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ScienceDirect
Renewable Energy 33 (2008) 2645–2652
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Technical Note

On the matter of proposed new low-latitude solar reference spectra

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Received 19 June 2007; accepted 10 February 2008
Available online 18 April 2008

Abstract

For decades, photovoltaic (PV) modules have been manufactured and tested under conditions that are not globally representative. With the emergence of renewable energy as a viable alternative to fossil fuel, a greater level of scrutiny is being targeted towards standards by which this renewable energy generation is being attended. Standard test conditions (STC) along with the established mid-latitude-based reference spectra are among the standards used to rate PV modules internationally. However, with the global impact that renewable energy technology is currently having and will continue to have in the future, such a new system that accounts for low-latitude regions of the world is imperative; and it has been proposed through this research paper. The model capitalizes on the gains of the current standards used, in order to account for the differences in the combination of spectral distribution, module temperature, solar irradiance and meteorological conditions that are representative of lower latitude regions. Equally important, the development of regional spectra is expected to increase the level of interest and investments in this technology, yielding an economy of scale reduction in the cost of solar PV systems in the region. This work centers on the need to develop a system of regional standardization using the Caribbean and Latin America as a test case. New reference spectra are proposed with the advantage of more relevant solar ratings for the region. The methodology employed in this research paper is also being proposed as a generic tool for other regions exploring regional standardization.

Keywords: Reference spectra; Spectral defining factors; Standard test conditions; Meteorological attenuation; Spectral irradiance

1. Background to photovoltaic standardization and testing

With the price of petroleum skyrocketing on the world market coupled with the environmental unfriendliness of fossil fuel, efforts to continue the process of globally standardizing renewable energy sources like solar, must now be accelerated. In order to encourage other regions that have not yet been established in solar technology to come on board, current standards will have to be revised to adequately reflect the solar conditions of those regions.

The need to standardize solar energy calculations has been a long-standing quest of solar energy pioneers. The earliest record of an attempt to standardize such calculations was back in 1940 when Moon, a solar technology pioneer attempted calculations on spectral reference in his pioneering document 'Proposed Standard Solar Radiation Curves for Engineering Use' [1]. These calculations lead to the adoption of E424-71 as reference, which was approved in 1971 [2]. The E424-71 was the initial test method developed to model the measurements of terrestrial solar transmission and reflectance, which was critical to the process of standardization and testing.

In 1982 The American Society for Testing and Materials (ASTM) committee E44 on Solar, Geothermal, and other Alternative Energy Sources developed the first standard spectra through its subcommittee E44-02 on Environmental Parameters. The committee developed procedures for standard reporting conditions (SRC) [3] or standard test conditions (STC), calibrating reference cells and modules and evaluating the performance of cells, modules and devices [4].

The committee made use of atmospheric spectral solar transmission models available at the time, measured data

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0960-1481/$ - see front matter
doi:10.1016/j.renene.2008.02.006

and standard atmospheric condition to produce two reference spectra thought to be representative of reasonable natural conditions and standard PV applications [2]. These spectra, originally ASTM E891-82 for direct spectral normal irradiance and E892-82 for total hemispheric spectral irradiance on a south facing 37°-tilted surface were first approved by ASTM in 1982. In 1998 the ASTM subcommittee G03.19 on solar radiometry combined both standards into ASTM G159-98. This move was formally adopted in 1999 [2].

In January of 2003, the G159 standard was revised extensively, and a new mid-latitude spectra, G173-03 with updated information was proposed [2,5].

Global usability is an issue among others, especially in the light of the increasing emphasis on sustainability and renewable energy. The time has come and the call has gone out for reference spectra to be developed that are more relevant to the locations in question [2]. This statement echoes succinctly the sentiments of this paper. It is felt that by developing reference spectra that uniquely relates to low-latitude regions, not only could the calculations be more relevant and done with greater ease, but the region in question would now have a tangible stake in the technology.

