A Solar ABCs **Proposed Standard** on:

Nameplate, Datasheet and Sampling Requirements for PV Modules

Mani G. TamizhMani
Arizona State University
manit@asu.edu

Alex Mikonowicz
PowerMark
acmmkr@verizon.net

Joseph Kuitche
Arizona State University
kuitche@asu.edu

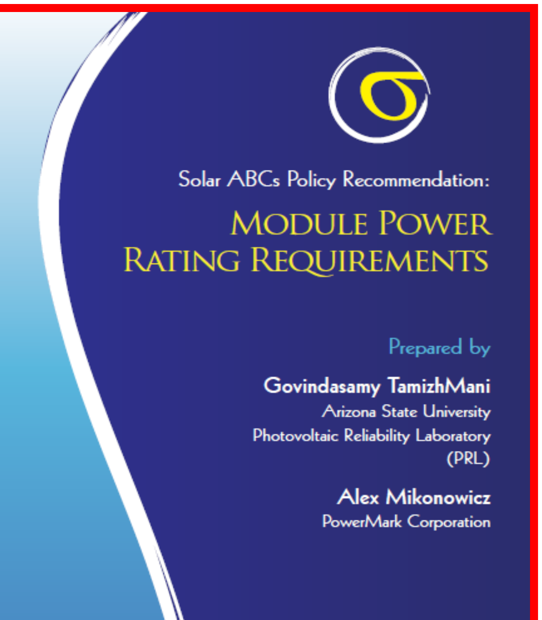
Solar ABCs Policy – Motivation

• **Without a power rating tolerance policy, some PV modules may continue to have a significantly lower power output than the module's rating indicates.**

• **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 (March 2011)

"It is recommended that photovoltaic modules 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 as per IEC 61215 (crystalline silicon) or IEC 61646 (thin film), the measured average 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 minimum four other reference conditions as per IEC 61853-1 standard: 200 W/m² & 25°C cell temperature; 500 W/m² & 15°C cell temperature; 1000 W/m² & 75°C cell temperature; 800 W/m² & 20°C ambient temperature."


Solar ABCs Policy Recommendation:

MODULE POWER RATING REQUIREMENTS

Prepared by

Govindasamy TamizhMani
Arizona State University
Photovoltaic Reliability Laboratory
(PRL)

Alex Mikonowicz
PowerMark Corporation

www.solarABCs.org

EN 50380 Standard and Proposed Standard – Differences

Difference 1: **The EN standard requirement can be represented as in the Equation 1 below:**

$$(P_{measured} + m) \geq (P_{rated} - t) \qquad [1]$$

where "m" is the measurement uncertainty and "t" is the production tolerance. The above EN standard requirement allows leniency, for the nameplate rating by the manufacturers, 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/nameplate tolerance. The proposed standard by Solar ABCs accounts for these issues of the EN standard.

Difference 2: **The EN 50380 standard requires reporting the module data only at 3 test conditions: STC, NOCT and low irradiance. The newly published (January 2011) standard IEC 61853-1 titled "*Photovoltaic Module Performance Testing and Energy Rating*" requires reporting the module data at 5 rating conditions (~~also, 23 test conditions~~). The proposed standard by Solar ABCs recommends the use of the rating/test conditions required by the IEC 61853-1 standard.**

Difference 3: **The EN 50380 standard does not impose any statistical sampling requirement to select the modules for the independent power rating measurements. The proposed standard by Solar ABCs incorporates a simple statistical sampling method to determine the number of samples required for the power rating measurements by the independent testing organizations.**

Standard - Proposed (IEEE, ASTM or IEC?)

- **Overall Requirements**

$$P_{\text{measured,average}} \geq P_{\text{rated,nominal}}$$

&

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

where:

$P_{\text{measured,average}}$ is the measured average power of “n” samples

$P_{\text{measured,individual}}$ is the measured power of “individual” samples

Standard - Proposed (IEEE, ASTM or IEC?)

