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Estimation of the daily global solar radiation based on Box–Jenkins and ANN models: A combined approach

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ABSTRACT

In this paper, a new combined model coupling the linear autoregressive moving average (ARMA) model and the nonlinear artificial neural network (ANN) model has been proposed in order to estimate the daily global solar radiation. The main feature of this approach lies in the fact that has the strength to capture the advantages containing in both models. The combined method have been developed and tested using global solar radiation data recorded during two years (2012–2013) for two different climate sites in Algeria. The obtained results showed an improvement of the combined model over ARMA and ANN models in term of mean absolute error (MPE) of about 18.1% and 2.7%, for the first site, of about 27.26% and 1.39% for the second site. Moreover, compared to the ARMA and ANN models, a decrease in the RMSE values of about 17.1% and 3.59% compared to the ARMA and ANN models has been observed.

Contents

1. Introduction

Energy plays an important socio-economic role in modern societies. However, the current sources of energy in particular oil, exhibits several drawbacks for instance world reserve, which is falling sharply and its exploitation is pollutant. Hence, the exploration of new energy sources is currently very required. Beyond any dough, renewable energies are excellent candidates.

In recent years, the world is becoming increasingly more interested in renewable energy sources, mainly to reduce the greenhouse effect, caused by the exploitation of fossil sources. In this context, Algeria has proved its commitment to contribute to the world efforts to fight against global warming and protect the environment of our planet. Within this objective, Algerian government has adopted an ambitious program to develop clean and efficient source of energy. The program aims to achieve renewable power installations reaching the 22,000 (MW) between 2011 and

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2030, from which 12,000 (MW) will be devoted to cover the national demand and 10,000 (MW) is for export. Hence, by the year 2030, about 40% of electricity production for domestic consumption expected to be from renewable sources [1–3].

The knowledge of solar radiation in a given site is vital to all solar energy conversion systems designer. This is why, measurements of global solar radiation reaching the surface of the earth and its two components direct and diffuse are essential to all solar energy research fields. The daily values as well as the hourly amount of solar radiation are needed to evaluate the performance of existing solar systems and to estimate the efficiency for future installations.

Unfortunately, in most cases there are no continuous local solar radiation data due to the limited number of recording stations, cost and maintenance of devices. Thus, the resort to methods and approaches for estimating and forecasting the solar radiation characteristics are more important. The intermittent character of solar energy brings serious limitations in most of its applications; therefore, accurate solar radiation predictions are needed then.

Many authors have estimated and forecasted the amount of solar radiation by adopting different models, based on time-series methods and artificial intelligence (AI) approaches in different sites around the world. Box–Jenkins (ARMA) model [4] has been successfully used to predict the global radiation due to both its simplicity and flexibility. Voyant et al. [5] discussed the solar radiation forecast at different time horizons using ARMA and ANN models. They found that if the time-series is not stationary, it is difficult to differentiate between the two methods. They concluded also, the ARMA model is more adequate for clear sky days while ANN is more convenient for cloudy days. Hassan [6] performed an ARIMA modeling for daily global solar radiation prediction in Mosul, Iraq. He found that ARIMA (2,1,1) model is the most suitable for clearness index adjustment. ARMA (2,1) model has been obtained by Hejase et al. [7] as the best one for global solar radiation estimation in Al-Ain city, UAE. They also combined ARMA method with a regression model to obtain optimal results.

