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Establishing new empirical models for predicting monthly mean horizontal diffuse solar radiation in city of Isfahan, Iran

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ABSTRACT

Diffuse solar radiation data are very required for many solar energy applications. The main objective of the present study is to establish new empirical models for predicting the monthly mean diffuse solar radiation on a horizontal surface for city of Isfahan situated in central part of Iran. For this aim, 16 empirical models from previous studies were nominated and categorized as: (1) diffuse fraction is function of relative sunshine duration; (2) diffuse fraction is function of clearness index. Also, using long-term sunshine duration and horizontal global solar radiation data as well as applying SRT (statistical regression technique), six new diffuse solar radiation models were established. The accuracy of the new models and those models selected from literature were evaluated in terms of different statistical indicators. It was found that all of the new models perform better than those nominated from literature. However, the best performance was achieved for the third degree model from category (1) in which sunshine duration plays role as a variable.

1. Introduction

Recently, the growing global energy demand alongside the limitation of the fossil fuel reserves and their negative effects on the environment have results in a great tendency toward renewable energy sources development. As one of the major renewable energy sources, solar energy can play a remarkable role in reducing the destructive effects of fossil fuel exploitation. Solar energy is considered as one of the greatest renewable energy sources due to its accessibility in the most parts of the world. Solar energy technologies are widely utilized in many applications such as solar–thermal systems and photovoltaic across the globe. However, accurate knowledge of the amount of global and diffuse solar radiation, especially in terms of monthly mean values, is of great significance in sizing and designing of the solar energy systems [1–5]. Unfortunately, in many countries such as Iran due to high price of measurement equipments as well as difficulties in their maintenance and calibration, solar radiation data particularly in terms of diffuse component are not readily affordable. As a consequence, dependency exists on prediction of the models to estimate monthly mean global and diffuse solar radiation based upon different input parameters.

Reviewing the literature indicates that several surveys have been conducted to develop models for prediction of diffuse solar radiation on a horizontal surface. In the most common way, the global solar radiation is utilized to correlate the diffuse fraction (the ratio of horizontal diffuse to global solar radiation) with clearness index. This correlation was first developed by Liu and Jordan [6] for modeling and predicting the horizontal diffuse solar radiation. Some researchers [7–10] have developed empirical relations using this model. Numerous researchers have proposed the empirical correlations of solar diffuse fraction with the clearness index [11–15], with sunshine fraction [16–18] and with a combination of clearness index and sunshine fraction [19–22]. Ulgen and Hepbasl [22] developed several empirical models to correlate the monthly average daily diffuse radiation with the monthly mean clearness index and relative sunshine hours for the three big cities in Turkey. They concluded that the new proposed models show better performance, for predicting the monthly mean horizontal diffuse radiation, in comparison with other available models. Karakoti et al. [23] carried out an investigation on the estimation of diffuse solar radiation for 23 stations of India. They developed several empirical models by correlating diffuse solar radiation with the sunshine duration, temperature and relative humidity. They found that the

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Nomenclature

G_{sc}	solar constant (equal to 1367 W/m^2)
$\overline{H}$	monthly mean global radiation on a horizontal surface (MJ/m^2)
$\overline{H}_d$	monthly mean daily diffuse radiation on a horizontal surface (MJ/m^2)
$\overline{H}_o$	monthly mean daily extraterrestrial on a horizontal surface (MJ/m^2)
$\overline{H}_{di,c}$, $\overline{H}_{di,m}$	ith calculated and measured values of $\overline{H}_d$ (MJ/m^2)
$\overline{H}_{dc,\text{avg}}$, $\overline{H}_{dm,\text{avg}}$	average calculated and measured values of $\overline{H}_d$ (MJ/m^2)
$\overline{K}_T = \overline{H}/\overline{H}_o$	monthly mean clearness index
MABE	mean absolute bias error (MJ/m^2)
MAPE	mean absolute percentage error (%)
$\overline{n}$	monthly mean daily sunshine hours (h)
n_{day}	number of days
$\overline{N}$	monthly mean daily maximum possible sunshine hours (h)
RMSE	root mean square error (MJ/m^2)
R^2	coefficient of determination

Greek letters

δ	solar declination angle (deg)
ϕ	latitude of the location (deg)
ω_s	sunrise hour angle (deg)

correlation of diffuse radiation with relative sunshine duration, temperature and relative humidity gives the best performance. Li et al. [24] compared the performance of H-based and Non-H models for calculating the diffuse solar radiation in regions without solar radiation measurements. The comparison was performed at eight meteorological stations in China. According to statistical error tests, their results showed that the Non-H models are more appropriate than the H-based models for estimating the diffuse solar radiation in these regions.

