THIN FILM PV TILE: LONG TERM OPERATIONAL EXPERIENCE IN MEDITERRANEAN CLIMATE

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ABSTRACT: The continuous monitoring carried out by ENEA in collaboration with KANEKA about the performance of thin film based tile modules has been updated adding some other years of in situ observations. The objective of the research is to evaluate first of all the reliability of the modules efficiency in terms of capacity to keep the energy conversion efficiency over long periods and then to test the behaviour of the modules that have been subjected to the hard marine environment conditions (temperature, corrosion etc.). Two plants of about 1 kWp have been monitoring: the first a-Si single junction modules in operation since June 2002; the second hybrid a-Si/μc-Si modules plant active since January 2006. Data collected after a long term of continuous monitoring are shown and discussed.
Keywords: Thin film, Energy Performance, Seasonal Variations

1 INTRODUCTION

Since the year 2002 ENEA - National Agency for New Technologies, Energy and Sustainable Economic Development - in collaboration with KANEKA manufacturer started at its test site a long term experimental activity on thin film silicon operational experience. In June 2002 a first plant with a-Si single junction modules was installed. Subsequently, at the beginning of 2006, a second plant of thin film (also called Hybrid) a-Si/μc-Si modules was then added.

The interest in this research derived by the discussions in the photovoltaic international sector about the real performance of amorphous thin film modules and how to compare their performances respect to the traditional crystalline Si module, especially on long-term reliability basis.

Long-term experiments of amorphous silicon photovoltaic modules have established that stabilization of the degradation occurs at levels that depend significantly on the operation conditions, as well as on the history of the modules. Experience and long term performance are very useful for operators not only for technical characterisation, but also for demonstrating the long term availability and the better performance in energy production (reflected on energy rated) in comparison to the crystalline silicon modules. The project was planned also to evaluate the reliability of the modules efficiency in terms of capacity to maintain the energy conversion efficiency over long periods and the behaviour of the modules structures subjected to the hard marine environment conditions (temperature, corrosion etc.).

Both the reduced thickness of thin film layers and the increase of the rated energy can thereby enable high mass productivity. Moreover the use of less material and the increase in energy rated can keep low at the end the module costs and make more favourable the comparison of PV kWh costs with other renewable sources.

2 EXPERIMENTAL PLANTS

2.1 PV Array

Both a-Si and Hybrid modules plants have the same structure being tiles mounted on steel plate and were installed close each other at a tilt angle of 20° South oriented (0° azimuth) on a wooden rack roof.

Ventilation is not provided and for this reason the cells temperature has been found to be a bit higher than the usual, especially in the summertime.

Figure 1 shows the plant site installation.

Figure 1: Plant site installation in Portici (NA)

Specifications of both the PV modules and systems at the STC condition obtained from the manufacturer are listed in Table I. The a-Si modules are model BR 28 (a-Si single junction). The Hybrid modules are model BRB 101 (double junction Hybrid: a-Si/μc-Si).

Table I: Systems and module/array Specifications

		a-Si Plant		Hybrid Plant*	
	Unit	**Module**	Array	**Module**	Array
Rated Power	**Wp**	**28**	**1008**	**37,5**	**1050**
Vmp Voltage	V	31,9	287,1	100	200
Imp Current	A	0,88	3,52	0,375	5,25
Voc Voltage	V	41,0	369	130	260
Isc Current	A	1,0	4,0	0,434	6,1
Module Area	**m^2**	**0,452**	**16,26**	**0,40**	**11,2**
Efficiency	**%**	**6,2**	**6,2**	**9,4**	**9,4**
Parallel	nr	/	4	/	14
Series	nr	/	9	/	2
Tilt	deg	/	20	/	20
Azimuth	deg	/	0	/	0

*Note: Hybrid module data are not commercial data

2.2 Data Acquisition System

The DAS (Data Acquisition System) has been designed in order to easily compare PV by normalized performance indicators. The evaluation procedures are based on the European Standard EN 61724 (International IEC 61724). Additional parameters have been introduced for the analysis in order to better quantify the system behaviour from a technical point of view [2,3]. The most appropriate performance indicators that have been utilized are:

- *final yield* Y_f
- *dc yield* Y_A
- *reference yield* Y_r
- *performance ratio PR* (Y_f/Y_r).

