POWER AND ENERGY PRODUCTION OF PV MODULES STATISTICAL CONSIDERATIONS OF 10 YEARS ACTIVITY

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

ABSTRACT

The Nominal Power of PV module (Pn) measured at STC, 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 (Wh/W) and power degradation over time.
The testing procedures we developed over the years were slightly modified in order to evaluate the initial degradation of silicon crystalline module.
In 10 years of activity around 80 different types of modules have been tested: a summary of this activity will also be presented in this paper.

1 INTRODUCTION

The nominal electrical parameters supplied by the manufacturers normally refer to typical parameters recorded during the manufacture of the modules which use specific or even calculated measurements. Project planners and installers are increasingly asked to provide production and behaviour estimates for the systems they install, in particular when they involve Solar Grants and Contracting. They therefore ask the following questions:

1. Is the electrical data supplied by the manufacturers useful for our purpose?
2. Do the modules degrade over time? In what way [1]?
3. Is there a difference in energy production (Wh/Wp) between the different types of modules [2]?
4. What is the actual energy output of the different modules [3]?

In order to answer such questions the LEEE-TISO testing centre for PV components has, since 1993, carried out systematic tests, under real operating conditions, on the most important modules currently on the market

The modules were selected from those most commonly found on the Swiss market or which had interesting innovations. In order to guarantee impartiality and neutrality regarding measurements, the modules were purchased anonymously unknown to the manufacturer. Two examples for each kind of module were acquired.

With just two modules of each type we are not engaged in statistic evaluation but just sampling what the manufacturers put on the market.

Since January 2000 at the LEEE-TISO a pulsed Sun Simulator has been operating for the I-V curve measurement of crystalline silicon module (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% without spectral mismatch correction.

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

Figure 1: View of the LEEE-TISO test facility with the 14 modules under test in cycle 8.

In this article the results obtained by the activity of our laboratory in the PV module testing are presented:

- **Test stand** characterized by the cycles.
- **Services** for third parties characterized by power verification of PV modules for manufacturers, buyers, designers and public bodies who subsidize PV plant.

2 DEFINITIONS

2.1 Testing procedure

During these procedures, the electrical characteristics of the modules were measured, at regular intervals, at standard test condition (STC) at the LEEE-TISO laboratory.

The first step consists in comparing initial power measured with the flash sun simulator with the manufacturer's declared power values.

The Pa measured value is defined as the real power at time of purchase before exposure of any type. After that a light soaking period of 20kWh/m2 insolation is introduced for all crystalline silicon module.

The modules are then re-measured before being exposed under real environmental conditions for 15 months. I-V measurements @STC are carried out every 3 months (P_0, P_3, P_6, P_9, P_{12}, P_{15}).

The initial P_0 measurement and the final P_{15} measurement are repeated at the ESTI laboratory of the Joint Research Centre in Ispra (I) for comparison.

The modules for each cycle of tests are fixed to an open-rack structure tilted at 45° and 7° south of azimuth.

Each module is equipped with a Maximum Power Point Tracker adapted for its voltage and current range for greater accuracy measurements. The range limits are: 100 V-10 A, and maximum installable power is 200W.

Table I: Electrical measurements during the tests.

Pn	**Nominal Power:** registration of the data of manufacturers
Pa	**Power at purchase**
	20kWh/m^2, light soaking (c-Si)
P_0	**Initial Power:** electrical behaviour @STC
	3 months degradation period for thin film module
P_3	**After 3 months:** electrical behaviour @STC
	Exposure under real environmental conditions at MPP during 1 YEAR.
P_6	**After 6 months:** electrical behaviour @STC
P_9	**After 9 months:** electrical behaviour @STC
P_{12}	**After 12 months:** electrical behaviour @STC
P_{15}	**After 15 months:** final tests @STC

2.2 Progress of testing procedure

The most important changes to improve the test procedure have been:

- power measurement of the tested modules every 3 months, with the LEEE Sun Simulator
- acquisition of the energy production
- recording of Vm and Im every minutes

To allow the testing of more types of module during a cycle only 2 modules per types are exposed outdoor, before they were 6.

The table II summarize the most important changes.

Table II: Evolution of the testing procedure.

Cycle	Year	N° modules	P_0 & P_{12}	+ P_6	+ P_3, P_9, P_{15}	+ P_a	Energy production	V_m and I_m every min
1	1993	6	✔					
2	1994	6	✔					
3	1995	6	✔				✔	
4	1996	6	✔				✔	
5	1998	2	✔	✔			✔	
6	1999	2	✔	✔			✔	
7	2000	2	✔	✔	✔		✔	✔
8	2001	2	✔	✔	✔	✔	✔	✔
9	2002	2	✔	✔	✔	✔	✔	✔

2.3 Manufacturer definitions on power and warranty

Over the past few years, module manufacturers have redefined power and warranty limits.

