Designation: E2848 – 13 (Reapproved 2018)

# Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance[1]

This standard is issued under the fixed designation E2848; 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 measurement and analysis procedures for determining the capacity of a specific photovoltaic system built in a particular place and in operation under natural sunlight.

1.2 This test method is used for the following purposes:

1.2.1 acceptance testing of newly installed photovoltaic systems,

1.2.2 reporting of dc or ac system performance, and

1.2.3 monitoring of photovoltaic system performance.

1.3 This test method should not be used for:

1.3.1 testing of individual photovoltaic modules for comparison to nameplate power ratings,

1.3.2 testing of individual photovoltaic modules or systems for comparison to other photovoltaic modules or systems,

1.3.3 testing of photovoltaic systems for the purpose of comparing the performance of photovoltaic systems located in different places.

1.4 In this test method, photovoltaic system power is reported with respect to a set of reporting conditions (RC) including: solar irradiance in the plane of the modules, ambient temperature, and wind speed (see Section 6). Measurements under a variety of reporting conditions are allowed to facilitate testing and comparison of results.

1.5 This test method assumes that the solar cell temperature is directly influenced by ambient temperature and wind speed; if not the regression results may be less meaningful.

1.6 The capacity measured according to this test method should not be used to make representations about the energy generation capabilities of the system.

1.7 This test method is not applicable to concentrator photovoltaic systems; as an alternative, Test Method E2527 should be considered for such systems.

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

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D6176 Practice for Measuring Surface Atmospheric Temperature with Electrical Resistance Temperature Sensors

E772 Terminology of Solar Energy Conversion

E824 Test Method for Transfer of Calibration From Reference to Field Radiometers

E927 Specification for Solar Simulation for Photovoltaic Testing

E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight

E973 Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1040 Specification for Physical Characteristics of Nonconcentrator Terrestrial Photovoltaic Reference Cells

E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum

[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.

Current edition approved May 1, 2018. Published May 2018. Originally approved in 2011. Last previous edition approved in 2013 as E2848-13. DOI: 10.1520/E2848-13R18.

[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.

E1362 Test Methods for Calibration of Non-Concentrator Photovoltaic Non-Primary Reference Cells
E2527 Test Method for Electrical Performance of Concentrator Terrestrial Photovoltaic Modules and Systems Under Natural Sunlight
G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance
G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer
G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface
G183 Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers

2.2 *IEEE Standards:*
IEEE 1526-2003 Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems
IEEE 1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems

2.3 *International Standards Organization Standards:*
ISO/IEC Guide 98-1:2009 Uncertainty of measurement—Part 1: Introduction to the expression of uncertainty in measurement
ISO/IEC Guide 98-3:2008 Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

2.4 *World Meteorological Organization (WMO) Standard:*
WMO-No. 8 Guide to Meteorological Instruments and Methods of Observation, Seventh Ed., 2008

## 3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E772, IEEE 1547-2003, and ISO/IEC Guide 98-1:2009 and ISO/IEC Guide 98-3:2008.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *averaging interval, n*—the time interval over which data are averaged to obtain one data point. The performance test uses these averaged data.

3.2.2 *data collection period, n*—the period of time defined by the user of this test method during which system output power, irradiance, ambient temperature, and wind speed are measured and recorded for the purposes of a single regression analysis.

3.2.3 *plane-of-array irradiance, POA, n*—see *solar irradiance, hemispherical* in Tables G173.

3.2.4 *reporting conditions, RC, n*—an agreed-upon set of conditions including the plane-of-array irradiance, ambient temperature, and wind speed conditions to which photovoltaic system performance are reported. The reporting conditions must also state the type of radiometer used to measure the plane-of-array irradiance. In the case where this test method is to be used for acceptance testing of a photovoltaic system or reporting of photovoltaic system performance for contractual purposes, RC, or the method that will be used to derive the RC, shall be stated in the contract or agreed upon in writing by the parties to the acceptance testing and reporting prior to the start of the test.