PR is independent of location and system size and indicates the overall losses on the array's nominal power due to module temperature, incomplete utilization of irradiance and system component inefficiencies or failures.

3 DEGRADATION

3.1 Mechanisms

The degradation phenomenon was characterized by the investigation about the effect of light intensity and temperature on module performance and by monitoring the performance of the two arrays.

The degradation due to the front surface soiling (accumulated dirt) are normally below 10% due to self-cleaning by wind and rain.

Modules have been inspected in detail for visual defects. Photographs are then taken from observed defects to provide evidence for future reference. The visual inspection last year, the 2009, revealed a severe discoloration and de-lamination for two a-Si modules likely as result of a mishandling during maintenance operations carried out at the plant and around it. These two module was affected by delamination and moisture penetration from the edges. The moisture ingress, in combination with to the UV radiation, resulted in the encapsulation degradation.

To the date no further optical degradation for the monitored plants has been observed from discoloration of the encapsulating material.

We know that the peak power degradation is typically composed of several important mechanisms. The first is the degradation to its "stabilized" value. This is the initial degradation seen mainly in the first year (Staebler-Wronski effect). Superimposed there is a gradual long-term degradation, typically about 0,5% to 2% per year. Since the long-term degradation factor is much less evident than the cyclic seasonal variations, it is much harder to see it and to accurately determine its value [6].
In previous studies [1,3,4] electrical degradation mechanisms was been observed and discussed.

3.2 Corrosion and availability

The plants are located just close to Mediterranean Sea cost. Even in these severe conditions, eight years after the installation for the a-Si modules and about four years after the installation for the hybrid modules, the module surfaces do not present any significant change that can be observed visually.

4 ARRAY PERFORMANCE ANALYSIS

Output performance are reported on the following for both the plants starting from February 2006 when the second plant was installed, in order to compare the performance in the same period of time.

However in the analysis it is important to keep in mind that the first plant modules had been already exposed and in operation since 2002 and the performance has been reported and commented in past report [1,3,4]. In this paper, the results of the evaluation for both the a-Si and the Hybrid modules which were carried out over four years in outdoor conditions are reported.

Two parameters were used to examine the performances of both type of PV module: the monthly average watt-hour efficiency and the monthly output energy.

The discussion is focused:
- for the a-Si module on the improvement of normalized efficiency during summertime;
- for the Hybrid module on their attitude to reduce degradation and on their dependence on solar spectral distribution.

4.1 Temperature and radiation vs. efficiency

Understanding the origin of the degradation mechanisms and how they affect the performance of PV modules is essential to improve the reliability of PV modules.

We remember that the Hybrid module should reduce the photodegradation of the a-Si solar cell because of its thinner cell thickness and low current density. Thus, the conversion efficiency can be earlier stabilized. On the other hand, the top or bottom cell of the PV module limits the output current of the whole staked PV module. Thus, the performance of the PV module should strongly depend on the spectral irradiance distribution.

The diagram of Figure 2 shows the seasonal variations in efficiency (monthly averages) and the behaviour of the operating efficiencies vs. temperature changes during the observation period.

After reaching the stabilized point the plants exhibited seasonal variations – higher efficiency in summer and lower in winter.

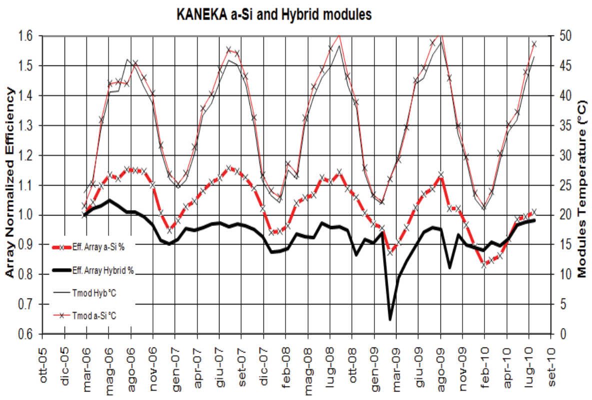

Figure 2: Temperature and efficiency normalized to their initial value between a-Si and hybrid modules. Seasonal variation of the operating efficiency (monthly average)

The normalized efficiencies reported refer to the initial efficiency at the starting of operation (February 2006). It is possible to note that the efficiency for the a-Si plant was stabilized because the module has been in operation since 2002. On the opposite the hybrid plant shows a decreasing due to the initial degradation.