Usually, apart from Nominal Power Pn warranty limits were expressed as a percentage and in years.

With the realisation that crystalline silicon modules undergo initial degradation (see chapter 3), production tolerances (± t) have been introduced in the manufacturers' power declarations for the modules and consequently a minimum power at purchase has been defined:

$$P_{\min} = P_n \pm t$$

If before the warranties were given referring to nominal power Pn, now manufacturers increasingly use minimum power Pmin. This means that if a 100W module has a production tolerance of t=±10W and a warranty of w=±20% in 20 years with respect to Pmin, real guaranteed power will be:

$$Pw = (P_n - 10\%) - 20\% - m$$

Where ±m is measurement tolerance (for example 3%). The real power of the module could be 69.84W without a claim against the guarantee.

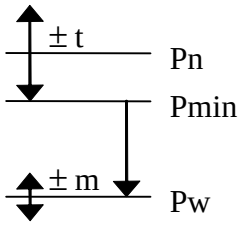

Figure 2: Relationship between the declared power parameters of the manufacturer

Where:

Pn : nominal power.
Pmin: minimum power.
Pw: limit of the warranty power output.
± t: production tolerance.
± m: measurement tolerance.

3 TESTING STANDS

3.1 Results of cycle 8

In Cycle 8 , finished on November 2002, has been tested the following modules:

- **4 sc-Si** (*BP Solar* BP5555F; *Siemens Solar* SM50H; *Atersa* A60; *Isofoton* I110).
- **5 mc-Si** (*Atersa* APX90; *Kyocera* KC70; *Photowatt* PW750; *Shell Solar* RSM70 and *BP Solar* MSX64).
- **1 a-Si** (*Uni Solar* US32)
- **1 CIS** (*Würth Solar* WS11007)

The modules were exposed from 20.6.2001 to 20.9.2002 for a total of 15 months so that a year at stable power would be completed after initial degradation.

Table III reports the nominal powers (P_n) and the minimum power (P_{min}) stated by the manufacturer, the P_0 powers measured @STC before exposure, and P_{15} final power measured after 15 months of outdoor testing on 14 types of modules.

Table III: Nominal power (P_n), warranty power (Pw) and measured power (P_a, P_{15}) of module type tested (average of two modules).

Type	Manufacturer	Cell	P_{max} @STC [W]					
			P_n	P_{min}	P_w	Years	P_a	P_{15}
BP555	BP Solar	sc-Si	***55***	***50.0***	***45.0***	***10***	54.4	53.8
SM50H	Siemens Solar	sc-Si	***50***	***45.0***	***40.5***	***10***	46.5	44.9
A60	Atersa	sc-Si	***60***	***54.0***	***n.a.***	***20***	55.1	53.9
I110	Isofoton	sc-Si	***110***	***99.0***	***88.0***	***25***	97.0	95.2
KC70	Kyocera	mc-Si	***70***	***66.5***	***63.0***	***12***	64.8	62.5
APX90	Atersa	mc-Si	***90***	***81.0***	***n.a.***	***20***	77.9	75.9
PW750	Photowatt	mc-Si	***75***	***70.0***	***55.5***	***26***	67.3	66.2
MSX64	BP Solar	mc-Si	***64***	***62.0***	***55.8***	***10***	63.3	60.0
RSM70	Shell Solar	mc-Si	***68***	***65.3***	***52.2***	***20***	66.0	65.5
US32	Uni Solar	a-Si	***32***	***28.8***	***25.6***	***20***	33.4	24.5
WS11007	Würth Solar	CIS	***57***	***51.3***	***51.3***	***10***	50.9	53.8
	Power ⇒		Nominal	Minimum	Warranty		Measured Acquired	Measured Stabilised

The results of the measurements carried out at LEEE-TISO show that real initial power @STC of the modules (Pa) differs from the nominal power of the manufacturer (Pn) (see table IV,1st column) by up to -13.5% (mean value of -7%). This is not surprising since the nominal value Pn is a mean indicative value, while the value of each single module should fall within the variance of the production parameters. In almost cases the initial value is lower than the production tolerance (± t), or the minimum power Pmin, given by the manufacturer and ranging from ±8%. The mean value of the initial power corresponds to -2% of Pmin for crystalline silicon module.

Only two modules have a Pa power greater than Pmin (BP555 and RSM70).

We can assume that it is more correct to define the installed power of a plant on the basis of the minimum power and not as a function of the nominal power.

