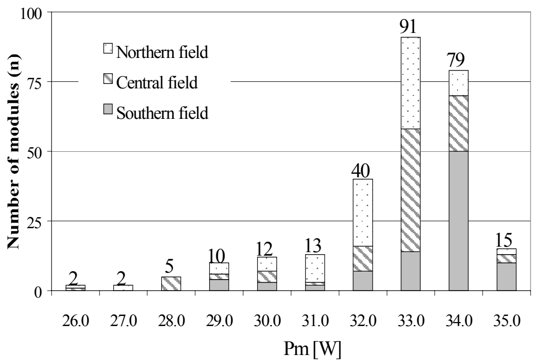


Figure 2: maximum power distribution of all plant modules.

5. ACCELERATED LIFETIME TESTS (CEI/IEC 61215)

5.1 Thermal cyclic and damp heat tests

Several repetitions of the CEI/IEC 61215 thermal cycling and damp heat tests were performed at ESTI on modules already exposed outdoors for 15 years.

After 1220 thermal cycles (from –40° up to 85°C), the modules did not present any major defect (according to CEI/IEC 61215) or exhibit any significant power degradation.

6000 hours of damp heat (85°C and 85% r.h.) provoked very dark yellowing of the module background and tedlar backsheet detachment (see Picture 3). The separation of the backsheet layers, which exposed the aluminium foil, might constitute an electrical safety hazard. However, the electrical power output of the module remained, to all intents and purposes, practically unchanged [5].

Picture 3: tedlar backsheet detachment.

5.2 Ageing in the field in comparison to accelerated ageing tests

Comparing module ageing under field condition and accelerated lifetime tests, two significant differences are observed:

- thermal cycling and damp heat tests did not provoke encapsulant delamination, while, under outdoor conditions, it appeared, to a greater or lesser extent, on 92% of modules.
- no naturally aged modules have so far exhibited tedlar backsheet detachment (as provoked by repeated damp heat test).

6. DAILY PRODUCTION DATA ANALYSIS

Since June 2000, individual string energy production has been continuously monitored and recorded, allowing analysis and comparison of string behaviour.

Figure 3, shows the plant Performance Ratio trend, from June 2000 to September 2001 (to simplify the plot, instead of the individual strings, the Performance Ratios of the positive and negative sub-fields are presented).

It should be noted that the lower Performance Ratio of negative field is due to the presence of most of the degraded modules, in particular, there are two panels with hot-spots on heavily delaminated cells.

Whether this is just coincidental or indicates some degradation process associated with the negative sub-field is unclear at this moment.

Also clearly visible in Figure 3 is the seasonal variation of plant energy production, which is strongly influenced by ambient temperature.

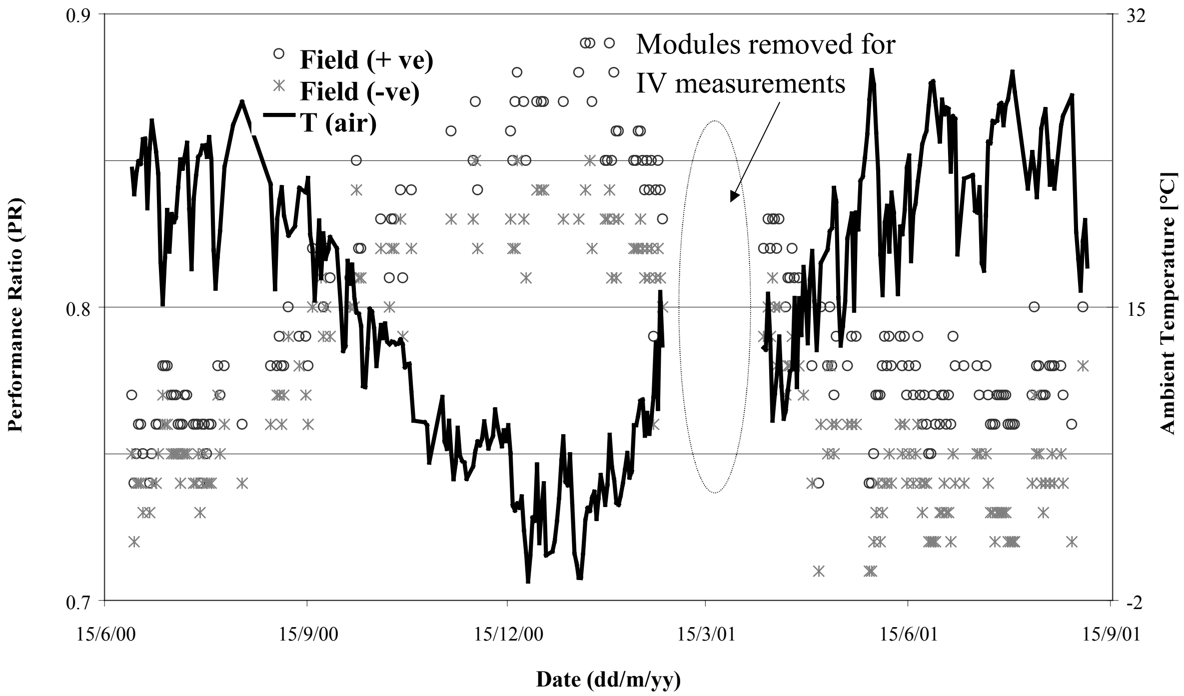


Figure 3: Performance Ratio (PR) of positive and negative sub-fields, and temperature trend from June 2000 to September 2001.

7. CONCLUSIONS

First results obtained on the study of the oldest grid connected PV plant in Europe show that, although it is not looking good from a visual aspect, the system is working in a very satisfactory manner.

The Arco Solar ASI 16-2300 modules proved to be remarkably resistant, showing that 20-year old technology was very good.

Regarding the determination of the Mean Time Before Failure of the plant, it is reasonable to assume, on the basis of results obtained from accelerated lifetime tests, that the modules could continue to provide useful electrical power for another 10-15 years.

This estimate significantly changes the economy of the system, as it greatly extends the mean lifetime of the plant.

In any case, in addition to the normal monitoring certain aspects of the plant will be kept under close observation including:

- increases in the number and frequency of hot-spots;
- evolution of the encapsulant delamination, in particular where it affects the active cell area;
- defect distribution between positive and negative sub-fields;
- possible detachment of tedlar backsheet (for electrical safety).

8. REFERENCES

[1] M. Camani, D. Chianese, S. Rezzonico, Proceedings 11th EC Photovoltaic Solar Energy Conference, Montreux (1992), p. 1235.

[2] G. Travaglini, N. Cereghetti, D. Chianese, S. Rezzonico, Proceedings 16th EC Photovoltaic Solar Energy Conference, Glasgow (2000), p. 2245.

[3] M. Camani, P. Ceppi, D. Iacobucci, "Operational characteristics of the grid connected photovoltaic plant TISO 15", Mediterranean Electrotechnical Conference IEEE, Madrid (1985).

[4] M. Camani, N. Cereghetti, D. Chianese, S. Rezzonico, Proceedings 14th EC Photovoltaic Solar Energy Conference, Barcelona (1997), p. 709.

[5] J. Bishop, L. Rigolini, W.J. Zaaiman, A. Realini, "Repeated Accelerated Lifetime Testing of Exposed PV Modules", Technical Note No.I.00.42 (February 2000).

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