- **Key Nameplate Requirements**
  - **Data at STC: Pmax, Voc, Isc, Vmax, Imax**
  - **Negative production tolerance (-%)**

- **Key Datasheet Requirements**
  - **A statement from the manufacturer declaring that the overall requirements of the standard are met**
  - **Data at STC: Pmax, Voc, Isc, Vmax, Imax**
  - **Negative production tolerance (-%)**
  - **Temperature coefficients (%/^{o}C) of V_{oc}, I_{sc}, V_{max}, I_{max} and P_{max} at STC**
  - **Power rating as per IEC 61853-1 at 5 ~~(23)~~ other test conditions**
    - ***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.***
  - **Number of samples (~~30?~~) used to obtain average power**
  - **Measured STC power of all the individual modules to obtain average power**
  - **Calibration traceability (test lab and calibrated modules at production)**

- **Key Sampling Procedure**
  - **Independent lab?**

Reviewers' Comments on the Proposed Standard: Number of rating conditions?

IEC 61853-1: 23 Reporting Conditions

(Best input data for system energy rating models/software)

Too many test conditions? Pushback from manufacturers?

Irradiance (W/m²)	Spectrum	Module Temperature			
		15°C	25°C	50°C	75°C
1100	AM1.5	NA			
1000	AM1.5				
800	AM1.5				
600	AM1.5				
400	AM1.5				NA
200	AM1.5				NA
100	AM1.5			NA	NA

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Abbrev.	Description	Irradiance (W/m²)	Module Temp. (°C)	Ambient Temp. (°C)	Wind Speed (m/s)	Spectrum
HTC	High temperature conditions	1000	75	---	---	AM 1.5
STC	Standard test conditions	1000	25	---	---	AM 1.5
NOCT	Nominal operating cell temperature conditions	800	---	20	1	AM 1.5
LTC	Low temperature conditions	500	15	---	---	AM 1.5
LIC	Low irradiance conditions	200	25	---	---	AM 1.5

FUTURE?

Already required by CEC

IEC 61853-1: 5 Rating Conditions

5 rating conditions OK? One or multiple sample?

Reviewers' Comments on the Proposed Standard: Number of samples for STC rating?

$$P_{measured,average} \geq P_{rated,nominal}$$

where:

$P_{measured,average}$ is the ~~INDEPENDENTLY~~ measured average power of "~~minimum 30~~" samples

CURRENT

30 is minimum for a normal statistical distribution BUT: 30 is too many? Pushback from manufacturers?

$$P_{measured,average} \geq P_{rated,nominal}$$

where:

$P_{measured,average}$ is the measured average power of "minimum 7" samples

FUTURE - option 1?

*** PowerMark: PV-3.4, Testing Requirements for Photovoltaic Module Power Rating (2003)**

7 modules are selected at random from a production batch or batches consisting of at least 100 modules produced on at least 5 different days.
Unfortunately, NO info on the statistical rationale for this approach!

7 samples OK?

Reviewers' Comments on the Proposed Standard: Number of samples for STC rating?

$$P_{measured,average} \geq P_{rated,nominal}$$

where:

$P_{measured,average}$ is the **INDEPENDENTLY** measured average power of "**1-to-100**" samples (n). The exact number of samples "**n**" to be used by the independent testing lab is determined (see table below) based on the percent **standard deviation "σ (%)" of 30 samples PROVIDED BY THE MANUFACTURER** from a production batch or batches acceptable to the sampling procedure of "responsible authority".

σ (%)	≥ 6.0	≥ 5.0, < 6.0	≥ 4.3, < 5.0	≥ 3.8, < 4.3	≥ 3.0, < 3.8	≥ 2.5, < 3.0	≥ 2.1, < 2.5	≥ 1.8, < 2.1	≥ 1.7, < 1.8	≥ 1.5, < 1.7	≥ 1.4, < 1.5	≥ 1.2, < 1.4	≥ 1.0, < 1.2	≥ 0.7, < 1.0	< 0.7
n	100	75	50	40	30	20	15	10	8	6	5	4	3	2	1

FUTURE - option 2?

