Solar ABCs Policy Recommendation:

# MODULE POWER RATING REQUIREMENTS

Prepared by

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Arizona State University
Photovoltaic Reliability Laboratory
(PRL)

**Alex Mikonowicz**
PowerMark Corporation

**Solar America Board for Codes and Standards**

www.solarabcs.org

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# DISCLAIMER

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# SOLAR AMERICA BOARD FOR CODES AND STANDARDS

The Solar America Board for Codes and Standards (Solar ABCs) is a collaborative effort among experts to formally gather and prioritize input from the broad spectrum of solar photovoltaic stakeholders including policy makers, manufacturers, installers, and consumers resulting in coordinated recommendations to codes and standards making bodies for existing and new solar technologies. The U.S. Department of Energy funds Solar ABCs as part of its commitment to facilitate widespread adoption of safe, reliable, and cost-effective solar technologies.

For more information, visit Solar ABC's website:
www.solarbcs.org

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# POLICY STATEMENT

## Objective:

Develop a Solar America Board for Codes and Standards (Solar ABCs) power rating policy statement that establishes requirements for the procurement of photovoltaic (PV) modules for consumers, states, and organizations providing incentives for PV systems in the United States.

## Goals:

The goals of this policy statement are to:

- increase customer awareness of the potential for discrepancy between the nameplate rating and performance of delivered PV modules and define a reasonable expectation for the consistency of these numbers;
- increase customer awareness of the power ratings available to them as a result of the IEC 61853-1 standard and empower customers to better compare the performance of modules under a range of conditions;
- improve the willingness of financial institutions to lend money for PV systems and reduce the risk of investments in PV systems by tightening the tolerance on module ratings.

## Audience for policy:

Stakeholders involved in manufacturing, purchasing, financing, or providing incentives for PV modules and systems.

## Scope and limitation of policy:

Solar ABCs will continue to recommend policies that address consumer and industry concerns related to the use of various performance, qualification, and safety standards. The power rating policy is a living document, and its scope is influenced by market requirements and the availability of existing standards. This recommended policy is written in conformity with the performance conditions in IEC 61853-1 standard titled *"Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating."*

## Motivation for policy:

Without a power rating tolerance policy, some PV modules may continue to have a significantly lower power output than the module's rating indicates. This results in reduced performance of installed PV systems that will not meet consumers' expectations. If overrating of modules continues, it will jeopardize the credibility of PV performance predictions with the general population and could slow progress toward wide adoption of solar energy technologies. This policy is the same as the existing standard used in Europe (EN 50380) with the addition of a specific lower/upper limit for the production tolerance and removing uncertainty on measured power as it varies from one lab to the other and from one test/reference technology to the other. In addition, without power rating data at various low/high irradiance and temperature conditions, the energy collection predictions for installed PV modules and systems will not be accurate.

## Solar ABCs Policy Recommendation:

*“It is recommended that photovoltaic module types sold or installed in the United States be independently measured and certified to the following power rating tolerance: after accounting for the light induced degradation[1] as per IEC 61215 (crystalline silicon) or IEC 61646 (thin film), the measured average[2] power shall be equal to or higher than the nominal nameplate power rating at STC (standard test conditions) and no individual module power shall be more than 3% below nominal. In addition, the modules shall be rated at a minimum at the four other reference conditions given in IEC 61853-1 standard: 200 W/m$^2$ & 25$^{o}$C cell temperature; 500 W/m$^2$ & 15$^{o}$C cell temperature; 1000 W/m$^2$ & 75$^{o}$C cell temperature; 800 W/m$^2$ & 20$^{o}$C ambient temperature.”*

*Notes:*

1. Values shall be measured after preconditioning according to IEC Standard 61215, Section 5, or after light-soaking according to IEC Standard 61646, Section 10.19. Other stabilizing methods may be utilized as recommended by the manufacturer if they are consistent with outdoor operation.

2. The required number of samples (n) for the average is dictated by the standard deviation ($\sigma$) of the measured values. A baseline value for $\sigma$ is calculated from a minimum number of 30 samples. Then this baseline value of $\sigma$ is used to determine the required number of samples (n) to meet the Policy recommendation. The required number of samples “n” shall be determined using the following method:

   - Note down the nameplate rated power ($P_0$ in watts).
   - Measure the individual power of 30 modules.
   - Calculate the standard deviation ($\sigma$ in watts) of these 30 modules.
   - Determine the sample size “n” using the following equation and table:

$$n = (z_{\sigma/2} * \sigma/0.03P_0)^2$$

| Desired Confidence Level | $z_{\sigma/2}$ |
|---|---|
| 90% | 1.645 |
| 95% | 1.96 |
| 99% | 2.58 |
| 99.9% | 3.3 |

If the “n” value is determined to be higher than 30, then the measured average power shall be based on “n” samples. If the “n’ value is determined to be less than 30, then the measured average power shall be based on 30 samples. The “n” value shall be rounded upward. The details on the sample size determination are presented in the appendix. The timeline for module sampling shall be mutually agreed upon between the supplier and customer.

