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Estimating the diffuse solar radiation using a coupled support vector machine–wavelet transform model

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ABSTRACT

Diffuse solar radiation is a fundamental parameter highly required in several solar energy applications. Despite its significance, diffuse solar radiation is not measured in many locations around the world due to technical and fiscal limitations. On this account, determining the amount of diffuse radiation alternatively based upon precise and reliable estimating methods is indeed essential. In this paper, a coupled model is developed for estimating daily horizontal diffuse solar radiation by integrating the support vector machine (SVM) with wavelet transform (WT) algorithm. To test the validity of the coupled SVM–WT method, daily measured global and diffuse solar radiation data sets for city of Kerman situated in a sunny part of Iran are utilized. For the developed SVM–WT model, diffuse fraction (cloudiness index) is correlated with clearness index as the only input parameter. The suitability of SVM–WT is evaluated against radial basis function SVM (SVM–RBF), artificial neural network (ANN) and a 3rd degree empirical model established for this study. It is found that the estimated diffuse solar radiation values by the SVM–WT model are in favourable agreements with measured data. According to the conducted statistical analysis, the obtained mean absolute bias error, root mean square error and correlation coefficient are 0.5757 MJ/m^2, 0.6940 MJ/m^2 and 0.9631, respectively. While for the SVM–RBF ranked next the attained values are 1.0877 MJ/m^2, 1.2583 MJ/m^2 and 0.8599, respectively. In fact, the study results indicate that SVM–WT is an efficient method which enjoys much higher precision than other models, especially the 3rd degree empirical model.

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1. Introduction

During the recent years, renewable energy based systems have been further invented and considered as appropriate alternatives for traditional energy systems. Applications of renewable energy systems have been recognized highly beneficial since it is possible to meet the energy demands in an environmental friendly manner. As a matter of fact, renewable energy harnessing is an especially attractive solution to diminish the large greenhouse emissions and climate changes [1,2]. Among renewables, solar energy is regarded as one of the most promising sources as it is widely available worldwide [3,4]. As a consequence, more and more penetration of solar energy technologies to the world's energy sector is indeed appealing for supplying a notable part of the electricity, heating, cooling and cooking demands. Basically, an appropriate utilization of solar energy is a particularly significant task which one of its primary requirements is gathering and processing precise solar radiation data. In fact, no solar energy project can be established without accessibility to the reliable solar radiation information. The terrestrial solar radiation components including the global and diffuse radiation are highly significant parameters in the applications which employ solar energy such as sizing, simulating and monitoring the solar energy technologies as well as building designing and etc. [5–11]. In addition, most of the solar energy systems contain inclined solar surface; thus, by obtaining the amount of diffuse solar radiation on a horizontal surface it is feasible to determine its knowledge on an inclined surface and subsequently evaluate the performance of flat plate solar surfaces adjusted on a tilted surface. Nevertheless, the diffuse solar radiation data are scarcely available in many parts of the globe owing to some existing limitations such as fiscal and technical obstacles.

Therefore, estimating the amount of diffuse solar radiation alternatively based upon estimating methods is a must. To fulfil this objective, during the last decades a considerable number of empirical models have been proposed by many researchers to estimate horizontal diffuse solar radiation using different input parameters [12–24]. Among all, clearness index is one of the most significant and popular parameters to estimate diffuse solar radiation. In fact, clearness index (i.e. the ratio of global solar radiation to extraterrestrial solar radiation) is closely correlated to diffuse solar radiation and would be considered as a determinant element for estimation of diffuse radiation [25].

The first investigation was conducted by Liu and Jordan [26] to develop a proper correlation between diffuse radiation and clearness index. The proposed model has been adapted as a pioneer study in the realm of diffuse solar radiation estimation so that from then various empirical models have been proposed to estimate diffuse solar radiation based upon clearness index as the sole input [27–36]. One of the major advantages of such correlations is that they require minimum measured parameters; moreover, they can be generalized to estimate the diffuse solar radiation in nearby regions and other locations which enjoy similar climate conditions with minimal level of inaccuracy and uncertainty [25]. In fact, only availability of the measured global solar radiation data can meet the requirements to estimate the diffuse solar radiation.

