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Next generation prediction model for daily solar radiation on horizontal surface using a hybrid neural network and simulated annealing method

Seyyed Mohammad Mousavi[a], Elham S. Mostafavi[b,c], Pengcheng Jiao[d,*]

[a] Department of Geography and Urban Planning, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Industrial Engineering, Isfahan University of Technology, Isfahan, Iran
[c] College of Engineering, Montana State University, Bozeman, MT, USA
[d] Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA, USA

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ABSTRACT

Accurate prediction of solar radiation is essential for optimal design of solar systems. This paper presents an innovative artificial intelligence approach for the determination of the daily solar radiation. A new nonlinear model was developed to predict the daily solar radiation on horizontal surface using a hybrid method coupling artificial neural network (ANN) and simulated annealing (SA), called ANN/SA. This method uses SA-based temperature cycling to improve the ANN calibration performance. A calculation procedure was presented to interpret the ANN/SA model and transform it into a practical design equation. The ANN/SA technique formulates the daily solar radiation in terms of several meteorological parameters. Thousands of daily observations during 1995–2014 in a nominal city in Iran were used to develop the solar radiation models. Validity of the model was verified through different phases. Sensitivity analysis was conducted and discussed. The ANN/SA model accurately predicts the daily solar radiation and outperforms the ANN, support vector machines (SVM), and existing regression and machine learning models.

1. Introduction

Solar energy is known as one of the major renewable and sustainable energy resources accessible in many parts of the world. The important role of solar radiation role in the energy balances of numerous processes is well-understood [1,2]. Fig. 1 shows the availability of the renewables and fossil fuels compared to global energy demand. As seen in this figure, the contribution of the renewable energy resources is much higher than the fossil fuels. Considering the scale of solar potential, the most promising area for an energy revolution is the solar energy. The global energy demand could be met many times over (~2850) through direct utilization of the suns radiation energy [3]. In addition, the solar energy is considered as a reliable alternative to fossil fuels because of its lower environmental pollution [4]. Nowadays, large solar farms are developed to harvest the solar energy for commercial uses [5]. Accurate determination of solar radiation is important for many industrial and manufacturing processes [6].

Over the past years, several studies have been focused on designing and modeling of solar energy systems (e.g. [6–10]). A compressive overview of different solar radiation models is reported by many researchers [11–13], and therefore, it is beyond the scope of the current study. These models are based on various meteorological and geographical parameters [14]. However, some of the well-known methods in this area are auto-regression, Markov chain, Gaussian process regression, or robust optimization techniques [15–19]. Besides, machine learning techniques such as artificial neural networks (ANNs), extreme learning machine (ELM) and support vector machines (SVM) have been extensively used to simulate the energy demand, solar radiation and many other real-world problems [17–40]. Voyant et al. [41] and Yadav et al. [42] have extensively reviewed the application of these techniques for solar radiation forecasting. It is worth mentioning that the focus of the majority of the exiting solar radiation research is on the prediction of monthly or annual solar radiation.

However, solar radiation is location dependent. Prediction of the solar radiation become more challenging for developing countries that have limited access to the solar radiation measurement, maintenance and calibration equipment due to the high prices. Among these countries is Iran which is among the 20 most populated and electricity consumer countries in the world [43]. Recently, significant effort has been made toward using renewable energies in Iran. In this context, Iran has focused on harnessing the solar energy from suitable sites in different parts of the country [43]. According to Hosseini et al. [44],

* Corresponding author.
E-mail addresses: elh.mostafavi@gmail.com (E.S. Mostafavi), pjiao@seas.upenn.edu (P. Jiao).

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Nomenclature

DSR	daily solar radiation
$E(x)$	configuration of energy
E	earth skin temperature
H	relative humidity
K	Boltzmann's constant
MAE	mean absolute error
P	atmospheric pressure
P_a	probability
R	correlation coefficient
R^2	coefficient of determination
RMSE	root mean squared error
$RMSE_p$	RMSE of persistence forecast
T	Temperature
T_{ave}	average of air temperature
T_{min}	minimum of air temperature
T_{max}	maximum of air temperature
V_n	normalized variable
WS	wind speed

