Consensus International Solar Resource Standards and Best Practices Development

Preprint

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***Abstract*—Standardization and best practices of data sets and models enable the industry to develop widely accepted protocols adapted to various stages of solar project development and operations. In collaboration with the International Energy Agency Photovoltaic Power Systems Programme Task 16, the National Renewable Energy Laboratory (NREL) developed and regularly updates the *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications*. In collaboration with ASTM's radiometry subcommittee, NREL leads the development of various radiometric standards. These contribute to increased accuracy in the measurement of the solar resource available to conversion systems and boost the development and improvement of radiative models. These models can then provide the long-term geographic or climatic distribution of solar radiation for areas where measured solar data are not available. Further, these standards play a preeminent role in all aspects of solar energy projects, including standard conditions, methods and instrumentation, accelerated testing, and service lifetime of materials.**

Keywords—ASTM, Best Practices, Standards, Solar Resource, Solar Radiation

I. INTRODUCTION

A lack of common terminology, common methods, and/or awareness of national and international best practices can lead to over- or underestimates of the available solar resource. In turn, this typically induces incorrect estimates of the long-term performance of a given solar power facility and consequently results in over- or undersized equipment, bankability risks, increased financing costs, or poor financial performance of any projected solar power plant.

The National Renewable Energy Laboratory (NREL) has been actively leading and participating in the International Energy Agency (IEA) Photovoltaic Power Systems (PVPS) Programme Task 16 and ASTM subcommittee G03.09 on radiometry standards development. Standards and best practices related to the solar resource contribute to a better understanding of the magnitude and uncertainty of the resource available to conversion systems. Such documents also contribute to the development and improvement of solar resource models for areas where solar radiation measurements are not available. Moreover, the service lifetime of materials used in solar conversion systems—including polymer encapsulants, mirrors, and coatings evaluation—requires solar resource information that is based on known traceable standards and gathered appropriately by following the proper best practices to maintain data quality [1]. Most importantly, the performance of photovoltaic (PV) cells, modules, and arrays that form large solar deployments rely on accurate measurements of the available solar resource. Determining the accuracy of the solar resource acquired through measurement or models therefore provides a better understanding of investment risks. This becomes especially important as the deployment sizes increase and investment costs reach many millions of dollars. Further, these standards play a preeminent role in all aspects of weathering and durability, including standard conditions, methods and instrumentation, accelerated testing, and service lifetime of materials systems. Because solar conversion systems are deployed outdoors, the performance over time of component materials of systems is important. Many system components are tested using accelerated weathering systems in the laboratory or natural exposure techniques outdoors. Overall, the standards and best practices being developed or updated support the present and future deployment of all solar conversion systems.

II. STANDARDS ACTIVITIES

The development of consensus standards and handbooks for solar resource modeling and measurement includes various topics: (i) calibration, measurement, application, and data processing; (ii) developing and providing guidelines or standard procedures for establishing data uncertainties; (iii) developing and validating test procedures for optical radiation applications; (iv) undertaking best practices measurement activities at selected high-value sites around the United States for benchmarking; and (v) understanding resource variability, solar resource modeling, and forecasting methodologies. All this constitutes essential information for various solar energy conversion stakeholders (Fig. 1).

NREL leads the ASTM G03.09 radiometry subcommittee, which is under ASTM Committee G03: Weathering and Durability. The subcommittee develops and maintains standards associated with the specification, calibration, measurement, and modeling of solar radiation. The latter encompasses the ultraviolet (UV), visible, and infrared radiation regions, regardless of the radiation source.

NREL is also a U.S. Technical Advisory Group in the International Organization for Standardization (ISO)/Technical Committee (TC) 180/SC 1 Climate - Measurement and Data. The committee promotes knowledge and stimulates research on the calibration and specification of radiometers, the development of reference spectral irradiance, and radiometers' recommended practice for use.

Fig.1. Standards and best practices activities.

III. ASTM Subcommittee G03.09: Current Standards

A. ASTM G213-17: Standard Guide for Evaluating Uncertainty in Calibration and Field Measurements of Broadband Irradiance with Pyranometers and Pyrheliometers

As stated in ASTM G213-17, this standard prescribes methods to evaluate uncertainties resulting from the calibration of pyranometers or pyrheliometers, or from field measurements made by them [2]. Moreover, the standard aims to maintain the measurement traceability with respect to the International System of Units, which ensures that the uncertainty quoted for radiometric measurements can be compared according to documented methods of derivation.

