Application of Artificial Neural Network for Wind Speed Prediction and Determination of Wind Power Generation Output

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Abstract: Wind power generation increases rapidly. The available wind energy depends on the wind speed, which is a random variable. For the wind-farm operator, this poses difficulty in the system scheduling and energy dispatching, as the schedule of the wind-power availability is not known in advance. In this research, we propose an intelligent technique for forecasting wind speed and power output of wind turbine from several hours up to 24 hours ahead. This technique is based on artificial neural network (ANN). The data was offered by the Japan Meteorological Agency. These data include the “multi-story meteorological data” and the “ground meteorological observation data” of Aomori area where is located in the north of Honshu, Japan. The Back-propagation (BP) neural network is then supplied with the data to establish the relationship between the inputs and the output. The model based on the neural network demonstrated a good agreement and produced the wind forecast with the accuracy of 90% and above.

Keywords: Wind power generation, Wind speed, Wind turbine, Artificial neural network.

1. Introduction
The other side of the wind-power spread of in recent years has worsening environmental problems in consumption of energy. IPCC (Intergovernmental Panel on Climate Change) told that atmospheric levels of greenhouse effect gas, i.e., carbon dioxide, methane, chlorofluocarbon, and the atmosphere of carbon monoxide was increasing certainly by human activities, and there is much correlation between global warming involve greenhouse gas and environmental problems.
It is solved that the degree of carbon dioxide of contribution is the largest of greenhouse gas. The main artificial source of discharge of the carbon dioxide is consumption of a fossil fuel. So, Attention has gathered in the renewable energy replaced with oil in cutting down consumption of a fossil fuel in recent years. Wind energy is also the precious resources contributed to solution of global warming.
But wind energy generation has some difficulty to manage. It arise from wind character. Wind blows because of unbalance of the quantity of heat on the earth by the energy from the sun. So wind is clean energy but unable to regulate artificially.
Experimentally, we know that wind speed changes a lot in short term. Wind speed is intermittent and irregularity. And as wind energy commensurate with area to catch wind and cubed wind speed, slight wind speed difference make wind energy undergo a lot of changes.

Wind power generation is transforming wind energy into electric energy. So, generated power may produce many difficulties.
What problem then arises from those difficulties? One of the problems is that the operator can’t carry out the generation scheduling. Also, there is no guarantee that when there is a need for power there would be the response from the wind energy sources. Another issue is, unlike the thermal and nuclear power which can be always generated, the wind power can’t be artificially secured.

However, still there is an option for overcoming this problem, and that is to predict the wind and provide information to the operator or planner. Basically, this is the core portion of this study which predicts the wind speed based on the actual and forecasted data and projects the hourly wind speed upto several hours ahead. By knowing the wind speed of several hours ahead, we would be able to determine the amount of power which wind turbine can produce.

2. Wind speed prediction technique
Wind speed is non-linear fluctuation. So forecasting is very difficult in normal method. As the technique of solving a nonlinear problem there is a method using the intelligent engineering represented by a neural network, a genetic algorithm, a chaos fractal, etc. These techniques are already adopted as numerical prediction, prediction of the weather, etc., and the practicality is proved. So we predict wind speed to adopt artificial neural network (ANN), which shows a high performance about pattern recognition and the prediction problem of each field, and as addition, determinate generation output from wind speed to use the characteristic curve of a wind generator. Because it was impossible to get the data of output generated wind turbine, which almost belong to the power company, generation output is predicted. In contradiction to this, it is easy to buy wind speed data from meteorological office.
ANN learns the correlation with the desired output made into the information and ideal of an input, and If a strange input is put into the network of the result, the approximation solution corresponding to it to will be calculated.
When carrying out wind speed prediction using ANN,
output is wind speed. It decided to use input the observation value of atmospheric pressure, temperature and humidity, which consider the cause of generating of a wind. For this study the “surface weather observation data” of year 1998 of Aomori prefecture of Japan has been offered by the Meteorological Agency. ANN learns these hourly data, and simulates wind speed of next 24 hours ahead and finally determinates the generator output of wind turbine. The research chart is shown in Fig. 1.

\[
x_{j}(t) ? 1 \quad \frac{2}{\sum_{j} w_{ij} x_{j}(t)} \quad \frac{?}{i \ ?} (1)
\]

Here \( x_{j} \) is the signal from neuron \( j \), \( w_{ij} \) is the connection weight from neuron \( j \) to neuron \( i \), \( ?_{i} \) is the threshold of neuron \( i \), and \( f(x) \) is the transfer function. A transfer function often uses sigmoid function, which is shown in (2).

\[
f(x) ? \frac{1}{1 + \exp(-x)} \quad (2)
\]

ANN has several advantages. It needs only enough data to learn the relation between inputs and outputs. And in the mathematics model like regression, before asking for a parameter, it is necessary to determine the form of a formula. It can be said that the way applies a neural network to the problem like an open algorithm, or the problem from which a situation changes in time is suitable. Moreover, since a neural network does parallel processing to a mathematics model carrying out calculation processing of series, even if some noises and the error are contained in input data, an output can take out an approximation solution. In addition to this, regional prediction can do by giving the fine data of various points, which is highly related.

3. Artificial neural network
As for the nervous system of a living thing, many neurons are combined intricately and each is performing parallel processing. McCulloch-Pitts proposed the model of the neuron shown in (1) based on the principle of the neuron in such a living thing system of operation in 1943.

\[
E_{p}(w) ? \frac{1}{2} \sum_{i \ ? j} w_{ij} \ x_{i} \ x_{j} \quad (3)
\]

\[
E(w) ? \frac{1}{p} \sum_{i \ ? p} E_{p}(w) \quad (4)
\]

Here, \( w \) is the connection weight vector, which has each connection weight \( w_{ij} \) of ANN as an ingredient.

