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An Expert System for the Estimation of Direct Solar Radiation in Indian Region

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Abstract : In this paper an expert system is developed for the estimation of direct solar radiation in Indian region. The basic premise is to have a software tool that shall provide comprehensive support to general users working in assorted fields like climatology, solar energy utilization and environmental impact assessment. The approach involves artificial neural network model and is envisioned to provide general users the power of an expert. It can also be adapted easily to change of climatic conditions.

Keywords: Solar radiation, Expert system**,** Artificial Neural Network.

1. Introduction

Radiant energy from sun is vital for life on our planet. It determines the surface temperature of earth as well as supplies all energy for natural processes both on earth's surface and its atmosphere. The solar radiation estimation is required in many disciplines such as Climatology, Solar energy utilization & Environmental impact assessment. All the users of solar resource do not have expertise and/or easy access to the solar resource data of the location of their requirement. Furthermore, the solar radiation is generally variable and enormously inconsistent and in practice the models of estimation of solar radiation are often used.

In this paper we have made an effort to widen the usability of the models for a larger cross-section of the users. This approach may be referred to as the expert system approach. The expert system is a software tool that is envisioned to provide general user the power of an expert.

2. Model Approach

Several models have been developed for the estimation of solar radiation at different geographical and meteorological conditions (Reddy 1971; Hottel 1976; Sabbagh et al. 1977; Barbaro et al.1978; Goh 1979; El-Nashar 1981; Ogeman et al. 1984; Supi & Van Kappel 1998: Mishra et al. 2008,). These models lack detailed consideration of parameters related to climate and weather phenomena. In recent years, the models of estimation of solar radiation using fuzzy random variables have been developed (Gautam & Kaushika 2002) which has defined the Clearness Index(CI) of extra-terrestrial radiation that reaches the earth's surface when the sky above the location of interest is obscured by the cloud cover or otherwise. More recently, Tomar et al. 2012, have used the ideas of neural nets, parallel distributed processing and connectionist network to determine Clearness Index. This approach is often termed as Artificial Neural Network (ANN) modeling. These models owing to their rigor are useful for the expert system approach.

3. The Algorithm

Solar energy is in the form of radiant energy and the radiation has nearly fixed intensity outside the earth's atmosphere. It is referred to as Extra-terrestrial radiation. It is characterized by the solar constant I_{sc}. It is defined as the energy received from the sun per unit area placed perpendicular to the sun rays outside the earth's atmosphere at sun-earth mean distance. Its value in the present software is taken to be 1364 W/m^2 (Mishra et al. 2008 and Tomar et al. 2012). Owing to the variation in the sun-earth distance, I_{sc} varies during the year round cycle. The value of I_{sc} on the nth day of the year (n = 1 for Jan 1), I_o may be calculated as follows

$$I_o = I_{sc}\left[1+0.034\cos\left(\frac{360n}{365.25}\right)\right]$$

The solar radiation is received at earth's surface after being subjected to the mechanisms of attenuation, reflection and scattering in the atmosphere which in turn are the functions of solar zenith angle or the solar incident angle on the horizontal plane, the declination angle and the hour angle(time of the day). The radiation received without change in the direction is referred to as beam radiation or direct solar radiation. As a first approximation, the solar beam radiation intensity can be obtained from a simple clear day model by Hottel 1976. The model is based on atmospheric transmittance calculation using the 1962 US standard atmosphere and has been subsequently corrected for climate conditions. So we have:

$$S_{bnc} = I_o\left(a_o + a_1 e^{-k\sec\theta_z}\right)$$

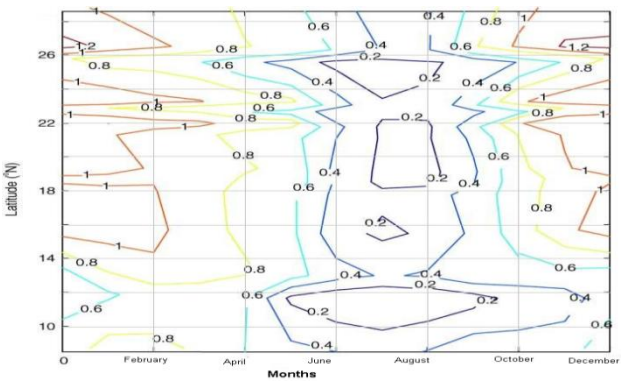

Fig. 1: Clearness Index graph

where the parameters a_o, a_1 and k are the functions of height above sea level in kilometers and the climate of the location (Duffie & Beckman 1991). The climate corrected calculated clear day values (S_{bnc}) are often higher than the observations (S_{bnm}). The deviations exhibit variability with time of the day, day of the year and meteorological parameters such as rainfall, relative humidity, mean duration of sunshine. A parameter characteristic of the weather phenomenon was referred to as Clearness index (Tomar et al. 2012). Following the neural network analysis procedure of Mishra et al. 2008 and Tomar et al. 2012 we have investigated the variation of

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Clearness Index as a function of latitude, longitude, time of the day and day of the year. The mean monthly variation of Clearness Index as a function of latitude is shown in fig. 1.

