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ScienceDirect

Solar Energy 103 (2014) 327–342

SOLAR ENERGY

www.elsevier.com/locate/solener

Artificial neural network model based on interrelationship of direct, diffuse and global solar radiations

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Received 26 June 2013; received in revised form 26 December 2013; accepted 6 February 2014

Communicated by: Associate Editor David Renne

Abstract

This paper presents a neural network model based on explicit approach using the interrelationship characteristics of direct, diffuse and global solar radiations. The computational algorithm includes the estimation of global, diffuse and direct components through clear sky conditions. The deviations of these estimates from measurements are considered to be due to random weather phenomena characterized by clearness indices. The clearness indices corresponding to direct, diffuse and global components of solar radiation are then mapped with long term monthly mean hourly data of weather-related parameters such as mean duration of sunshine per hour, relative humidity and total rainfall in the artificial neural network (ANN) analysis. The estimates of ANN model exhibit excellent compatibility with observations with overall root mean square error RMSE (%) and mean biased error MBE (%) for the global radiation as 5.19 and −0.194 respectively. The RMSE values for wet months (July, August, September, October) are relatively higher than those of the dry months (January, February, March, April) due to intensive monsoon in Indian region. Contour maps of ANN model calculations of global radiation as a function of latitude, time of the day and month of the year are presented. The model offers promise of being useable for the prediction of direct, diffuse and global components of solar radiation at an arbitrary location. A comparative study of the estimates of present ANN model with NASA surface meteorology and solar-energy data sets exhibits good compatibility. The global solar radiation on tilted planes has also been investigated using isotropic and anisotropic sky conditions. The results seem to be favouring an isotropic model during the year-round cycle at New Delhi (28.58°N).

Keywords: Solar radiation estimates; Artificial neural network; Computational model; Solar radiation on tilted surfaces

1. Introduction

In recent years, global warming has become an international issue and the energy generated from renewable resources, in particular, from solar radiant energy is being seriously considered to combat the associated climate changes. This in turn has sped the research and development activities on solar systems for various applications. The global, diffuse and direct solar radiation data at horizontal and inclined surfaces is an essential element in solar system modelling and performance evaluation. For example, monthly mean hourly performance during the year round cycle of tilted flat plate collectors, photovoltaic modules, energy needs of the building, solar fraction of hybrid systems and design of control logic for the operation of solar power plants can be estimated using such data. Most of the Indian region receives an abundant quantity of solar energy due to its geographical position.

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http://dx.doi.org/10.1016/j.solener.2014.02.015
0038-092X/

Nomenclature

A	altitude of location above mean sea level in km
a_o	empirical constant
a_1	empirical constant
ANN	artificial neural network
BSRN	baseline surface radiation network
CI	atmospheric clearness index
CI_b	atmospheric clearness index (direct)
CI_d	atmospheric clearness index (diffuse)
CI_g	atmospheric clearness index (global)
$^{\circ}E$	degree east
G_m	arithmetic mean of measured values
IMD	India meteorological department
I_o	extra-terrestrial radiation
I_{sc}	solar constant
k	empirical constant
k_s	constant related to sky conditions
km	kilometer
MBE	mean biased error
MLP	multilayer perceptron
N	number of day of the year (January 17, $N = 17$)
NASA	national aeronautics and space administration
$^{\circ}N$	degree north
R	regression value
RMSE	root mean square error
R_b	beam radiation tilt factor
R_d	diffuse radiation tilt factor
R_r	ground reflected radiation tilt factor
R_t	total radiation tilt factor
S_{bn}	beam solar radiation at normal incidence
S_{bh}	beam radiation on horizontal surface
S_{dh}	diffuse radiation on a horizontal surface
S_{gh}	global radiation on horizontal surface
S_t	total radiation on a tilted surface
SSE	surface meteorology and solar energy
t	solar time
x_i	ith measured value
y_i	ith calculated value
θ	the incident angle of beam radiation on a tilted surface
θ_z	solar zenith angle
α	solar altitude angle
δ	declination angle
ϕ	latitude angle
ω	hour angle
β	surface tilt angle with horizontal (deg)
ρ	ground reflectivity

Therefore, the availability of solar resource data can play a vital role in the development of solar systems. Not all the users of solar systems have expertise and/or an easy access to solar radiation data of location of their interest. For example, solar-energy applications are most cost-effective in the remote areas where measurements of solar radiation with reliable and calibrated pyranometers are either absent or scarce. However other meteorological parameters such as atmospheric temperature, mean duration of sunshine per hour, relative humidity and total rainfall, etc. are available for these regions due to their application in other fields such as meteorology and agriculture. It, therefore, makes sense to develop a reliable model with available data. Solar radiation during its propagation through the atmosphere is subjected to scatter, reflection and absorption by air molecules, water vapours, dust, ozone, volcanic eruptions, aerosols and cloud cover. The earth's atmosphere is generally variable and enormously inconsistent. Physical models based on the complex atmospheric processes have, therefore, received rare attention in solar-energy utilization context (Iqbal, 1983; Mueller et al., 2004). However, models of estimation based on the co-relationship of available parameters such as atmospheric temperature, relative humidity, extra terrestrial radiation have been developed (Liu and Jordan, 1960; Modi and Sukhatme, 1979; Gopinathan, 1988; Zarzalejo et al., 2005; Yorukoglu and Celik, 2006; Li et al., 2010; Kaplanis and Kaplani, 2010; Chandel and Aggarwal, 2011; Pandey and Soupir, 2012). These estimates lack rigor in consideration of climate and weather-related atmospheric processes, which are fuzzy random in nature (Gautam and Kaushika, 2002; Boata and Gravila, 2012). Stochastic models based on time series analysis of solar radiation data have, therefore, been used. The approach includes autoregressive (AR) model Bacher et al., 2009 which specifies that the output variable depends linearly on its previous values. The generalized versions of AR such as autoregressive-moving-average (ARMA) model Wu and Chan, 2011 as well as autoregressive integrated moving average (ARIMA) model Reikard, 2009 have also been developed with marginal improvement in precision of estimation. The ideas of neural network (Sfetsos and Coonick, 2000; Mishra et al., 2008), wavelet network (Mellit et al., 2005), adaptive neuro fuzzy inference system (ANFIS) Moghaddamnia et al., 2009 and several hybrid systems such as ANN–wavelet (Mandal et al., 2012), ANN-AR-ARMA (Voyant et al., 2013), autoregressive moving averages time delay neural network (ARMA-TDNN) Wu and Chan, 2011, hidden Markov model and generalized fuzzy model (Bhardwaj et al., 2013) have also been used. In most of these investigations the time series of solar radiation data was presented in 1-D form along an axis of hours which mixed daily and seasonal variations. A 2-D representation of the data was presented by Hocaoğlu et al. (2007, 2008) to better highlight the predictable