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Preliminary Investigations of Outdoor Meteorological Broadband and Spectral Conditions for Evaluating Photovoltaic Modules and Systems

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ABSTRACT

Historically, flat-plate photovoltaic (PV) modules have been rated at "peak-output" for power generated under Standard Reporting Conditions (SRC) of 1000 Watts per square meter W/m^2 global irradiance at a standard temperature (25°C) and reference spectral distribution. We examine the direct-normal irradiance, spectral distribution, ambient temperature, and wind speed to be used for evaluating flat-plate and concentrator module performance. Our study is based upon the 30-year U.S. National Solar Radiation Data Base for conditions observed when the global irradiance on a 2-axis-tracked surface is 1000 W/m^2. Results show commonly-used values for concentrator testing of 850 W/m^2 for direct-normal irradiance and 20°C for ambient temperature are appropriate. Wind speed should be increased from 1 m/s to a more frequently observed 4 m/s. Differences between the reference direct-normal spectrum and spectra measured at three sites when broadband direct-normal irradiance and global-normal irradiance are near SRC irradiances suggest revisions to the reference spectra may be needed.

1. Performance Reporting Conditions

Various existing standards address the performance of PV devices, as shown in Table 1. Device performance is commonly reported with respect to a fixed set of conditions for total irradiance, device temperature, and reference spectral distribution. Note that only PV for Utility Scale Applications (PVUSA) test conditions and this work address PV concentrator test conditions.

DNI and GNI correspond to Direct Normal Irradiance and Global Normal Irradiance, respectively. Standard Test Conditions (STC) or Standard Reporting Conditions (SRC) are defined only for flat-plate collectors as 1000 W/m² irradiance on the module at 25° C Cell temperature, under a reference spectral distribution (American Society for Testing and Materials, ASTM E891 and ASTM E892). The 1000 W/m² irradiance is an arbitrary but convenient achievable "peak" performance condition.

Flat-plate PV devices are often tested indoors, under simulated sunlight near SRC per ASTM Standard Test Method 1036. Indoor testing of PV-concentrator modules is difficult. There are currently no consensus standards for reporting PV-concentrating collector performance so the PV-concentrator industry reports performance based on conditions (PVUSA test conditions, or PTC) developed as part of technology procurements.

Table 1. Summary of Standard PV Test Conditions.

Standard Name	Irradiance W/m^2	Temp.	Wind speed	Comments
STC or SRC (Standard Test/Reporting Conditions) [1]	1000 global AM1.5 Spectrum E892	25°C cell	Not applic-able	Indoor peak performance (most catalogues)
PTC (PVUSA test conditions) [2,3]	1000 global 850 DNI	20°C ambient	1 m/s at 10 m	Outdoor peak performance (utilities)
Nominal operating conditions [1]	800 global	20°C ambient	1 m/s at module height	nominal operating cell temperature (NOCT) [1]
This work	***1000 global 836 ± 44 DNI***	***23.7 ° ±8.8 °C ambient***	***4.5 ± 2.8 m/s at 10 m***	***Observed when GNI is 1000 W/m^2.***

2. Technical Approach

This study provides a technical basis for choosing outdoor-rating conditions, compatible with existing SRC, as described in references [4] and [5]. Hours from the 30-year (1961-1990) NREL National Solar Radiation Database (NSRDB) with the GNI at 1000 W/m^2 ± 25 W/m^2 were selected. We analyzed the direct-normal irradiance, turbidity, temperature, total column water vapor, and wind speed for these hours. NSRDB does not contain GNI. We modeled GNI using the Perez Anisotropic Model [6] with an albedo of 0.2. Two years of modeled and measured GNI showed the model unbiased with root-mean-square error of 2.5%, similar to measurement uncertainty.

We are investigating comparisons of the ASTM E892 reference spectrum to measured spectra extracted from the Solar Energy Research Institute (SERI) Solar Spectral Data Base [7] for GNI and DNI within 10 W/m² of 1000 W/m² and 850 W/m², respectively.

3. Results

Table 2 compares SRC, PVUSA, and the mean results of our analysis for 37 NSRDB sites in the American southwest with outdoor conditions near SRC. The frequency distributions of DNI, ambient temperature, wind speed, atmospheric turbidity, and precipitable water vapor were found to be non-Gaussian and site dependent. Figure 1 shows the distribution of median DNI for all sites when outdoor conditions approximate SRC. Individual distributions are discussed in detail in references [4] and [5].