Table IV: Difference between declared and measured value (see Table II)

Type	Cell	ΔP			
		$(P_a-P_n)/P_n$	$(P_a-P_{min})/P_{min}$	$(P_{15}-P_n)/P_n$	$(P_{15}-P_w)/P_w$
BP555	sc-Si	-1.2%	7.5%	-2.3%	19.4%
SM50H	sc-Si	-7.0%	-0.2%	-10.2%	10.9%
A60	sc-Si	-8.2%	-0.2%	-10.2%	---
I110	sc-Si	-11.8%	-3.8%	-13.5%	8.2%
KC70	mc-Si	-7.5%	-6.1%	-10.8%	-0.9%
APX90	mc-Si	-13.5%	-6.3%	-15.7%	---
PW750	mc-Si	-10.3%	-5.5%	-11.8%	19.2%
MSX64	mc-Si	-1.1%	-3.3%	-6.3%	7.4%
RSM70	mc-Si	-2.9%	0.3%	-3.7%	25.4%
US32	a-Si	4.4%	-14.9%	-23.4%	-4.3%
WS11007	CIS	-10.8%	4.8%	-5.7%	4.8%

The technology used (single or multi-crystalline) has no bearing on the failure to respect limits. This means that either the manufacturers don't know the variance with respect to their products or their system of measurement differs from the World PV Scale (WPVS), adopted by JRC at ISPRA where reference measurements @STC were carried out.

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

Table V: Degradation of the power of the module during 15 months exposure (cycle 8).

Type	Manufacturer	Cell	P_{max} @STC [W]			ΔP	
			P_a	P_3	P_{15}	$(P_3-P_a)/P_a$	$(P_{15}-P_3)/P_3$
BP555	BP Solar	sc-Si	54.4	53.7	53.8	-1.3%	0.2%
SM50H	Siemens Solar	sc-Si	46.5	44.8	44.9	-3.7%	0.2%
A60	Atersa	sc-Si	55.1	54.3	53.9	-1.4%	-0.8%
I110	Isofoton	sc-Si	97.0	96.0	95.2	-1.0%	-0.8%
KC70	Kyocera	mc-Si	64.8	62.6	62.5	-3.4%	-0.2%
APX90	Atersa	mc-Si	77.9	76.1	75.9	-2.2%	-0.3%
PW750	Photowatt	mc-Si	67.3	66.6	66.2	-1.1%	-0.6%
MSX64	BP Solar	mc-Si	63.3	60.0	60.0	-5.3%	0.0%
RSM70	Shell Solar	mc-Si	66.0	65.7	65.5	-0.5%	-0.3%
US32	Uni Solar	a-Si	33.4	26.1	24.5	-21.9%	-6.1%
WS11007	Würth Solar	CIS	50.9	55.4	* 53.8	8.8%	-2.9%
			* WS11007 at P12			3 months	1 year

Stabilised power P_{15} of c-Si module is on average 9.4% lower with respect to P_n for this type of module and ranging from -2.3% and -15.7% (see Table III).

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.

With respect to the minimum power Pmin, the stabilised power P15 is on average only -2.0% lower and ranging from +7.5% and -6.3%.

For PV power plant evaluation minimum power Pmin should be taken as reference.

In the standard modules with c-S cells, the average reduction after one year of exposure (from P0 to P15) were within the reproducibility error limits of the measurements using the flash sun simulator (see Table V).

In the case of PV plants the modules should be substituted or partially reimbursed by the manufacturer. In practice, however, it is still difficult for the consumer to verify the real power of the modules.

How can a PV-installer then get the real stabilised power of his module?

To solve this problem there is the need for further improvements in the existing or draft standards and a quality control of the production lines and especially of the simulators and procedures used by the manufacturers to measure the nominal power. In practice the manufacturers declared power and tolerance values must be improved. The PV industries need rules for power and warranty declaration in order to clearly compare the purchase power of the module.

3.2 Summary of all cycles

Since 1993 the LEEE-TISO has tested 78 types of modules mainly with crystalline silicon as the world PV market: sc-Si (31), mc-Si (33), a-Si (12) and CIS (2).

Table VI: Power differences of all the crystalline silicon tested module

	$\Delta(P_n/P_a)$	$\Delta(P_a/P_{12})$	$\Delta(P_n/P_{12})$
sc-Si	-7.0%	-3.7%	-10.9%
mc-Si	-5.9%	-4.0%	-10.7%
All c-Si	**-6.4%**	**-3.8%**	**-10.8%**

The mean difference between the power of crystalline modules given by the manufacturer and the measured one is around -6%; no important improvement during the time has been noticed.

During the exposure there is a decrease of the power value, mainly in the first hours, of 4%; no differences as been detected between single and multicristalline silicon modules.