3.2.5 *sampling interval, n*—the elapsed time between scans of the sensors used to measure power, irradiance, ambient temperature and wind speed. Individual data points used for the performance test are averages of the values recorded in these scans. There are multiple sampling intervals in each averaging interval.

3.2.6 *utility grid, n*—see **electric power system** in IEEE 1547-2003.

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

3.3.1 $\alpha$—reference cell $I_{SC}$ temperature coefficient, $°C^{-1}$

3.3.2 $a_1$, $a_2$, $a_3$, $a_4$—linear regression coefficients, arbitrary

3.3.3 *a, b, c, d*—spectral mismatch factor calibration constants, arbitrary

3.3.4 $C$—reference cell calibration constant, $Am^2W^{-1}$

3.3.5 $C_o$—reference cell calibration constant at SRC, $Am^2W^{-1}$

3.3.6 $E$—plane-of-array irradiance, $W/m^2$

3.3.7 $E_o$—irradiance at SRC, plane-of-array, $W/m^2$

3.3.8 $E_o(\lambda)$—reference spectral irradiance distribution, $Wm^{-2}\ nm^{-1}$

3.3.9 $E_{RC}$—RC rating irradiance, plane-of-array, $W/m^2$

3.3.10 $E_{RC}(\lambda)$—spectral irradiance distribution at RC, $Wm^{-2}\ nm^{-1}$

3.3.11 $E_T(\lambda)$—spectral irradiance distribution, test light source, $Wm^{-2}\ nm^{-1}$

3.3.12 $F$—fractional error in short-circuit current, dimensionless

3.3.13 $I_{SC}$—short-circuit current, A

3.3.14 $M$—spectral mismatch factor, dimensionless

3.3.15 $p$—p-value, dimensionless quantity used to determine the significance of an individual regression coefficient to the overall rating result

3.3.16 $P$—photovoltaic system power, ac or dc, W

3.3.17 $P_{RC}$—photovoltaic system power at RC, ac or dc, W

3.3.18 *RC*—reporting conditions

3.3.19 $R_R(\lambda)$—reference cell spectral responsivity, A/W

3.3.20 $R_T(\lambda)$—test device spectral responsivity, A/W

3.3.21 *SRC*—standard reporting conditions

3.3.22 *SE*—standard error, W

3.3.23 $T_a$—ambient temperature, °C

3.3.24 $T_{RC}$—RC rating temperature, °C

3.3.25 $U_{95}$—expanded uncertainty with a 95 % coverage probability of photovoltaic system power at RC, W

3.3.26 $\lambda$—wavelength, nm

3.3.27 $v$—wind speed, m/s

3.3.28 $v_{RC}$—RC rating wind speed, m/s

## 4. Summary of Test Method

4.1 Photovoltaic system power, solar irradiance, ambient temperature, and wind speed data are collected over a defined period of time using a data acquisition system.

4.2 Multiple linear regression is then used to fit the collected data to the performance equation (Eq 1) and thereby calculate the regression coefficients $a_1$, $a_2$, $a_3$, and $a_4$.

$$P = E(a_1 + a_2 \cdot E + a_3 \cdot T_a + a_4 \cdot v) \quad (1)$$

4.3 Substitution of the RC values $E_o$, $T_o$, and $v_o$ into Eq 1 then gives the ac or dc power at the reporting conditions.

$$P_{RC} = E_{RC}(a_1 + a_2 \cdot E_{RC} + a_3 \cdot T_{RC} + a_4 \cdot v_{RC}) \quad (2)$$

4.4 The collected input data and the performance at the reporting conditions are then reported.

## 5. Significance and Use

5.1 Because there are a number of choices in this test method that depend on different applications and system configurations, it is the responsibility of the user of this test method to specify the details and protocol of an individual system power measurement prior to the beginning of a measurement.

5.2 Unlike device-level measurements that report performance at a fixed device temperature of 25°C, such as Test Methods E1036, this test method uses regression to a reference ambient air temperature.

