

HOW LONG WILL MY PV PLANT LAST?

M. Camani, N. Cereghetti, D. Chianese and S. Rezzonico

TISO, Centrale di collaudo per componenti PV
Laboratorio di Energia, Ecologia ed Economia (LEEE)
Scuola Universitaria Professionale (SUPSI), CH - 6952 Canobbio
Tel.: ++41 91 940.47.78, Fax.: ++41 91 942.88.65
E-mail.: chianese@dct.supsi.ch

ABSTRACT: The TISO 10kW monocrystalline silicon PV plant has been in operation for more than 16 years. It was the first PV plant in Europe to be connected to the electricity grid (13 May 1982). At first, the aim of the plant was to study possible technical and safety problems when connecting a plant to a public grid, whilst now, the aim is the study of mechanical and electrical degradation as well as that of the lifespan of PV modules. The detailed observations of the various PV components and, above all, of the modules supply important information on the critical spots of the photovoltaic plants. Observation of the life cycle of the modules makes it possible in particular to verify reliability and working life predictions which are also used for economic evaluation.

A second grid-connected PV-plant, using amorphous silicon ARCO G4000 modules, has reached its tenth year in service. The degradation and regeneration cycle of the performance of the a-Si modules has been constantly monitored over the ten-year period. Initially, the plant was made up of three types of modules with a total power of 4kWp. At present, only one type of module with a nominal power of 2.9kWp, corresponding to ca. 2kW in real terms, is linked to the grid.

A new 0.5 kW plant with a-Si triple junction Canon modules will be connected shortly, the aim being to compare the behaviour of old and new generation amorphous modules.

1 10kW m-Si POWER PLANT



Main features of the 10kW m-Si plant:

Connection to the grid:	13 May 1982
Nominal power @STC:	9.324 kWp
Type of modules:	Arco Solar ASI 16-2300 m-Si
Module power @STC:	37Wp
N° of modules:	252
Configuration:	12 strings of 21 modules
Array tilt:	55°
Inverter:	Ecopower, 15kW

1.1 Introduction

The TISO 10 kWp m-Si PV plant was set up on 13th May 1982. It is situated on the flat roof of the Lugano School of Engineering in Trevano. It was the first plant in Europe to be connected to the electricity grid.

Initially, the main aim of the project was the study of safety and technical problems posed by the connection of PV plants to the public grid. The plant is now used in the study of mechanical and electrical degradation and PV module lifespan. During all its 16 years in operation, the principal electrical parameters have been recorded.

The configuration of the plant has been modified twice for research purposes. The initial configuration and the modifications have already been described in the preceding papers [1].

1.2 16 years measurement at Standard Test Conditions

The electrical data at STC of a sample of 18 modules have been periodically observed during 16 years of operation. This has highlighted the stable electrical efficiency of this kind of module, whilst more recent modules show a decrease in power after only one year of exposure ([1], [2] and [3]).

The average power @STC of the 18 reference modules measured between 1982 and 1998 remained stable at 35W, corresponding to 5.4% less than the manufacturer's given value. Detailed measurements show that 16 modules out of 18 did not suffer any obvious degradation (maximum measurement error 2.24%). The decreases experienced by the two modules were 7.4% and 12.2% respectively; in both modules there is serious water infiltration (see chapter 1.5) and performance varies according to the level of dampness.

1.3 Performances at real operating conditions

During the course of its 15th year of service, the plant produced 941 kWh/kWp.year (data December'97) against the Swiss average of 890 [4]. Comparison with other Swiss plants is difficult because of the differing meteorological conditions (G,T.etc.). The TISO plant could have produced more however, since it is linked to an oversized converter.

The *Performance Ratio* (PR) of the plant shows seasonal variation, strongly influenced by the operating temperature of the modules. The mean value of the PR calculated on DC is 78.6%. The oscillations occur around the same value, thus confirming the performance stability of the modules. Meanwhile the PR_{AC}/PR_{DC} ratio has tended to decrease. This could be due to a drop in performance of the ECOPOWER inverter or to a different load on the inverter due to meteorological atmospheric conditions.

1.4 Thermic behaviour

During the first few months of 1998 the thermic behaviour of the ASI 16-2300 was studied under real operating conditions. In particular, it was possible to precisely determine the actual β coefficient. The values found, at 800 W/m²

irradiation, are $-2.132 \text{ mV}/^\circ\text{C}$ for the cell and $-0.0746 \text{ V}/^\circ\text{C}$ for the module respectively. From this data, it emerges that, although these modules are not of the latest type, their thermic behaviour is similar to the most recent modules ($\beta = -2.152 \text{ mV}/^\circ\text{C}\cdot\text{cell}$ for the modules measured at TISO).