This standard is relevant for solar conversion systems, such as PV and concentrating solar power (CSP). To evaluate the performance of PV or CSP plants, accurate measurements of the available solar resource with known uncertainty are necessary for design purposes, for a better understanding of investment risks and for meeting contractual obligations. As the deployment size of these technologies increases and investment costs reach hundreds of millions of dollars for large utility-scale power plants, characterizing the accuracy of measurements becomes essential. Therefore, having traceable methods for estimating the measurement uncertainty of the solar resource assists in reducing risks in project design and financing, shortening deployment times, and enhancing system operational efficiency.

B. ASTM G214-16: Test Method for Integration of Digital Spectral Data for Weathering and Durability Applications

This standard discusses and recommends the modified trapezoid rule, a simple integration method frequently used to compute the total integrated irradiance over a given wavelength interval [3]. The standard describes a method to derive uniform and consistent integrated digital or tabulated spectral data for various applications. Among them, PV characterization requires the short-circuit current, which is estimated by integrating both the incident spectral irradiance and the cell's spectral response [4]. Another application is the comparison of calibration results from narrow- and broadband UV radiometers that are calibrated using spectroradiometers [5]; see subsection *G* below.

C. ASTM E816-15 Standard Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers

This standard describes two methods to transfer calibration of pyrheliometers: (i) The calibration of a secondary reference pyrheliometer using an absolute cavity radiometer as the primary standard instrument (e.g., NREL's Broadband Outdoor Radiometer Calibration [BORCAL] method). According to this standard, the outdoor exposure of these two instruments shall be limited to calibration or intercomparison events only; and (ii) The transfer of calibration from a secondary reference to one or more field pyrheliometers [6]. This test method recommends the calibration chain and traceability to the World Radiometric Reference (WRR). This standard is technically comparable to and consistent with ISO 9059 [7].

D. ASTM G167-15 Standard Test Method for Calibration of a Pyranometer Using a Pyrheliometer

This standard [8] details two types of calibration methods: one involves a self-calibrating, absolute cavity radiometer, which is similar to NREL's BORCAL method (Fig. 2), whereas the other uses a secondary reference pyrheliometer as the reference standard as defined by the World Meteorological Organization and ISO 9060 [9].

Fig. 2. NREL's BORCAL method, which involves a self-calibrating, absolute cavity radiometer (left) and a diffuse pyranometer on a tracker (right). *Photos by NREL*

E. ASTM E824-10 (2018)e1 Standard Test Method for Transfer of Calibration from Reference to Field Radiometers

This standard describes a step-by-step method for the transfer to field radiometers of the calibration from reference radiometers that are traceable to the WRR [10]. The reference radiometers are calibrated using ASTM G167. The method described in ASTM E824 applies to radiometers, such as pyranometers, that measure hemispherical radiation incident on a flat surface.

F. ASTM G138-12 Standard Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance

In this standard, reference lamps that are traceable to national metrological institutes (NMIs) are used to calibrate spectroradiometers for the measurement of spectral irradiance. According to this standard, each NMI shall participate in intercomparisons of the spectral irradiance standards [11]. NREL's ISO 17025 spectral calibration accreditation depends on this standard (Fig. 3).

