POWER AND ENERGY PRODUCTION OF PV MODULES (CYCLE 8)

D. Chianese, N. Cereghetti, G. Friesen, E. Burà, 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: 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 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. The most important aspect of the tests is to compare energy output of modules exposed in identical real outdoor conditions. The aim of these tests is to answer the questions which need to be posed when planning a PV plant.

During the eighth test cycle, carried out in 2001-2, the results confirmed the observations of the previous cycles. The testing procedures we developed over the years were slightly modified at the beginning of cycle 8 in order to evaluate the initial degradation of silicon crystalline module. Keywords: Qualification and testing - 1: PV Module - 2: Degradation - 3:

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?
3. Is there a difference in energy production (Wh/Wp) between the different types of modules?
4. What is the actual energy output of the different modules?

In order to answer such questions the LEEE-TISO testing centre for PV components has, since 1991, 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: Pmax : ± 2.0%; Voc : ± 1.0%; Isc : ± 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 testing fourteen (cycle 8) module types are presented:

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

Three modules repeated the test cycle (RWE/ASE ASE-100-GT-FT; Siemens Solar ST40; Arco Solar ASI16-2300). 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.

2 DEFINITIONS

2.1 Testing procedure

The testing procedures we developed over the years were slightly modified at the beginning of cycle 8. During these procedures, the electrical characteristics of the modules were measured, at regular intervals, at standard test condition (STC) at the LEEE-TISO laboratory as described in the following table:
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 20 kWh/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 (P6, P9, P12, P15). The initial P0 measurement and the final P15 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 (c-Si) and re-defined power and warranty limits.

2.2  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:

$$P_{\text{min}} = P_a + t$$

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:

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

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

3.1  Power before any exposure (P0)

The results of the measurements carried out at LEEETISO show that real initial power @STC of the modules (P0) differs from the nominal power of the manufacturer (Pn) (see table III, 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 RMS70). 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 I:  Electrical measurements during the tests.

| Pn | Nominal Power: registration of the data of manufacturers |
| P0 | Power at purchase |
| ±t | 20kWh/m², light soaking (c-Si) |
| P0 | Initial Power: electrical behaviour @STC |
| P6 | After 3 months: electrical behaviour @STC |
| P9 | After 6 months: electrical behaviour @STC |
| P12 | After 9 months: electrical behaviour @STC |
| P15 | After 12 months: electrical behaviour @STC |
| Pw | After 15 months: final tests @STC |

Table II: Difference between nominal power (Pn), warranty power (Pw) and measured power (Pa) of module type tested (average of two modules).

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer</th>
<th>Cell</th>
<th>P0</th>
<th>Pmin</th>
<th>Pw</th>
<th>Years</th>
<th>Pa</th>
<th>P15</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP555</td>
<td>BP Solar</td>
<td>sc-Si</td>
<td>55</td>
<td>50.0</td>
<td>45.0</td>
<td>10</td>
<td>54.6</td>
<td>53.8</td>
</tr>
<tr>
<td>SMS041</td>
<td>Siemens Solar</td>
<td>sc-Si</td>
<td>50</td>
<td>45.0</td>
<td>40.5</td>
<td>70</td>
<td>46.5</td>
<td>44.6</td>
</tr>
<tr>
<td>A60</td>
<td>Atersa</td>
<td>mc-Si</td>
<td>60</td>
<td>54.0</td>
<td>n.a.</td>
<td>20</td>
<td>55.1</td>
<td>53.9</td>
</tr>
<tr>
<td>1110</td>
<td>Isolotom</td>
<td>sc-Si</td>
<td>110</td>
<td>99.0</td>
<td>88.0</td>
<td>25</td>
<td>97.0</td>
<td>95.2</td>
</tr>
<tr>
<td>KG70</td>
<td>Kyocera</td>
<td>mc-Si</td>
<td>70</td>
<td>66.5</td>
<td>63.0</td>
<td>12</td>
<td>64.8</td>
<td>62.5</td>
</tr>
<tr>
<td>A70X6</td>
<td>Atersa</td>
<td>mc-Si</td>
<td>90</td>
<td>81.0</td>
<td>n.a.</td>
<td>20</td>
<td>77.9</td>
<td>75.9</td>
</tr>
<tr>
<td>PW750</td>
<td>Photowatt</td>
<td>mc-Si</td>
<td>75</td>
<td>70.0</td>
<td>55.5</td>
<td>20</td>
<td>67.3</td>
<td>66.2</td>
</tr>
<tr>
<td>MSX64</td>
<td>BP Solar</td>
<td>mc-Si</td>
<td>64</td>
<td>62.0</td>
<td>55.8</td>
<td>10</td>
<td>63.3</td>
<td>62.0</td>
</tr>
<tr>
<td>RS707</td>
<td>Shell Solar</td>
<td>mc-Si</td>
<td>68</td>
<td>65.5</td>
<td>52.2</td>
<td>20</td>
<td>66.0</td>
<td>65.5</td>
</tr>
<tr>
<td>US32</td>
<td>Uni Solar</td>
<td>a-Si</td>
<td>32</td>
<td>28.8</td>
<td>26.0</td>
<td>20</td>
<td>33.4</td>
<td>24.5</td>
</tr>
<tr>
<td>RB1100</td>
<td>Würth Solar</td>
<td>Lta</td>
<td>37</td>
<td>37.3</td>
<td>37.3</td>
<td>10</td>
<td>30.2</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Table II:  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.

