Renewable and Sustainable Energy Reviews 61 (2016) 384–397

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Solar radiation prediction using different techniques: model evaluation and comparison

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ARTICLE INFO

Article history:
Received 27 December 2015
Received in revised form
12 March 2016
Accepted 7 April 2016
Available online 22 April 2016

Keywords:
Solar radiation
Generalized regression neural network
Multilayer perceptron
Radial basis neural network
Improved Bristow-Campbell model
Model evaluation

ABSTRACT

Daily observations of meteorological parameters, air temperature, air pressure, relative humidity, water vapor pressure and sunshine duration hours observed at 12 stations in different climatic zones during 1961–2014 are reported for testing, validating and comparing different solar radiation models. Three types of Artificial Neural Network (ANN)methods, Multilayer Perceptron (MLP), Generalized Regression Neural Network (GRNN) and Radial Basis Neural Network (RBNN) are applied in this study for predicting the daily global solar radiation (*Hg*) using above meteorological variables as model inputs. The Bristow-Campbell model has also been improved by considering the factors influencing the incoming solar radiation, such as relative humidity, cloud cover, etc. The results indicate that there are large differences in model accuracies for each model at different stations, the ANN models can estimate daily Hg with satisfactory accuracy at most stations in different climate zones, and MLP and RBNN models provide better accuracy than the GRNN and IBC models, for example, the MAE and RMSE values range 1.53–2.29 and 1.94-3.27 MJ m^{-2} day^{-1}, respectively for MLP model. The model performances also show some differences at different stations for each model, for example, the RMSE values from MLP model are 1.94 and 3.27 MJ m^{-2} day^{-1}at NN and HZ stations, respectively. Meanwhile, ANN models underestimate few high radiation values at some stations, which may due to the differences in training and testing data ranges and distributions of the stations. Finally, the differences in model performances from different solar radiation models have been further analyzed.

Contents

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http://dx.doi.org/10.1016/j.rser.2016.04.024
1364-0321/

1. Introduction

Solar radiation reaching the Earth's surface plays an important role in the energy balances of numerous physical, chemical, and biological processes [1–3]. The changes in the amount of solar radiation greatly influences the fluxes of sensible and latent heat, the hydrological cycle, terrestrial ecological ecosystems and the climate [4,5]. Meanwhile, the solar energy has a much lower environmental pollution than the conventional sources like fossil fuels [6], and it is the most abundant of all renewable and sustainable energy resources at places around the world, which can be harnessed for commercial uses through large solar array farms to meet the global energy challenges [7,8]. Thus, accurate determination and clear understanding of the spatial-temporal variability of solar radiation is of great importance to meteorological and hydrological processes, photosynthesis, ecological functions, agricultural and industrial production, energy development and utilization [9,10].

Though Meteonorm version 6.0 is a global climatological database designed for planners of active solar systems like PV plants or solar thermal systems, which contains monthly mean values of *Hg* of several databases [11,12], the radiation data has not been routinely observed at most meteorological stations around the world due to the high instrument cost and technical requirements [13], for example, the ratio between stations observing solar radiation and those observing T_a is lower than 1:100 in America [14]. Therefore, developing and applying proper methods to estimate solar radiation has been the focus of numerous studies in locations without direct radiation measurements in recent years [15,16]. One of the most widely used methods is to establish the relationships between solar radiation and other measured meteorological parameters such as T_a, h and water vapor contents [17,18], for example, Yacef et al. [19] estimated the daily *Hg* from T_a in Algeria; Li et al. [20] calculated the *Hg* in Tibet, China from h. Among the temperature-based models, the BC model can relate diurnal air temperature range ($T_M - T_m$) to incoming solar radiation, which has been widely used for modeling solar energy [21], for example, Almorox et al. [22] estimated the daily *Hg* from measured T_a at Cañada de Luque, Córdoba, Argentina. Due to the effects of geographical, meteorological and terrestrial factors (albedo, aerosol, cloudiness, etc.), the amount of solar radiation reaching the surface are greatly affected, above empirical models should be recalibrated [23], for example, the Ångström-Prescott model has been modified to the quadratic, cubic, exponential and logarithmic forms in many places of the world [24].