- **PowerMark procedure:**
  - **Selected at random from a production batch or batches consisting of at least 100 modules produced on at least 5 different days.**
  - **Samples selected by third party**

FUTURE?

- **ANSI/ASQ Z1.4-2003*:**
  - **The samples shall be drawn at random without regard to their quality as defined in ANSI/ASQ A3534-2-1993. The number of units in the sample shall be selected in proportion to the size of production lines or batches.**
  - **When specified by the responsible authority, this standard shall be referenced in the specification, contract, inspection, instructions, or other documents. The "responsible authority" shall be designated in one of the above documents, as agreed to by the purchases and seller or producer and user.**

*ANSI/ASQ Z1.4-2003, Sampling procedures and tables for inspection by attributes

Information Slides

Sample Size Determination (Brief)

The required number of samples (n) for the average is dictated by the standard deviation (σ) of the measured values. A baseline value for σ is calculated from a minimum number of 30 samples. Then this baseline value of σ 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 (σ in watts) of these 30 modules
- Determine the sample size “n” using the following equation and table

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

Confidence level	$z_{\alpha/2}$
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.

Sample size (n) determination (Detailed)

Assume that the measured average power of "n" samples (say, P_r) is to be within +/-3% of the rated nominal value (say, P_0). That is, if one draws 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 sight 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
σ = 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.

CURRENT

The commonly used values of $z_{\alpha/2}$ are shown in the following table.
If the target half-width is 3% P_0 as stated, then

$3\%P_0 = z_{\alpha/2}{}^* \sigma/\sqrt{n}$
$n = (z_{\alpha/2}{}^* \sigma/0.03P_0)^2$

Confidence level	$z_{\alpha/2}$
90%	1.645
95%	1.96
99%	2.58
99.9%	3.3

<u>Note</u>
The value of "σ" 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 preconditioning (crystalline silicon) or light-soaking (thin film)

Sample size (n) determination (Detailed)

The required number of samples (n) for the average is dictated by 3 parameters:

- The maximum production tolerance (E) allowed by the specification, currently 3%
- The population standard deviation, σ
- The degree of confidence

Assuming a normal population,

Let $\lambda = E/\sigma$, the ratio of the production tolerance and standard deviation; i.e. $3\%P/\sigma$

We hypothesize that:

- Ho: The measured mean (a) is equal to the nominal mean (μ)
- H1: The two means are not equal

The degree of confidence defines the risk involved in rejecting Ho when it is actually true. Such probability is set to 5% (i.e. 95% confidence level).

To choose a proper sample size for 95% confidence level, the table below, derived from operating curves (OC) of Figure 1, will be used. It plots the risk of mistakenly accepting that the measured mean is equal to the nominal mean, against λ for given sample size. Note that the table was generated based on the fact that every independently measured Pmax data shall be within 3% of the rated value.

How to estimate standard deviation σ?

When historical data is available [assuming the sample size larger than 30], it can be used to estimate the population standard deviation σ. However, when there is no such historical data, conventional statistical wisdom calls for a minimum of 30 samples to obtain a normal distribution. The standard deviation (in %) shall be supplied by the manufacturer based on the in-line flash tests and the sampling procedure accepted between the manufacturer and “responsible authority”. The flash tester shall be calibrated using calibrated modules as per the quality system traceability requirements of the standard.

How to estimate sample size n?

For example, assuming a maximum population standard deviation of 1% (based on historical data), from Table 1, a minimum of 3 samples would be required.

σ (%)	≥ 6.0	≥ 5.0, < 6.0	≥ 4.3, < 5.0	≥ 3.8, < 4.3	≥ 3.0, < 3.8	≥ 2.5, < 3.0	≥ 2.1, < 2.5	≥ 1.8, < 2.1	≥ 1.7, < 1.8	≥ 1.5, < 1.7	≥ 1.4, < 1.5	≥ 1.2, < 1.4	≥ 1.0, < 1.2	≥ 0.7, < 1.0	< 0.7
n	100	75	50	40	30	20	15	10	8	6	5	4	3	2	1

Sample size (n) determination (Detailed) (contd.)

