Renewable and Sustainable Energy Reviews 15 (2011) 2378–2384

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Evaluation of different diffuse radiation models for Indian stations and predicting the best fit model

Indira Karakoti[a,*], Bimal Pande[b], Kavita Pandey[b]

[a] Solar Energy Centre, Ministry of New and Renewable Energy, New Delhi 110003, India
[b] Department of Physics, Kumaun University, Nainital, Uttarakhand 263002, India

ARTICLE INFO

Article history:
Received 1 September 2010
Accepted 4 February 2011

Keywords:
Percent possible sunshine
Empirical models
Diffuse fraction
Clearness index
Parametric model
Decomposition model

ABSTRACT

In the present study, the non-linear solar radiation models for predicting the monthly average daily diffuse radiation are developed using the measured data on global radiation, diffuse radiation and sunshine hours for 12 locations of India. Statistical method is used to derive these correlations. The developed models are employed to estimate the monthly average daily diffuse radiation. The performance of these correlations is compared with existing model. Accuracy of developed relationships is also tested using statistical indicators viz. Percentage error (PE), root mean square error (RMSE), mean percentage error (MPE) and mean bias error (MBE). The study finds that these statistical parameters have very low values for the proposed models. A cubic correlation of diffuse coefficient with percent possible sunshine gives the best fit. The maximum values of RMSE, MPE and MBE for the proposed third order equation are 4.33%, 8.68% and −1.25% respectively while in the case of existing model these values are 13.28%, 13.39% and −3.83% respectively. Hence, it is possible to apply the cubic equation for the prediction of monthly mean daily diffuse radiation.

Contents

1. Introduction

The power obtained from solar radiation reaching the Earth is many times greater than the power generated by man by other conventional sources. If it is trapped in a useful and effective manner, all the present and future human energy needs may be met on a continual basis.

The energy received from the Sun is absorbed and also reflected back, a part of which is trapped in the atmosphere of the Earth. At any place the sum of direct and diffuse radiation is known as global or total radiation. Solar energy can be utilized for different applications by a suitable choice of tapping device. The availability of solar radiation will depend on place, on tilt of the surface on which it is received and also upon a number of other factors.

Since the solar radiation reaching the Earth's surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is necessary. This knowledge of local solar-radiation is essential for the proper design of buildings, energy systems, solar energy systems and a good evaluation of thermal environment within buildings [1–6]. It is measured in terms of sunshine duration or in terms of direct, diffuse and global radiation. In the absence of solar radiation data, the need for an empirical model for prediction of solar radiation is desirable.

Solar radiation models are of two categories namely parametric model in which detailed information of atmospheric conditions is required and decomposition models which require global radiation for the estimation of direct and diffuse component [7]. The

* Corresponding author. Tel.: +91 124 2579085/9654955529; fax: +91 124 2579207.
E-mail address: indira_ntl@yahoo.co.in (I. Karakoti).

1364-0321/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2011.02.020

metrological parameters such as amount and distribution of clouds, fractional sunshine, atmospheric turbidity and perceptible water content are used in parametric models [8].

Several empirical correlations have been developed to estimate solar radiation [9–16]. Orgill and Hollands [17] have used the following diffuse radiation model based on the hourly data of Toronto (Canada) correlating the diffuse fraction K_d and clearness index K_T:

$$\frac{H_d}{H_g} = 1 - 0.249\,K_T, \quad K_T < 0.35$$

$$\frac{H_d}{H_g} = 1.577 - 1.84\,K_T, \quad 0.35 \le K_T \le 0.75$$

$$\frac{H_d}{H_g} = 0.177, \quad K_T > 0.75 \tag{a}$$

Erbs et al. [18] studied the data from location of USA and have given the relations as:

$$\frac{H_d}{H_g} = 1 - 0.09\,K_T, \quad K_T \le 0.22$$

$$\frac{H_d}{H_g} = 0.9511 - 0.1604\,K_T + 4.388\,K_T^2 + 16.638\,K_T^3 + 12.336\,K_T^4,$$
$$0.22 \le K_T 0.22 \le 0.8$$

$$\frac{H_d}{H_g} = 0.165, \quad K_T > 0.8 \tag{b}$$

Reindl et al. [19] proposed two models for hourly diffuse radiation using the data of USA and Europe. The first model is in terms of clearness index and is given by:

