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Assessment of diffuse radiation models for cloudy atmospheric conditions in the Azores region

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Abstract

Measurements of diffuse, global and direct solar irradiance are key to a proper assessment of the potential of solar energy technologies. Unfortunately, worldwide measured irradiance databases usually consist of only global solar radiation data, often with limited spatial coverage. The estimation of the diffuse fraction from global radiation is therefore essential. Solar radiation models for prediction hourly diffuse fraction from global radiation are reviewed in this paper in order to explore their applicability to the Azorean region. Since models of diffuse fraction exhibit some degree of location dependence, a correction to the best performance model to improve the results for the studied region by considering the zenith angle is also presented.

Keywords: Diffuse solar radiation; Correlation models; Cloudy atmospheric conditions; Azores

1. Introduction

Solar thermal and photovoltaic systems design depends upon the available information of the expected incident solar radiation. Total global radiation comprises its direct component, viewed as the quantity of radiation inside a narrow cone enveloping the sun, and the diffuse component, the radiation from all other parts of the sky. The ratio of direct to diffuse radiation varies greatly with the air mass and the state of the atmosphere (Kalma and Fleming, 1972).

Throughout the world, measured irradiance databases consist almost entirely of global solar radiation; additionally, its spatial coverage is limited. Driven by these limitations, several solar radiation models have been developed. Estimating the fraction of global radiation which is diffuse is a valuable asset, in particular for the project of solar energy conversion systems which require detailed information of the two components. It is not only the performance of the system which is at stake but also the appropriate selection of solar technology, e.g. the option for concentrated photovoltaics may not be adequate for a location with a significant fraction of diffuse radiation.

The range of solar radiation models differ mainly on the parameters used as input. The simplest, and most common, are models which only use global radiation information (e.g. Liu and Jordan, 1960; Erbs et al., 1982). More sophisticated models may require meteorological parameters such

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Nomenclature

k_t	clearness index	G	global irradiance
k_d	diffuse fraction	G_{ex}	global extraterrestrial irradiation
σ	hour-to-hour variability index	RMSE	Root Mean Square Error
ρ	clear sky index	MAE	Mean Absolute Error
m	air mass	MAPE	Mean Absolute Percentual Error
θ	zenith angle	MBE	Mean Bias Error
I	direct beam irradiance	S	skill score
D	diffuse irradiance		

as information from clouds, atmospheric turbidity, temperature or precipitable water content (e.g. Kasten, 1983, cited in Davies, et al. 1988, p. 22; Hollands and Crha, 1987).

Most models rely on correlations with the clearness index, k_t (portion of horizontal extra-terrestrial radiation reaching the Earth's surface) to estimate the diffuse fraction k_d (portion of diffuse component from global radiation). These are expressed in terms of 1st to 4th degree polynomials, logistic or exponential models (Miguel et al., 2001; Jacovides et al., 2006).

Liu and Jordan (1960) work was pioneer in the development of solar radiation models. These authors presented empirical relationships between daily diffuse to daily total radiation and monthly average daily diffuse to monthly average daily total solar radiation. The measurements of global radiation used to develop these methods were collected in Massachusetts, United States of America. Following the work by Liu and Jordan, Orgill and Hollands used the same approach to estimate the diffuse fraction, also using the clearness index as the only variable (Orgill and Hollands, 1977). Hollands and Crha accounted the scattering of radiation between two atmospheric layers and the ground including variables of ground albedo, transmittance of the upper layer of the atmosphere and scattering albedo of the lower layer (Hollands and Crha, 1987). Orgil–Hollands and Hollands–Crha model developments and validation were based in solar radiation values recorded in Canada. The model proposed by Maxwell (1987) also stands out among those based in US data. It is a model developed as a quasi-physical model. It incorporates parametric variables associated to discrete changes in the atmospheric transmittances, rather than to the magnitude of atmospheric transmittances, leading to a simple model in which the effect of those parametric variables is intrinsically accounted.

The applicability of the different models is obviously related to the local atmospheric conditions and its climatic characteristics. Models are not of general validity and can only be applied to where the albedo of the surrounding terrain and the atmospheric contamination by dust are not greatly different from those where the corresponding methods were developed. Driven by this reason an effort to expand the range of diffuse fraction models has been made throughout time by several authors. Models adjusted to data acquired in Europe are mainly linked to Northern, Central or, more recently, Mediterranean areas (e.g.: Skartveit et al. (1998); Reindl et al. (1990); Karatasou et al. (2003); Miguel et al. (2001)). To the authors' knowledge, there are no published studies focused in Azores or in any place with similar climate/cloud characteristics. The existence of Mid latitude islands is scarce and, notwithstanding, the typical Atlantic climate of Azores Islands is not very common in other regions. The Azorean climate reveals in its annual cycle an important amount of cloud cover with a variability which is more complex than the common summer/winter pattern.

This study explores the applicability of different existing correlation models of diffuse fraction and clearness index or other plain parameters in the Azorean region. Furthermore, after assessing their performance, a correction of the best performing model is suggested for improving the global solar radiation decomposition for Azores.

2. Models and methods

The diffuse solar radiation models available in literature have been developed for use with hourly, daily and monthly averaged values of global radiation. This work evaluates existing models focusing on hourly data since it is the most widely used time step when estimating the dynamic behaviour and performance of solar energy systems.

The selection of hourly models was mainly based on three features: model simplicity, where simplicity stands for the minimum input of meteorological parameters and models' implementation ease of use, the reported model performance and the availability of the required measurement data. Additionally, a broad range of locations from where models derived was also considered.

2.1. Diffuse fraction – clearness index regression models

The simplest, practical and most common diffuse radiation models attempt to correlate the diffuse fraction (the ratio of diffuse component (D) from global radiation (G), k_d) with the clearness index (ratio of horizontal extra-terrestrial radiation (G_{ex}) reaching the Earth's surface, ($k_t = G/G_{ex}$). They are usually developed through piecewise fitting and divided in three intervals according to the k_t