Wind Power Forecasting Based on Time Series and Neural Network

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Abstract—The wind farm output power have the characteristics of dynamic, random, large capacity etc, which brought great difficulty for incorporating the wind farm in the bulk power system. In order to rationally regulate the power supply system in large grid connected wind power system and reduce the spinning reserve capacity of the power supply system and operating costs, it is necessary to forecasting the capacity of wind power. For the randomness of the wind farm output, we use the ARMA (q, p) model of time series to forecast wind speed and atmospheric pressure, and using the RBF neural network based on this to forecast wind power. Taking the data of measured wind speed and atmospheric pressure from a wind farm as example, to validate the method described above, and the result show that the method has a certain practicality.

Index Terms—wind power, forecasting, time series, RBF neural network

I. INTRODUCTION

Wind power is a kind of renewable clean green energy the world’s fastest growing at present, and is generally accepted alternative energy technology within a global range. It has become the one of the new main power supply of European and the United States, and also is the important development direction of the renewable energy strategy in China. However, the wind power have the shortcomings of intermittent and volatility etc, the wind power fluctuations need to be balanced through the regulation of standby generators and energy storage system when it was accessed to grid, which is a problem long plagued wind power. If the forecasting of wind power is available, we can reasonable arrange the operation of conventional generator sets, reduce standby installed capacity of power system, improve power system stability and increase the ability of large power grid to accept the wind power, so it has great significance to implement the forecasting of wind power.

Currently, there are two major steps to complete the short term forecasting of wind farm generated energy: 1, To forecast the wind speed and wind direction in the hight of wind wheel hub of wind generator by using wind speed model, then to calculate the orthogonal wind speed component of the wind speed and wind swept round plane. 2, To calculate the actual output power by using wind generator model. At present, there are two main ways for the latest research: one is based on the physical model; the other is based on the statistical model.

The errors of wind speed forecasting of wind farm mainly related with the forecasting methods, the forecasting cycle and the wind speed characteristics in the forecasting place. In general, the shorter the forecasting cycle and the more relaxed the wind speed change in forecasting site, the forecasting errors will be smaller; on the contrary, the forecasting errors will be larger. Wind speed forecasting can be divided into the short-term wind speed forecasting and the long-term wind speed forecasting. Accurate short-term wind speed forecasting is beneficial to adjust the dispatching plan for the power dispatching departments and reduce the adverse effects to the grid from the wind farm, thus effectively reducing the operating costs and spinning reserve of the power system and beneficial to develop the right electricity exchange program in an open electricity market environment; accurate mid long term wind speed forecasting is beneficial to the planning of wind farm. This article focuses on the short-term forecasting of wind speed.

In this paper, to forecast wind speed by using the method of time series, which the data requirement is low and the cost used to forecast is also low, so it is suitable for the actual operation of businesses. Considering the high degree non-linear relationship showed between the wind speed data and the corresponded generation power, RBF neural network to be used to forecast generation power. And to verify the feasibility and effectiveness of the method in this paper through the experimental data from a wind farm.

Algorithm flow is shown in Figure 1:

[Diagram of data flow]

Fig.1 Data flow
II. THE INFLUENCING FACTORS OF THE OUTPUT POWER OF WIND FARM

The wind power captured by wind turbine can be represent use\(^{(1)}\),
\[ P = C_p S \rho v^3 / 2. \]

Where: \( P \) is output power of Fan, KW; \( C_p \) is the power coefficient of Fan; \( \rho \) is air density, \( \text{kg/m}^3 \); \( S \) is the area of the wind swept round, \( \text{m}^2 \); \( v \) is the wind speed of the fan windward;

\[ \frac{P}{\rho} \]

Figure 2 is a power curve of a variable speed wind turbines, in the region of the power curve with more steep, the smaller changes in wind speed will cause the larger changes in power. Figure 3 is a scatter diagram of the measured output power of wind turbines and wind speed, we can see the wind turbines output power has a certain dispersion. This is due to the effects of mechanical turbulence and thermal turbulence, and the spatial distribution of wind speed did not fully comply with the logarithmic wind profile; the other hand, the Yaw device of wind turbines make fans to align the wind direction according to the vane and the wind speed in the height of hub, but there may be some delay, and fans not always being right to the wind direction. This has resulted the different output power with the seemingly similar wind speed

Air density \( \rho \) is also an important factor affecting the output power. The power curve of the variable speed wind turbines with different air density is shown in Figure 4. We can see from the figure, the wind turbines output power will be larger correspondingly with the air density increasing. Air density closely related with humidity, temperature and pressure. Therefore, the pressure factors need to be considered in wind power prediction.

We can see from the above equation of fan output power, \( C_p \) and \( S \) are constants can not be changed, and only the air density \( \rho \) and the fan windward wind speed \( v \) are variable. So we can know that the main factor affecting power generation of the wind turbine is wind speed and atmospheric pressure.

III. TO FORECAST WIND SPEED USING TIME SERIES

Time series is a modern approach in data processing. At present, the correlation analysis and the cycle burst are the widely used traditional methods. The most fundamental difference between the two is that the parameter model is used to analyse and pretreat dynamic data (time series) for the former method. This method is to set the parameter model that is series model for time dynamic data, and then to obtain the statistical characteristic of dynamic data through this parameter model; and the time series also show the order relationship of the data when it demonstrate the data size.