As we have already learned from the previous experience the efficiency for a-Si thin film is higher in the summer closely following the modules temperature due to the thermal recovery of performances. Instead in the wintertime the Air-Mass increases so a reduced irradiance on the earth results producing a shift of the spectral distribution toward the longer wavelengths where the a-Si material exhibits not a very good spectral response. In addition the lower temperatures also slow down the thermal-recovery rate. Both are negative factors reducing the output current of the a-Si module and result in a reduction of its efficiency and output energy. Figure 2 shows also that module temperatures are almost the same for the two plants.

Experimental data about the efficiencies of both the investigated modules vs. the monthly average modules temperature show that the a-Si single junction module exhibits a normalized efficiency higher than that of the hybrid module so proving a more effective thermal-recovery during summertime.

This is confirmed looking at the electric energy performance (dc side) per square meter of the a-Si and Hybrid modules (see figure 3)

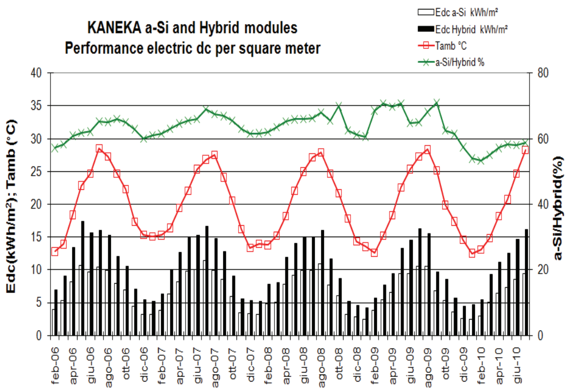

Figure 3: Performance between a-Si and hybrid modules.

Although in absolute terms the electric dc hybrid plant performance is higher than a-Si (because the original higher module efficiency and the performance of Hybrid modules are approximately 40% better than the one of a-Si modules), it is interesting to observe that in normalised terms the specific performance ratio of the "a-Si/Hybrid" is largely variable with temperature. That value is higher in summer than in winter so still proving that the recovery affects the a-Si more than the hybrid. This is a clear indication that of the two processes referred the recovery is surely more important.

One of the purposes of the experimentation that will be prosecuted in the future will be the need to evaluate separately the influence of the effect of solar spectral irradiance and the effect of thermal recovery of the light induced degradation on a-Si module and Hybrid module.

4.2 Energy performance

Figures 4 and 5 show separately the performance index for the two plants and the degradation in performance with time. It should be observed the stabilized performance of a-Si plant and the initial degradation (see PR) of the hybrid plant during the first and second year.