*The measurement uncertainty of each test sample at STC along with calibration traceability chain for the measuring equipment and calibrated modules shall be reported. The independent measurements shall be carried out by an ISO 17025 accredited laboratory acceptable to the customer.*

# POLICY JUSTIFICATION

## Past Issues:

Most consumers, system integrators, and agencies providing incentives have relied on the module nameplate ratings to estimate the power and/or energy delivered by installed PV systems. Unfortunately, those estimations often have not met expectations. A possible outcome of this common trend of overstating module power ratings may be a loss of consumer and government confidence in the ability of PV modules and systems to perform as expected. It is important to recognize that the credibility of PV technology depends not only on the quality of the PV products, but also on industry practices. The nominal power ratings listed on the nameplates of PV modules were often found by independent test laboratories to be much higher than the actual measured power. As shown in Figure 1, module testing by the Florida Solar Energy Center indicated that the measured peak power of PV modules in the United States marketplace was typically less than the nameplate value (Atmaram, TamizhMani, & Ventre, 2008). In some cases, the measured power of the modules sourced from the open market was found to be nearly ten percent below the nameplate rating. BEW Engineering reported similar data on installed PV arrays, as illustrated in Figure 2 (Lilly et al., 2006).

In the past, this overrating issue was often attributed to the ANSI/UL 1703 standard (ANSI/UL 1703, 2008, etc.), which states that "the short-circuit current (Isc), rated current (Ir) maximum power (Pmax), and open-circuit voltage (Voc) shall be within ± 10 percent of the rated value." To be clear, the ANSI/UL 1703 standard is a safety standard for PV modules that specifies requirements for the electrical and mechanical safety—it is not a performance or power rating standard—and the use of a safety standard to support the overrating practice is not justifiable.

Initially, a major reason for accepting this wide tolerance was the high measurement reproducibility error among the test labs. But the biggest reason is likely that most modules were used in standalone systems that almost never operated at peak power. The standalone systems were designed to provide power for the worst months of the year, not the best.

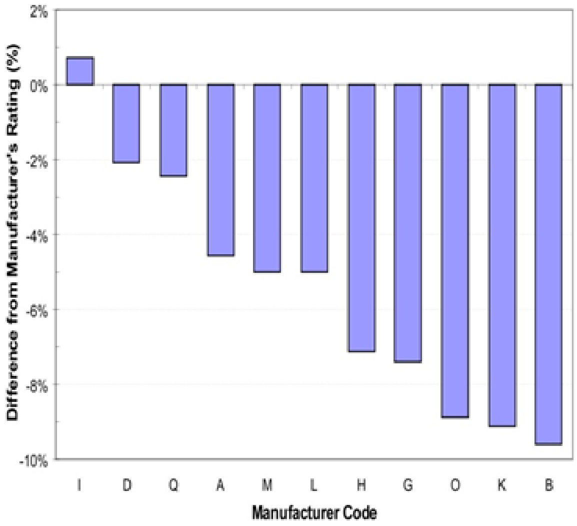

*Figure 1: Comparison of measured power with nameplate ratings of modules sourced from open market (Atmaram et al., 2008)*

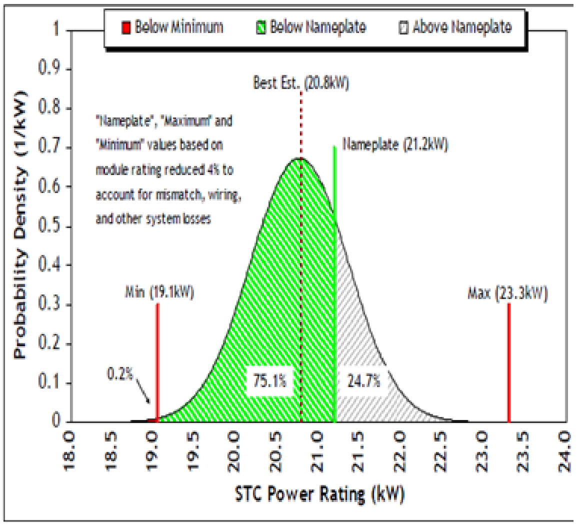

*Figure 2: Comparison of the measured power with nameplate ratings of fielded modules (Lilly et al., 2006)*

## Present Evidence:

Tightening the nameplate power rating tolerance should address the measurement issue related to the reproducibility among test laboratories and the binning/tolerance issue in production lines. Three pieces of objective evidence are presented here—one example to address the first issue and two examples to address the second issue.

