Research Paper

APPLICATION OF ANN TECHNIQUE FOR THE PREDICTION OF GLOBAL SOLAR RADIATION FOR SOLAR THERMAL SYSTEMS

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ABSTRACT

Generally, it is essential to expand the knowledge of variation in global solar radiation for effective utilization of solar energy equipment. However, in most of the places, measurement of solar energy potential by direct method is not widely available due to the cost and maintenance of measuring equipment. To predict the daily average global solar radiation (GSR) in the present work, ANN model was developed, trained and tested by using four different algorithms like, levenberg-marquardt (LM), gradient descent (GD), resilient back propagation (RP) and scaled conjugate gradient (SCG) algorithm. In order to train and test the ANN model, the data measured from Madurai city, located in Tamilnadu state, southern part of India was utilized. From the obtained results, it is very clear that, ANN model trained and tested by levenberg marquardt (LM) algorithm, outperforms the other cases with minimum RMSE, MAE and maximum linear correlation coefficient (R). The MAPE was calculated for the LM algorithm and the result was compared with other similar studies. Therefore the developed ANN model (LM algorithm) in the present work can be used for estimating daily average GSR accurately by using various meteorological parameters of Madurai city, located in Tamilnadu state, southern part of India.

KEYWORDS: Global solar radiation, Artificial neural network, Levenberg marquardt algorithm, Gradient descent algorithm, Resilient back propagation algorithm, Scaled conjugate gradient algorithm.

1. INTRODUCTION

Direct measurement of solar radiation was done particularly in few places due to its cost, maintenance and requirement of technical expert. Therefore a number of indirect approaches used for the solar radiation measurement. Among this, one of the approaches consists of using the empirical relations among the global radiation and the meteorological parameters [1].

Empirical correlation models performed well for monthly values. However, in case of daily values, the expressions obtained from daily value correlations do not produce good results, because the daily values of global solar radiation are particularly depending upon the average of hourly values. But this hourly values are very sensitive to cloud type. Therefore to avoid the variation of results from empirical correlation models, the daily global solar radiation values are estimated using an artificial neural network model [2].

Solar radiation intercepted at the earth's surface is most important for various applications, such as in the development of infrastructure, to improve the productivity in agriculture, to create a pollution free environment and for the installation of renewable energy resource operated equipment. In our day today life more number of applications demanding solar radiation data, therefore representation of alternate techniques are essential. There are three distinctive methodologies for the estimation of global solar radiation are physical models, empirical relationships and ANN approaches. But, ANN technique is widely accepted as an alternative way to predict the global solar radiation [3].

Emmanuel Quansah et al. [4] evaluated the performance of empirical models based on air temperature and sunshine for the global solar radiation estimation in the Ashanti region of Ghana. The comparison of results between the measured global solar radiation and the calculated global solar radiation revealed that the empirical models can be used to predict the daily mean global solar radiation with minimum root mean square error. Rehman et al. [5] presented an outcome for predicting the solar radiation using artificial neural network method for Abha city in Saudi Arabia. Thus the developed ANN model can be used for estimating solar radiation for locations having temperature and humidity value. Monica Bocco et al. [6] developed linear models and neural network models, by using various meteorological variables to predict the daily global solar radiation, for a region of the province of Salta, Argentina. Good results with both prediction methods were obtained, even though neural network models are most consistent to estimate daily solar radiation by using a reduced number of meteorological parameters. Karoro Angela et al. [7] estimated daily average global solar radiation on a horizontal surface, based on a single parameter sunshine hours, using an artificial neural network method. The station under the study is located in Kampala, Uganda. Results obtained using the proposed model shows good agreement between the estimated and actual values of global solar radiation.