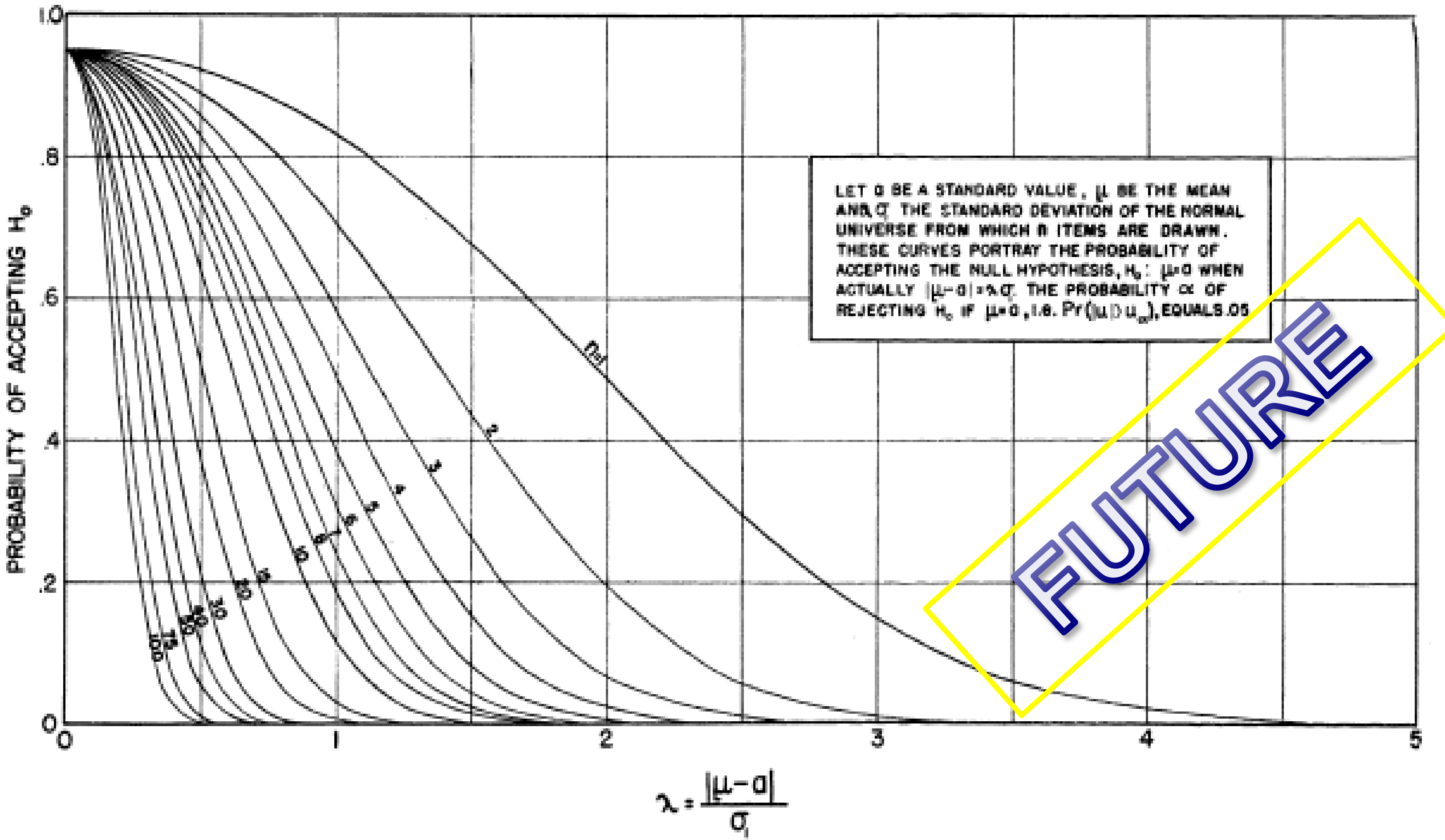


Figure 1: Operating Characteristic curve for 95% confidence and available historical data

