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Performance evaluation of hybrid adaptive neuro-fuzzy inference system models for predicting monthly global solar radiation

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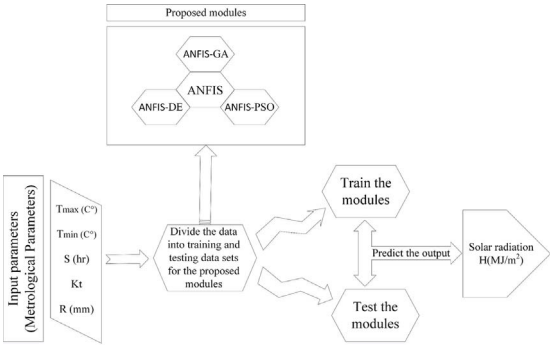
HIGHLIGHTS

- A novel hybrid adaptive neuro-fuzzy inference system models have been developed.
- The performance evaluation of the models has showed high correlation for all developed modules.
- A comparison with other studies proved the models' reliability & accurate estimation capability.

GRAPHICAL ABSTRACT



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ABSTRACT

Solar energy plays a vital role in the field of sustainable energy by providing clean, efficient and reliable alternative source of energy. Where, the output of solar energy systems is highly dependent on the solar radiation. Thus, accurate prediction of solar radiation is considered as a very important factor for such applications. In this paper, standalone adaptive neuro-fuzzy inference system and hybrid models have been developed to predict monthly global solar radiation from different meteorological parameters such as sunshine duration S (h), and air temperature. The proposed hybrid models include particle swarm optimization, genetic algorithm and differential evolution. To evaluate the capability and efficiency of the proposed models, several statistical indicators such as; root mean square error, co-efficient of determination and mean absolute bias error are used. All prediction models' results showed good agreements with measured datasets. The performance evaluation over different statistical indicators showed high correlation for all developed modules. Whereas, hybrid particle swarm optimization has achieved the best statistical indicators over all models in training and testing models. A detailed comparison with other studies is carried out to validate the prediction accuracy and suitability of the proposed models. The results showed that the developed hybrid models have the most reliable and accurate estimation capability and deemed to be the efficient methods for predicting global solar radiation for various applications.

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1. Introduction

The need of clean, reliable and sustainable energy source that could be used in different fields are became essential in the last century to come over fossil fuels harmful effects, which are represented in the harmful concerns towards the surrounding environment such as air pollution and global warming [1]. Solar energy offers the best reliable and environmental friendly solution, as well as most freely available and in-exhaustible energy source around the world [2,3]. It has many advantages in providing sustainable\unlimited energy as well as providing a free – maintenance source of energy. It significantly reduces the harmful emissions and environmental pollutions and leads to be less dependent on fossil fuels [4,5]. Energy generation delivered by solar renewable energy sources has the potential to be used in remote areas, especially for replacing or upgrading diesel system [6]. Based on these facts, using hybrid RE systems – mainly solar energy is regarded as a promising technology and trends to achieve the international technical and environmental efforts [7]. Currently, the national trends are moving towards using renewable energy for future development and meeting world energy demands [8].

Malaysia has planned to be a developed country by 2020. One of the applied plans to achieve this aim is to increase the renewable energy production and being one of the leading countries in this field [9]. However, many meteorological stations in Malaysia have no solar radiation records or records with many missing intervals. This happens because of the complex structure, improper calibration and high-maintenance cost of the measuring equipment. Also, it is worth to mention that special instruments with high celebration and maintenance costs are usually used to measure the solar radiation [10]. Whereas, the design of most solar applications requires long-term or accurate solar radiation datasets which are regarded as the main input for such applications in both thermal and electrical photovoltaic systems. Without proper and accurate datasets, the design would be inaccurate and unreliable [11].