Saurabh Karsoliya [8] made a survey about different techniques/assumptions elaborated, for calculating the number of hidden layer and hidden neurons. Evaluating the number of hidden layers and number of neurons is a difficult task for any complex problem. The results obtained in this paper shows that the, unnecessary increment in the neurons or layer may cause increase in the complexity of network. Shafiqur Rehman al. [9] compared the observed and estimated values of global solar radiation on horizontal surfaces by using their developed correlation with linear Angstrom type of correlation. The comparison was done based on root mean square error and mean percent error. The results confirm that the empirical correlation developed in the work can be used to estimate the monthly mean daily global solar radiation with minimum error.

Premalatha and Valan Arasu [10] developed two different artificial neural network (ANN) models to predict daily average global solar radiation (GSR), by using two different algorithms for Madurai city, located in Tamilnadu state, southern part of India. Two inputs day of the year, mean ambient air temperature is used for ANN model 1 and three inputs like day of the year, daily average mean ambient air temperature and daily average mean relative humidity are used for ANN model 2. The results from two artificial neural network models show that, by using mean ambient air temperature and day of the year and levenberg-marquardt (LM) algorithm outperforms the other cases with minimum root mean square error. The mean absolute percentage error (MAPE) based on LM algorithm was 5.49%. ANN models are capable of predicting GSR from easily measurable and minimum number of input parameters.

The major purpose of the present work is to predict still more accurately the daily average global solar radiation, with the help of artificial neural network model. For this, seven inputs such as date, month, year, daily average air temperature, daily average atmospheric pressure, daily average relative humidity and daily average wind speed were used to predict the daily average GSR. Four different algorithms like, gradient descent (GD), levenberg marquardt (LM), resilient back propagation (RP) and scaled conjugate gradient (SCG) algorithms are used for training and testing of ANN model. Finally best algorithm for this work was found based on minimum mean absolute error (MAE), minimum root mean square error (RMSE) and maximum correlation coefficient (R).

2. METHODOLOGY

In general, ANN has been used in a broad range of applications including statistical analysis, modeling, forecasting and many others. ANN is a branch of artificial intelligence (AI), which belongs to the group of computational algorithms. ANN models are learns from examples by constructing an input output mapping without precise derivation of the model equation.

The back propagation neural network consists of several layers of neurons connected to each other. A neuron is a simplified mathematical model and it is a fundamental processing element of a neural network. The adjustment of weights was done in the training process to achieve the minimum error. The following steps involved in the design of ANN model, (i) Normalize the input and target values (ii) Divide the dataset for training and testing (iii) Create and train the neural network (iv) Minimize the mean square error and generate output values (v) Un normalize the outputs and evaluate their accuracy by correlating the predicted outputs with the measured target values.

In the present work, feed-forward, back-propagation, multilayer artificial neural network model was developed and trained by using four different algorithms such as LM, GD, RP and SCG algorithm on 'Neural Network Toolbox' in MATLAB version 2012. This ANN model was used to predict the daily average global solar radiation (GSR) by using the measured data of Madurai city, located in Tamilnadu, southern part of India.

3. RESULTS AND DISCUSSION

3.1 Normalization of Collected Data

In the present work, daily average air temperature, daily average atmospheric pressure, daily average relative humidity, daily average wind speed and daily average global solar radiation data were collected for Madurai city, from January 2013 to December 2013. The same set of data as used in the previous work by the authors [10] was used again in order to compare the error in the prediction between the previous and present studies.

The four different algorithms, levenberg marquardt (LM), gradient descent (GD), resilient back propagation (RP) and scaled conjugate gradient (SCG) algorithm are used to predict the daily average global solar radiation (GSR). The following seven inputs like, date, month, year, daily average air temperature, daily average atmospheric pressure, daily average wind speed and daily average relative humidity are used to predict the daily average global solar radiation as an output.

After collecting the data both input and output data sets were normalized based on the activation function used in hidden layer. Here tangent sigmoid function is used as an activation function in the hidden layer.