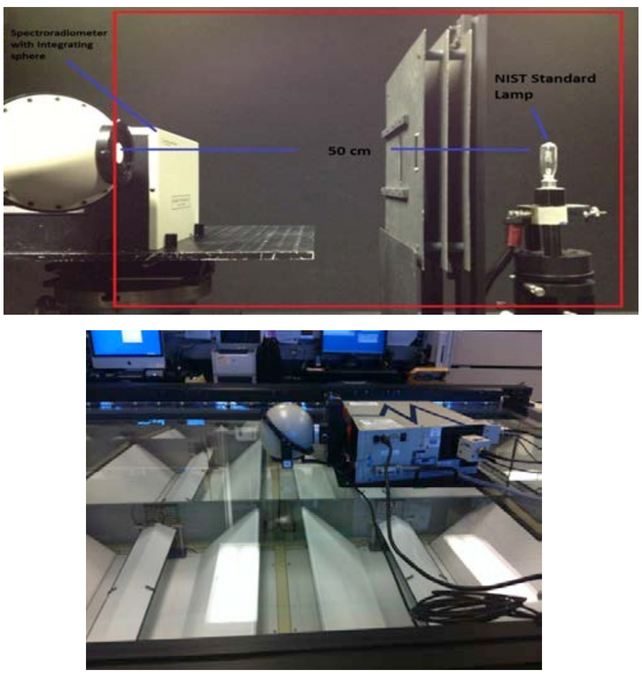

Fig. 3. NREL's spectroradiometer calibration setup traceable to the National Institute of Standards and Technology: a tungsten-filament, 1,000-W quartz-halogen FEL (top), and a spectroradiometer (bottom) are used to calibrate a solar simulator. *Photos by NREL*

G. ASTM G130-12 Standard Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer

This standard prescribes a scanning or linear-diode-array spectroradiometer calibrated using ASTM G138 to calibrate narrow- or broadband UV radiometers [5]. The calibration accuracy resulting from the use of this standard depends on the accuracy of the light source and calibration setup; therefore, care should be taken to minimize the errors during calibration. The Solar Radiation Research Laboratory at NREL performs UV calibrations using this standard.

H. ASTM G173-03(2012) Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

This standard is widely used by the solar community to generate spectral clear-sky reference data for use in understanding absorptance, reflectance, and transmittance of solar energy materials [12], which are important factors in solar PV system performance, material reliability studies, solar thermal system performance, and solar simulation activities. The direct normal irradiance spectrum is typically applied to the determination of spectral matching ratios [13]. The two spectra are for an air mass of 1.5 and form the basis of the International Electrotechnical Commission standard used for the rating of flat-plate PV devices and concentrating PV terrestrial solar cells. Subordinate standards—derived for different atmospheric conditions than those selected to establish G173—have also been proposed [14], and they are under consideration by ISO.

I. ASTM G177-03(2012) Standard Tables for Reference Solar Ultraviolet Spectral Distributions: Hemispherical on 37° Tilted Surface

Similar to ASTM G173, this standard contains a reference spectral irradiance, but limited here to UV wavelengths (0.28–0.40 µm). The specified spectral irradiance distribution has many applications, such as in exposure testing where light sources are evaluated against this reference [15]. This UV spectrum is for a low air mass (1.05) and high atmospheric transparency; hence, by design, its magnitude is significantly larger than that of the global spectrum in G173 (Fig. 4).

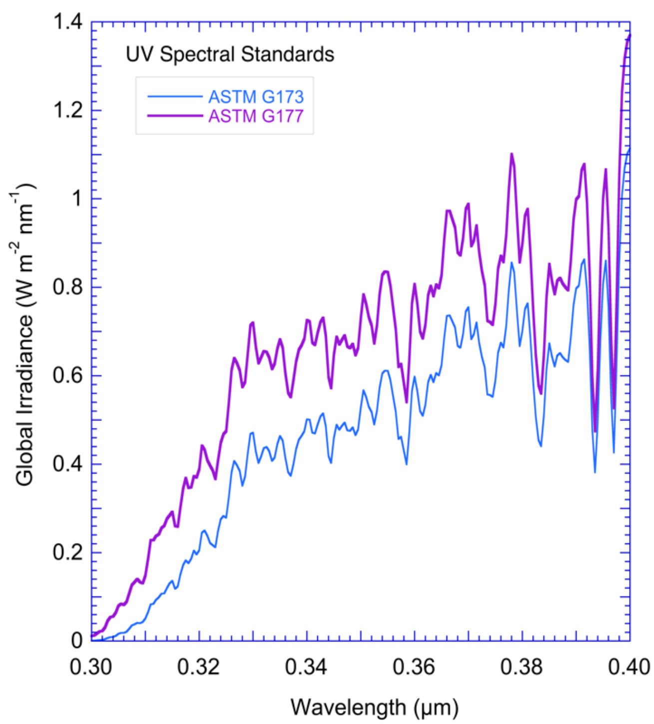

Fig. 4. Global irradiance spectral distribution in the UV according to ASTM G173 and G177.

J. *ASTM G183-15 Standard Practice for Field Use of Pyranometers, Pyrheliometers and UV Radiometers*

This standard describes best practices of station commissioning conditions, periodical upkeep requirements, operations feedback, and calibration intervals for use of pyranometers, pyrheliometers, and UV radiometers in outdoor testing environments [16] (Fig. 5). This best practice also discusses the conditions that prescribe the level of accuracy required for various radiometer types.