The physical radiation models take into considerations of radiative transferring process (aerosol absorption and scattering), which is proved as an effective method for predicting solar radiation around the world, for example, Pyrina et al. [25] investigated the cloud effects on the shortwave, longwave and all-wave radiation budget of the Mediterranean basin. Gueymard et al. [26] developed an atmospheric transmittance model for calculating the clear-sky beam, diffuse and global photosynthetically active radiation. Yang et al. [27] estimated the hourly, daily and monthly solar radiation by importing global data sets using a hybrid model, which was also validated as one of the best broadband radiation models [28]. Hybrid models that coupled both the physical and empirical aspects have also been developed over the years as elaborated in Schmetz [29], Noia et al. [30], Pinker et al. [31] and Perez et al. [32]. Rigollier et al. [33] demonstrated a clear-sky model, which was developed in the framework of the new digital European Solar Radiation Atlas and compared with the Heliosat method. The above model was validated as one of the most accurate with respect to robustness and accuracy because it considered the Linke turbidity factor and the elevation of the sites. Kambezidis et al. [34] reported the recent improvements of the meteorological radiation model in predicting solar radiation under all-sky conditions at Athens, Greece, which indicated that the inclusion of the aerosol properties in the radiation model can significantly improve the estimations. Shamim et al. [35] presented an improved technique (Mesoscale meteorological model) that utilizes information from a numerical weather prediction model for determining the cloud cover index and solar radiation at Brue catchment situated in the southwest of England. The results clearly showed an improvement in the estimated *Hg* in comparison to the prevailing approach.

Meanwhile, artificial intelligence is a particularly promising approach for modeling solar radiation variation in recent years [36,37], a number of ANN methods have been optimized for estimating solar radiation in different regions of the world [38,39]. Olatomiwa et al. [40] developed an adaptive neuro-fuzzy approach for predicting solar radiation in Nigeria using T_M, T_m and h. Park et al. [8] tried to estimate the spatial distribution of solar radiation using topographic factor and h in South Korea. Aguiaret al. [41] proposed the Markov transitions matrix approach for estimating daily radiation values using only the clearness index as input. Aguiar and Collares-Pereira [42] also developed a time-dependent, autoregressive, Gaussian model for generating synthetic hourly radiation, which has been widely used and modified in predicting solar radiation [43]. Amrouche and Pivert [44] predicted daily *G* with satisfactory accuracy at two sites in France using combined spatial modeling and ANN techniques. Olatomiwa et al. [45] developed an efficient support vector machines firefly algorithm, ANN and Genetic Programming models for estimating solar radiation at the Iranian city. Linares-Rodríguez et al. [46] applied ANN for predicting solar radiation in Spain based on latitude, longitude, day of the year and general climatic parameters, and the results showed that RMSE values were in the range of 13.52–14.2%. Emad et al. [47] predicted the monthly average *Hg* using ANN model in Qena, Upper Egypt, the RMSE and R^2 values were 115 Wh/m^2 and 0.977, respectively. Shamshirband et al. [48] proposed a hybrid support vector machine-firefly optimization method for estimating monthly mean *Hg* in Iran, the results revealed that this method was greatly capable to give favorable predictions with much higher precision than other examined methods. Rizwan et al. [49] used fuzzy logic technique to estimate monthly mean *Hg* in four Indian stations using different input data. They reported that the developed model was accurate since the amounts of obtained errors are limited. Bhardwaj et al. [50] introduced a hybrid approach which includes hidden Markov models and generalized fuzzy models to prediction solar irradiation in India. The results indicated that the predicted values obtained using the proposed model are in favorable agreements with the measured data. Aguiar et al. [51] employed a library of Markov transition matrices, each corresponding to a specific interval in clearness indices, and explained how they were used