Nevertheless, the mentioned methodology requires stationary data and since the solar radiation is non-stationary and has a nonlinear character, the ARMA model is not fit enough for its estimation and prediction. This shortcoming will be solved using nonlinear approaches such as AI techniques, which are considered as a powerful tool. Artificial neural network (ANN) can be found in the first rank, where, they are processed by many authors for forecasting the global solar radiation. The main advantage of such models is the need of less adjustable parameters for providing accuracy compared to those obtained by mean of classical techniques. Numerous papers dealing with the solar radiation prediction from ANN, using multiple meteorological, geographical and astronomical parameters (temperature, humidity, precipitation, wind speed, latitude, longitude, altitude, declination, hour angle, zenith angle, etc.) as input in the network. Yadav et al. [8] have reviewed different ANN techniques for solar radiation forecast. They indicated that the ANN models can predict solar radiation more accurately than conventional, linear, nonlinear and fuzzy-logic models. In addition, sunshine hour and air temperature was found to be as effective inputs for ANN with correlation coefficient can reach 97.65%. The work conducted by Voyant et al. [9] highlights the importance of exogenous meteorological parameters in solar radiation prediction when the MLP neural network is optimized. Their approach has been compared with different forecasting methods and the obtained outcomes show a decrease of nRMSE values from 0.5% until 1%, once the exogenous data are used. A new methodology for forecasting daily global radiation has been examined by Amrouche et al. [10]. This methodology is a combination of spatial modeling and ANN techniques. The enabled results indicated that the proposed model can estimate daily global radiation with acceptable accuracy. Rehman et al. [11] have estimated the global radiation through the neural network. A combination of several input parameters were performed to see the case that gives the better prediction. It has been averred that, when the relative humidity and daily mean temperature is employed as inputs, the mean absolute error was about 4.49%. Unlike other cases, the mean absolute error was about 10.3% and 11.8%. In the study carried out by authors in [12,13], the comparison between estimated values by ANN and those predicted by conventional empirical models, concluded that the ANN technique has ability to generate accurate predictions. Gani et al. [14] used nonlinear autoregressive (NAR) neural network model to predict the daily global radiation received on a horizontal surface for seven cities in Iran, employing day of the year as unique input to the network. The validated model was compared with the adaptive neuro-fuzzy inference system (ANFIS) and the achieved result shows lower values of statistical performances of NAR model against ANFIS.

Certain researchers used support vector machine (SVM), support vector regression (SVR) and genetic algorithm as new tools for developing global solar radiation predictor models. Chen et al. [15] have proposed an application of SVM for estimating the daily solar radiation using sunshine duration. A combination of seven SVM methods and five empirical sunshine based models has been evaluated. The developed approach outperforms the conventional models. Bektas [16] investigated a least squares support vector machines (LS-SVM) method in daily global solar radiation forecasting. Data of Elazig area (Turkey) have been used. Then, the obtained outcomes are compared with existing AI techniques and empirical methods. It seems that, LS-SVM model is very effective for forecasting the daily insolation through a root mean square error (RMS) of about 0.0043 and a coefficient correlation (R^2) of about 0.992. SVM methodology was applied by Wu et al. [17] to estimate the monthly mean daily solar radiation, using maximum, minimum and mean air temperature for 24 sites in China. Five SVM methods and two empirical temperature based models has been developed. Results analysis illustrates that, SVM with $(T_{max}-T_{min})$, and T_{mean}, SVM with $(T_{max}-T_{min})$, and SVM with T_{max} and T_{min} guarantees better precision than classical approaches. Kisi [18] examines the aptitude of the fazzy-genetic approach in modeling solar radiation. The geographical coordinates of seven cities in Turkey, as well as the month number have been introduced as inputs for fuzzy-genetic model to estimate one month ahead solar radiation. The obtained results have been compared to ANN and ANFIS models according to statistical indices. It appears that, fazzy-genetic approach performs better than ANN and ANFIS.

However, employing single model for forecasting time-series may present big errors. So, coupling several approaches to improve the model precision can offer an alternative solution. These techniques are commonly exposed by many researchers in the field of solar energy forecasting. Wu et al. [19] and Benmouiza et al [20] proposed a novel method to forecast the hourly global solar radiation. It consists of combining both ARMA and Time Delay Neural Network (TDNN) models in the wish to improve the prediction accuracy. The use of ARMA model aimed to capture the linear component containing in the solar radiation, and the TDNN to find the nonlinear pattern lying in the residual. Results show the improvement of combined model over ARMA and TDNN. Chaabene et al. [21] consider in their study a dynamic forecasting of solar radiation, coupling ARMA, Kalman filter and neuro-fuzzy estimators. ARMA model has been performed for short-term forecasting associated with Kalman filter, whereas, a neuro-fuzzy predictor was used to forecast the daily behavior of the global solar radiation. Benmouiza et al. [22] have combined k-means clustering algorithm with the NAR model. k-means algorithm was used to extracting information from the time-series and find