Designation: E 973M – 96

METRIC

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

This standard is issued under the fixed designation E 973M; 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 covers 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, caused by mismatch between the spectral responses of the photovoltaic device and the photovoltaic reference cell, as well as mismatch between the test light source and the reference spectral irradiance distribution to which the photovoltaic reference cell was calibrated. Examples of reference spectral irradiance distributions are Tables E 490, E 891, or E 892.

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

1.4 This test method is intended for use with linear photovoltaic devices.

1.5 There is no similar or equivalent ISO Standard.

1.6 *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.*

1.7 The values stated in SI units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

E 380 Practice for Use of the International System of Units (SI) (the Modernized Metric System)[2]

E 490 Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables[3]

E 772 Terminology Relating to Solar Energy Conversion[4]

E 891 Tables for Terrestrial Direct Normal Solar Spectral Irradiance for Air Mass 1.5[2]

E 892 Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37° Tilted Surface[2]

E 948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight[4]

E 1021 Test Methods for Measuring Spectral Response of Photovoltaic Cells[4]

E 1036/E1036M Test Methods for Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Modules and Arrays using Reference Cells[4]

E 1039 Test Method for Calibration of Silicon Non-Concentrator Photovoltaic Primary Reference Cells Under Global Irradiation[4]

E 1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum[4]

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion[4]

E 1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells[4]

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E 772 and Terminology E 1328.

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.

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

M—spectral mismatch parameter,

ϵ—measurement error in short-circuit current,

[1] This test method is under the jurisdiction of ASTM Committee E-44 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] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] *Annual Book of ASTM Standards*, Vol 12.02.

λ—wavelength, μm or nm,

$R_r(\lambda)$—spectral response of reference cell, AW^{-1},

$R_t(\lambda)$—spectral response of photovoltaic device, AW^{-1},

E—irradiance, Wm^{-2},

$E(\lambda)$—spectral irradiance, $Wm^{-2}\mu m^{-1}$ or $Wm^{-2} nm^{-1}$, and

$E_o(\lambda)$—reference spectral irradiance, $Wm^{-2}\mu m^{-1}$ or $Wm^{-2} nm^{-1}$.

NOTE 1—Following normal SI rules for compound units (see Practice E 380), the units for spectral irradiance, the derivative of irradiance with respect to wavelength $dE/d(\lambda)$, would be Wm^{-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 E891 and E892.

4. Summary of Test Method

4.1 Determination of the spectral mismatch parameter M requires the spectral response characteristics of the photovoltaic device and the spectral irradiance distribution of the test light source, along with the spectral response and the reference spectral irradiance distribution used for the reference cell calibration.

4.2 Because all four 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. 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 differences.[5,6]

5.2.2 Error due to spectral mismatch can be corrected by dividing the measured photovoltaic cell current by M, a procedure used in Test Methods E 948 and E 1036/E 1036M.

6. Apparatus

6.1 In addition to the apparatus required by Test Methods E 1021, the following apparatus is required.

6.1.1 *Spectral Irradiance Measurement Instrument*—A spectroradiometer or a wavelength-scanning monochrometer with a suitable detector calibrated against a light source with a known spectral irradiance distribution.[7]

6.1.1.1 The wavelength resolution shall be no greater than 10 nm.

6.1.1.2 The wavelength pass-bandwidth shall be no greater than 6 nm.

6.1.1.3 The wavelength range shall be wide enough to include the spectral response of the photovoltaic device and the photovoltaic reference cell.

6.1.1.4 The spectral irradiance measurement instrument must be able to scan the required wavelength range in a time period short enough such that the spectral irradiance at any wavelength does not vary more than ± 5 % during the entire scan.

7. Procedure

7.1 Determine the spectral response $R_t(\lambda)$ of the photovoltaic device using Test Methods E 1021.

7.2 Obtain the spectral response $R_r(\lambda)$ of the photovoltaic reference cell.

NOTE 2—Test Methods E 1039, E 1125, and E 1362 require the spectral response to be provided as part of the reference cell calibration certificate.