Therefore the collected data was normalized in the range of -1 to +1 [14], by using the following equation,

$$X_N = 0.8\left(\frac{X_R - X_{max}}{X_{max} - X_{min}}\right) + 0.1$$

Where,

X_N = Normalized value

X_R = Value to be normalized

X_{max} = Maximum value among all the values for related variable

X_{min} = Minimum value among all the values for related variable

3.2. Selection of Hidden Neurons

After completing the normalization process, the entire dataset was divided into two categories one for training and another for testing of an artificial neural network model. In the present work, daily average data for 12 months period (one year) measured from Madurai station are used for training and testing. Among the collected data, 80% of data (24 data from each month) are used for training and testing was done by 20% of data (6/7 data from each month).

In an ANN model, it is important to find the appropriate number of neurons in the hidden layer to attain the accurate predicted output with minimum error as compared to measured target value. Generally a trial and error method is used for creating and selecting hidden neurons. For any hidden layer, initially few random numbers of neurons are taken and samples are allowed to train, if the network fails to converge after a reasonable period, then training was restarted after adding few more neurons in the layer. This process is repeated until the minimum mean square error results found. From the performance results of MSE and R, the exact number of neurons in hidden layer is finalized. The appropriate number of neurons in hidden layer was selected when MSE value reaches its minimum value and R value attains maximum [8].

In the present work, the mean square error value was minimum and R value was found maximum at 15 neurons in both training and testing. Based on the above discussion, artificial neural network structure with seven inputs, 15 neurons in one hidden layer and one output was found best to predict the daily average global solar radiation with minimum error and also used to compare the performance of all the four algorithms. Artificial neural network structure for the present work is shown in figure 1.

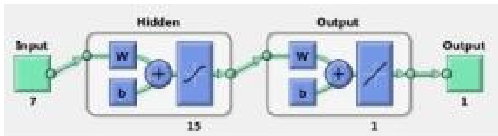

Fig. 1. ANN Structure for the present work

The performance of ANN model was evaluated by using the MAE, RMSE and R. According to [14], mean absolute error (MAE) and root mean square error (RMSE) are expressed by the following equations:

$$MAE = \frac{1}{N}\sum_{i=1}^{N} |X_i - Y_i|$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - Y_i)^2}$$

Where,

N = Total number of data.

X_i = Measured monthly average global solar radiation.

Y_i = ANN predicted monthly average global solar radiation.

i = Month

3.3 Selection of best ANN Algorithm

The performance results obtained from ANN model, with seven inputs, one hidden layer with 15 neurons and only one output is given in table 1, for both training and testing data set. Results obtained was analyzed and found that, the mean absolute error (MAE) for training data was 8.63, 1.72, 5.07, 3.58 and for testing data was 16.10, 3.36, 10.91, 7.05, for GD, LM, RP and SCG algorithms respectively. The above results indicate clearly that levenberg marquardt (LM) algorithm performs well with minimum mean absolute error (MAE) of 0.01 and 0.05 for training and testing respectively as compared to other algorithms.

Table 1. Performance results of ANN model for the present work

Name of the algorithm	Training			Testing		
	MAE	RMSE	R	MAE	RMSE	R
GD	8.63	9.76	0.8918	16.10	18.53	0.8375
LM	**1.72**	**2.00**	**0.9996**	**3.36**	**4.84**	**0.9994**
RP	5.07	7.01	0.9982	10.91	16.32	0.9946
SCG	3.58	4.82	0.9984	7.05	11.15	0.9983

Now the results from same artificial neural network model were analyzed based on the obtained root mean square error (RMSE). It was found that, for GD, LM, RP and SCG algorithms are 9.76, 2.00, 7.01, 4.82 for the training data and 18.53, 4.84, 16.32, 11.15 for the testing data respectively. Here also root mean square error for LM algorithm was minimum and found best algorithm as compared to others.

