SOLAR RADIATION ESTIMATION WITH NEURAL NETWORK APPROACH USING METEOROLOGICAL DATA IN INDONESIA

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ABSTRACT. The objective of this study is to determine the solar energy potential in Indonesia using artificial neural networks (ANNs) approach. In this study, the meteorological data during 2005 to 2009 from 3 cities (Jakarta, Manado, Bengkulu) are used for training the neural networks and the data from 1 city (Makasar) is used for testing the estimated values. The testing data are not used in the training of the network in order to give an indication of the performance of the system at unknown locations. Fifteen combinations of ANN models were developed and evaluated. The multi layer perceptron ANNs model, with 7 inputs variables (average temperature, average relative humidity, average sunshine duration, longitude, latitude, latitude, month of the year) are proposed to estimate the global solar irradiation as output. To evaluate the performance of ANN models, statistical error analyses in terms of mean absolute percentage error (MAPE) are conducted for testing data. The best result of MAPE are found to be 7.4% when 7 neurons were set up in the hidden layer. The result demonstrates the capability of ANN approach to generate the solar radiation estimation in Indonesia using meteorological data.

Keywords: solar radiation, artificial neural network, meteorological data

INTRODUCTION

In Indonesia, some meteorological station only has relative humidity, temperature, wind speed, and sunshine duration recorder. Measurement of solar radiation with reliable and calibrated pyranometers is not available or only available in the limited location.

This study proposes the ANN based for solar radiation potential in many locations in Indonesia. The proposed approach can be used as a method to estimate the solar irradiation potential in the remote and rural locations in the islands with no direct measurement devices.

This paper is organized as follows: literature review about ANN theory and previous works on predicting solar irradiance is described in section 2. The database and the method of ANN application for predicting solar irradiations are presented in section 3. The result of simulation ANN model and evaluations are shown in section 4. Conclusion is given in section 5.

LITERATURE RAVIEW AND PREVIOUS WORK

ANNs consist of an interconnection of a number of neurons. There are many varieties of connection under study, in this study only discuss about one type of the network which is called the multi layer perceptron (MLP). The MLP is the most popular learning rule is the error back propagation algorithm. Back Propagation (BP) learning is a kind of supervised learning. The BP algorithm minimizes the mean square difference between the network

output and the desired output. The MLP have ability to learn complex relationship between input and output patterns.

The advantage of neural networks is their learning ability to perform specific tasks. Learning is accomplished by adjusting the weights of the connections between neurons. Weights are adjusted so that the network can be producing the outputs as close as possible to the known correct answers of training data. During the training stage, the network is learning the rule for associating the inputs with the target outputs. Due to the generalization capabilities of the neural networks, it performs similarly on data for testing that have not used for training (Mohandes et al, 1998).

There are several studies to predict monthly average global solar irradiation potential based on ANN method. Since ANN are highly nonlinear and require no prior assumption concerning the data relationship, they have become useful tool for predicting solar irradiation. Particularly, in the meteorological and solar energy resources fields, ANN based models have been successfully developed to model different solar radiation variable in many location. Jiang (2008) developed estimation of monthly mean daily global solar irradiation using ANN method in China. The data period used are from 1995 to 2004 and the inputs for the networks are latitude, altitude and mean sunshine duration.

Alawi and Hinai (1998) developed ANN model in Oman for analyzing the relationship between the solar radiation and climatological variables in areas not covered by direct measurement instrumentation. Zhou et al (2005) found the estimation of solar irradiation in China based on ANN is superior to other available model. Result indicated that Ann model shows promise for evaluating solar possibilities; however that model is only suitable for Beijing.

From the above reviewed, ANN models have been successfully demonstrated to have potential in estimating monthly average global solar irradiation by many researchers in many countries. However, these ANN models are location dependent and specific to each location. So far, there is no report about estimation of solar radiation potential for Indonesia by using ANN method in many locations, except previous work by authors. In the previous work, Rumbayan and Nagasaka (2010) have developed ANN to estimate solar radiation in Manado location, a city in Indonesia.