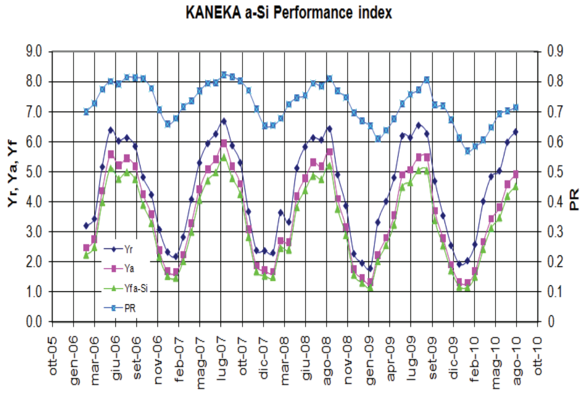

Figure 4: Performance index for a-Si modules

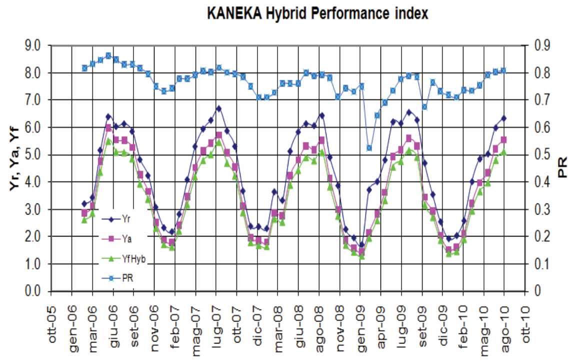

Figure 5: Performance index for Hybrid modules

Performance ratio scores high level from 0.70 to 0.81 even after 4-year operation. The lowest PR value is in February and the highest PR is in July. This data also shows that a-Si technology can produce higher output at higher temperature.

Finally it is possible to summarize in Table II for the two examined plants the principal performance index average annual comparison along the global more than four years of operation.

Table II: Annual average over four years monitoring

	Yr	Yf	PR	Eac	Eac	System Efficiency
	h/d	h/d		kWh/kWp	kWh/m²	%
a-Si	4,36	3,29	**0,75**	1194	74	**4,6**
Hybrid	4,37	3,38	**0,77**	1217	114	**7,2**

In detail the yearly performance of each plant are reported in table III and IV (annual average index).

Table III: Annual detail performance index a-Si plant

	Yr	Yf	PR	Eac	Eac	System Efficiency
Year	H/d	h/d		kWh/kWp	kWh/m²	%
2006	4,40	3,40	0,77	1237	77	4,7
2007	4,41	3,41	0,77	1246	77	4,7
2008	4,32	3,25	0,75	1190	74	4,6
2009	4,32	3,09	0,72	1103	69	4,3
Av.	**4,36**	**3,29**	**0,75**	**1194**	**74**	**4,6**

Table IV: Annual detail performance index Hybrid plant

	Yr	Yf	PR	Eac	Eac	System Efficiency
Year	h/d	h/d		kWh/kWp	kWh/m²	%
2006	4,40	3,61	0,82	1315	123	7,6
2007	4,41	3,48	0,79	1272	119	7,3
2008	4,32	3,30	0,76	1209	113	7,1
2009	4,34	3,14	0,72	1073	101	6,7
Av.	**4,37**	**3,38**	**0,77**	**1217**	**114**	**7,2**

The Table III for the a-Si plant shows that after the stabilization since the year 2002 there was in the year 2009 a sudden decrease; in fact the efficiency falls from 4.6 to 4.3. One of the reasons is the degradation of the two modules subject to failure that has been then replaced. Others mode are light-induced degradation and heavy transitory front surface soiling. At this moment it is not possible to conclude if this process has been temporary or it will be permanent and this will be investigated by further monitoring in the coming years.

The Table IV for the Hybrid plant shows a decrease also in the same year; this was due to loss of electrical insulation for the junction contacts of some modules after a very long and unusual heavy raining period. That problem has been solved and the Figure 5 (see 2010 data) shows that the PR values after that period turn to take on the expected values and seems to have reached the long term stabilization.

In order to be able to compare more closely the difference in the performance of the different plant technologies, the energy output per year has to be normalized to the relative maximum power rating of each plant. The relative performance ratio is a good method to compare technologies, however it was essential to note that the comparison was totally dependent on the selection of the given watt-peak of the module. In this investigation the producer label value Pmax of the modules have been chosen for reference.

The most significant observation is that the Energy production per watt-peak for Hybrid a-Si/μc-Si is slightly higher than the energy production per watt-peak of the a-Si module.

5 CONCLUSION

Comparing the degradation process of both the monitored plants it could be concluded that:

- a-Si plant after having reached a stabilization has then shown a new rate of degradation that will be investigated next.
- Hybrid plant apart some spot problems, seems to have reached the stabilization that has to be confirmed also.

It has been confirmed that the a-Si is more sensitive to the temperature even after some years of operating conditions.

The effect of the temperature on the performance is more effective for the a-Si respect to the Hybrid due to the thermal-recovery during Summertime.

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