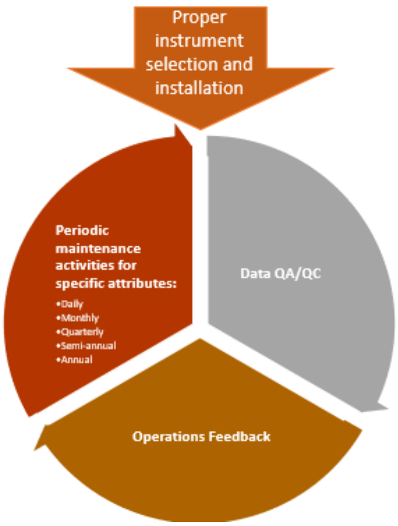

Fig. 5. Best practices sequence according to ASTM G183.

K. *ASTM G197-14 Standard Table for Reference Solar Spectral Distributions: Direct and Diffuse on 20° Tilted and Vertical Surfaces*

This standard provides solar spectral irradiance distributions that are necessary to develop spectral weighting functions of the optical properties of fenestration systems or the performance of PV device technologies in buildings [17]. This standard is used by the National Fenestration Rating Council, for instance. The impact of receiver tilt (20° and 90° for G197, vs. 37° for G173) on spectral distribution is shown in Fig. 6.

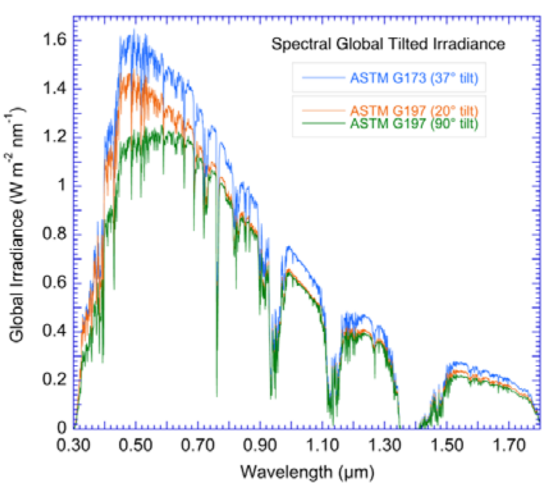

Fig. 6. Global irradiance spectral distribution on various tilts according to ASTM G173 and G197.

L. *ASTM G207-11(2019)e1 Standard Test Method for Indoor Transfer of Calibration from Reference to Field Pyranometers*

The method described in this standard is similar to ASTM E824 except that standard G207 is pertinent to the indoor transfer of calibration from reference to field radiometers. The radiometers calibrated using this standard are used for various applications, such as for measuring and monitoring outdoor radiant exposure levels [18], while avoiding the difficulties and time requirements of outdoor calibration. Most radiometer manufacturers depend on this standard.

M. *ISO 9060:2018 Solar energy – Specification and classification of instruments for measuring*

The ISO/TC 180/SC 1 subcommittee recently updated ISO 9060:2018. That standard describes the available international specifications for the performance classification for instruments that measure irradiance [9]. The changes contained in the update include new classes of sensors as well as notes on spectral selectivity, spectral error calculation, application of correction function, and discussion about shading devices.

N. *Update of Solar Resource for Solar Energy Applications Handbook*

In collaboration with international partners within the IEA-PVPS Task 16, NREL is leading the revision of the *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications: Second Edition* [19]. The third edition of this widely used *Handbook*, slated for publication at the end of 2020, will include current progress of solar resource measurement and modeling, progress in solar forecasting, and expert advice on various solar resource aspects of solar energy applications.

IV. Conclusion

NREL is involved in the development and update of standards and best practices relevant to solar energy applications. This effort supports the development of international consensus standards in solar measurement and modeling to represent the state-of-the-art knowledge through continuous formal engagement of various stakeholders. Standardization and best practices of data sets and models enables the industry to develop fair and widely accepted protocols for various stages of solar energy project development and operations, strengthen consumer confidence, and assist in refining the efficiency and durability of their products. This also reduces barriers to seeking and successfully obtaining financing and reduces warranty costs for solar energy projects.

To reinforce these efforts, NREL, national and international organizations, and international standards bodies continuously seek support to increase participation and develop new capabilities within the committees.

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