5.2.1 System power values calculated using this test method are therefore much more indicative of the power a system actually produces compared with reporting performance at a relatively cold device temperature such as 25°C.

5.2.2 Using ambient temperature reduces the complexity of the data acquisition and analysis by avoiding the issues associated with defining and measuring the device temperature of an entire photovoltaic system.

5.2.3 The user of this test method must select the time period over which system data are collected, and the averaging interval for the data collection within the constraints of 8.3.

5.2.4 It is assumed that the system performance does not degrade or change during the data collection time period. This assumption influences the selection of the data collection period because system performance can have seasonal variations.

5.3 The irradiance shall be measured in the plane of the modules under test. If multiple planes exist (particularly in the case of rolling terrain), then the plane or planes in which irradiance measurement will occur must be reported with the test results. In the case where this test method is to be used for acceptance testing of a photovoltaic system or reporting of photovoltaic system performance for contractual purposes, the plane or planes in which irradiance measurement will occur must be agreed upon by the parties to the test prior to the start of the test.

NOTE 1—In general, the irradiance measurement should occur in the plane in which the majority of modules are oriented. Placing the measurement device in a plane with a larger tilt than the majority will cause apparent under-performance in the winter and over-performance in the summer.

5.3.1 The linear regression results will be most reliable when the measured irradiance, ambient temperature, and wind speed data during the data collection period are distributed around the reporting conditions. When this is not the case, the reported power will be an extrapolation to the reporting conditions.

5.4 Accumulation of dirt (soiling) on the photovoltaic modules can have a significant impact on the system rating. The user of this test may want to eliminate or quantify the level of soiling on the modules prior to conducting the test.

5.5 Repeated regression calculations on the same system to the same RC and using the same type of irradiance measurement device over successive data collection periods can be used to monitor performance changes as a function of time.

5.6 Capacity determinations are power measurements and are adequate to demonstrate system completeness. However, a single capacity measurement does not provide sufficient information to project the energy generation potential of the system over time. Factors that may affect energy generation over time include: module power degradation, inverter clipping and overloading, shading, backtracking, extreme orientations, and filtering criteria.

## 6. Reporting Conditions

6.1 The user of this test method shall select appropriate RC. In the case where this test method is to be used for acceptance testing of a photovoltaic system or reporting of photovoltaic system performance for contractual purposes, the RC, or the method that will be used to derive the RC, must be agreed upon by the parties to the test.

6.1.1 Reporting conditions may be selected either on the basis of expected conditions or actual conditions during the data collection period. Choose RC irradiance and ambient air temperature values that are representative of the POA irradiance and ambient air temperature for the system location for a clear day in the data collection period. When the selection is based on expected conditions, irradiance can be evaluated from a year-long hourly dataset of projected POA values calculated from historical data measured directly on the system site or at a nearby site. Ambient temperatures can be evaluated by a review of historical data from the site or a nearby location. Reporting conditions should be chosen such that the system is not subject to frequent shading, inverter clipping or other non-linear operation at or around the RC. For instance, in larger photovoltaic systems, the ratio of installed DC capacity to AC inverter capacity may be such that the inverter limits the production of the modules under certain conditions. If this is the case, care should be taken to choose a reference within the normal operating range of the inverters.

NOTE 2—There are many publicly-available irradiance modeling tools that can be used to develop an hourly year-long dataset for POA irradiance at a project site based on historical global horizontal irradiance data or, if available, from data measured directly at the project site.

NOTE 3—Historically, a specific case of RC known as "Performance Test Conditions", or "PTC", have been used commonly. PTC conditions use plane-of-array irradiance equal to 1000 W/m$^2$, ambient temperature equal to 20°C, and wind speed equal to 1 m/s. The PTC parameters were based on the Nominal Terrestrial Environment (NTE) conditions that define the Nominal Operating Cell Temperature (NOCT) of an individual