

POWER AND ENERGY PRODUCTION OF PV MODULES

N. Cereghetti, A. Realini, D. Chianese and S. Rezzonico
LEEE-TISO, CH-Testing Centre for PV-modules
University of Applied Sciences of Southern Switzerland (SUPSI)
CP 110, CH - 6952 Canobbio
Phone: +41 91 / 935 13 55, Fax: +41 91 / 935 13 49
Internet: <http://www.lee.dct.supsi.ch/>, E-mail: lee@dct.supsi.ch

ABSTRACT:

Power P “at STC” (1000 W/m², T_c=25°C, AM1.5 spectrum) of PV modules, the only standard parameter stated by the manufacturers, only partially describes module performance and does not give any information about energy production: in fact two modules with equal power may have dissimilar energy production.

At the LEEE-TISO Test Centre, the most commonly sold modules on the market undergo a series of tests in order to examine their quality and reliability in terms of energy production (either PR or Wh/W) and power degradation over time.

Not only do the amorphous-Silicon modules undergo initial degradation, but also a number of crystalline-Silicon modules show significant degradation.

Keywords: Qualification and testing - 1: PV Module - 2: Degradation - 3:

1. INTRODUCTION

The systematic tests carried out on PV modules ([1] to [3]), since 1991, should help to determine their quality and behaviour.

Since January 2000 at the LEEE-TISO a pulsed Sun Simulator has been operating for the I-V curve measurement (IEC 60904-1); this measurement has also been accredited (ISO 17025) by the Swiss Accreditation Service (SAS). The measure errors are: P_{max} : ± 2.0%; V_{oc} : ± 1.0%; I_{sc} : ± 1.4%

With this simulator frequent and different I-V measurements can be carried out.



Figure 1: View of the LEEE-TISO test facility with the 17 modules under test.

In this article the results obtained by testing seventeen (cycle 7) module types are presented:

- **7 sc-Si** (*Arco Solar* ASI16-2300; *Atlantis* Sunslates; *BP Solar* BP275F; *Eurosolare* M500A; *Siemens* SM55; *Sunware* SW50T and *Trimex* Tesla M-S36-53)
- **7 mc-Si** (*ASE* ASE-100-GT-FT; *Atersa* APX90; *GPV* GPV75P; *Kyocera* KC60; *Photowatt* PW1000; *Shell Solar* RSM50 and *Solarex* MSX-83)
- **2 a-Si** (*Dunasolar* DS40 and *Uni Solar* US64)
- **1 CIS** (*Siemens* ST40)

The modules were exposed from 4.3.2000 to 5.6.2001 for a total of 15 months so that a year at stable power would be completed after initial degradation.

2. TESTING PROCEDURE

The testing procedures [3], are the same as past cycles of tests with some improvements:

- Exposure under real environmental conditions for 15 months
- I-V measurements @STC every 3 months (P₀, P₃, P₆, P₉, P₁₂, P₁₅)
- I-V measurements @STC are taken at the LEEE-TISO Sun Simulator and also in Ispra (P₀ and P₁₅)
- I-V measurements indoor at differences irradiances (200, 400, 600, 800 and 1000 W/m²)

3. ELECTRICAL CHARACTERISTICS OF THE MODULES

Table 1 reports the nominal powers (P_n) stated by the manufacturer, the P₀ powers measured @STC before exposure, and the P₃ and P₁₅ powers measured after 3 and 15 months, respectively, of outdoor testing on 17 types of modules.

3.1 Initial Power (P₀)

Crystalline-Silicon: P₀ Power, measured @STC before exposure, is lower than P_n power stated by the manufacturer in 12 out of 13 types (without considering the ARCO ASI 16-2300 modules). For three of these, power before testing is even lower than the 10% guarantee limits; in particular, there is a notable difference between P_n and P₀ in the APX90 modules (-23.2%). The behaviour of the SW50T modules is peculiar in that, apart from having an initial power 17.4% lower with respect to the

manufacturer's stated value, during the exposure these continue to lose power.

For 4 modules out of 13, final power measured @STC is lower than the guarantee limits (-10%).

Thin film: For these modules, powers @STC must be interpreted with due caution, in that response times for a-Si modules can be longer than flash duration (dynamic effects, especially for ST40), the reference cell does not have the same spectral response as the modules and, finally, a lot depends on the past of the panels themselves (memory effect).

As a whole, the data in Table 1 reveals a clear tendency by the manufacturer to declare a much higher P_n power with respect to the P_0 which the modules actually produce; apart from being lower, P_0 is subject to degradation through time.