*Measurement Reproducibility:* Every test laboratory has its own inherent uncertainty issues related to measuring the performance of PV modules. These are due to the uncertainties related to the measuring equipment (the I-V curve tracer, for example) and calibration (of the reference cell, for example). The measurement uncertainties vary from one lab to another but they are typically less than 4% for crystalline silicon technologies and as high as 6.5% for thin-film technologies. A major contributor to this module measurement uncertainty is the uncertainty related to reference cell calibration. These uncertainties in turn influence the reproducibility of the results between the test labs. Table 1 indicates that the measurements between a large number of test laboratories can be typically reproduced within about 5% for all the module technologies (Rummel et al., 2006). This indicates great progress by the test/measurement laboratories to tighten measurement uncertainties and improve reproducibility. Measurement uncertainty can be reduced by utilizing reference devices from the same source.

Table 1: Pmax reproducibility between the test/measurement laboratories
(% deviation from average)

### Reproducibility Tolerance

| NREL Round Robin Testing – 2006 (WCPEC4-2006) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <Pmax>.W | NREL pre | SNL | ASU | FSEC | ESTI | LEEE | TUV | ISE | JET | NREL post |
| **Mono-Si** | | | | | | | | | | | |
| SIE0577 | 66.84 | -2.9 | 3.2 | 1.6 | -4.2 | 0.4 | -0.2 | -0.2 | 0.8 | 1.3 | -2.6 |
| SIE0586 | 67.22 | -3.2 | 2.9 | 1.3 | -4.2 | 0.4 | 0.6 | -0.6 | 0.7 | 1.7 | -2.8 |
| **Thin Film Si** | | | | | | | | | | | |
| AsP0123 | 51.54 | -3.5 | 1.7 | 0.7 | | 0.9 | -1.4 | 0.3 | 0.8 | -0.6 | -2.4 |
| AsP0247 | 52.87 | -3.1 | 1.8 | 0.6 | | 1.4 | -1.5 | 0.1 | 0.6 | -0.9 | -2.1 |
| **a-Si/a-Si/a:Ge** | | | | | | | | | | | |
| BPS4213 | 41.04 | 4.8 | -0.3 | 2.3 | | -7.2* | | 3.3 | | | 1.8 |
| BPS4223 | 36.82 | 3.7 | 1.8 | 3.7 | | -3.3* | | -3.9 | | | 1.6 |
| **a-Si/a-Si/a-Si** | | | | | | | | | | | |
| USSC234 | 19.24 | 3.2 | -0.6 | -0.2 | | -7.8* | | 9.1 | | | -0.5 |
| USSC234 | 19.41 | 2.7 | -0.5 | -0.6 | | -7.2* | | 8.7 | | | -0.5 |
| **CdTe** | | | | | | | | | | | |
| BP4405 | 84.13 | 0.1 | -0.7 | 4.7 | | -2.9 | | -1.0 | | | -0.1 |
| BP4505 | 87.96 | -1 .3 | -0.5 | 4.1 | | -3.4 | | -1.0 | | | 0.7 |
| **CIS** | | | | | | | | | | | |
| Sie9257 | 40.54 | -3.3 | 5.0 | 3.1 | | -3.1 | | -1.3 | | | -3.7 |
| Sie9260 | 40.10 | -3.5 | 7.6 | 4.2 | | -4.7 | | -3.0 | | | -4.1 |
| **Concentrator** | | | | | | | | | | | |
| PTEL#1 | 3.015 | 3.3 | 0.8 | | | -3.8 | | | | | 3.0 |
| PTEL#2 | 2.913 | -0.3 | 3.0 | | | -7.3 | | | | | 4.3 |

*No special mismatch correction applied.