4 SERVICES

4.1 Third parties work

Since 26th June 2001 the I-V curve measurement of crystalline silicon modules (IEC 60904-1) with our Sun Simulator is accredited (ISO 17025) by the Swiss Accreditation Services.

For a quality control periodical Round Robin tests with other Laboratories are executed.

The costumers of this service are manufacturers, buyers, designers and public bodies.

Until now 38 types of modules of 17 manufacturers have been tested.

The differences between the measured power value and the declared one of the 146 modules is -4.1% in agreement with the testing cycles value.

4.2 Evaluation of PV-plant power

Another LEEE-TISO service is the verification of PV-pant nominal power by the check of a sample of modules.

5 randomly selected modules, have been measured for every plants of the subsidy program (80% of the total costs) promoted from the Canton Ticino.

The LEEE measured power value is determinant for the amount of the corresponded subsidy.

The next graphs shows the difference between measured value and the declared one of the first 24 plants; only in 2 cases the difference has been more than 5% the limit below which the subsidy decreases.

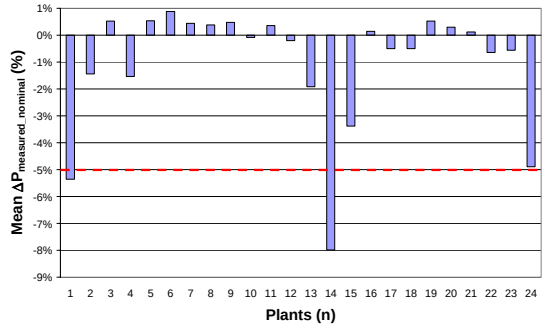

Figure 3: Results of measurements for the subsidized PV plant in Canton Ticino

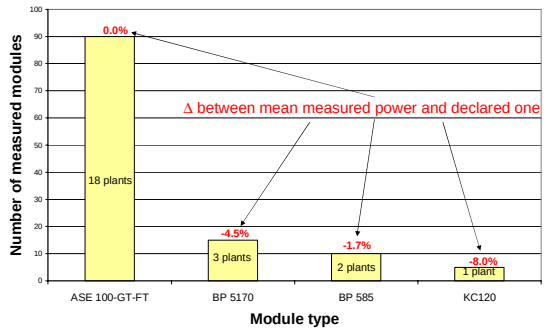

Figure 4: Module type distribution for the subsidized PV plant in Canton Ticino

Why the greatest part of the plants have been realized with the same module?

The reason is quite simple: this type of module has been tested several times from LEEE-TISO and its measured power was always as the declared one so many regional installers have decided to realize the PV plants with this module. As you can see on figure 4 the mean power measured of 90 modules, corresponding to18 PV-plants , was exactly 100W as the declared one.

5 CONCLUSIONS

The LEEE-TISO test procedure has improved during the time: 18 types of modules at time, power measurements every 3 months, recording of Vm and Im every minutes.

Real initial power @STC of the c-Si modules (Pa) differs from the nominal power of the manufacturer (Pn) of -6.4% (mean value of all types of tested modules).

In c-Si Modules there is a decrease, mainly in the first hours of exposure, of the power value around 4%.

In general, each measurement at STC of new c-Si modules must be preceded by a short period of exposure.

Power measurements of thin film modules with pulsed solar simulator don't give reliable results; an outdoor characterisation has to be found.

Over the past few years, module manufacturers have redefined power and warranty limits, introducing production tolerances (± t) in the manufacturers' power declarations. If before the warranties were given referring to nominal power Pn, now manufacturers increasingly use minimum power Pmin.

Further improvements in the existing or draft standards and a quality control of the production lines must be done.

The PV industries need rules for power and warranty declaration in order to clearly compare the purchase power of the module. For example:

- Pmin = Pn ± 3% and
- Pw = Pn ± 5% (10 years)

Where:
Pmin is the minimum power after first exposure.
Pw is the warranty power.

6 REFERENCES

[1] D. Chianese, E. Burà, N. Cereghetti, G. Friesen, A. Realini and S. Rezzonico, "Analysis of Weathered c-Si PV modules", *3nd World Conference on Photovoltaic Energy Conversion*, Osaka (J), May 2003.

[2] D. Chianese, N. Cereghetti, S. Rezzonico and G. Travaglini, "Power and energy production of PV modules", *17th EPVSEC*, München, 2001.

[3] R. P Kenny, G. Friesen, D. Chianese and E. D. Dunlop, "Energy Rating of PV Modules: Comparison of Methods and Approch", *3nd World Conference on Photovoltaic Energy Conversion*, Osaka (J), May 2003.

7 ACKNOWLEDGEMENTS

This project is financially supported by the Swiss Federal Office of Energy (SFOE) 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.