Type	Cell	P _{MAX} @ STC [W]				ΔP (%)		
		P _n	P ₀	P ₃	P ₁₅	$\frac{P_0 - P_n}{P_n}$	$\frac{P_3 - P_0}{P_0}$	$\frac{P_{15} - P_n}{P_n}$
APX90	p-Si	90	69.2	68.6	66.7	-23.1	-0.9	-25.9
ASE-100	p-Si	100	100.7	97.5	96.9	0.7	-3.2	-3.1
ASI16-2300	m-Si	37	33.6	33.9	34.0	-9.2	0.9	-8.1
BP275F	m-Si	75	69.2	70.0	68.5	-7.7	1.2	-8.7
DS40	a-Si	40	38.7	34.4	32.1	-3.2	-11.1	-19.8
GPV75P	p-Si	75	63.1	63.2	62.0	-15.9	0.2	-17.3
KC60	p-Si	60	55.1	53.7	54.1	-8.2	-2.5	-9.8
M500A	m-Si	55	49.3	48.8	48.9	-10.4	-1.0	-11.1
M-S36-53	m-Si	53	48.4	48.6	47.5	-8.7	0.4	-10.4
MSX83	p-Si	83	78.8	75.2	75.1	-5.1	-4.6	-9.5
PW1000	p-Si	91	84.5	84.4	85.2	-7.1	-0.1	-6.4
RSM50	p-Si	49	45.3	44.9	44.6	-7.6	-0.9	-9.0
SM55	m-Si	55	52.6	50.1	49.5	-4.4	-4.8	-10.0
ST40	CIS	38	38.4	35.4	32.8	1.1	-7.8	-13.7
Sunslates	m-Si	12	10.9	10.2	10.2	-9.2	-6.4	-15.0
SW50T ¹	m-Si	50	40.5	36.7	31.6	-19.0	-9.4	-36.8
US64 ¹	a-Si	64	68.7	58.9	57.0	7.3	-14.3	-10.9

Table I: Difference between nominal power (P_n) and measured power (P_0 , P_3 , P_{15}) of module type tested (average of two modules; ¹ just one module). Modules no longer under guarantee on grey background. Measurement error @STC: absolute $\pm 2.0\%$ and repeatability $\pm 1.1\%$ on P.

3.2 Initial degradation $P_0 \rightarrow P_3$

PV solar modules with c-Si cells also show a degradation in performance when exposed to light at real operating conditions ([4] to [6]).

In order to better understand when the initial degradation occurs a special test has been done:

Four modules (2 sc-Si and 2 mc-Si) were exposed in open circuit on the laboratory roof while various I-V@STC were carried out. This experiment shows (figure 2) that such power degradation occurs during the first hours of exposure ($H=2.5 \text{ kWh/m}^2$) and is in the region of 3% with respect to P_0 .

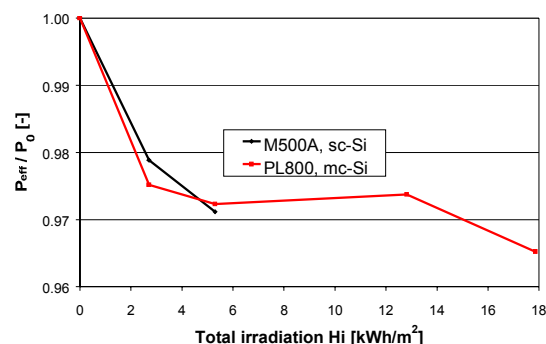


Figure 2: Initial degradation of power for the tested c-Si modules.

This type of degradation is significantly present only in some of the modules tested (see values in bold type in table 2); some types were probably exposed to sunlight prior to purchase.

The reason for power reduction for the SW50T module lies elsewhere. During the final check (P_{15}), a “problem” occurred with one module: as the power obtained varied from one flash to the next. From the analysis of all acquired data a possible conclusion could be that power floating is caused by a leak in one interconnection ribbon. In particular, that break could correspond to the point where one of the terminal ribbons has been bent to exit from the module in order to connect to the cable.

For the a-Si modules (DS40 and US64) the initial degradation occurs more slowly and is much greater. (10-15%).

The power @STC (P_3 and P_{15}) of the CIS modules is probably incorrect because if we look at the PR value (see figure 7), during the exposure, it's quite stable.