$$\frac{H_d}{H_g} = 1.02 - 0.248\,K_T, \quad K_T \le 0.3$$

$$\frac{H_d}{H_g} = 1.45 - 1.67\,K_T, \quad 0.3 < K_T < 0.78 \tag{c}$$

The second model has been given in terms of clearness index and solar elevation α and is as follow:

$$\frac{H_d}{H_g} = 1.02 - 0.248\,K_T + 0.0123\,\sin\alpha, \quad K_T \le 0.3$$

$$\frac{H_d}{H_g} = 1.4 - 1.749\,K_T + 0.177\,\sin\alpha, \quad 0.3 < K_T < 0.78$$

$$\frac{H_d}{H_g} = 0.486\,K_T - 0.182\,\sin\alpha, \quad K_T \ge 0.78 \tag{d}$$

Lam and Li [20] have developed following relationship for the prediction of hourly diffuse components of global radiation for Hong Kong.

$$\frac{H_d}{H_g} = 0.977, \quad K_T \le 0.15$$

$$\frac{H_d}{H_g} = 1.237 - 1.361\,K_T, \quad 0.15 < K_T \le 0.7$$

$$\frac{H_d}{H_g} = 0.273, \quad K_T > 0.7 \tag{e}$$

Mondel et al. [21] have presented diffuse-global model using the hourly data for Northen Ireland as:

$$\frac{H_d}{H_g} = 1.237 - 1.361\,K_T,$$

$$\frac{H_d}{H_g} = 0.61092 + 3.6259\,K_T - 10.171\,K_T^2 + 6.338\,K_T^3,$$
$$0.2 < K_T \le 0.7$$

$$\frac{H_d}{H_g} = 0.672 - 0.474\,K_T, \quad K_T > 0.7 \tag{f}$$

Studies [22–24] have also been made to estimate hourly diffuse solar radiation based on artificial neural network technique. Liu and Jorden [25] have developed model for estimating the diffuse components of daily global radiation which is given by:

$$\frac{H_d}{H_g} = 0.384 - 0.416K_T, \tag{g}$$

Spencer [26] studied the mean daily data from the localities in Australia and proposed following latitude (ϕ) dependent relationship between diffuse fraction of global radiation and clearness index.

$$\frac{H_d}{H_g} = a - b \quad K_T, \quad 0.35 \le K_T \le 0.75$$

where,

$$a = 0.94 + 0.0118|\phi|, \quad b = 1.185 + 0.0135|\phi|, \tag{h}$$

Boland et al. [27] have given a logistic function of the form $f(x) = a_o/1 + a_1 e^{a_2 x}$ for estimating diffuse solar radiation for Australian condition and Jacovides et al. [28] have proved its validity for locations in Cyprus.

The objective of the work reported in this paper is the development of non-linear relations for estimating the diffuse component of global radiation on a horizontal surface and to compare these relationships with the calculations based on existing model and then to find out the most suitable correlation for computing diffuse radiation for locations in India. The monthly average data of solar radiation are employed in partial regression analysis to derive the models.

2. Methodology

Despite using different approaches almost all the authors viz. Page [29], Gupta et al. [30], Modi and Sukhatme [31], Mani and Rangrajan [32] and Gopinathan [33] have given following linear equation for the estimation of monthly mean daily diffuse radiation:

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) \tag{1}$$

where H_d is the monthly mean daily diffuse radiation on a horizontal surface in kWh/m^2, H_g is the monthly mean daily global radiation on a horizontal surface in kWh/m^2 and H_o is the monthly mean of extra-terrestrial radiation in kWh/m^2. a and b are correlation coefficients.

In our study, the experimental data on global radiation, diffuse radiation and sunshine hours reported by Mani and Rangarajan [34] have been analyzed for 14 locations of India. We have taken a group of following relation:

(i) models correlating diffuse fraction H_d/H_g with clearness index K_T and fraction of possible number of sunshine S/S_{max}

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{S}{S_{max}}\right) \tag{2}$$

$$\frac{H_d}{H_g} = a + b\left(\frac{H_g}{H_o}\right) + c\left(\frac{H_g}{H_o}\right)^2 \tag{3}$$