*Production Tolerance:* When the industry was producing PV modules at just a few megawatts per year, consumers accepted a wide production tolerance of +/- 10% because of the measurement reproducibility issues, the inherent variations in production lines, and the fact that most modules went to standalone systems where performance variations were not readily apparent. In 2010, the industry produced 18.2 gigawatts of PV modules (SolarBuzz, 2011), and consumers, especially in Europe, have tightened their procurement specifications including the power rating tolerance requirement. In response to increased consumer expectations, all the major manufacturers serving the European market have tightened their nameplate specifications to meet the requirement of the EN 50380 standard (EN 50380, 2003). The EN standard requirement can be presented as the following equation, where "m" is the measurement uncertainty and "t" is the production tolerance.

$$(P_{\text{measured}} + m) \geq (P_{\text{rated}} - t)$$

The EN standard allows leniency on both sides of the equation: the production tolerance leniency on the right side of the equation and the measurement uncertainty leniency on the left side of the equation. Unfortunately, the measurement uncertainty varies from one lab to another, and one technology to another. Also, the EN standard does not impose any specific lower/upper limit for the production tolerance. Many manufacturers offer data sheets meeting the requirements of the EN standard as shown below. The sampling of major manufactures' data sheets from the Web during 2010 clearly indicates that the manufacturers now have better quality assurance practices (due to improved sorting and better measurement accuracy) and are able to tighten the production tolerances to +/- 3%.

Manufacturer # 1
- Production tolerance = +/- 3%
- The datasheet complies with the requirements of EN 50380 (EN 50380, 2003)

Manufacturer # 2
- Production tolerance = +/- 3%
- The datasheet complies with the requirements of EN 50380

Manufacturer # 3
- Production tolerance = +/- 3%
- No indication of the datasheet complying with the requirements of EN 50380

Manufacturer # 4
- Production tolerance = -5% and +10%
- No indication of the datasheet complying with the requirements of EN 50380

Manufacturer # 5
- Production tolerance = -0% and +5%
- No indication of the datasheet complying with the requirements of EN 50380 but it indirectly complies with EN 50380 as the negative tolerance is 0%

Figure 3 compares the nameplate ratings with the independently measured values of 9,422 modules sold for power plant applications in Europe (Vaassen, 2010). This figure clearly indicates that less than 0.7% of these modules have measured values of less than -3% of the nameplate rated values. Well over 50% of all modules in the study exceeded their rated nameplate power. Again, this confirms that the manufacturers now have better quality assurance practices that allow them to maintain nearly 100% of the production modules above the -3% tolerance limit. Therefore, the Solar ABCs policy has been designed based on the following two equations, where $P_{\text{measured-average}}$ is the measured average power of "n" samples and $P_{\text{measured-individual}}$ is the measured power of individual samples.

$$P_{\text{measured-average}} \geq P_{\text{rated}}$$

$$\&$$

$$P_{\text{measured-individual}} \geq (P_{\text{rated}} - 3\%\ \text{tolerance})$$