This study aims to develop neural network based models for estimating monthly average global solar irradiation potential in many locations of Indonesia based on meteorological data available.

DATA AND DEVELOPED MODEL OF ANN

This section is described about the database used and the method of ANN application for estimating the global solar radiation in the island area of Indonesia. The data were gathered from meteorological station in four cities namely Manado, Jakarta, Bengkulu, Makasar that represent one region in the four big islands of Indonesia that spread over in the part of east and middle of Indonesia. The map of Indonesia with the four locations where the data has been taken are presented in Figure 1.

The database consists of measured value of average solar radiation, temperature, relative humidity, sunshine duration covering the four cities in Indonesia for 5 years (2005-2009) recorded by meteorological station. The data were split into two, as 3 cities (Manado, Jakarta, Bengkulu) were used for training a neural network and 1 city (Makasar) for testing.

Figure 1. Map of Indonesia and location of data.

The training of the models uses a feed-forward neural network with Back Propagation training algorithm. The inputs were monthly average sunshine duration, monthly average relative humidity, monthly average temperature, latitude, longitude, altitude and month of the year. The output was monthly average global solar irradiation potential. Training the model was done using a neural net simulator known as "NeuroShell". The steps are used in this study is described in Figure 2.

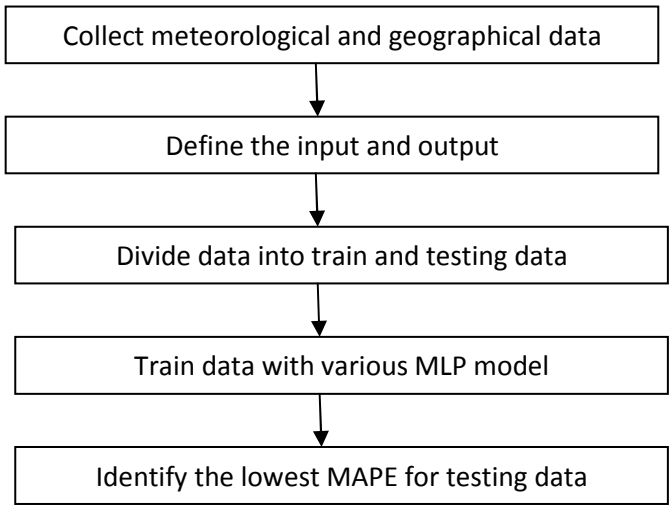

Figure 2. The methodology used in this study

The processes of neural networks for estimating the monthly global solar radiation potential were divided into two sections, i.e training and testing. First, training data, the group of data by which the network adjusts, in order to reach the test fitting of the non linear function representing the phenomenon. In this case, the recorded data in three cities (Manado, Jakarta, Bengkulu) during the period of 2005-2009 were chosen as the training set. Second, testing data, a set of data which is not include in the training data. The function of the testing data is to predict whether the model has effectively approached the general function representative of the learning pattern phenomenon. In this case, the data recorded in Makasar during the period of 2005-2009 as a test data. Data for Makasar were not included as a part of training set in order to make the results can demonstrate the generalization capability of the model to produce accurate estimation for solar radiation as unknown location.

The feed-forward back propagation algorithm with single hidden layer is used in this analysis. Several attempts of ANNs model by changing the number of neuron at hidden layer

in order to find the best MAPE. Predicted values of global solar irradiation were compared with measured values taken from meteorological data through analysis of error, in terms of Mean Absolute Percentage Error (MAPE).

Models are evaluated in terms of errors that are given by Eq. (1) where H_{mi} is measured values and H_{pi} is predicted values for monthly average global solar irradiation, n is the number of testing examples.

The mean absolute percentage error (MAPE) is defined by Eq. (1).

$$\text{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{H_{mi}-H_{pi}}{H_{mi}}\right| \quad (1)$$

In MAPE, sign of errors are neglected and percentage errors are added up to obtain the average. MAPE is commonly used in quantitative forecasting methods because it produces a measure of relative overall fit. It usually expresses accuracy as a percentage.

