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Regression models for hourly diffuse solar radiation

Eugenia Paulescu*, Robert Blaga

West University of Timisoara, Physics Department, V. Parvan 4, 300223 Timisoara, Romania

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Abstract

Accurate information about the available solar radiation is a key factor in designing efficient photovoltaic systems. In general, the meteorological stations measure global solar irradiance on the horizontal surface. In order to estimate the total solar irradiation on surfaces with different spatial orientations, the knowledge of all components on the horizontal plane is required. This paper proposes eight new models for estimating hourly diffuse solar irradiation at the ground level. The estimates of the models are statistically significant at least 97.4% confidence level. The models estimate the diffuse fraction on the basis of the traditional predictor clearness index and various other astronomical and meteorological predictors. The hourly relative sunshine is introduced as a new predictor. The study was conducted on data measured in Timisoara, Romania. The proposed models were compared against twelve different empirical models for the hourly diffuse fraction previously reported by different authors. The results show that the best performing model includes two predictors: clearness index and relative sunshine. The performance of this new model ($R^2 = 0.930$) is comparable to the one reported for models based on more numerous and more sophisticated predictors.

Keywords: Hourly diffuse fraction; Clearness index; Relative sunshine

1. Introduction

The efficiency of a solar cell is defined by the ratio of the generated electricity to the incoming global solar irradiance (Joshi et al., 2009). Thus, the accuracy of modeling the PV systems depends on the accuracy of knowledge of the global solar irradiance at the ground level. By summing up solar irradiance over a finite time period one obtains the solar irradiation. There are two components of the global solar irradiation at the ground level: the direct component and the diffuse component. The most precise way to estimate the solar irradiation components is by in-situ measurements. While most of the radiometric stations are usually equipped with pyranometers for global solar irradiance measurements, only few stations are equipped with pyranometers for measuring the diffuse component. In such cases, the solution consists in numerical estimation of the fraction of the global irradiation which is diffuse.

There are many studies devoted to the estimation of the diffuse solar irradiation, numerous researchers establishing different correlations between the diffuse fraction and various predictors. The diffuse fraction k_d is defined as the ratio of diffuse solar irradiation H_d to global solar irradiation H at the ground level.

$$k_d = \frac{H_d}{H} \tag{1}$$

The predictor typically used in such studies is not precisely the global solar irradiation, but the clearness index k_t defined as the ratio of global solar irradiation on the ground to extraterrestrial irradiation H_{ext}

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* Corresponding author.
E-mail address: eugeniat@physics.uvt.ro (E. Paulescu).

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$$k_t = \frac{H}{H_{\text{ext}}} \tag{2}$$

The range of k_t is between 0 and 1. A low value of the clearness index implies that only a small part of the solar radiation reaches the ground, which means an overcast sky. A high value of the clearness index means a mostly sunny sky.

In the pioneering work of Liu and Jordan (1960) a relationship between the daily diffuse fraction and the global irradiation is reported. This relationship is sometimes used also for estimating the hourly diffuse fraction.

During the time, specific correlations for hourly diffuse fraction were developed. Orgill and Hollands (1977), Lam and Li (1996a) and Reindl et al. (1990) estimated the diffuse fraction using the clearness index as the single predictor. These models are all piecewise linear, with the domain of k_t split in three intervals. These models are known in the literature as the Liu and Jordan type correlations (Orgill and Hollands, 1977). Jacovides et al. (2006) developed a model with a polynomial of the order three in k_t. The works of Erbs et al. (1982), Oliveira et al. (2002) and Soares et al. (2004) developed models with polynomials of the order four in k_t. Boland et al. (2001) developed a model using a logistic function. Except the models of Reindl (1990), all these models were fitted to local data, thus having a limited geographical area of applicability.

In order to generalize the models for diffuse fraction different other astronomical and meteorological variables were considered as predictors. Models with two predictors are reported by Reindl et al. (1990) (k_t and solar altitude) and by Boland et al. (2001) (k_t and the time within the day). Following a stepwise regression procedure Reindl et al. (1990) established, four significant predictors for the diffuse fraction, namely, hourly values for clearness index, solar altitude, air temperature and relative humidity. Ridley et al. (2010) and Kuo et al. (2014) reported models with five predictors: clearness index, solar altitude, apparent solar time, daily clearness index and a measure for the persistence of the global soalar irradiation level. The sophisticated model reported in Furlan et al. (2012) contains 23 different input variables, including predictors accounting for the effect of clouds.

From the above, we can conclude that regression models are popular tools for estimating and predicting the diffuse fraction. The surface meteorological control variables ascribe more generality to models. However, in practice, the choice of such a model is strongly limited by the availability of the surface meteorological data needed as input. A practical model for diffuse fraction is the outcome of a trade-off between the number of predictors and their availability. In other words, the practical usefulness of these models is greater as they have fewer and more easily available variables.

This work is focused on the development of practical models for estimating the hourly diffuse solar irradiation based on the clearness index and other astronomical and meteorological variables routinely measured by weather stations. In view of the above, the attributes of the new models should be: high performance, simplicity and general availability of predictors. The main novelty reported here is the use of the relative sunshine as predictor for estimating the hourly diffuse solar irradiation.

There are some reports regarding the use of relative sunshine for estimating the diffuse fraction. But all these correlations have been developed between monthly mean of hourly diffuse solar irradiation and monthly mean of hourly sunshine duration (e.g. Jain (1990) using data from Italy and Zimbabwe; Gopinathan (1992a,b) using data from southern African region; Lam and Li (1996b) using data from Hong Kong). In contrast to these studies, two models for estimating the hourly diffuse solar irradiation values using the relative sunshine as predictor are reported in this paper.

The new models were validated against measured data and by comparison with twelve models for estimating diffuse fraction reported in prestigious scientific journals (Wong and Chow, 2001; Torres et al., 2010; Dervishy and Mahdavi, 2012). The models were selected according two criteria: (1) the same number of predictors as the new fitted models and (2) the availability of the required input data.

The paper is structured as follows. The database is presented in Section 2. In Section 3 the construction of the models is described in detail and twelve models of different degree of complexity from the literature are compared with our models. The models are presented in the order of increasing complexity. Section 4 summarizes the novelties and concludes the paper.

2. Instruments and data set

In this study we use radiometric and meteorological data recorded on the Solar Platform of the West University of Timisoara, Romania (Solar Platform, 2015).

The town of Timisoara (latitude 45°46′N, longitude 21°25′E and 85 m a.s.l.) has a warm temperate climate, fully humid, with warm summer, typical for the Pannonian Basin. The Köppen climate classification is *Cfb*. This is based on the Kottek et al. (2006) digital Köppen–Geiger world map on climate classification, build with data from the second half of the 20th century. The dominating temperate air masses during spring and summer are of oceanic origin and come with precipitations. Frequently, even during winter period, the Atlantic humid air masses bring rainy and snowy weather, rarely cold weather. The multi-year averages of monthly minimum, mean and maximum ambient temperatures range, respectively, between −5.2 °C, −1.5 °C and 2.7 °C, (in January) and 15.1 °C, 21.5 °C and 28.2 °C (in July). The multi-year average number of days with precipitations ranges between 7 days (in September) and 13 days (in May). The average annual hours of sunshine is about 2130 with a minimum of 57 h in December and a maximum of 301 h in July (Badescu and Zamfir, 1999).