3.3 Final Power (P_{15})

After 15 months of exposure only 4 modules out of 14 (c-Si) were found to be outside the limits of the guarantee (see figure 3). Power P_{15} is on average 11% lower with respect to P_n for this type of module.

Moreover, if we consider that the powers measured @STC are at 25°C cell temperature (much lower than real outdoor ones), it is imperative that during plant planning and sizing stage the total power value for the photovoltaic field is carefully considered so that a suitable inverter can be chosen and a precise estimate can be made for total annual plant energy production.

For the thin film modules we can't confirm the STC indoor measurements; but from the energy production we can estimate the power, which should be close to the declared one.

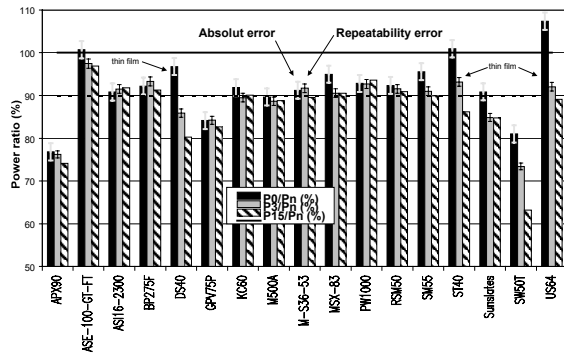


Figure 3: Power ratio of measured value (P_0 , P_6 , P_{12}) vs. nominal power.

3.4 Power at differences irradiance

In order to better characterise the modules, at the end of the exposure, I-V measurements at different irradiances have been carried out (see figure 4).

Most of the modules show proportional linearity between irradiance and power reduction.

The US64 module (with triple junction) and the one at low irradiance show highest normalised power. This behaviour, found also with the outdoor measurements, is due to the presence of three junctions sensitive to various wavelengths in the solar spectrum.

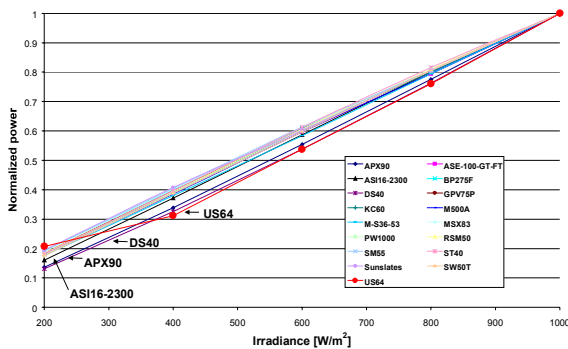


Figure 4: Normalised power (P at 1000W/m^2 as reference) as a function of irradiance; measured with the LEEE-TISO Sun Simulator.

It should be noted that this type of analysis has been carried out on an experimental basis. The spectrum of the lamp with low irradiance values is not in fact known.

4. ENERGY RATINGS

In order to have a whole year of energy production at stable power (without initial degradation, the modules were exposed for 15 months. During the twelve months under consideration, irradiation was measured at 1361kWh/m^2 (excluding days given over to measuring power @STC).

4.1 Technical comparison

Figure 5 shows energy ratings in the form of Performance Ratio (PR) calculated on the basis of real measured power values ($P_{\text{eff.}} = (P_3 + P_{15})/2$). The relative

percentage differences are calculated with respect to the first module on the left.

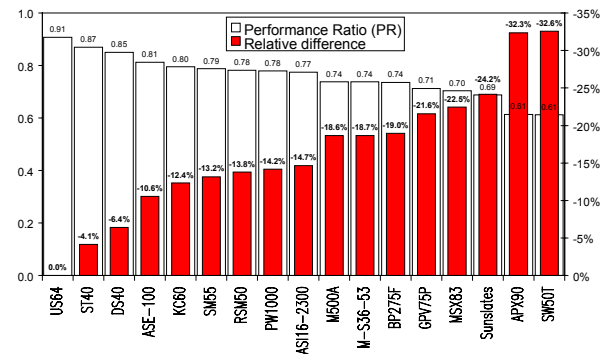


Figure 5: Performance Ratio and relative difference with respect to the power measured (P_{eff}).

The thin film modules do not appear in the graph since power measurement @STC using a pulsed solar simulator should not be regarded as correct.

As observed in the preceding tests, the differences can be greater than 10%. The SW50T module value should be treated with caution. There does not seem to be specific behaviours within the two types of technology (sc-Si, mc-Si).

4.2 Consumer viewpoint comparison

Figure 6 represents the Performance Ratio calculated on the basis of nominal power (P_n) declared by the manufacturer.

