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Solar simulator spectrum and measurement uncertainties

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Abstract

The qualification of solar simulators is specified in the IEC standard 60904-9:2007. However, this standard is a trade-off considering PV device performance, simulator design technology and measurement instrumentation at the time of its writing. Technological advances in all three sectors ask for a review of the standard.
Based on the formula (IEC 60904-7) of the spectral mismatch correction factor (*MM*), a device independent formula of a solar simulator quality factor *f1´* is proposed, similar to the quality factor of a photometer commonly used in photometry. This factor is calculated and discussed for the different solar simulator spectra of a LED light engine, a industry standard xenon light source and a high-end laboratory dual-lamp system consisting of xenon and halogen.
With an analysis of the spectral contributions to the overall *Jsc* values of a typical Si solar cell and a sensitivity analysis of the *MM*, the relation of *f1´* and the *MM* are investigated.

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1. Introduction

Advances in LED technology have led to development activities within the PV community on LED light source applications in different characterization tools over recent years [1-5]. One focus of research is the imitation of solar radiation with LEDs for indoor solar simulators. As such, they partially compete with the conventional xenon light sources used today, but also might be complementing each other for new hybrid simulators. Composing the spectrum with the discrete bell-curves of LEDs has a certain intellectual charm, as the individual control of the LEDs makes the equivalence of the spectral responsivity method [6] and the integral solar simulator method obvious and measurable with the same setup.

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The spectral response $SR(\lambda)$ of a solar cell is given as

$$SR(\lambda) = \frac{q\lambda}{hc} EQE(\lambda) \left[\frac{A}{W} \right], \tag{1}$$

where λ is the wavelength, q is the elementary charge, h is Planck's constant, c the speed of light and $EQE(\lambda)$ the external quantum efficiency, respectively. The short circuit current density J_{sc} can be calculated from the $SR(\lambda)$ as

$$J_{sc} = \int SR(\lambda) E(\lambda) d\lambda, \tag{2}$$

where $E(\lambda)$ is the spectral irradiance of the incident light.

The spectral mismatch factor correction MM takes into account the differences of reference and test cell as well as the differences of reference and solar simulator spectrum:

$$MM = \frac{J_{sc}^{RC,ERef} J_{sc}^{TC,ESim}}{J_{sc}^{RC,ESim} J_{sc}^{TC,ERef}} = \frac{\int SR_{RC}(\lambda) E_{Ref}(\lambda) d\lambda \int SR_{TC}(\lambda) E_{Sim}(\lambda) d\lambda}{\int SR_{RC}(\lambda) E_{Sim}(\lambda) d\lambda \int SR_{TC}(\lambda) E_{Ref}(\lambda) d\lambda}, \tag{3}$$

where TC indicates the test cell, RC indicates the reference cell, E_{Ref} is the spectral irradiance of the reference spectrum and E_{Sim} is the spectral irradiance of the solar simulator spectrum, respectively. Fig. 1 shows AM1.5g as reference spectrum together with the solar simulator spectra used. For the LED light engine, a high-quality type with 19 different wavelengths was choosen.

A calculation of the MM [7] for different practical sets of test cells revealed larger errors for the LED light engine compared with filtered xenon.

A simple visual comparison of the presented spectra reveals that the black-body radiation nature of the xenon light sources is in very good congruence with the sun's spectrum, with the exception of the emission lines. Thus, up to approximately 800nm the bumps of the LED spectrum deviate much more from the target spectrum. At higher wavelengths, the xenon light intensity is reduced with optical filters to compensate for the emission lines. The IEC standard weakens its requirements by integrating the intensity over a 200nm interval. This contradicts to the impact

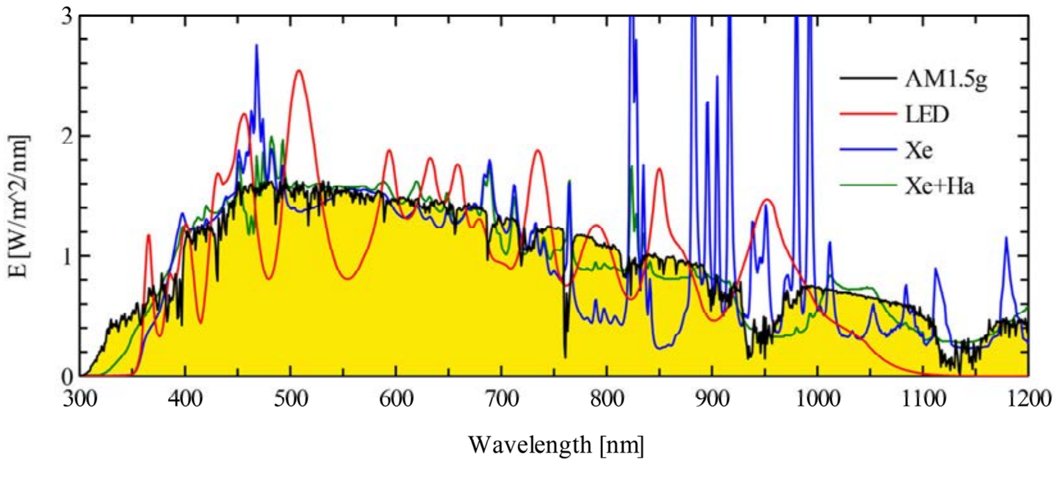

Fig. 1. Spectral irradiance of the reference spectrum AM1.5g and the solar simulator spectra.

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