Finally the linear correlation coefficient (R) value of ANN model was compared to conclude the best algorithm. The R value results are 0.8918, 0.9996, 0.9982, 0.9984 for training and 0.8375, 0.9994, 0.9946, 0.9983 for testing respectively. Finally Maximum R value was obtained for LM algorithm.

From the analysis of results as shown in table 1, it is important to select the most suitable algorithm to predict the accurate daily average global solar radiation. In the present work, minimum MAE, RMSE and maximum R values in both training and testing was found for levenberg marquardt back propagation (LM) algorithm, which shows the most excellent performance, among the other algorithms. Therefore LM algorithm is selected as best algorithm for the present work.

3.4 Performance of ANN Model

The performance graph for measured and predicted values of daily average global solar radiation (GSR) in both training and testing stage for the best algorithm (LM) is shown in fig. 2 and fig. 3 respectively. It can be observed from the graph that, ANN predicted results of GSR by our proposed best (LM) algorithm are most consistent with measured data for almost all the datasets.

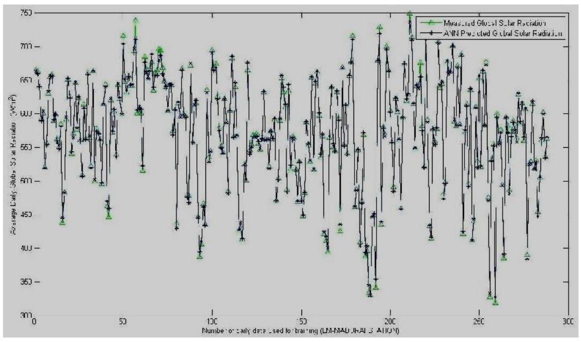

Fig. 2. Comparison of measured GSR with ANN predicted GSR for training data by our proposed best algorithm

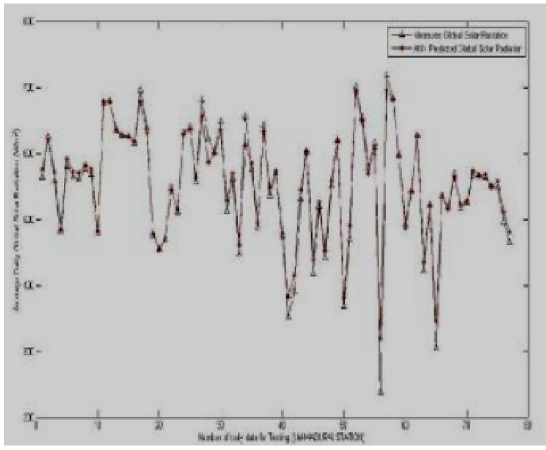

Fig. 3. Comparison of measured GSR with ANN predicted GSR for testing data by our proposed best algorithm

3.5 Error Analysis

The statistical error analysis like mean absolute percentage error (MAPE) and coefficient of determination for the testing data was calculated by using the following formula,

$$MAPE = \frac{\sum_{i=1}^{N} \left| \frac{X_i - Y_i}{X_i} \right|}{N} \times 100$$

$$C_D^2 = 1 - \left(\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{\sum_{i=1}^{n} (Y_i)^2} \right)$$

The statistical error analysis result of all the twelve months for a period from Jan 2013 to Dec 2013 by our proposed best LM algorithm was given in table 2.

Table 2. Monthly testing data error analysis results

S.No	Month	MAPE (%)	C_D^2 (%)
1	JAN	0.4286	99.99
2	FEB	0.5000	99.99
3	MAR	0.1428	99.99
4	APR	0.3333	99.99
5	MAY	0.5714	99.99
6	JUNE	0.8333	99.98
7	JULY	1.2857	99.98
8	AUG	0.7143	99.98
9	SEP	0.8247	99.99
10	OCT	0.5785	99.99
11	NOV	0.6667	99.99
12	DEC	0.8571	99.98

The calculated result in table 2 show that the calculated values of coefficient of determination was same for all the twelve months. The above results clearly indicates that the 99.98% of the predicted global solar radiation values are very close to the measured values for all the months in a year by the best ANN algorithm i.e. LM algorithm in the present work.