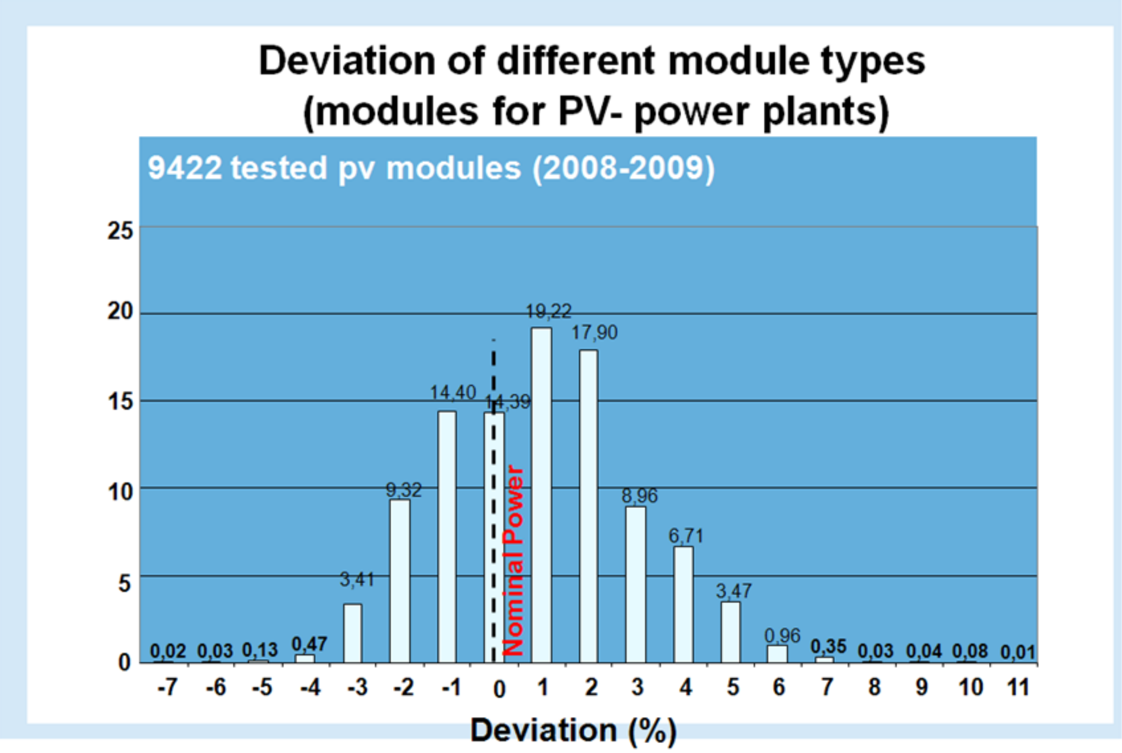

*Figure 3: Comparison of the measured power with nameplate ratings of power plant modules (Vaassen, 2010)*

# REFERENCES

ANSI/UL 1703: Flat-Plate Photovoltaic Modules and Panels. (2008, 2004, and prior versions).

Atmaram, G., TamizhMani, G., & Ventre, G. (May 2008). Need for uniform photovoltaic module performance testing and ratings. *IEEE Photovoltaic Specialists Conference.* San Diego, CA.

EN 50380: Datasheet and nameplate information for photovoltaic modules. (2003).

Lilly, P., Carpenter, M., Kitto, W., Soroushian, F., Whitaker, C., & Zaininger, H. (March 2006). *PIER renewables multi-programmatic workshop.* Sacramento, CA.

Rummel, S., Anderberg, A., Emery, K., King, D., TamizhMani, G., Arends, T., Atmaram, G., Demetrius, L., Zaaiman, W., Cereghetti, N., Herrmann, W., Warta, W., Neuberger, F., & Morita, K. (2006). Results from the second international module intercomparison. *World conference on photovoltaic energy conversion.* Hawaii.

SolarBuzz (March 2011), SolarBuzz Reports World Solar Photovoltaic Market Grew to 18.2 Gigawatts in 2010, retrieved on March 24, 2011 from http://www.solarbuzz.com/our-research/recent-findings/solarbuzz-reports-world-solar-photovoltaic-market-grew-182-gigawatts-20

Vaassen, W. (August 2010). *Quality assurance for PV power plants.* Cologne, Germany: TUV Rheinland.

# APPENDIX

**Sample size (n) determination** (J. Kuitche, Arizona State University, personal communication January 2011)

Let's assume we want the measured average power of "n" samples (say, $P_r$) to be within +/- 3% of the rated value (say, $P_0$). That is, if we draw a random sample (for example 30 modules) from a production line and compute the average or mean of 30 samples (say, P), then that value (average) shall fall between $0.97P_0$ and $1.03P_0$; with a certain degree of confidence.

We can set our sights on a 95% (2-sigma) or 99% (3-sigma) confidence level, for example. So a 95% confidence interval can be computed as $P_r \pm 2\sigma_P$, where:

$\sigma_P = \sigma/\sqrt{n}$ = standard error of the mean
$\sigma$ = standard deviation of the sample drawn (30 samples)
$n$ = sample size

Thus, the half-width confidence interval is given by:

$$w = 2 * \sigma/\sqrt{n}$$

More accurately, 95% confidence level <--> $z_{\alpha/2}$ -sigma; so:

$$w = z_{\alpha/2} * \sigma/\sqrt{n}$$

where $z_{\alpha/2}$ can be obtained from statistical tables for any confidence level.
The commonly used values of $z_{\alpha/2}$ are shown in the following table:

| Desired Confidence Level | $z_{\sigma/2}$ |
|---|---|
| 90% | 1.645 |
| 95% | 1.96 |
| 99% | 2.58 |
| 99.9% | 3.3 |

If the target half-width is 3% $P_0$ as stated, then:

$$3\% P_0 = z_{\alpha/2} * \sigma/\sqrt{n}$$

$$n = (z_{\alpha/2} * \sigma/0.03P0)^2$$

Notes:
The value of "$\sigma$" is estimated from a prior sample (of size 30 above).
The value of "n" obtained shall be rounded upward.
$P_r$ is the average of "n" samples after accounting for the light induced degradation.