Table 2. Prevailing Conditions Near SRC

Parameter	Average Median	Standard Deviation	SRC	PVUSA
DNI W/m²	834.4	22.8	N/A	850
GNI W/m²	1001.0	1.3	1000	1000
Temp °C	24.4	4.0	25*	20
Wind Speed m/s	4.4	1.1	N/A	1.0
Total Water cm	1.4	0.5	1.42	N/A
Aerosol Optical Depth	0.08	0.27	N/A	N/A
Air Mass	1.43	0.09	1.50	N/A

* Cell temperature

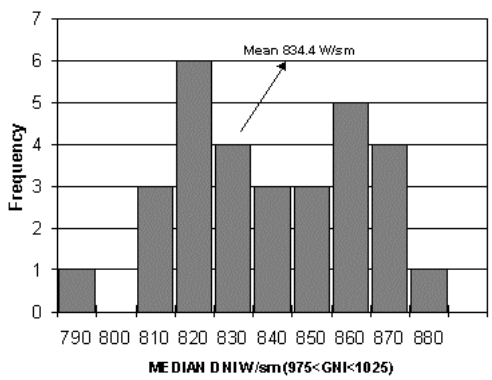

Fig 1. Histogram of median DNI for GNI ~1kW/m², all sites. Median for all sites = 834.4 W/m²

Correlation between observed temperature and wind speed at outdoor conditions near SRC, and annual average temperatures and wind speed are shown in figure 2. In the future these correlations may be used to relate outdoor conditions representing SRC to readily available meteorological data.

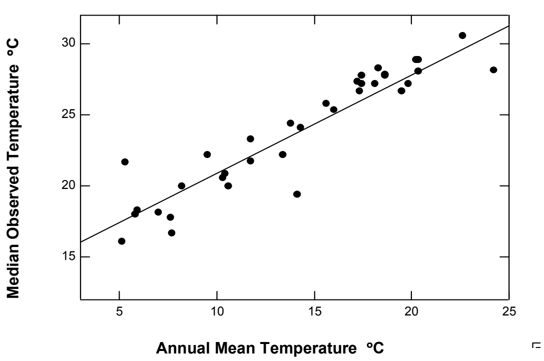

Figure 2. Correlation of observed temperature for outdoor conditions near SRC with Annual Average Temperatures

The frequency of occurrences of DNI greater than of 800 W/m² for all hours between 8 a.m. and 6 p.m. are being examined. As shown in figure 3, these conditions occur more than 30% of the time for five of the six sites shown.

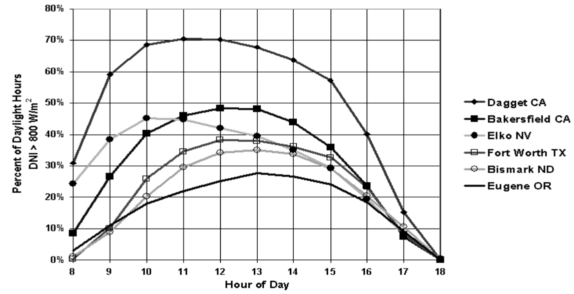

Figure 3. Relative percentage of time by hour between 8 a.m. and 6 p.m. (1961-1990) when DNI exceeds 800 W/m² for six sites.

We searched the NREL/SERI Solar Spectral Data Base, available at http://rredc.nrel.gov/solar/old_data/spectral/, for measured DNI spectra when DNI was near 850 W/m² and GNI was near 1000 W/m². Figure 4 compares measured spectra at Cape Canaveral, Florida, San Ramon, California, and Denver, Colorado with the ASTM E892 DNI Spectrum.

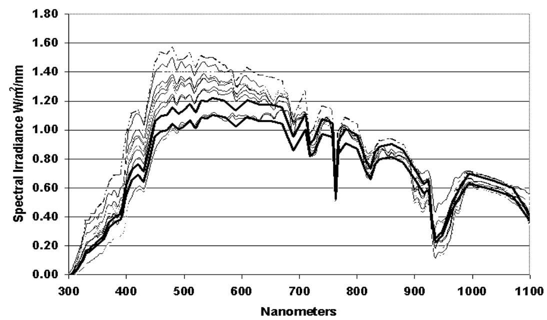

Fig. 4. ASTM E 892 AM 1.5 DNI (thick line) and measured DNI spectra (thin lines) for DNI and GNI near 850 W/m² and 1000 W/m².

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