Energy Conversion and Management 93 (2015) 406–413

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Potential of adaptive neuro-fuzzy system for prediction of daily global solar radiation by day of the year

Kasra Mohammadi [a,*], Shahaboddin Shamshirband [b,*], Chong Wen Tong [c], Khubaib Amjad Alam [d], Dalibor Petković [e]

[a] Faculty of Mechanical Engineering, University of Kashan, Kashan, Iran
[b] Department of Computer System and Technology, Faculty of Computer Science and Information Technology, University of Malaya, 50603 Kuala Lumpur, Malaysia
[c] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[d] Department of Software Engineering, Faculty of Computer Science and Information Technology, University of Malaya, 50603 Kuala Lumpur, Malaysia
[e] University of Niš, Faculty of Mechanical Engineering, Department for Mechatronics and Control, Aleksandra Medvedeva 14, 18000 Niš, Serbia

ARTICLE INFO

Article history:
Received 8 October 2014
Accepted 10 January 2015
Available online 4 February 2015

Keywords:
Global solar radiation estimation
ANFIS technique
Day of year
Empirical models

ABSTRACT

Estimating the horizontal global solar radiation by day of the year (n_{day}) is particularly appealing since there is no need to any specific meteorological input data or even pre-calculation analysis. In this study, an intelligent optimization scheme based upon the adaptive neuro-fuzzy inference system (ANFIS) was applied to develop a model for estimation of daily horizontal global solar radiation using n_{day} as the only input. The chief goal was identifying the suitability of ANFIS technique for this aim. Long-term measured data for Iranian city of Tabass was used to train and test the ANFIS model. The statistical results verified that the ANFIS model provides accurate and reliable predictions. Making comparisons with the predictions of six day of the year-based empirical models revealed the superiority of ANFIS model. For the ANFIS model, the mean absolute percentage error, mean absolute bias error, root mean square error and correlation coefficient were 3.9569%, 0.6911 MJ/m^2, 0.8917 MJ/m^2 and 0.9908, respectively. Also, the daily bias errors between the ANFIS predictions and measured data fell in the favorable range of −3 to 3 MJ/m^2. In a nutshell, the survey results highly encouraged the application of ANFIS to estimate daily horizontal global solar radiation using only n_{day}.

1. Introduction

Solar energy has been recognized in recent years as a proper alternative energy source owing to its unique characteristics which is free, environmental friendly and broadly accessible in most locations across the globe [1,2]. In this regard, countries are performing tremendous efforts to assign a high priority to solar energy harnessing. Nevertheless, prior to devoting any attempt for each project, accessibility to reliable and accurate solar radiation information is highly essential for experts to install and design solar energy technologies effectively [3–6]. In fact, lack of precise information on solar radiation has been a fundamental limitation in development of solar energy applications. Therefore, over the previous decades, developing suitable models and techniques to estimate the horizontal global solar radiation has been the primary objective of many researches. For this aim, a considerable number of meteorological and geographical parameters have been utilized as input elements to estimate the horizontal global solar radiation via proposed models [7–19]. Basically, despite the great history of above-mentioned empirical models as well as their relatively accurate global solar radiation estimates for many locations, the major deficiency of such models is their dependency to one or more certain meteorological or geographical input parameters.

In addition to the above-mentioned models, developing and establishing some simple models to estimate daily horizontal global solar radiation based upon day of the year as the sole input element have been the focus of some investigations in recent years [20–26]. These day of the year-based (DYB) models enjoy two significant advantages. The first merit of them is that they can be conveniently applied as there is no need to use any specific input element. Furthermore, unlike the other empirical models, applying the DYB models does not require any pre-calculation analysis such as calculating some parameters including the maximum possible sunshine duration or extraterrestrial solar radiation.

In the realm of DYB models, a sine wave model was proposed by Bulut and Büyükalaca [20] to estimate the global solar radiation on

* Correspondent authors. Tel.: +98 9121955642 (K. Mohammadi), +60 146266763 (S. Shamshirband).
E-mail addresses: kasra278@yahoo.com (K. Mohammadi), shamshirband@um.edu.my (S. Shamshirband).

http://dx.doi.org/10.1016/j.enconman.2015.01.021
0196-8904/

Nomenclature

ANFIS	adaptive neuro-fuzzy inferences system
A and B	fuzzy set
a, b and c	membership function parameters
BE	bias error (MJ/m^2)
DYB	day of the year-based
H	daily global radiation on a horizontal surface (MJ/m^2)
H_o	daily extraterrestrial solar radiation on a horizontal surface (MJ/m^2)
$H_{i,c}$, $H_{i,m}$	ith calculated and measured values of H (MJ/m^2)
$H_{c,avg}$, $H_{m,avg}$	average calculated and measured values of H (MJ/m^2)
K_T	daily clearness index (dimensionless)
MABE	mean absolute bias error (MJ/m^2)
MAPE	mean absolute percentage error (%)
n_{day}	number of days
$O_{l,i}$	output of the ith node in layer l
RMSE	root mean square error (MJ/m^2)
R	correlation coefficient

