2.3 Silicon Solar Cell Characterization and Modeling

The PV industry needs a thorough revision of code IEC 60904

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Every stakeholder along the PV value chain is forced to minimize costs and improve value, mainly efficiency. Therefore, the current practice to measure efficiency according to the outdated code IEC 60904-9 is surprising. The paper highlights weaknesses of the code and proposes revisions.

All major requirements of the code are evaluated regarding their relevance, clarity and completeness. Examples are given for errors in efficiency measurement that may occur albeit full accordance with the code is maintained. Also, examples are given when requirements of the code can be over-achieved due to technological improvements in lighting technology (*e.g.*, LED instead of Xenon lamps).

The paper will also address requirements that need to be added due to the increasing application of LEDs. For example, the code deals with the subject matter of intensity inhomogeneity. However, it does not classify solar simulators regarding their spectral inhomogeneity, which may be substantial for LED solar simulators in a simple array configuration.

In order to demonstrate the need for an industry-wide discussion, the paper gives examples for the technical and economical consequences of the weaknesses of the current code.

Explanatory Pages

For the time being, a wide range of metrology experts are aware of the weaknesses of the present code. However, the code is not changed. As a consequence, “good” solar simulators are classified in the same class (class A) as solar simulators that show weaknesses which are not tolerable in today’s highly competitive industry. Hence, the industry has to come up with a new code acknowledging the requirements of solar cell and module manufacturers, their customers and considering today’s possibilities with new lighting technologies (*e.g.*, LEDs).

The core rule of efficiency measurement is the code IEC 60904-9 which defines the classes. An overview of the major weaknesses is given in the following table.

Paragraph	Subject	Comment
3.10	Inhomogeneity	Lack of criteria for the spectral inhomogeneity. This is particularly important for LED array solar simulators, for multi lamp simulators and Xenon lamps.
3.11	Temporal instability	Lack of criteria for the short-term and long-term spectral instability (see Herm1, Hund1).
4	Classes A, B, C	The spectral quality for class A is insufficient. Reason 1: Solar cells with slightly different quantum efficiencies are not measured correctly with a class A solar simulator. Reason 2: New light sources based on LED exceed the class A criteria by approximately one order of magnitude. Furthermore, the classification lacks a class for the spectral homogeneity and temporal stability of the spectrum (see 3.10 and 3.11)

In addition, the code lacks criteria for the stability of the spectrum when the intensity of the light is changed (*e.g.*, 0.5 suns instead of 1 sun, see Herm1). This is relevant for the measurement of the series resistance and other characteristics.

Old classes

The quality of a solar simulator is defined by three classes. The requirements are given in the following table.

Class	Spectral conformity	Inhomogeneity	STI	LTI
A	0.75 / 1.25	2%	0.5%	2%
B	0.6 / 1.4	5%	2%	5%
C	0.4 / 2.0	10%	10%	10%

Proposal for new classes

The weak and not comprehensive definition of the requirements of the present code needs a substantial revision. A new definition of the classes is proposed which is summarized in the next table.

Class	Spectral conformity*	Inhomogeneity**	STI**	LTI**
A	0.99 / 1.01	1%	0.1%	0.1%
B	0.95 / 1.05	2%	1%	1%
C	0.75 / 1.25	3%	3%	3%

* the six spectral ranges need to be converted into 12 spectral ranges (400-450nm, 450-500nm, …). The spectral conformity is not only measured at 1 sun but also at 0.3 suns and 0.1 suns.

** measured for the total intensity AND the spectral ranges

Example for potential of LED light sources

The achievable quality in spectrum by using LEDs is illustrated in Figure 1. LEDs of different color and population were used to match the sun's spectrum. The deviation from the sun's spectrum is below 1%. This would allow a substantially improved accuracy in efficiency measurement.