SIMULATION RESULT AND EVALUATION

This section presents the results of ANN model simulation and evaluation by comparing between measured and predicted neural network values based on statistical error.

The neural networks with multilayer perceptron (MLP) type were trained to estimate global solar irradiation potential in Makasar as testing. Data testing were not included as part of ANN training data. Hence, these results demonstrate the generalization capability of this method over unseen data.

One hidden layer was used in order to minimize the complexity of the proposed ANN model. One hidden layer is chosen to simplify the network architecture proposed. The parameters of learning rate, momentum, initial weight were selected from trial and error attempts, by setting 2 parameters fixed and vary 1 parameter in software simulation. These parameters were optimized during learning step of the ANN, with criteria of statistical error based on MAPE. The parameter selection of learning rate, momentum, initial weight of 0.1, 0.3, 0.5 respectively were used as optimum parameter for ANN model for reporting the result of estimation. The above parameter has been used for training the ANN model with varying neurons in single hidden layer by MLP type.

This study explores 15 models of MLP structures i. e 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 neurons at hidden layer. The performance of the neural networks model in term of MAPE versus number of hidden layer is presented in Figure 3.

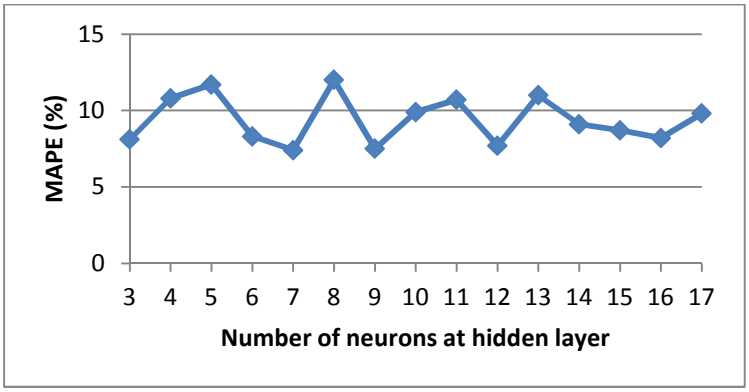

Figure 3. The MAPE versus number of neurons at hidden layer.

After several trials in varying the number of hidden neuron, it was found 7 amounts of neuron to be least error (MAPE = 7.4%) for the testing process in the neural network. The best estimator with the minimum error with 7 neurons at hidden layer was chosen to be presented in this paper as described in Figure 4.

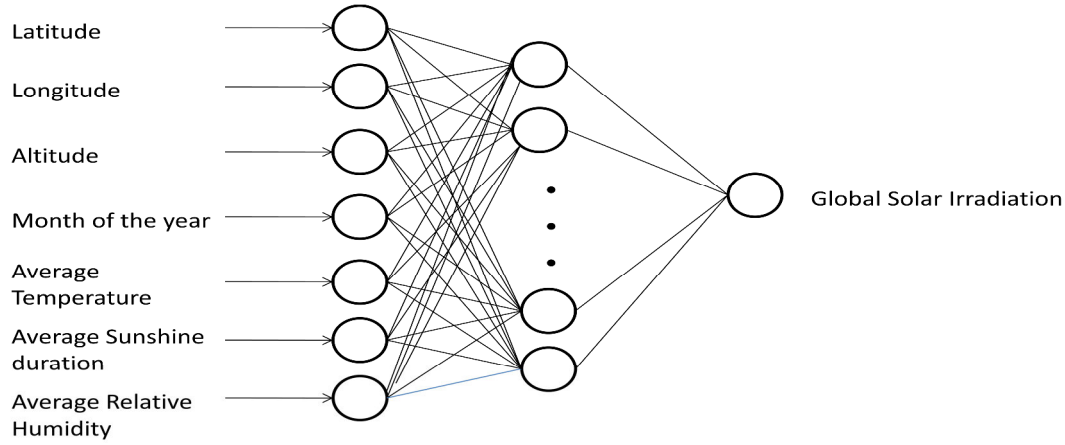

Figure 4. ANN model developed for estimating monthly global solar radiation potential in Indonesia.