Mean absolute percentage error (MAPE) expresses accuracy as a percentage in terms of number of data used. The MAPE calculated for the LM algorithm lies within the minimum error range of 0.1428% to 1.2857%, which confirms the accurate prediction of GSR by the developed ANN-LM algorithm.

The mean absolute percentage error of the present work is compared with other similar works and is given in table 3. The result displayed in table 3 clearly indicates that the MAPE value for the present work is lower than the others. The value of MAPE for the present model is within the range of 0.1428% to 1.2857% by using the LM algorithm. The maximum mean absolute percentage error ($MAPE_{max}$ = 1.2857%) obtained in the present work is better than those of the similar studies carried out using ANN model for various regions in the world.

In our previous research work [10], ANN Model 1 is designed and trained by LM algorithm based on two input parameters such as daily average mean ambient air temperature and day of the year to predict the daily average global solar radiation. When two input parameters are used, the calculated mean absolute percentage error (MAPE) was 5.36 %. Similarly an ANN model 2 was developed by using the following three inputs, day of the year, daily average mean ambient air temperature and mean relative humidity. The mean absolute percentage error (MAPE) based on LM algorithm was 5.49%.

The present work was carried out to examine the outcome with more number of input parameters. The following seven inputs date, month, year, daily average air temperature, daily average atmospheric pressure, daily average relative humidity and daily average wind speed are used to predict the daily average global solar radiation. The mean absolute percentage error for the present work is found as 1.2857%, which is very much lower value as compared to our previous research work carried out by using minimum number of input parameters.

Generally accuracy of ANN model depends upon the training dataset. From the result analysis of our present and previous work, it clearly indicates that the more accurate results are produced when more number of input parameters is used to train ANN model. This confirms one of the important characteristics of ANN model i.e. the number of input data improves the accuracy of prediction for an intended application. Because, solar radiation incident on the earth depends largely on the atmospheric conditions and hence the atmospheric factors which affect the solar radiation are to be given as input to the ANN model for the precise prediction of solar radiation. Hence, the ANN model developed in the present work can be used for the accurate prediction of daily average solar radiation for Madurai city, located in Tamilnadu state, southern part of India.

Table 3. Comparison of present work with other similar studies

Study	Station	MAPE max (%)
Mohandes [11]	Saudi Arabia	19.10
Ghanbarzadeh [12]	Dezful (Iran)	14.50
Alawi [13]	Seeb (Oman)	7.30
Karoro Angela [7]	Kampala (Uganda)	1.97
Present study	**Madurai (India)**	**1.28**

4. CONCLUSION

Generally global solar radiation (GSR) measuring stations are not installed in many places because of its cost and continuous attention of skilled manpower. The major objective of the research work is to predict daily average global solar radiation (GSR), with the help of artificial neural network (ANN) model, by using easily measurable parameters.

In the present work, an ANN model was developed to predict the daily average global solar radiation based on easily measurable parameters like daily average air temperature, daily average atmospheric pressure, daily average relative humidity and daily average wind speed. The data was collected from a weather monitoring station installed in Thiagarajar College of Engineering, Madurai for a period of twelve months.

The collected data was randomly divided for training and testing in a developed ANN model by using four different algorithms, such as levenberg-marquardt (LM) algorithm, gradient descent (GD) algorithm, resilient back propagation (RP) algorithm and scaled conjugate gradient (SCG) algorithm. To find the best algorithm the results obtained from the four different algorithms were investigated, based on mean absolute error (MAE), root mean square error (RMSE) and linear correlation coefficient (R).

From the analysis it was found that ANN model using the LM algorithm outperforms the other cases with minimum mean absolute error, minimum root mean square error and maximum linear correlation coefficient value for both training and testing.