2. Standard test conditions

Standardizing solar spectra is a necessary preliminary stage to the standardization of the testing of photovoltaic (PV) cells, modules and devices. One of the international standards that utilize the current mid-latitude spectra for its implementation is STC. Conversion efficiency of PV energy of a particular device depends primarily on the cell temperature, the illumination source intensity and the spectral distribution of the source [6]. A set of STCs are defined by the ASTM, and these are:

1. Irradiance of 1000 W/m^2, also known as the "one sun" or "peak sun."
2. Spectral distribution defined by AM1.5 (global radiation).
3. PV cell temperature of 25 ± 2 °C.

Other standards are sometimes used, for an example, in earth orbiting satellite stations, the spectral distribution defined by Air Mass zero (AM0) is used as this refers to measurements beyond the atmosphere of the earth. Another standard used is standard working conditions (SWC), with the only difference between STC and SWC being a change of module temperature from 25 to 45 °C for SWC [7]. The effects of using the mid-latitude-based STC in the rating of modules manufactured and distributed in low-latitude regions are yet to be fully quantified.

2.1. Solar geometry in current standard

Fig. 1 illustrates the geometry chosen to represent the mid-latitude spectra. The geometric conditions selected to represent the solar spectral standard for mid-latitude was chosen as the average values of flat plate modules deployed in the USA [5]. This is also agreed on by Gueymard et al. [2]. The receiving surface is defined as an inclined plane tilted at 37° from the horizontal towards the equator facing south in the northern hemisphere. The only specification of the solar position is that the air mass is 1.5 for the observer at sea level, with no corrections for refraction. At AM1.5 the zenith angle is 48.19° and the elevation above the horizon 41.81° [5]. Once again the reason given by Myers et al. [5] and Gonzalez and Ross [8] is that the median air mass for solar radiation for locations ranging from Caribou Maine and Phoenix Arizona is AM1.5. The solar azimuth is 180°, in the same plane as the normal to the "south facing" in the northern hemisphere. The surface is tilted toward the equator.

2.2. Atmospheric conditions in current standard

Atmospheric conditions specified in ASTM G173-03 mid-latitude reference spectra follows (see also Table 3 for complete list of spectral defining factors):

1. The 1976 US Standard Atmosphere (USSA) profiles of temperature, pressure, air and molecular densities specified in 33 layers from sea level is the atmosphere model used [9].
2. An absolute air mass of 1.5 (solar zenith angle 48.19°) at sea level
3. Angstrom turbidity (base e) at 500 nm of 0.084, or an aerosol optical depth (AOD) or turbidity said to correspond to a sea level meteorological range of 23 km was chosen.
4. A non-Lambertian albedo reflectivity model based on light sandy soil that is wavelength dependent [2].
5. Total precipitable water vapor content equal to 1.42 cm.
6. Total ozone content equal to 0.34 atm cm.

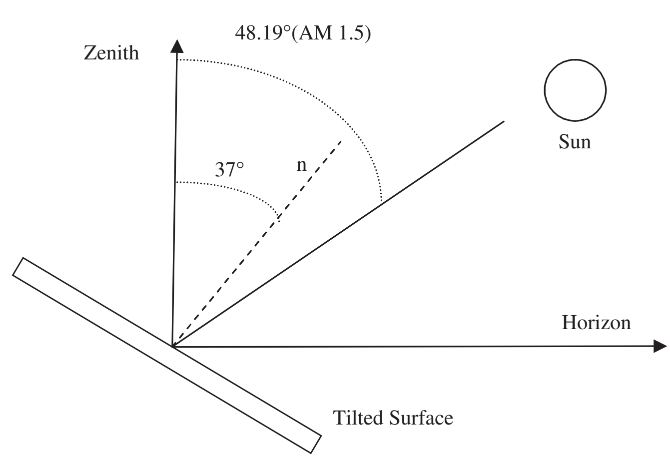

Fig. 1. Solar geometry for mid-latitude solar reference spectra.