From thermographic analysis, all the ASI 16-2300 modules show local overheating of a cell linked to the terminal box averaging 4°C . In the plant, after 16 years of service, 48 cells show overheating of over 10°C more than the other cells (16.7% of the modules of the field) of which only one is not linked to the terminal box of the module. On the whole, temperature distribution inside the module is very.

1.5 Reliability of ASI 162300 modules

During the 16 years of operation only 7 modules broke down out of a total of 288 modules (2.4% of the modules). In 4 cases, the breakdown was caused by water infiltration of the cell linked to the terminal box.

After 16 years of exposure under real conditions, the modules show various visible signs of ageing. Nevertheless, the modules haven't suffered a drop in performance.

A second visual inspection, 2 years later, of the 288 modules (10,080 cells) has shown a 40% increase in infiltrations of different kinds (646 infiltrations). **Only 5.4% of the modules show no infiltrations.** In 42 cases of infiltration a cell is slightly damaged (in 28 modules).

The brownish colouring on a number of modules found in the first years of operation of the plant, did not spread and the modules did not suffer any electrical degradation. The oxidization of the conduction grills of the cell linked to the terminal box, which occurred in some modules in the first years of service, has not affected their efficiency in the years that have followed.

2 4kW a-Si POWER PLANT



Main features of the 4kW a-Si plant:

Connection to the grid:	3 May 1988
Nominal power @STC:	2.88 kWp
Type of modules:	Arco Solar G4000 a-Si
Module power @STC:	30 Wp
N° of modules:	96
Configuration:	16 strings of 6 modules
Array tilt:	55°
Inverter:	Solcon, 3.3kW

2.1 Introduction

The TISO PV plant with a-Si modules linked to the electricity grid was put into operation in May 1988. The first years of service were marked by tests to verify the level of initial degradation in the three types of module installed in the plant and by the removal of two of these due to the various defects of the modules themselves ([5], [6] and [7]).

2.2 Evolution of operating performance

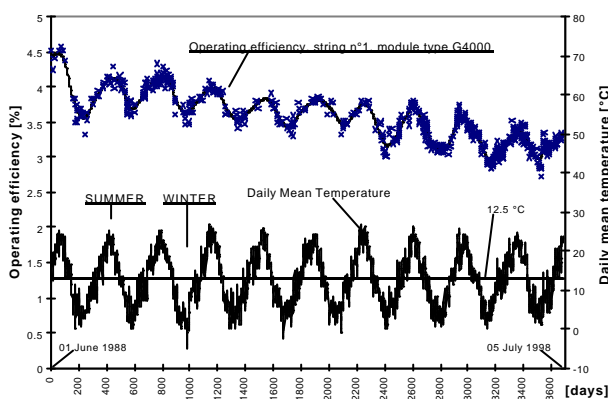


Figure 1: Efficiency of string 1 and ambient temperature vs. time.

The drop in operating efficiency cannot be put down to a homogeneous degradation of all the modules of the strings. In fact the measurements at STC carried out periodically on the no. 1 string demonstrate that the loss of power in all these modules can be almost totally attributed to a **decrease in the Fill Factor**, whilst both the short-circuit current and the open circuit voltage remained unchanged. The wide scatter in the performance of the modules at STC is mainly provoked by differences in the series resistance (see Variable Illumination Measurements [8]). **The modules do not all degrade in the same way.**

The degradation occurring between the different measurements is in fact irregular.

The mismatch losses, calculated using the values of the current-voltage characteristics at standard test conditions, are irrelevant when compared to the drop in performance since 1989 (-0.5% and -19% respectively of the total power of the strings). Therefore the constant degradation observed in the last few years of service does not reflect a constant degradation in all the modules but only in some of them.

2.3 Energy Production

In 10 years of operation (3 May 1988 to 3 May 1998), the plant has produced 28'017kWh. Since the last modification of the plant (1992), the G4000 modules have produced 743 kWh/kWp per year when calculated using the power declared by the manufacturer. Using real power at STC, which is ca. 2 kWp -i.e 30% less than the nominal power of the manufacturer- the annual production factor becomes **1069 kWh/kWp** per year.