So the grey day radiation may be determined by multiplying the solar radiation values with the Clearness index defined as follows:

$$\text{Clearness Index (CI)} = \frac{S_{bnm}}{S_{bnc}}$$

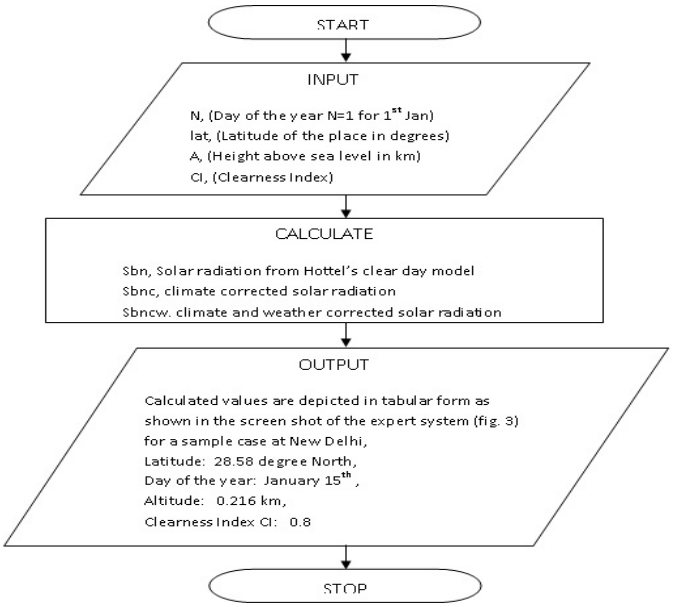

Fig. 2: Flowchart of the program execution

4. Computational Flowchart

From the above algorithm it is clear that the solar radiation value at a particular location is the function of the height above sea level in kilometers, the latitude of the location, day of the year, time of the day and the Clearness index. Using these input parameters, computational process is illustrated in the flowchart depicted in Fig: 2.

5. Structure of the Expert System

The graphical user interface (GUI) of the expert system is illustrated in Fig. 3. Upon providing the values in the input boxes, the press of **calculate button** shows the results in the output box which can either be printed or saved in a text file.

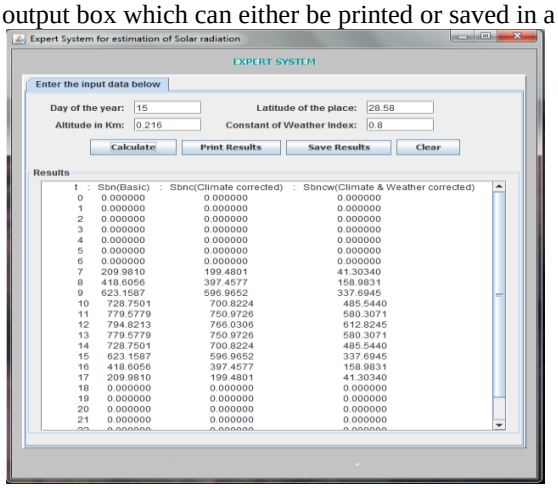

Fig. 3: GUI of Expert System

6. Validation of results

With a view to examine the compatibility of the predictions of the expert system approach, we have investigated the RMSE (%) values for the stations spread all over India. The RMSE (%) ranges for most of the stations used in the analysis were in the range of 13.36 - 24.64 for direct solar radiation. The range is of the right order of magnitude in view of the prediction errors reported by earlier researchers, for example 22.73% reported by NASA SSE data sets. However, it was noticed that the RMSE (%) values of costal locations are relatively higher owing to intensive monsoon activities and their effect on observed data.

7. Summary and conclusion

The estimation and prediction of direct solar radiation is useful for a wide spectrum of users such as energy planner, engineers, architects, solar scientists and researchers. In this paper an artificial neural network based computational models for the estimation and prediction of solar radiation in Indian zone is presented. The analysis is based on the data of the stations cover by far the widest range of latitudes (8.48^0N to 34.08^0N) and longitudes (72.18^0E to 92.72^0E) spread over the entire Indian continent. The contour maps of atmospheric clearness index as a function of latitude, month of the year and time of the day are drawn. Finally the methodology for the prediction of direct solar radiation at an arbitrary location using these maps is developed. The computational scheme is embedded in a graphical user interface designed to be usable, as an easy to understand expert system, by a wider cross section of investigators. The computational results obtained from GUI exhibit good compatibility with earlier models and recent measurements carried out at arbitrary locations in Indian region.

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