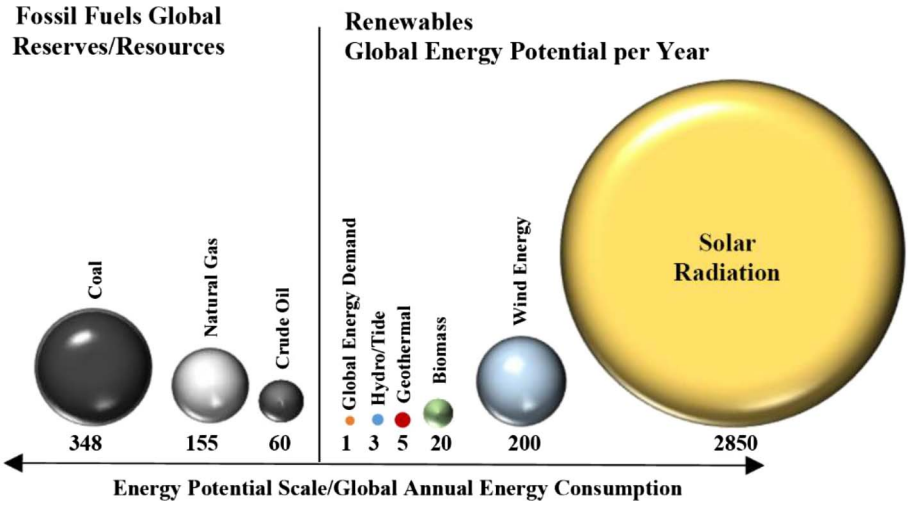

Fig. 1. Availability of the renewables and fossil fuels compared to energy demand (data from [3]).

installing solar panels in 1% of the Iranian deserts will result in 5 time more energy than the annual electricity production in the country. Arguably, there is a serious need for the development of new methodologies to estimate the solar radiation as an important input in solar collector design. There are some studies that focus on predicting the solar radiation in Iran using the AI techniques, particularly ANNs [8,30,32]. ANNs are called black-box systems because they usually do not provide the functions relating the input to the output. They are also prone to being stuck in local minima [45]. Training of ANNs with optimization algorithms has proved to be an effective approach to find optimal solutions [46,47]. In this area, simulated annealing (SA) has found to be an efficient tool in different scientific domains [48–50]. In a combined method of ANN and SA (ANN/SA), SA plays a key role in the training of the ANN algorithm. Some of the successful applications of the hybrid ANN and SA method are improving response surface methodology [51], predicting the accuracy of components produced by wire electrical discharge machining [52], predicting groundwater inflow to an open pit mine [53], predicting pyrite oxidation in a coal washing waste pile [54]. While the ANN/SA method has a remarkable prediction performance [49], there are almost no studies on its application in the field of energy conversion and management up to now.

This study proposes a new ANN/SA approach to estimate the daily solar radiation on horizontal surface in Iran. The role of SA in this hybrid algorithm is to provide good initial values for the ANN weights. In order to facilitate the use of the optimal ANN/SA model, it was transformed it into a functional representation. A database containing thousands of the daily solar radiation measurements in Mashhad city in Iran is used to develop the models. The results are further compared with those provided by the regular ANN and other existing models. The applications of the proposed ANN/SA method and the interpretation process is not merely limited to the current problem and can be extended to a variety of energy-related problems.

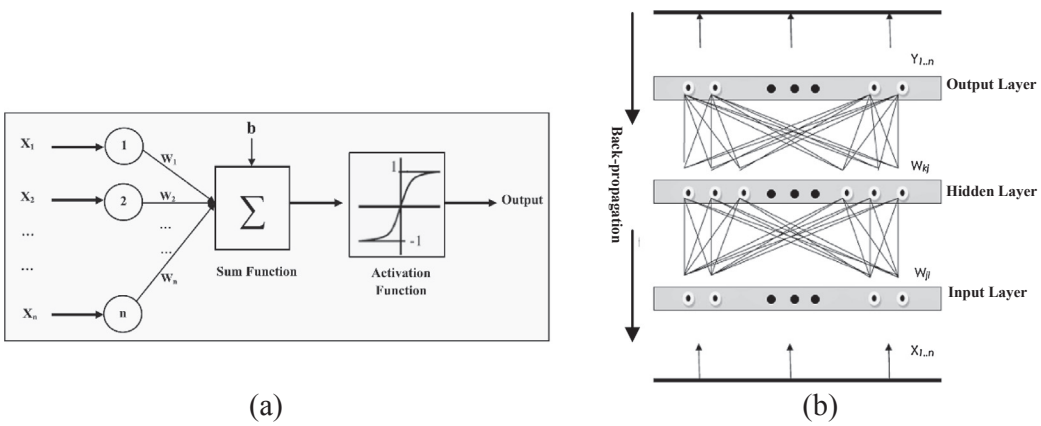

Fig. 2. (a) An artificial neuron, (b) representation of back-propagation algorithm in MLP.

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