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

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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).

### 3.2 Initial degradation (Pₐ / P₀)

PV solar modules with c-Si cells also show a degradation in performance when exposed to light at real operating conditions. Such power degradation occurs during the first hours of exposure (H=2.5 kWh/m²) and is in the region of 3% with respect to P₀.

In the c-Si module there is a mean degradation of -2.2% in the first 20 kWh/m² light soaking (Pₐ / P₃, in table IV). The degradation mainly occurs in short circuit current Isc.

This type of degradation is significantly present only in some of the modules; some types were probably exposed to sunlight prior to purchase.

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Manufacturer</th>
<th>Cell</th>
<th>Pₐ (@STC [W])</th>
<th>Pₐ / P₀</th>
<th>ΔP / P₀</th>
<th>Pₐ / P₃</th>
<th>Pₐ / P₉</th>
<th>Pₐ / P₉</th>
<th>Pₐ / P₉</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP555</td>
<td>BP Solar</td>
<td>sc-Si</td>
<td>65.4</td>
<td>100.0</td>
<td>-1.3%</td>
<td>54.9</td>
<td>62.7</td>
<td>63.5</td>
<td>62.7</td>
</tr>
<tr>
<td>SM50H</td>
<td>Siemens Solar</td>
<td>sc-Si</td>
<td>64.6</td>
<td>100.0</td>
<td>-3.1%</td>
<td>45.6</td>
<td>44.5</td>
<td>44.9</td>
<td>44.9</td>
</tr>
<tr>
<td>A60</td>
<td>Alenia</td>
<td>mc-Si</td>
<td>55.1</td>
<td>100.0</td>
<td>-1.4%</td>
<td>54.4</td>
<td>54.3</td>
<td>53.7</td>
<td>53.7</td>
</tr>
<tr>
<td>KYC60</td>
<td>Kyocera</td>
<td>mc-Si</td>
<td>67.6</td>
<td>100.0</td>
<td>-1.0%</td>
<td>49.0</td>
<td>48.5</td>
<td>48.0</td>
<td>48.0</td>
</tr>
<tr>
<td>APX60</td>
<td>Alenia</td>
<td>mc-Si</td>
<td>77.9</td>
<td>100.0</td>
<td>-2.2%</td>
<td>69.7</td>
<td>68.7</td>
<td>68.1</td>
<td>68.1</td>
</tr>
<tr>
<td>PW750</td>
<td>Photowatt</td>
<td>mc-Si</td>
<td>71.3</td>
<td>100.0</td>
<td>-1.1%</td>
<td>66.3</td>
<td>65.6</td>
<td>65.1</td>
<td>65.1</td>
</tr>
<tr>
<td>MSX64</td>
<td>BP Solar</td>
<td>mc-Si</td>
<td>63.6</td>
<td>100.0</td>
<td>-3.3%</td>
<td>43.1</td>
<td>42.5</td>
<td>41.9</td>
<td>41.9</td>
</tr>
<tr>
<td>RW750</td>
<td>Shell Solar</td>
<td>mc-Si</td>
<td>66.8</td>
<td>100.0</td>
<td>-3.8%</td>
<td>47.5</td>
<td>46.7</td>
<td>46.2</td>
<td>46.2</td>
</tr>
<tr>
<td>US32</td>
<td>Uni Solar</td>
<td>a-Si</td>
<td>35.0</td>
<td>100.0</td>
<td>-6.6%</td>
<td>28.6</td>
<td>27.4</td>
<td>26.9</td>
<td>26.9</td>
</tr>
</tbody>
</table>

For the a-Si module (US32) the initial degradation occurs more slowly and is much greater (-21.9%). Degradation occurs both in open-circuit voltage (Voc), and in short current (Isc). The Fill Factor FF decreased by 10%, and the stabilised FF value corresponds to that declared by the manufacturer.

