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Effects of changing spectral radiation distribution on the performance of photodiode pyranometers

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Abstract

The effect of changes in the spectral distribution of the incident solar radiation on the direct normal responsivity of the LI-COR photodiode pyranometer is examined using DNI spectral data from a PMOD spectroradiometer and the generic spectral response of a LI-COR pyranometer. The direct normal responsivity is found to vary over the day under all weather conditions at Payerne, Switzerland in a systematic manner that can be modeled as a function of air mass or solar zenith angle. This suggests that scattering of other atmospheric constituents plays as a subsidiary role to Rayleigh scattering that preferentially scatters more blue light as the path through the atmosphere increases. The SMARTS2 model is used to examine the effect on the full spectral response range of the photodiode based pyranometer and to refine the estimated response changes. The use of this information is discussed relative to improving adjustments made to Rotating Shadowband Irradiometers measurements. Similar methodology can be used to estimate the spectral effect on the performance of solar modules.

Keywords: Pyranometer; Spectral radiation; Photodiode; DNI; RSI

1. Introduction

Accurate knowledge of the solar resource is important for the planning, operating, and financing of a solar electric generating facility and for validating the system performance. Often the biggest source of uncertainty is in the knowledge of the magnitude and variability of the solar resource. While estimates of the solar resource can be deduced from satellite images, higher levels of accuracy are important, especially for optimum financing and accurate validation of system performance.

Monitoring the solar resource with a high degree of accuracy at potential locations is expensive and takes time. The most accurate data come from the highest quality pyrheliometers and pyranometers that are mounted on automatic trackers, calibrated regularly and maintained on a near daily basis. The cost of such monitoring systems is often prohibitive, especially for initial evaluations of potential sites. Even the most expensive instruments can have significant sources of uncertainties and the instruments more commonly in use, especially those that are based on photodiode pyranometers, have uncertainties that

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limit or preclude their use for investigations that require high accuracy. Thus, in order to improve the accuracy of the irradiance measurements, it is necessary to characterize the source of these uncertainties and develop algorithms than can explain and significantly reduce these uncertainties. This is especially true for Rotating Shadowband Irradiometers (RSI) instruments that use these adjustment algorithms to improve their irradiance measurements (King and Myers, 1997; King et al., 1997; Vignola, 1999, 2006; Augustyn et al., 2004; Alados-Arboledas et al., 1995; Batlles et al., 1995; Geuder et al., 2008, 2011).

The deviation from true cosine response, spectral effects, and temperature dependence of pyranometers used on most RSI instruments are among many sources of uncertainties that need to be characterized. Comprehensive algorithms taking into account these effects have been developed in order to reduce these uncertainties (King and Myers, 1997; King et al., 1997; Vignola, 1999, 2006; Augustyn et al., 2004; Alados-Arboledas et al., 1995; Batlles et al., 1995; Geuder et al., 2008, 2011). However, these adjustment algorithms were developed for a given location and are used assuming that these algorithms are universally applicable. The development of adjustment algorithms adapted to different local environments or situations without having to reestablish unique correlation-based algorithm for each new location requires the understanding of the source of the deviations and the knowledge of how the algorithms are affected by environmental or situational effects that generate the increased uncertainty. This study is limited to the evaluation of the effects on photodiode pyranometers of changes in the spectral irradiance distribution over the day and season. The goal of this study is to develop and evaluate a technique that can then be used to examine and possibly improve the spectral adjustment algorithms used by RSI instruments under atmospheres that have constituents that are significantly different from locations where the spectral adjustment algorithms were developed. These results only apply to RSI that use photodiode pyranometers. Other sources of uncertainties such as the angular and temperature response of the pyranometer are not considered in this study.

Use of Rotating Shadowband Irradiometers has increased as a practical alternative to the most expensive equipment. The RSI measures the global (GHI) and diffuse irradiance (D_fHI) using a photodiode based pyranometer, and calculates the direct normal irradiance (DNI) from GHI and D_fHI. There are hundreds of RSI deployed around the world, especially in remote locations because they are simple to maintain and operate, are powered by a small solar panel, and are less prone to soiling problems. In addition, they are a fraction of the cost of a high quality solar monitoring station (Maxwell et al., 1999; Pape et al., 2009; Geuder and Quaschning, 2006).

Most current models of RSI use the LI-COR photodiode pyranometer as sensor, which is essentially an instrument measuring the short circuit current of a solar cell. As a solar cell performance depends on the solar spectrum, the responsivity of a photodiode pyranometer also depends on the incoming spectral distribution (see Fig. 1), a major source of uncertainty for this instrument. The average responsivity of a pyranometer is the voltage output signal that is produced by an incident irradiance of $1\ \mathrm{W\,m^{-2}}$

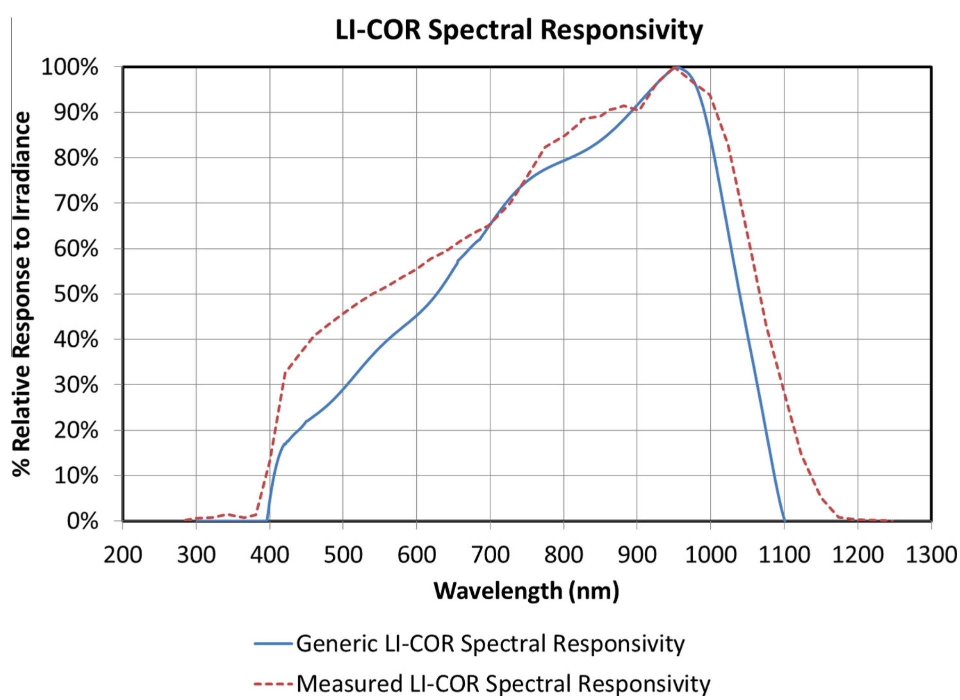

Fig. 1. Typical spectral responsivity of a LI-COR pyranometer. Solid line is from the spectral responsivity published by LI-COR. The dashed line is for the spectral responsivity of one LI-COR pyranometer measured at NREL.