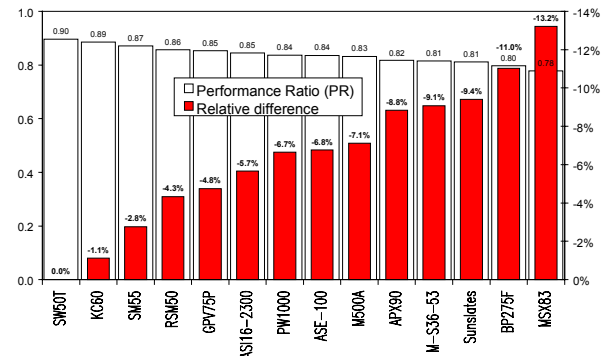


Figure 6: Performance Ratio and relative difference with respect to the manufacturer's given power value (P_n).

This type of comparison reveals significant differences (up to 30%) since various manufacturers declare fictitious power figures.

The graph clearly demonstrates thin film modules have a higher PR. Since their power remains constant through time [7], they clearly represent a valid solution for future energy production.

As can be seen in graph 7 the CIS (ST40) modules have the same thermic behaviour (seasonal cyclical variations of PR during the year) as the sc-Si (SM55) modules; moreover, in contrast to measurement @STC results, real power during exposure must have been stable since mean PR is constant.

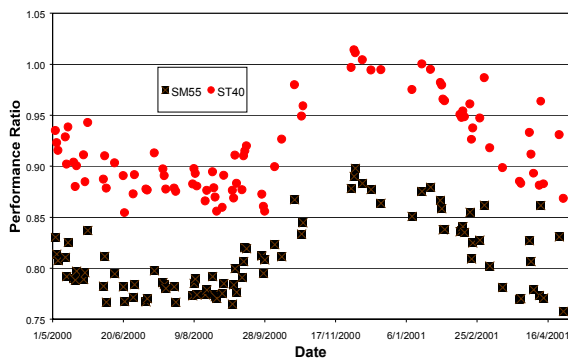


Figure 7 Performance Ratio vs time with respect to P_n of ST40 and SM55 modules.

5. CONCLUSIONS

- Power @STC alone is not enough to characterise it and to estimate energy production; moreover manufacturers often declare powers well above the real ones.
- After 15 months of exposure only 4 type of modules out of 14 (c-Si) have a power 10% below that declared.
- The thin film measurement @STC using a pulsed solar simulator is not reliable.
- Initial degradation of c.-Si modules occurs above all during the first hours of exposure.
- The CIS modules behave in a similar way to the c-Si modules.
- Thin film modules, with reference to the declared power of the manufacturer, are those with the greatest production of energy (Wh/W).
- Measurements @STC (P_0 e P_{15}) carried out at Ispra and using the LEEE-TISO simulator confirm the latter's good working capability.

REFERENCES

- [1] M. Camani et al.: Tests of reliability on crystalline and amorphous silicon modules, 14th EPVSEC, Barcelona, June 1997.
- [2] M. Camani, N. Cereghetti, D. Chianese and S. Rezzonico, Comparison and behaviour of PV modules, 2nd World PVSEC, Vienna, July 1998.
- [3] D. Chianese, N. Cereghetti, S. Rezzonico and G. Travaglini: 18 types of PV modules under the lens, 16th EPVSEC, Glasgow, May 2000.
- [4] S. Sterk, K.A. Münzer, S.W. Glunz, Investigation of the Degradation of Crystalline Silicon Solar Cells, 14th EPVSEC, Barcelona, July 1997.
- [5] J. Schmidt, A.G. Aberle, R. Hezel, Investigation of Carrier Lifetime Instabilities in CZ-grown Silicon, 26th IEEE PVSC, Anaheim (US), October 1997.
- [6] A. Moehlecke et al., Stability Problems in (n)p⁺pp⁺ Silicon Solar Cells, 2nd World PVSEC, Wien, 1998.
- [7] N. Cereghetti et al., Behaviour of Triple Junction a-Si modules, 16th EPVSEC, Glasgow, May 2000.

- [8] S. Rezzonico et al., PV Module Behaviour in Real Conditions: Emphasis on thin film modules, this conference.

ACKNOWLEDGEMENTS

This project is financially supported by the Swiss Federal Office of Energy and the AET (Azienda Elettrica Ticinese). The authors would like to extend particular thanks to the staff of the ESTI of the Joint Research Centre (JRC) in Ispra.