(Reproduced from "Operating Characteristics For The Common Statistical Tests Of Significance", C. D. Ferris, F. E. Grubbs, and C. L. Weaver, The Annals of Mathematical Statistics, June 1946)

PAST issues in the United States

Allowed nameplate tolerance in the Past

Measured power = Nameplate rated power +/- 10%

Past practice by manufacturers (example)

Nameplate rated power: 100W
Measured power: > 90W ~ < 110W

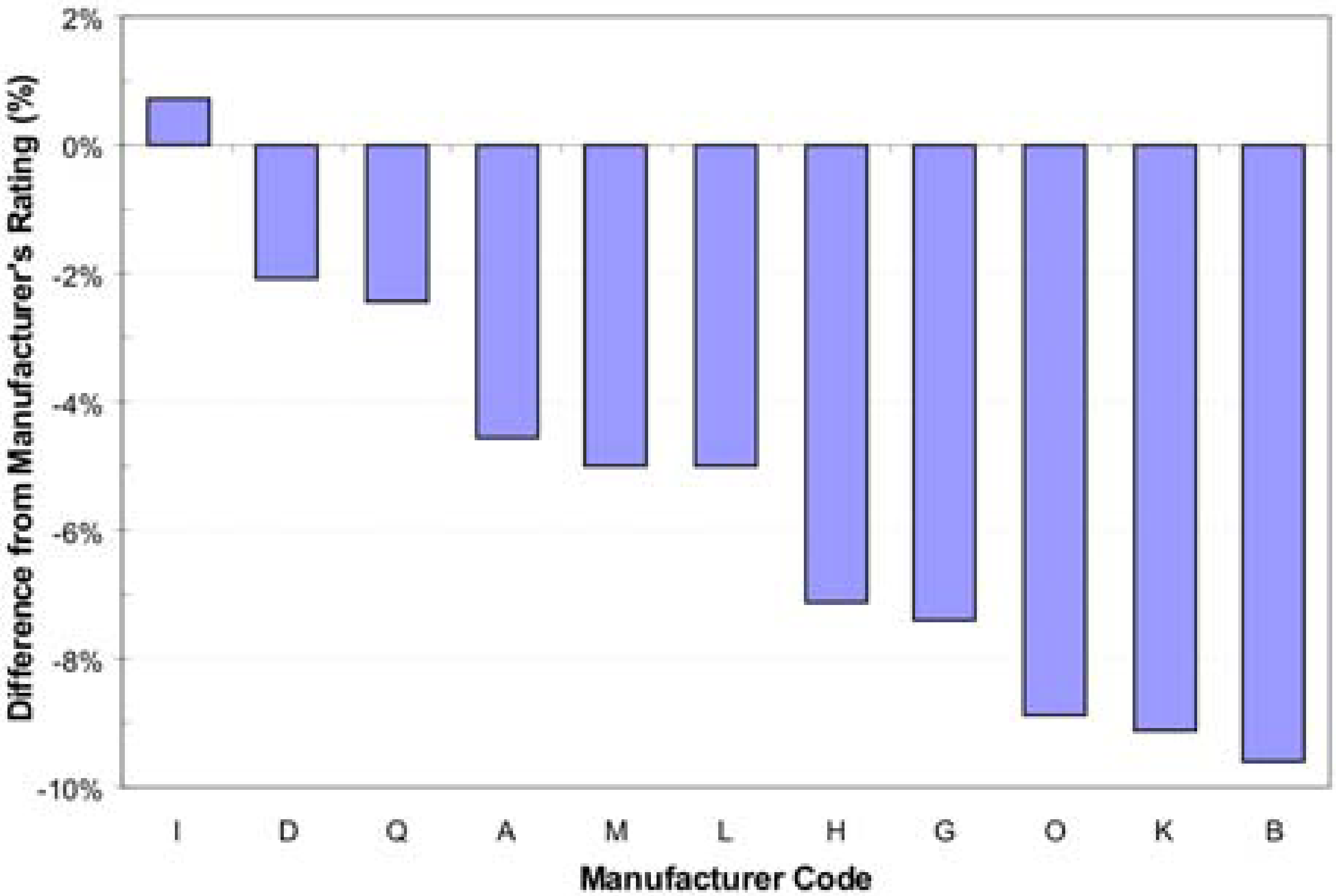
Reason for the past allowed tolerance

- **Measurement uncertainty was high in the past!**
- **Reproducibility error between test labs was high in the past!**

Past market issue

- **Measured power: Tended to be towards 90W but priced at 100 W (see FSEC's data next page)**

Past market issue



Comparison of PV Module Measured Peak Power at STC with the Module Nameplate Ratings (Source: FSEC Data 2002-2006)

Solar ABCs' Previous Policy (November 2008)

