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Investigating the performance of support vector machine and artificial neural networks in predicting solar radiation on a tilted surface: Saudi Arabia case study

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ABSTRACT

In this paper, investigation of the performance of a support vector machine (SVM) and artificial neural networks (ANN) in predicting solar radiation on PV panel surfaces with particular tilt angles was carried out on two sites in Saudi Arabia. The diffuse, direct, and global solar radiation data on a horizontal surface were used as the basis for predicting the radiation on a tilted surface. The amount of data used is equivalent to 360 days, averaged from the 5-min basis data. By solving the tilt angle equation, an optimum value of solar radiation was obtained using a tilt angle of 16° and 37.5° for Jeddah and Qassim locations, respectively. The evaluation of performance and comparison of results of ANN as well as SVM and the measured/calculated data are made on the basis of statistical measures including the root mean square error (RMSE), coefficient of correlation (CC), and magnitude of relative error (MRE). The speed of computation of the algorithms is also considered for comparison. Results indicate that for Jeddah, the CC for SVM is between 0.918 and 0.967 for training and in the range of 0.91981–0.97641 for testing while that of ANN is in the range of 0.517–0.9692 for training and 0.0361–0.0961 for testing. For Qassim, the results are even better with CC of 0.999 for training and 0.987 for testing ANN showed higher values of MRE ranging between 0.19 and 1.16 and SVM is between 0.33 and 0.51 for training and testing respectively. In terms of speed of computation, it is observed that SVM is faster than ANN in predicting solar radiation data with a lower speed of 2.15 s compared to 4.56 s for ANN during training. Moreover, SVM has lower values of RMSE indicating that it is robust and has the capability to minimize errors during computations. Therefore, SVM has significantly higher accuracy, robust during computation and is faster in predicting the radiation on the tilted surfaces in comparison with ANN.

1. Introduction

Solar energy is a major source of renewable energy in which solar cells and other technologies are used to convert solar energy to electrical energy. Renewable energy, solar energy in particular, is becoming increasingly popular due to several factors including increasing energy demand and continued depletion of conventional energy sources [1]. Fossil fuels are almost exhausted, which is having a devastating effect on the environment, a factor that has placed RE in the spotlight around the world [2]. In solar energy applications like photovoltaic (PV), solar thermal as well as passive solar designs, solar radiation data are vital [3].

A multitude of terms are used to describe the solar radiation received from the sun by the converting device, including diffuse, direct, and global solar radiation. Diffuse and global radiation intensities are computed on horizontal planes, while fixed solar systems such as PV panels and flat plate solar collector are oriented to track the sun purposely, in order to extract the greatest quantity of radiation incident on the solar panels [4]. Therefore, it is always practical to ensure that a proper tilt angle is determined for a given station where the solar systems are to be mounted. Researchers and engineers have devised numerous tools and methodologies to aid in determining the optimal tilt angle of PV panel. Besides estimating the radiation of the tilted surface, some methods measure radiation on a horizontal surface [5,6]. This is due to the fact that such information regarding horizontal radiation is always

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required for solar system applications, but sometimes it is difficult to have metrological stations which are very expensive to set up.

Various researches have been carried out regarding the measurement and prediction of solar radiation on both horizontal and tilted surfaces. Authors, for example, evaluated solar energy resources by formulating diffuse solar radiation models and determining optimum tilt angle for a given location in the southern region of Sindh, Pakistan [7]. The researchers in [8] evaluated six different empirical models for estimating the solar radiation on tilted surfaces. It was observed that the use of the Jordan and Liu model is useful in the prediction of solar radiation on tilted surfaces in places where the weather is mainly cloudy. With regard to tilted plane models, David et al. evaluated four solar radiation models using comprehensive testing procedures, with Perez model exhibiting the best performance [9]. Transfer-models were also validated to predict solar radiation on the south-oriented tilted surfaces [10]. The authors presented the analysis of four years of solar radiation measurements performed on inclined and horizontal surfaces. It was found that the monthly mean ratio of tilted/horizontal solar irradiation reaches values of 1.25 and 0.95 for winter and summer respectively, whereas the solar global spectra ratio rises to 1.70 and 0.85 for the same months [11]. Several models have been evaluated by Demain et al. to estimate global solar radiation on inclined surfaces [12]. In further development, the transposition and decomposition models for converting global solar irradiance from tilted surface to horizontal in tropical regions were evaluated in [13], who used the data collected at various tilts and azimuths to perform the analysis. The performance of diffuse hourly irradiation models on tilted surfaces was assessed by formulating a database of hourly diffuse and global solar irradiation on a horizontal and global solar irradiation on a tilted surface according to utilization models [14]. The nationwide output energies of PV modules in Japan were estimated using separation methods [15]. The results indicated that using performance and meteorological data is valuable for estimating the output energy of the PV modules. An algorithm was developed to generate synthetic hourly cloudiness data in Western Australia for tilted PV and concentrating solar power systems [16]. Hourly data were generated from the daily data by utilizing a first order autoregression algorithm with time changing mean and standard deviation.