During its 10 years in service, the operating performance of the G4000 module strings was measured. The data taken into consideration was that obtained during days with a regular irradiation which was above 800W/m².

The measurements carried out showed a drop in performance of 25% over the first weeks of exposure and subsequent seasonal variations of $\pm 5\%$ with respect to a decreasing value ([5], [6] and [7]).

2.4 Comparison with other types of a-Si modules

Near the 4kW plant, a plant with a-Si triple junction modules has been installed. The aim is to compare the behaviour of old and new generation amorphous modules.



Main features of the 0.5 kW m-Si plant:

Connection to the grid:	14 July 1998
Nominal power @STC:	0.496 kWp
Type of modules:	Canon a-Si
Module power @STC:	62Wp
N° of modules:	8
Configuration:	2 strings of 4 modules
Array tilt:	55°
Inverter:	Dorfmüller DMI500 500W

After a month and a half in operation, the plant has produced more than 100 kWh, with daily peaks of up to 2.5 kWh. During a day of good weather the efficiency of the Dorfmüller DMI500 inverter is over 90% and the overall efficiency of the plant (PR_{AC}) reaches 1'84%.

2.5 Variable Illumination Measurements (VIM)

Observation of the FF degradation of the a-Si modules of the 4kW plant does not allow a clear distinction to be made between the degradation processes caused by the Staebler-Wronski effect and those related to the technical features of cell construction. This problem can be overcome by carrying out Variable Illumination Measurements (VIM) of I-V characteristic. To this end, measurements are being carried out in collaboration with the University of Barcelona (S) ([8]).

3 CONCLUSIONS

TISO 10 kW m-Si plant

- After 16 years of operation under real conditions, the plant shows no electrical degradation unlike many recently manufactured modules (see VC4.18, [5]).
- **Monocrystalline silicon modules** have shown their reliability: only 2.4% of the modules broke down.
- Visual inspections, during the last 2 years, show an increase of infiltrations in the modules of 40%.
- **Only 5.4% of the modules show no infiltrations.**
- Mechanical degradation (air-bubble and minor infiltration) doesn't affect module performance.
- Hot-spots, in these modules, are generally linked to the terminal box.
- A rapid ageing test has been carried out on 10 modules of the plant at the JRC-ESTI centre.

TISO 4kW a-Si plant

- **Average degradation** of -19% in 10 years cannot be put down to a homogeneous degradation of all the modules of the strings. **The a-Si G4000 modules do not all degrade in the same way.**
- The loss of power in a-Si modules can be almost totally attributed to a **decrease in the Fill Factor**; short-circuit current and the open circuit voltage remained unchanged.
- In a-Si modules with different degradation **mismatch losses are small** due to lower Fill Factor.
- Variable Illumination Measurements (VIM) of 8 modules in the plant, performed at the University of Barcelona, show that the limiting factor in a-Si modules at one-sun illumination is the series resistance ([8]). However the **difference** between the modules in the string of the plant is not critical for the performance of the plant.

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REFERENCES

- [1] M. Camani et al.: 15 years of experience: long term behaviour of plants with m-Si and a-Si modules, 14th EC PV Solar Energy Conference, Barcelona (S), June 1997.
- [2] M. Camani et al.: TISO: Test of reliability on crystalline and amorphous silicon modules, 13th EC PV Solar Energy Conference, Nice (F), October 1995.
- [3] M. Camani et al.: Comparison and behaviour of PV modules, Proceedings 15th EC PV Solar Energy Conference, Vienna (A), July 1998.
- [4] C. Meier et al.: Photovoltaik-Energiestatistik 1997, Bulletin VSE 10/1998.
- [5] M. Camani et al.: utility interconnected 4kW Amorphous Silicon PV Power Plant, 9th EC PV Solar Energy Conference, Freiburg (D), September 1989.
- [6] M. Camani et al.: TISO: Installation photovoltaïque de 4 kWp avec modules au silicium amorphe, raccordée au réseau; Photovoltaik-Nutzung 1990, Zürich (CH), January 1990.
- [7] D. Chianese et al.: TISO: 4kW Experimental Amorphous Silicon PV Power Plant, 10th EC PV Solar Energy Conference, Lisbon (P), April 1991.
- [8] J. Merten et al.: Ten Years Operating Amorphous Silicon Solar Modules: Assessment by Variable Illumination Measurements (VIM), Proceedings 15th EC PV Solar Energy Conference, Vienna (A), July 1998.