In recent years, many studies have been also carried out by Iranian researches to develop several models for estimating monthly mean daily global and diffuse solar radiation on a horizontal surface. Behrang et al. [25] used PSO (particle swarm optimization technique) to establish, develop and test sunshine-based models for calculating the monthly average daily global radiation for 17 Iranian cities. For these cities the empirical coefficients for Angström-Prescott model based on PSO had more accuracy than those obtained using SRT (statistical regression technique). Sabziparvar and Shetaee [26] and also Sabziparvar [27] used various meteorological parameters to develop height-dependent formulas for predicting of global monthly average solar radiation for some arid and semi-arid locations in west and east as well as some locations in central arid deserts of Iran, respectively. Safaripour and Mehrabian [28] estimated the monthly mean daily global, diffuse and direct solar radiation on a horizontal surface for city of Kerman located in south-east of Iran. The models were function of various meteorological and geographical parameters. Khorasanizadeh and Mohammadi [29] tested performance of 11 empirical models from 3 different categories to predict the monthly mean daily global solar radiation over six major cities of Iran. For the cities studied the best model was from categories in which sunshine duration was a variable. Khorasanizadeh and Mohammadi [30], in another study, tested the 6 day of the year based empirical models for prediction of daily global solar radiation in four Iranian cities of Bandarabass, Isfahan, Kerman and Tabass. In Bandarabass, Kerman and Tabass, the hybrid sine and cosine wave model and in Isfahan the 4th order polynomial model provided the highest accuracy for predicting purposes. Mostafavi et al. [31] presented an innovative hybrid approach for estimating the monthly average daily global solar radiation in two nominal cities in Iran. They developed new prediction equations for the global radiation using an integrated search method of GP (genetic programming) and SA (simulated annealing), called GP/SA. Their results showed that the new models provide accurate predictions and notably outperform the existing models. Khorasanizadeh et. al. [34] established a diffuse solar radiation model for determination of the optimum tilt angle of solar surfaces in city of Tabass, Iran. They tested the nine diffuse solar radiation models. Based on statistical indicators; they concluded that the model, in which both clearness index and relative sunshine duration are variables, was recognized the best accuracy.

Clearly, there has been no enough effort to set up models to predict diffuse solar radiation in various parts of Iran. Thus, in line with increased tendency toward different type of solar energy systems utilization in Iran, the prime goal of this study is to establish some empirical models for calculating the monthly mean diffuse solar radiation on a horizontal surface, in the absence of measured diffuse radiation data, for city of Isfahan. To achieve this goal, 16 models are nominated from previous studies and afterwards are categorized as: (1) diffuse fraction is function of relative sunshine duration; (2) diffuse fraction is function of clearness index. In addition, six new models from the two categories are established. To compare the new models with those models taken from literature and test the accuracy of the models, several statistical indicators such as MAPE (mean absolute percentage error), MABE (mean absolute bias error), RMSE (root mean square error) and coefficient of determination (R^2) are calculated and the best model is introduced according to these statistical indicators.

2. Data collection

Isfahan province is one of the 34 provinces of Iran located in the central part of Iran and about 10% of Iranian deserts are placed in this province. Isfahan province with an area of 107,027 km^2 is located between 30°43/N and 34°27/N and also between 49°36/E and 55°31/E. City of Isfahan is the center of the province situated at 32°37/N and 51°40/E and its elevation is 1550.4 m above sea level. The location of Isfahan city on the map of Iran is shown in Fig. 1.

Weather condition in Isfahan is totally mild and dry and amount of rainfall and snowfall is low [32]. Based on the Köppen

Fig. 1. Map of Iran indicating city of Isfahan (Isfahan province is shown in highlight).