Greek symbols

μ_A	membership function

a horizontal surface in Turkey. They applied the model for 68 provinces across the Turkey and found favorable accuracy for the suggested model. In another study, a cosine wave model was developed by Kaplanis and Kaplani [21] to calculate daily horizontal global solar radiation over the six climatic zones in Greece. Their results indicated high capability of the model to estimate global solar radiation. Al-Salaymeh [22] recommended three DYB models with different functional forms of sine wave, Gaussian correlation and 4th order polynomial degree for Amman, Jordan. Based upon statistical analysis the sine wave model was introduced as the most precise model compared to others. Li et al. [23] developed a model with hybrid sine and cosine functional form to predict daily global solar radiation on a horizontal surface in China. By making a comparison with the previously proposed DYB models, they found higher precision for their new proposed model. Zang et al. [24] proposed a new model with similar functional form as that of Li et al. [23] to estimate global solar radiation in China. Their results demonstrated that the new model enjoys the highest performance to estimate daily global solar radiation at six typical climatic zones of China. Khorasanizadeh and Mohammadi [25] assessed the performance of 6 DYB models to predict the daily global solar radiation in four cities situated in sunny regions of Iran. They developed the new regression coefficients for the nominated models and compared their performance based upon several statistical indicators. The achieved results showed that predictions of all nominated models are accurate; however, the hybrid sine and cosine wave and the 4th order polynomial models have the maximum precision. Khorasanizadeh et al. [26] performed an investigation to assess the merit of DYB models by providing statistical comparisons with different sunshine duration-based and temperature-based models. Their results demonstrated that DYB models perform superior compared to temperature-based models and place with minor difference after sunshine duration-based models. They suggested that DYB models can be utilized as suitable substitute for sunshine duration-based models.

To offer further accuracy, reliability and convenience in the estimation of solar radiation, application of artificial and computational intelligence techniques has attracted many attentions in recent years. Artificial neural network (ANN) has been applied to estimate the global solar radiation using various geographical and meteorological parameters [27–31]. Some authors have made efforts to utilize soft computing methodologies for global solar radiation prediction in various locations [32–36].

Adaptive neuro-fuzzy inferences system (ANFIS) is a type of soft computing methodologies employed by some researchers to estimate daily global solar radiation. It is a hybrid intelligent system that merges technique of the learning power of the ANNs with the knowledge representation of fuzzy logic. The main advantages of the ANFIS model are computationally efficiency and adaptability. The ANFIS model can be embedded as a module for estimating solar radiation data.

Mellit et al. [37] used ANFIS techniques to model the global solar radiation based upon sunshine duration and air temperature in Algeria. Moghaddamnia et al. [38] provided a comparison between different nonlinear models such as ANFIS to estimate the daily global solar radiation using extraterrestrial radiation, precipitation, air temperature and wind speed in Brue catchment, UK. Mohanty [39] presented an ANFIS-based model to predict monthly mean global solar radiation in Bhubaneswar, India. The ANFIS predictions were compared with Angström-Prescott model and some other intelligent approaches. Mohanty et al. [40] carried out a comparative study between three soft computing methodologies including ANFIS, Multi layer Perceptron (MLP) and Radial Basis Function (RBF) for prediction of monthly mean global solar radiation in three locations of India. Güçlü et al. [41] performed an investigation to apply ANFIS model, Angström-Prescott model and some proposed models named dependency models for estimating the global solar radiation in Turkey using sunshine duration as input. Piri and Kisi [42] employed ANFIS technique and some more techniques to predict global solar radiation in two Iranian cities based on sunshine hour, air temperature and relative humidity as input parameters.

Inspection of published articles in the realm of solar radiation prediction reveals that no study has been devoted to estimate global solar radiation by day of the year via any artificial and computational intelligence techniques such as ANFIS. Consequently, in this study, an application of adaptive neuro-fuzzy inferences system (ANFIS) is proposed to develop a soft computing-based model for estimation of daily horizontal global solar radiation by day of the year as a single input. The prime aim is evaluating the sufficiency of ANFIS scheme to provide a convenient way for accurately predicting the daily global solar radiation using only one simple input. For this purpose, long-term measured daily horizontal global solar radiation for city of Tabass situated in a sunny region of Iran has been used. The potential of developed ANFIS model is further appraised and verified by providing statistical comparisons between its predictions with those of six DYB models established in a previous study.

2. Study area and data set

In this study, the long-term measured daily global solar radiation on a horizontal surface (H) for city of Tabass was utilized. Tabass is located in South-Khorasan province with geographical location of 33°36′N and 56°55′E and elevation of 711 m above the sea level. Tabass climate is characterized with hot summers and rare snowfall in the winters [43]. Also, based upon the Köppen