Over the years, several empirical models have been developed for estimation of solar radiation including Tiris et al., Page model, Angstrom–Prescott–Page, and Benson et al. model [17]. However, some of these models have suffered from uncertainties, which have been noted by some researchers in the prediction of solar radiation. Gueymard investigated direct and indirect uncertainties in the prediction process for the irradiance on the tilt surface of solar engineering applications [18]. The authors in [19] noted that the most widely employed correlation method for measuring beam radiation on tilted surfaces is that recommended by Jordan and Liu. However, they stressed that the yearly beam radiation on a tilted surface computed based on the Jordan and Liu technique deviates from that attained based on monthly horizontal radiation and predicted from clear sky situation rises with the increase in tilt angles and azimuth. Therefore, they considered these as approximate methods. A comparative study of diffuse, direct and total solar irradiance has been conducted by using various models on horizontal and inclined surfaces, namely, the statistical values of relative root mean square error (RMSE), mean biased error (MBE), and mean percentage error (MPE). The values of correlation coefficients (R^2) and the *t*-test were used as a yardstick for comparison [20]. The R^2 was found to be more than 0.95, while the values of RMSE were found to be between 3.13 and 6.34, thus indicating a good accuracy in measuring the solar radiation data. Yoon et al. proposed a photographical method (PM), with the purpose of increasing the prediction accuracy of solar radiation on an inclined surface, by considering the shape of obstacles in the sky view [21]. They concluded that the application of the PM method is more suitable for utilization in an urban region with buildings, than in a region of wide grasslands and sunny climate.

Solar irradiation calculations depend on atmospheric variations and sunshine duration record interval. Generally, solar irradiation is calculated by using the classical Ångström–Prescott equation, which provides a linear relationship between the solar irradiation and sunshine duration. Ångström–Prescott model is one of the highly rated global solar radiation models based on sunshine though it is often limited by scarcity of model parameters [22]. Additionally, 2nd and 3rd degree solar radiation and sunshine duration models are used. Some models for estimating daily solar radiation have been presented by different researchers. In a comparative study, three models, i.e. dependency, fuzzy logic ANFIS and Angström–Prescott models were compared [23]. It was revealed that dependency model is superior to others. ARMA–GARCH models have been empirically investigated for modeling and forecasting solar radiation [24]. It has been observed that these models produce more accurate radiation forecasting than conventional methods. Moreover, ARMA–GARCH models are more effective for forecasting solar radiation mean and volatility. With an aim of creating a map of solar radiation using sunshine hours and topography, the authors used an empirical model to estimate solar radiation from sunshine duration data over South Korea [25]. It was demonstrated that empirical models based on sunshine hours performs significantly well. Another study compared the performance and accuracy of the day of the year-based (DYB) models with sunshine duration-based (SDB) and temperature-based (TB) models for prediction of the horizontal daily global solar radiation [26]. It is found out that DYB is as competitive as SDB and TB in terms of accuracy of prediction of the daily solar radiation. In another development, 89 monthly average daily global solar radiation models and 19 daily global solar radiation models were compared and analyzed by 42 years meteorological data [27]. It was highlighted that direct parameters such as latitude, altitude, solar altitude and sunshine duration can improve the accuracy of the models and that multi-parameter models are more accurate than single-parameter models.

Elsewhere, an isotropic model and two anisotropic models were tested using the calculated and measured values of total radiation on tilted surfaces in Dhahran, Saudi Arabia [28]. The models were compared on the basis of the statistical error tests using RMSE and the mean bias error (MBE) where it was demonstrated that the anisotropic models, i.e. Klucher and Hay were found to be more accurate than the isotropic model. Gueymard et al. presented a review of the performance of 24 radiative models used to predict the clear-sky surface direct normal irradiance (DNI) at a 1-min time resolution [29]. Coincident radiometric and sunphotometric databases recorded at seven stations located in arid environments were used for this analysis and results show good consistency between the different stations, with generally higher prediction uncertainties at sites experiencing larger mean aerosol optical depth (AOD). The examination of the models' performance when considering the simultaneous effects of both AOD (β) and Ångström exponent (α) reveals a clear pattern in the models' error, which is influenced by the frequency distribution of α values. This indicates that most models may have difficulty of capturing the effect of α, and/or that observational and instrumental issues at high AOD values may also enhance the apparent model prediction errors.

Artificial intelligence methods have also been used to predict the solar radiation on tilted surfaces. Of particular importance to mention, ANN algorithms have been proven to be excellent tools for research as they are able to handle non-linear interactions (non-linear function approximation), separate data (data classification), and locate hidden relations in data groups (clustering).