Designation: E973 – 15

StandardTest Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell [1]

This standard is issued under the fixed designation E973; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method provides a procedure for the determination of a spectral mismatch parameter used in performance testing of photovoltaic devices.

1.2 The spectral mismatch parameter is a measure of the error introduced in the testing of a photovoltaic device that is caused by the photovoltaic device under test and the photovoltaic reference cell having non-identical quantum efficiencies, as well as mismatch between the test light source and the reference spectral irradiance distribution to which the photovoltaic reference cell was calibrated.

1.2.1 Examples of reference spectral irradiance distributions are Tables E490 or G173.

1.3 The spectral mismatch parameter can be used to correct photovoltaic performance data for spectral mismatch error.

1.4 Temperature-dependent quantum efficiencies are used to quantify the effects of temperature differences between test conditions and reporting conditions.

1.5 This test method is intended for use with linear photovoltaic devices in which short-circuit is directly proportional to incident irradiance.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables
E772 Terminology of Solar Energy Conversion
E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight
E1021 Test Method for Spectral Responsivity Measurements of Photovoltaic Devices
E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells
E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum
E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells
G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance
G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface
SI10 Standard for Use of the International System of Units (SI): The Modern Metric System

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E772.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *test light source, n*—a source of illumination whose spectral irradiance will be used for the spectral mismatch calculation. The light source may be natural sunlight or a solar simulator.

3.3 *Symbols:* The following symbols and units are used in this test method:

[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.3.1 *λ*—wavelength (µm or nm).

3.3.2 *D*—as a subscript, refers to the device to be tested.

3.3.3 *R*—as a subscript, refers to the reference cell.

3.3.4 *S*—as a subscript, refers to the test light source.

3.3.5 *0*—as a subscript, refers to the reference spectral irradiance distribution.

3.3.6 *A*—active area, (m^2).

3.3.7 *E*—irradiance ($W \cdot m^{-2}$).

3.3.8 $E_S(\lambda)$—spectral irradiance, test light source ($W \cdot m^{-2} \cdot \mu m^{-1}$ or $W \cdot m^{-2} \cdot nm^{-1}$).

3.3.9 $E_0(\lambda)$—spectral irradiance, to which the reference cell is calibrated ($W \cdot m^{-2} \cdot \mu m^{-1}$ or $W \cdot m^{-2} \cdot nm^{-1}$).

3.3.9.1 *Discussion*—Following normal SI rules for compound units (see Practice SI10), the units for spectral irradiance, the derivative of irradiance, with respect to wavelength, dE/dλ, would be $W \cdot m^{-3}$. However, to avoid possible confusion with a volumetric power density unit and for convenience in numerical calculations, it is common practice to separate the wavelength in the compound unit. This compound unit is also used in Tables G173.

3.3.10 *I*—short-circuit current (A).

3.3.11 J_L—light-generated photocurrent density ($A \cdot m^{-2}$).

3.3.12 *M*—spectral mismatch parameter (dimensionless).

3.3.13 $Q(\lambda,T)$—quantum efficiency (electrons per photon or %).

3.3.14 $\Theta(\lambda)$—partial derivative of quantum efficiency with respect to temperature (electrons per photon·°C^{-1} or %·°C^{-1}).

3.3.15 $R(\lambda)$—spectral responsivity ($A \cdot W^{-1}$).

3.3.16 *T*—temperature (°C).

3.3.17 T_{R0}—temperature, at which the reference cell is calibrated (°C).

3.3.18 T_{D0}—temperature, to which the short-circuit current of the device to be tested will be reported (°C).

3.3.18.1 *Discussion*—When reporting photovoltaic performance to Standard Reporting Conditions (SRC), it is common for $T_{R0} = T_{D0} = 25°C$.

3.3.19 *q*—electron charge (C).

3.3.20 *h*—Planck constant (J·s).

3.3.21 *c*—speed of light ($m \cdot s^{-1}$).

3.3.22 ΔT—temperature difference (°C).

3.3.23 *ε*—measurement error in short-circuit current (dimensionless).

4. Summary of Test Method

4.1 Spectral mismatch error occurs when a calibrated reference cell is used to measure total irradiance of a test light source (such as a solar simulator) during a photovoltaic device performance measurement, and the incident spectral irradiance of the test light source differs from the reference spectral irradiance distribution to which the reference cell is calibrated.

4.2 The magnitude of the error depends on how the quantum efficiencies of the photovoltaic reference cell and the device to be tested differ from one another; these quantum efficiencies vary with temperature.

4.3 Determination of the spectral mismatch parameter *M* requires six spectral quantities.

4.3.1 The spectral irradiance distribution of the test light source $E_S(\lambda)$.

4.3.2 The reference spectral irradiance distribution to which the photovoltaic reference cell was calibrated $E_0(\lambda)$.

4.3.3 *Photovolatic Reference Cell:*

4.3.3.1 The quantum efficiency at the temperature corresponding to its calibration constant, $Q_R(\lambda T_0)$

4.3.3.2 The partial derivative of the quantum efficiency with respect to temperature, $\Theta_R(\lambda) = \partial Q_R / \partial T(\lambda)$.

4.3.4 *Device to be Tested:*

4.3.4.1 The quantum efficiency at the temperature at which its performance will be reported, $Q_D(\lambda,T_{D0})$.

4.3.4.2 The derivative of the quantum efficiency with respect to temperature, $\Theta_R(\lambda) = \partial Q_D / \partial T(\lambda)$

4.4 Temperatures of both devices are measured, and *M* is calculated using Eq 1 and numerical integration.

5. Significance and Use

5.1 The calculated error in the photovoltaic device current determined from the spectral mismatch parameter can be used to determine if a measurement will be within specified limits before the actual measurement is performed.

5.2 The spectral mismatch parameter also provides a means of correcting the error in the measured device current due to spectral mismatch.

5.2.1 The spectral mismatch parameter is formulated as the fractional error in the short-circuit current due to spectral and temperature differences.

5.2.2 Error due to spectral mismatch is corrected by multiplying a reference cell's measured short-circuit current by *M*, a technique used in Test Methods E948 and E1036.

5.3 Because all spectral quantities appear in both the numerator and the denominator in the calculation of the spectral mismatch parameter (see 8.1), multiplicative calibration errors cancel, and therefore only relative quantities are needed (although absolute spectral quantities may be used if available).

5.4 Temperature-dependent spectral mismatch is a more accurate method to correct photovoltaic current measurements compared with fixed-value temperature coefficients.[3]

6. Apparatus

6.1 *Quantum Efficiency Measurement Apparatus*—As required by Test Method E1021 for spectral responsivity measurements.

6.2 *Spectral Irradiance Measurement Equipment*—A spectroradiometer as defined and required by Test Method G138 and calibrated according to Test Method G138.

[3] Osterwald, C. R., Campanelli, M., Moriarty, T., Emery, K. A., and Williams, R., "Temperature-Dependent Spectral Mismatch Corrections," *IEEE Journal of Photovoltaics*, Vol 5, No. 6, November 2015, pp. 1692–1697. DOI:10.1109/JPHOTOV.2015.2459914