The power measured @STC of the CIS module WS11007 is probably incorrect.

Photo-degradation in the performance of the c-Si modules when exposed to light was also observed in the previous cycles.

As reported also by other authors [9,10,11], this is principally linked to a decrease of carrier lifetime in the bulk material. Part of this degradation also occurs if the modules are stored in the dark over a time of some weeks, but final stable module efficiency after photodegradation is equal even after predegradation in the dark [9]. Prior sunlight exposure and storage time and subsequent predegradation of the modules purchased is not known, so the initial Pa value could correspond to the power of the c-Si modules which have undergone the degradation described above.

### 3.3 Stabilised Power (P15)

Stabilised power P15 of c-Si module is on average 9.4% lower with respect to Pₐ, 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.

![Figure 3: Initial degradation of power for the tested c-Si modules.](image)

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 IV).
Energy Rating

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, tilt insolation (Hi) was measured at 1522kWh/m².

4.1 Consumer viewpoint comparison

Figure 5 represents the 1 year energy production normalised to the nominal power (Pn) declared by the manufacturer. It represents a purchase comparison and not a technological comparison. It is in fact the energy production for the powers actually purchased by the consumers.

The relative differences as a percentage of energy production of the various types of modules are calculated with respect to the first on the left.

This type of comparison reveals significant differences (up to 16% for c-Si) since various manufacturers declare fictitious power figures. (see chapter 3).

The differences between the two modules of each type are around 2% on average as shows in figure 5 with errors bars of ±1%.

The manufacturer’s choice of nominal power should reflect technical rather than economic criteria.

With these great differences, it is not easy for designers and customers to compare module power, energy and final cost.

4.2 Technical comparison

Figures 6 shows energy ratings normalised on the basis of real measured power values (Pnab=(P1+P13)/2). The relative percentage differences are calculated with respect to the first module on the left.

As observed in the preceding tests, the differences can be greater than 6%. This is a technological comparison, which does not depend on the manufacturer’s declarations, but on the real measurements carried out. The more real power differs from the declared power, the more it appears to buyers and designers that the module produces less. When declared values conform to reality and there is an acceptable production tolerance, then reliable calculations regarding Energy Rating prediction can be made.

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.

5 CONCLUSIONS

The testing procedures we developed over the years were slightly modified at the beginning of cycle 8 in order to evaluate the initial degradation of silicon crystalline module in the first light soaking period (20kWh/m² insolation).

The new photovoltaic solar c-Si modules of cycle 8, show a degradation in performance when exposed to light of up to -5%. The initial degradation of c-Si modules takes place during the first hours of exposure.

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 $P_n$, now manufacturers increasingly use minimum power $P_{min}$.

Real initial power $@STC$ of the modules ($P_a$) differs from the nominal power of the manufacturer ($P_n$) by up to -13.5% (mean value of -7%).

In almost cases the initial value is lower than the production tolerance (± t), or the minimum power $P_{min}$, given by the manufacturer and ranging from ±8% of $P_{min}$.

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

Stabilised power $P_{15}$ of c-Si module is on average 9.4% lower with respect to $P_a$ for this type of module and ranging from -2.3% and -15.7%.

With respect to the minimum power $P_{min}$, the stabilised power $P_{15}$ is on average only -2.0% lower and ranging from +7.5% and -6.3%. However, no modules are outside the warranty.

The energy production of the various types of c-Si modules, normalised to the nominal power, shows significant differences of up to 16%.

With these great differences, it is not easy for designers and customers to compare module power, energy and final cost. Respect to the stabilised power $P_{15}$ the differences are only of 6%.

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:

- $P_{min} = P_n \pm 3\%$
- $P_w = P_n \pm 5\%$ (10 years)

Where:

$P_{min}$ is the minimum power after first exposure.

$P_w$ is the warranty power.

6 REFERENCES


7 ACKNOWLEDGEMENTS

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