From the analysis of MAPE results, it was found that maximum $MAPE_{max}$ was obtained for the present work is smaller as compared with ANN models reported in other studies carried out for various regions in the world. Further, the present study ascertains that, as solar radiation incident on the surface of the earth depends on the atmospheric conditions, more accurate prediction of solar radiation by ANN models require the factors affecting the solar radiation to be given as inputs to the model.

Hence, the ANN model based on LM algorithm developed in the present work can be used to predict the daily average global solar radiation more accurately for Madurai city, located in Tamilnadu, southern part of India, by using commonly available and easily measurable meteorological data.

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REFERENCES

1. Inci Turk Togrul, Hasan Togrul, Dugyu Evin, "Estimation of monthly global solar radiation from sunshine duration measurement in Elazig", Renewable Energy, vol. 19, pp. 587- 595, 2000.
2. Jacyra Soares, Amauri P. Oliveira, Marija Zlata Boznar, Primoz Mlakar, Joao F. Escobedo, Antonio J. Machado, "Modeling hourly diffuse solar-radiation in the city of Sao Paulo using a neural-network technique", Applied Energy, vol. 79, pp. 201–214, 2004.
3. Tymvios FS, Jacovides CP, Michaelides SC, Scouteli C, "Comparative study of Angstroms and artificial neural networks methodologies in estimating global solar radiation", Solar Energy, vol. 78, pp. 752–762, 2005.
4. Emmanuel Quansah, Leonard K. Amekudzi, Kwasi Preko, Jeffrey Aryee, Osei R. Boakye, Dziewornu Boli, Mubarick R. Salifu, "Empirical Models for Estimating Global Solar Radiation over the Ashanti Region of Ghana", Journal of Solar Energy, Article ID 897970, pp. 1-6, 2014.
5. Rehman S, Mohandes M, "Estimation of diffuse fraction of global solar radiation using artificial neural networks", Energy Sources Part A, vol. 31, pp. 974–984, 2009.
6. Monica Bocco, Enrique Willington, Monica Arias, "Comparison of regression and neural networks models to estimate solar radiation", Chilean Journal of Agricultural Research, vol. 70, no. 3, pp. 428-435, 2010.
7. Karoro Angela, Ssenyonga Taddeo, Mubiru James, "Predicting global solar radiation using an artificial neural network single-parameter model", Advances in artificial neural systems, Article ID 751908, 1-6, 2011.
8. Saurabh Karsoliya, "Approximating number of hidden layer neurons in multiple hidden layer BPNN architecture", International Journal of Engineering Trends and Technology, vol. 3, no. 6, pp. 714-717, 2012.

9. Shafiqur Rehman and Talal Omar Halawani, "Global solar radiation estimation", Renewable Energy, vol.12, no. 4, pp. 369-385, 1997.
10. Premalatha N, Valan Arasu A, "Estimation of global solar radiation in south India using artificial neural network", International Journal of Applied Environmental Sciences, vol. 9, no. 6, pp. 2817-2826, 2014.
11. Mohandes M, Rehman S, Halawani TO, "Estimation of global solar radiation using artificial neural network", Renewable Energy, vol. 14, no. 1-4, pp. 179-184, 1998.
12. Ghanbarzadeh A, Noghrehabadi AR, Assareh E, Behrang MA, "Solar radiation forecasting based on meteorological data using artificial neural networks", 7th IEEE International Conference on Industrial Informatics (INDIN 2009), 2009.
13. Alawi SM, Hinai HA, "An ANN-based approach for predicting global radiation in locations with no direct measurement instrumentation", Renewable Energy, vol. 14, no. 1–4, pp. 199–204, 1998.
14. Ozgur Solmaz, Muammer Ozgoren, "Prediction of hourly solar radiation in six provinces in turkey by artificial neural networks", Journal of energy engineering, vol. 138, pp. 194-204, 2012.