Artificial intelligence and other prediction methods provide the best solution to overcome measurement tools problems. The motivation behind selecting any method is related to each method features like; reliability, efficiency and complexity. The most common method is the empirical method which was discussed by many researchers over the years [12,13]. A recent new empirical model was developed to estimate the global solar radiation on the horizontal surface in Turkey, the results have compared to other empirical techniques and showed a good prediction capability [14]. Several methods have also discussed such as; Angstrom–Prescott linear equation method [15], stochastic algorithm model [16] and Satellite-derived model [17]. Besides, various artificial intelligence techniques such as artificial neural network (ANN) [18,19], adaptive neuro-fuzzy inference system (ANFIS) [10], particle swarm optimization (PSO) [20], support vector machine (SVM) [21], hybrid neural network (NN) [22] and other methods that reported in literature. These methods have received high attention in predicting solar radiation to support the different agriculture and industrial applications. In these regards, a study developed to predict the temperature and sold in complex environment which revealed the natural and human effects in an urbanized environment [23]. The study used a multitier structure called Fog Computing Architecture Network (FOCAN). The results confirmed the significant impact of the FOCAN in providing an energy-efficient model; by usage of low energy in an efficient manner. Besides, supported application management with scalable energy role for small areas. While, enhancing the prediction accuracy over complex environments such as mobile cloud computing and industrial conditions, resource utilization as shown in [24], and improving the energy management as shown in [25] have received the attention to embrace wide range of applications. Furthermore, the extreme learning machine (ELM) was developed to forecast the future output power of a grid-tide photovoltaic (PV) system in Malaysia [26]. The results indicated that there is a direct relation between the metrological parameters and the PV system output. Besides, it demonstrates the accuracy of the proposed ELM model by compare it to other techniques. Similar work has been developed to forecast the PV output to design better energy management system based on daily weather forecast as shown in [27]. The results demonstrated the capability of the proposed method mainly where few metrological parameters are found.

Some researchers have found sunshine duration and air temperature as the best combination to predict solar radiation using different empirical models [22,28–30]. Meanwhile, various empirical models have been discussed that include; Temperature-based models (TB), Cloud factor and Sunshine duration - based models as shown in [31]. However, TB empirical model for estimating the horizontal global solar radiation has been modified over the years in many literatures [32,33]. Similarly, satellite methods have the advantage of collecting and estimating solar radiation where there are rare special collecting stations [34]. Although, satellite methods are regarded as relatively new methods and their related applications usually have excessive costs. It suffers from the deficit of historical information and the prediction of solar radiation mainly affected by the clouds [35]. However, over long-term basis prediction of solar radiation, these methods (empirical and satellite) show low performance and both required full datasets without any missing data.

Many studies developed to estimate solar radiation from routinely measured meteorological data, including temperature and geographical parameters in different parts around the world [36–38]. A new model called Global Solar Radiation on Horizontal Surface (GSRHS) using transmission function developed to predict solar radiation in four locations in the United States (US). It used different variables such as; hours in a day, latitude, and longitude. The results have showed that the use of such inputs are useful and have a very good potential in predicting solar radiation [39]. A study applied comparison between ANN technique and TB empirical method to predict global solar radiation from air temperatures, where maximum and minimum air temperatures and extraterrestrial radiation have used as input for training purposes. The results showed the ANN technique exhibit higher accuracy than TB method [40]. Similar work is done in Turkey, using ANN, ANFIS, multiple linear regression (MLR) models and empirical equations' method and showed ANN has better performance than all other methods for that location [41], where similar work is found in [42]. Another study used hybrid algorithm to predict the monthly global solar radiation in Saudi Arabia. ANN technique was trained using PSO algorithm, where sunshine duration, months number and location parameters, including latitude, longitude, and altitude were the input in this study. The result showed better evaluation compared to the neural network back propagation trained method (BP-NN) [20]. Moreover, a recent study performed to predict daily global solar radiation in China using three optimized methods. Two hybrid ANFIS models and M5 model Tree method (M5Tree) are developed and used [43]. The optimized hybrid ANFIS models include; ANFIS with grid partition (ANFIS-GP) and ANFIS with subtractive clustering (ANFIS-SC). The study used 21 metrological datasets for various locations in China. It contains sunshine duration hours, air pressure, minimum temperature, maximum temperature, average temperature, water vapor pressure, and relatively humidity. The results were compared with calibrated empirical Ångström and demonstrates the high capability of the developed ANFIS models over the M5Tree and empirical Ångström methods. Moreover, it indicates that the solar radiation data can be estimated using such routine metrological data and the high accuracy of the hybrid ANFIS models in this field. Similarly, a study carried out to investigate the applicability of using ANFIS method for predicting the performance parameters of a solar thermal energy system for a system operating under Canadian seasons conditions. The indicates that ANFIS provides high accuracy and reliability for predicting the performance of energy systems [44]. A case study based on SVM was conducted in China [45] for predicting global solar radiation using maximum and