7.3 Measure the spectral irradiance $E(\lambda)$ of the test light source, using the spectral irradiance measurement instrument (see 6.1.1).

7.4 Obtain the reference spectral irradiance distribution $E_o(\lambda)$ that corresponds to the calibration of the photovoltaic reference cell, such as Tables E 490, E 891, or E 892.

8. Calculation of Results

8.1 Calculate the spectral mismatch parameter with:[5,6]

$$M = \frac{\int_{\lambda 1}^{\lambda 2} E(\lambda)R_t(\lambda)d\lambda}{\int_{\lambda 3}^{\lambda 4} E(\lambda)R_r(\lambda)d\lambda} \times \frac{\int_{\lambda 3}^{\lambda 4} E_o(\lambda)R_r(\lambda)d\lambda}{\int_{\lambda 1}^{\lambda 2} E_o(\lambda)R_t(\lambda)d\lambda} \quad (1)$$

using a suitable numerical integration scheme such as those described in Tables E 891 or E 892.

8.1.1 The wavelength integration limits λ1 and λ2 shall correspond to the spectral response limits of the photovoltaic device.

8.1.2 The wavelength integration limits λ3 and λ4 shall correspond to the spectral response limits of the photovoltaic reference cell.

8.2 Calculate the measurement error due to spectral mismatch using:

$$\epsilon = |M - 1| \quad (2)$$

9. Precision and Bias

9.1 *Precision*—Imprecision in the spectral irradiance and the spectral response measurements will introduce errors in the calculated spectral mismatch parameter.

9.1.1 It is not practicable to specify the precision of the spectral mismatch test method using results of an interlaboratory study, because such a study would require circulating at least six stable test light sources between all participating laboratories.

[5] Seaman, C., "Calibration of Solar Cells by the Reference Cell Method—The Spectral Mismatch Problem," *Solar Energy*, Vol 29, 1982, pp. 291–298.

[6] Osterwald, C. R., "Translation of Device Performance Measurements to Reference Conditions," *Solar Cells*, Vol 18, 1986, pp. 269–279.

[7] Cannon, T. W., "Spectral Solar Irradiance Instrumentation and Measurement Techniques," *Solar Cells*, Vol 18, 1986, pp. 233–241.

9.1.2 Monte-Carlo perturbation simulations[8] using precision errors as large as 5 % in the spectral measurements have shown that the imprecision associated with the calculated spectral mismatch parameter is no more than 1 %.

TABLE 1 Estimated Limits of Imprecision in Spectral Measurements

Source of Imprecision	Estimated Limit, %
Spectral response measurement	2.0
Spectral irradiance measurement	5.0

9.1.3 Table 1 lists estimated maximum limits of imprecision that may be associated with spectral measurements at any one wavelength.

[8] Emery, K. A., Osterwald, C. R., and Wells, C. V., "Uncertainty Analysis of Photovoltaic Efficiency Measurements," *Proceedings of the 19th IEEE Photovoltaics Specialists Conference—1987* , pp. 153–159, Institute of Electrical and Electronics Engineers, New York, NY, 1987.

9.2 *Bias*—Bias associated with the spectral measurements used in the spectral mismatch calculation can be either independent of wavelength or can vary with wavelength.

9.2.1 Numerical calculations using wavelength-independent bias errors of 2 % added to the spectral quantities show the error introduced in the spectral mismatch parameter to be less than 1 %.

9.2.2 Estimates of maximum bias that may be associated with the spectral measurements are listed in Table 2. These limits are listed for guidance only and in actual practice will depend on the calibration of the spectral measurements.

10. Keywords

10.1 cell; mismatch; photovoltaic; reference; solar; spectral; testing

TABLE 2 Estimated Limits of Bias in Spectral Measurements

Source of Bias	Estimated Limit, %
Spectral response measurement	3.0
Spectral irradiance measurement	5.0