"The permissible deviation from module nameplate output for current, power, and voltage for modules installed in the U.S. shall be ±5%. A more detailed *Solar ABCs* policy shall be developed to address related issues such as stabilization, measurement uncertainty, warrantees and other issues."

PRESENT status of the industry

Current Measurement Tolerance

- **Measurement uncertainty is now smaller (for example, +/- 3% for c-Si)**

- **Reproducibility error between test labs is now smaller (for example, +/- 3% for c-Si; see NREL's round robin data)**

- **Nameplate tolerance is, typically, low (+/- 3% for c-Si) (see manufacturers' nameplate tolerance data)**

Reproducibility Error

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: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
USSC382	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 spectral mismatch correction applied.

Nameplate tolerance of various major manufacturers (Feb 2010)

Manufacturer # 1
- Nameplate tolerance = +/- 3%

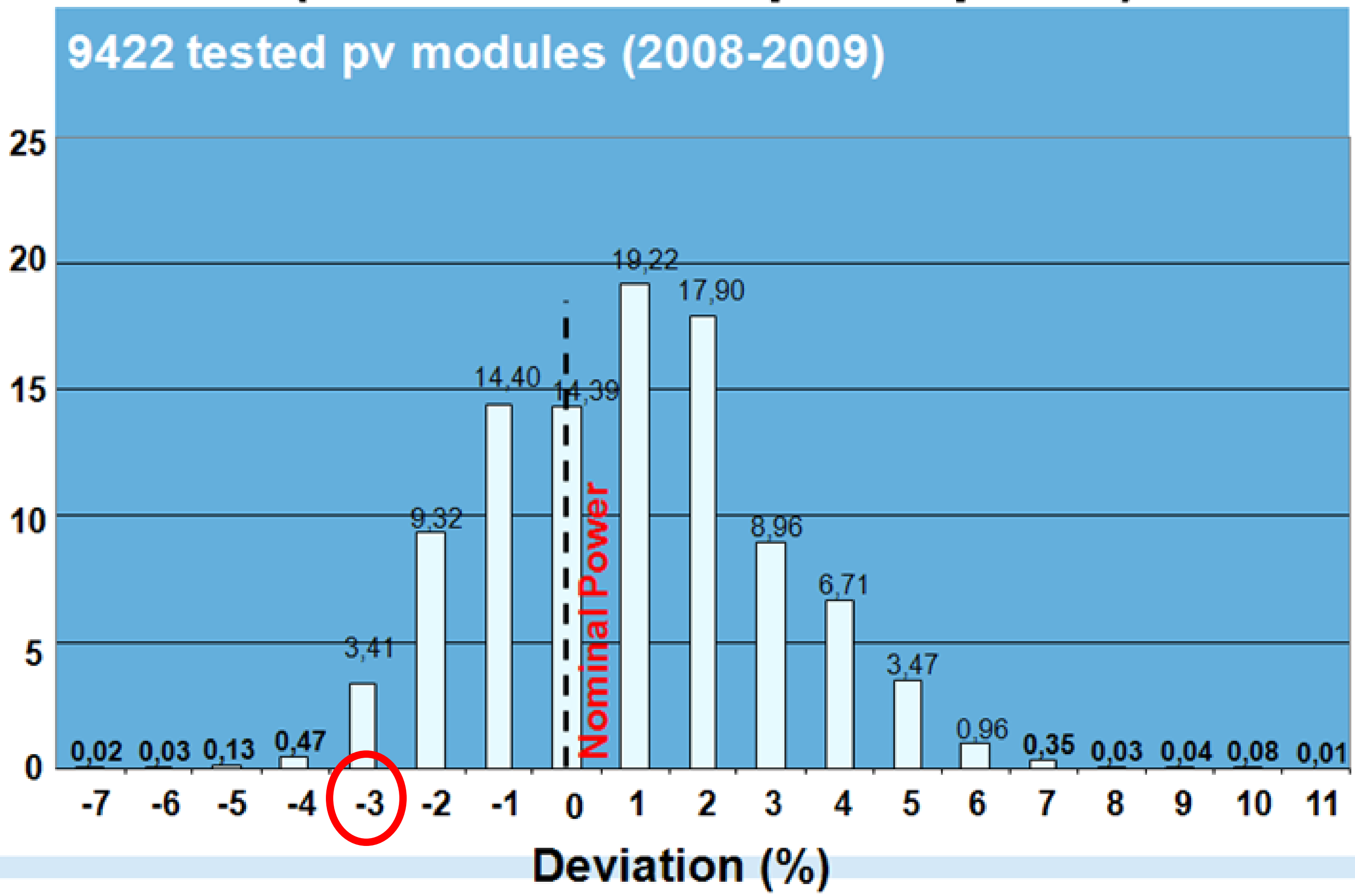
Manufacturer # 2
- Nameplate tolerance = +/- 3%