Nowadays, applications of artificial intelligence (AI) and computational intelligence (CI) techniques are recognized as powerful tools for solving the real problems and determining the optimal values and functions in various scientific fields. In order to predict the global solar radiation, different AI and CI techniques have been utilized effectively so far [37–47]; however, they have found only limited applications on diffuse solar radiation predictions.

Boland and Scott [48] provided comparisons between the regression models and a fuzzy logic based model to predict hourly diffuse solar radiation in some locations of Australia. They found that coefficients of determination achieved for the fuzzy logic model are comparable, and in most cases more favorable than those of regression models. Soares et al. [49] developed a methodology based upon neural network technique for prediction of hourly diffuse solar radiation in the city of São Paulo, Brazil. The achieved results demonstrated that the predicted diffuse solar radiation values by neural network are more accurate than those of empirical models. Elminir et al. [50] proposed an artificial neural network (ANN) model to predict hourly and daily diffuse solar radiation in some locations of Egypt. They also established some empirical models for the locations under consideration. They found that applying ANN is more appropriate compared to empirical models for diffuse solar radiation prediction in Egyptian locations. Jiang [51] developed a model based on ANN technique to estimate monthly mean daily diffuse solar radiation in China. They used measured data of eight typical locations for training and data of one location for testing. They compared the predictions of ANN model with those of empirical models. Their result showed that ANN is able to offer favorable predictions and outperforms the empirical models. Alam et al. [52] applied ANN to predict monthly mean hourly and daily diffuse solar radiation in 10 Indian locations with different weather conditions. They used different parameter as inputs and employed the feedforward back-propagation algorithm to train the ANN model. They compared the performance of ANN with empirical models and found that the ANN model is more precise and effective for estimation of diffuse solar radiation. Lazarevska and Trpovski [53] utilized neuro fuzzy inference system with a relevance vector Machine mechanism for prediction of diffuse solar radiation. They considered global solar radiation and solar elevation angle as inputs to model the diffuse solar radiation. Their results indicated that the new developed model is really effective and remarkably outperforms the existing empirical models.

During the last decades, a vast number of investigations have been carried out for prediction of diffuse solar radiation chiefly by developing conventional and empirical models, but there is still a main challenge regarding the development of powerful techniques and models with high level of reliability and adaptability to achieve accurate predictions. Lately, coupling different approaches to build a hybrid model has received a considerable attention in the solar radiation area. Generally, it is possible to take the advantage of specific nature of each technique for enhancing the precision. In fact, the particular features of each technique are able to capture different patterns in the data series. Based upon the theoretical and empirical findings it has been proved that hybrid approaches would be particularly effective and promising for different applications of solar radiation to enhance the prediction accuracy and reliability [54–56].

In this research work, therefore, a combined SVM–WT model by coupling the support vector machine (SVM) with wavelet transform (WT) algorithm is developed to estimate daily diffuse solar radiation on a horizontal surface. Clearness index as a highly significant parameter for estimation of diffuse radiation is considered as the only input. Thus, the estimations can be performed conveniently with only availability of the measured global solar radiation data. To examine the viability of the developed SVM–WT model, the daily measured horizontal global and diffuse solar radiation data sets for city of Kerman located in the south central part of Iran have been used. Wavelet analysis is utilized for decomposing the time series of data into its various components, after which the decomposed components are utilized as inputs for the SVM model. The primary aim is achieving further accuracy and reliability in estimations by taking the advantages of specific nature of both approaches. The efficiency of the SVM–WT model is validated by providing comparisons with radial basis function SVM (SVM–RBF), ANN and an empirical model.