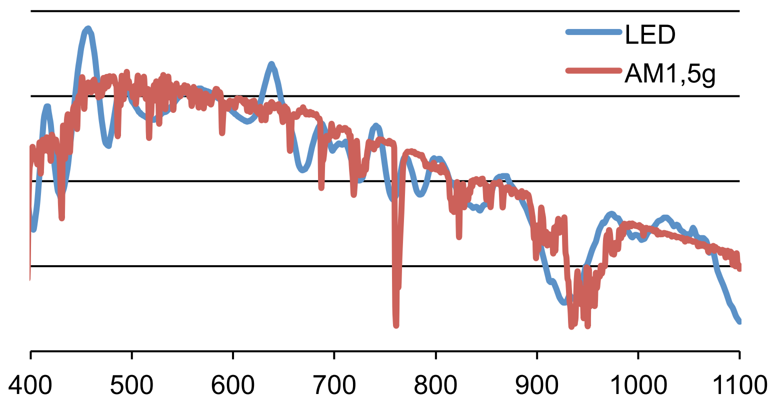

Figure 1: Comparison of the sun's spectrum with the spectrum achievable with state-of-the-art LEDs. The deviation from the target values for the ranges 400-500nm, 500-600nm, … is below 1%.

Example for the weaknesses of the present code

An example for new requirements is the definition of the minimum exposure time for a specific solar cell. High-efficiency solar cells need a longer exposure time (*e.g.*, 100 ms instead of only 10 ms). This is illustrated in Figure 2, where the *measured* fill factor of a high-efficiency solar cell is plotted as a function of the time for the IV curve measurement. The graph shows that for a conventional exposure time of 20 ms/V the fill factor would be underestimated for this specific solar cell. A sweep time of more than 80 ms/V is required to measure the true fill factor. Similar graphs can be measured for highly-efficient solar modules.

Solar simulator suppliers, cell and module manufacturers and their customers have established various ways of handling this issue. One approach to guess the "more" accurate fill factor is to use a forward AND a reverse sweep and using the average value of both measurements. However, this and other approaches originate from the limitation to short exposure time of standard solar simulators. Instead, the code should specify an accurate method.

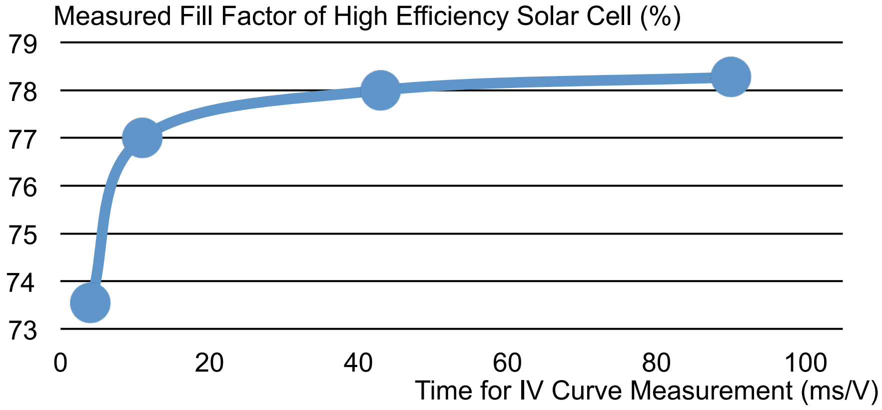

Figure 2: Measured fill factor of a single high efficiency solar cell for different voltage sweep times. The measurement shows that this specific high efficiency solar cells needs a minimum sweep time of 80 ms/V.

Economic effects

The weaknesses in accuracy (*e.g.*, low spectral conformity) and precision (*e.g.*, temporal drift of spectrum) can be partially compensated by, for example, frequent calibrations. This increases running costs due to the extra labor and material costs. But even greatest care does not protect against negative impact on the production line and R+D work. In case the weaknesses of the light source are underestimated cell and module manufacturers might sell at a price too high or too low. In case the price is too high the manufacturer will increase the safety margin on pricing so that customer complaints are reduced. Automatically, this manufacturer will sell at a price too low.

A higher quality in measurement also allows a tighter process control. Therefore, natural fluctuations in solar cell processing are detected more accurate and precise. This allows for a faster learning curve for process optimization and transfer of R+D results into production lines.

A simple analysis shows the economical relevance. A single line with an assumed capacity of 50 MW would generate 150.000 EUR more profit per year (assuming a module prize of 0.5 EUR/W) if the efficiency was increased from 17% to 17.1%.

Summary

In summary, the code needs an open discussion and thorough revision in order to remain the relevant industry source for the measurement of the efficiency, the most important parameter in PV next to costs.

References

Herm1: W. Hermann et al, p. 3015, Proceedings of 27th European Photovoltaic Solar Energy Conference, 24-28 September 2008, Frankfurt, Germany

Hund1: B. Hund et al., Proceedings of 23rd European Photovoltaic Solar Energy Conference, 1-5 September 2008, Valencia, Spain