The BP method deals with the minimization problem of this total error function \( E(w) \).

4. Simulation
The wind power generation output will be influenced according to wind speed difference. If wind power generation output is not known to some extent, wind power will become what it is very hard to treat, when adjusting the whole system of the amount of power generation compared with the thermal power generation and nuclear power generation. Therefore, based on the feature of a wind, the necessity of predicting the amount of power generation outputs in a short term in advance comes out.

In this research, wind speed will be predicted using the
neural network for 1998 of "surface weather observation data" of Meteorological Agency offer using the data of Aomori Prefecture. Suppose that the target term of prediction is from several hours of the point to 24 hours from research data, and the optimum network is examined by the try-and-error method about each element in connection with the simulation in ANN.

First, concrete input data is selected. Input data is based on air pressure, temperature, humidity, and time. It extended and considered from these categories. As the result, in addition to the selected inputs, the following information is also added for better performance of the wind prediction. They are, past 1 hour and past 24 hours of each temperature, humidity, and air pressure. Minimum, maximum, and average values of temperature, humidity, and air pressure were also added to the data. Moreover, difference between the present and these past an hour were also taken into account.

Second, the form of training (learning) and test (prediction) data is decided. In wind speed prediction, it has the characteristic that accuracy falls. So, validation data is prepared in training data. Validation data sets up in order to improve a prediction result more. In training, total error function is changed by whole training data. But the result network is decided by the best validation data. This has improved the result of prediction. The composition data is shown in Fig. 2.

Fig. 2 Training Data & Test Data

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<tr>
<th>month</th>
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Next, the structure of ANN is decided. As wind speed in changing continuously, it is needed to predict some hours ahead based on the very recent changes. For this purpose, we used another form of ANN, known as Recurrent Back Propagation, RBP (Fig. 3). RBP will feedback the output of period \( t \), which will feed forward again to the hidden layer and then produce the output for period \( t+1 \). Therefore, the output of \( t+1 \) will have the recent information of period \( t \) as well as the newly fed inputs.

Finally, parameter of ANN is selected, i.e., learning rate, momentum, number of hidden neurons, and length of training data. After simulation of ANN in these situations, it is predicted wind speed up to 24 hours ahead. Here, an example of wind speed predictions for September 6th, 1998 is given in Fig. 4.

Fig. 4 Result of Wind Speed Prediction in September 6th

After predicting the wind speed, then we can proceed to determination of wind turbine output. For this purpose, the power curve of a 300kW wind turbine (Made by Mitsubishi Heavy Industry) is assumed at a wind farm in Aomori Prefecture (Fig. 5).
Generated output is determination by Fig. 5 curve. Wind speed is rectified in the altitude of the wind turbine given in equation (5). Therefore in order to calculate the wind turbine output, we have to use the following equations and the power curve of each turbine, respectively.

\[ V_Z = \frac{V_1 Z}{Z_1} \left( \frac{n}{N} \right) \]  

(5)

\( V_Z \): Wind speed at the point of height \( Z \)  
\( V_1 \): Wind speed at the point of height \( Z_1 \)  
\( n \): The case of relative roughness of surface

A typical result is shown in Fig. 6.

Fig. 6 Result of Determined Wind Turbine Output

5. Discussions and Concluding Remarks

Wind power generation, as a disperse power resources, is expected to connected to the power grids than ever in the future. This is based on the attention of people to the environment, which comes from the increase of clean energy power resources. Wind power generation together with solar power generation play an important role for this purpose.

Basically, wind power generation is used as reserve power supply for peak period. Nowadays, many power utilities have combined the wind power generation to their existing power generation. However, as the wind turbine output is produced by the power of wind, and as the wind is often fluctuating, thus determination of wind turbine output becomes difficult. Therefore, there is no guarantee that wind turbine produce power when there is a demand for electricity. In another words, the planner cannot count on wind power generation as the peak power resources. However, if we can forecast the wind speed, then we are able to determine the turbine output. This is the main contribution of this study.

For this purpose, in this study, we applied the artificial neural network, which is an efficient tool for prediction of wind speed and determination of wind power generation output. In order to persuade this research, the authors have prompted several simulations on selection of proper neural network structures, parameters and optimized length of necessary data.

As the result of these simulations, a recurrent neural network which consists of three layers in which its hidden layer has 11 neurons. Also we obtained that three month of regional data which is belong to Aomori Prefecture wind park is sufficient for recognizing the relationship between our target wind speed and the correlated factors which have the most impacts. After proceed many simulations, we could successfully predict the wind speed from 1 to 24 hours ahead with the accuracy of about 90%. Less than 45kW prediction error, as tolerance level, has been set for the judgment of results. The object was a Mitsubishi-made 300kW wind turbine.

In addition, it should be noted that the output of wind turbine shown in Fig. 6 is determined using the result of predicted wind speed (Fig. 4) after employing equation (1) and then adjusted to the power curve of wind turbine (Fig. 5). Still there are many rooms for further research such as; improve the accuracy of wind speed prediction, search for better network structure (if possible), apply the proposed method to different size of wind turbines. Also, in order to achieve better results, it is considered that it is better to give more input elements like geographical factors than increase of learning data, and so forth.

References