Manufacturer # 3
- Nameplate tolerance = +/- 3%

Manufacturer # 4
- Nameplate tolerance = -5% and +10%

Manufacturer # 5
- Nameplate tolerance = -0% and +5%

Deviation of different module types (modules for PV- power plants)



Source: TÜV Rheinland PV-Lab

Solar America Board for Codes and Standards

Existing Options for Module Power Rating Tolerance

1) EN 50380 / IEC 61853-1 (draft):
$(P_{measured} + \underline{m}) > (P_{rated} - \underline{t})$

Major issue: Leniency on both sides of the equation!

2) California Energy Commission:
$P_{measured} > (P_{rated} - 5\%)$

Major issue: Higher negative tolerance than needed (-3%)!

$\underline{m}$ = Measurement tolerance

$\underline{t}$ = Production tolerance

EXAMPLE **EN 50380:**

A PV module is rated with a nominal power of "P_{max}" of 50 watts at STC (with consideration of pre-ageing at start of operation) and production tolerances "$\pm$ *t*" of $\pm$ 10 %. This module is measured in an external test laboratory with measurement tolerances "$\pm$ *m*" of $\pm$ 4 %.

In the unfavourable case (lower tolerance limit), the photovoltaic module from production has an electrical power "P" of

$$P = P_{max} \cdot \left(1 - \frac{t[\%]}{100}\right) \qquad (1)$$

Pmax = Nominal rated power = 50 W
Production tolerance = -10%
P=Minimum rated power = 50 x 0.9 = 45 W

In this example, P = 45 watts.

In the unfavourable case (lower measurement tolerance), the external test laboratory measures the electrical power "$P_{measurement}$" of

$$P_{measurement} = P \cdot \left(1 - \frac{m[\%]}{100}\right) \qquad (2)$$

Measurement tolerance = -4%
Pmeasurement = 45 x 0.96 = 43.2 W

If the measured power is higher than 43.2 W, the datasheet complies with the requirements of EN 50380

In this example, $P_{measurement}$ = 43,2 watts.

This means in this example that a photovoltaic module, measured with 43,2 watts, agrees with the statement "Nominal power of 50 watts with production tolerances of $\pm$ 10 %".