Performance the best ANN model (i.e 7-7-1) between measured and predicted values (five years period) of monthly average global solar radiation for Makasar as testing data were presented in Figure 5.

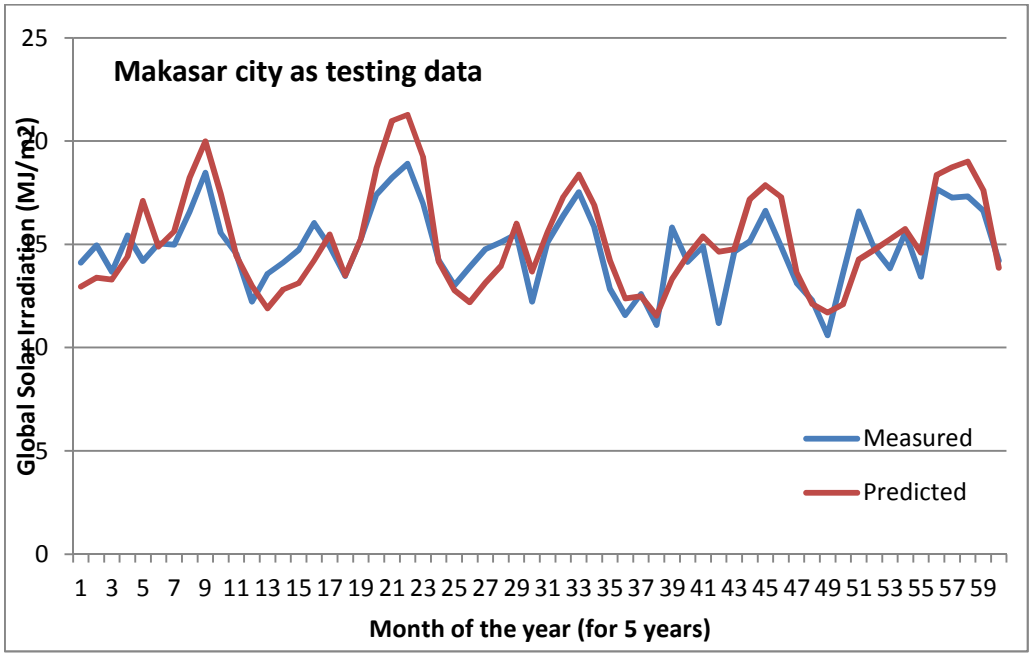

Figure 5. Measured and predicted values with 7-7-1 MLP structure in Makasar (as testing data) for 5 years, during 2005 to 2009.

It was found that the prediction of global solar irradiation obtained for the testing data well compared with the actual measured value, giving a correlation coefficient of 0.86 and MAPE is 7.4 % for testing data. It can be seen that in general, there is a good agreement between measured and predicted value of monthly global solar irradiation potential in Indonesia. This

shows the potential of ANN technique to estimate monthly global solar irradiation in island area of Indonesia in reasonable accuracy.

CONCLUSION

This study has been proposed the model of ANN to predict monthly average global solar radiation in islands of Indonesia. The results of this study indicate that the best of neural networks model for solar radiation potential can achieve 92% accuracy and MAPE of 7.4% when 7 neurons were set up at the hidden layer with the 7 inputs layer, i.e. latitude, longitude, altitude, month of the year, average sunshine duration, average relative humidity and average sunshine duration. Result of this ANN model has shown good agreement between the estimated and measured values of monthly average global solar irradiation.

This study proves that ANN can be used for estimating global solar irradiation potential in some locations in Indonesia by using meteorological data. The use of ANN method can be useful in the remote location for islands sites in Indonesia which there are no solar measurement devices. For further work, the predicted solar irradiation potential values by ANN method were presented in the form of solar mapping for the entire country.

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