The wind speed has a very good timing and randomness, and using time series to forecast is more suitable. This paper prepare to forecast the wind speed of wind farm using the Auto Regressive Moving Average model (ARMA) of time series, and this method can forecast only need a single wind speed time series. As follow is the ARMA \((p, q)\) model of wind speed data use\(^{(2)}\):
\[ X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \cdots + \phi_p X_{t-p} - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q}. \]

Where: \( p \) is the autoregressive order of model; \( q \) is the moving average order of model; \( \phi, \theta \) are the nonzero undetermined coefficients; \( \varepsilon_t \) is an independent error term, and the \( \{\varepsilon_t\} \) is normal white noise process. It’s mean is zero and the variance is \( \delta^2 \); \( \{X_t\} \) is the time series of wind speed.

The most complex problem of ARMA \((p, q)\) model is to determine the order of model. In this paper, using AIC (Akaike information criterion) standard: the minimum
information criterion, while giving the ARMA model technology and the best estimate of parameters, and using the sample with fewer problems. Judging what kind of random process is close to the development process of forecasting goal. Because only when the sample size is large enough, the autocorrelation function of sample can be very close to the autocorrelation function of original time series. For the specific application, making the model order range from low to high within prescribed limits and calculating the AIC value, and finally determining the order made its value is minimum, which is the right order of the model.

The maximum likelihood estimate of model parameters use $(3)$, 
\[
AIC = (n - d) \log \delta^2 + 2(p + q + 2). \tag{3}
\]

The least-squares estimate of model parameters use $(4)$, 
\[
AIC = (n - d) \log \delta^2 + 2(p + q + 1) \log n. \tag{4}
\]

Where: $n$ is the sample number, $\delta^2$ is the fitting residual square sum, $d$, $p$ and $q$ are parameters. To calculate the values of $\varphi_1, \varphi_2 \cdots \varphi_p$ and $\theta_1, \theta_2 \cdots \theta_q$ by the maximum likelihood estimate and the least-squares estimate after the model order was determined, then the ARMA $(p, q)$ model is determined. Testing the applicability of the model after the model was determined, and testing whether the $\{e_t\}$ is white noise, if it is then the model is available, if not then need to re-build model until the test is set up.

In this paper, the raw data are the measured wind speed of a wind farm. The ARMA $(4, 3)$ model modeling by using the method of time series, which is the average wind speed, and building a mathematical model using the data of 30 days; the result is shown in Figure.5(a) and autocorrelation of the prediction error in Figure.5(b). The absolute mean error of forecasting was about $24\%$; the maximum error was $41\%$ emerged in where the wind speed changes most violently. This also indicates that the regularity is stronger and the forecasting accuracy is higher in where the wind speed changes more gentle;

while the regularity is weaker and the forecast accuracy is lower in where the wind speed changes more rapid.

IV. EURAL NETWORK FORECASTING OUTPUT POWER OF WIND FARM

The random changes of wind farm output power mainly due to the fluctuations of wind speed and wind direction, while the different fans located in the same wind farm have the almost same wind speed and wind direction. So we can assume all fans in the same wind farm have the same wind speed and wind direction. Using an equivalent wind turbines to simulate the wind farm, and the tail flow coefficient was setted to 0.9.

The relationship between the wind turbines output power $P_w$ and wind speed $v$ in the height of hub can be approximately expressed by the power curve of wind turbines (Figure 2) or the sub-function use $(5).$

\[
P_w = \begin{cases} 
0 & v \geq v_{ci} \text{ or } v \leq v_{ci} \\
\frac{P_r}{v_{ci}^3 - v_{ci}^3} v^3 & v_{ci} \leq v \leq v_{ri} \\
\frac{P_r}{v_{ri}^3 - v_{ci}^3} v_{ci}^3 & v \geq v_{ri} 
\end{cases} \tag{5}
\]

Where: $P_r$ is the rated output power of fan, kW; $v$ is the wind speed in the height of fan wheel hub, m / s; $v_{ci}$ is the cut in wind speed, the automatic device moves the fan into the power grid when the wind speed is higher than this setting value; $v_{co}$ is the cut out wind speed, the fan stops powering and lists from the power system when the wind speed is higher than this value; $v_{ri}$ is the rated wind speed, the fans contribute is rating when the wind speed is higher than or equal to this value but less than the cut out wind speed.

We can see that the strong regularity of the wind speed was further damaged by the wind turbines power curve from the above generation power curve, and got the regularity of wind power is more weaker. Therefore, we introducing the RBF neural network to forecast it in this paper.
Neural network is established based on the basic principles of the biological neural networks, which is a class of adaptive system composed of many simple processing units called neurons. Multilayer feedforward neural network can be seen as the non-linear mapping from the input space to output space. It was proved that the forward neural network with one or more hidden layers can approximate any consequent non-linear function at any degree of accuracy. The study process of neural network is to find a suitable weight vector, and thus be able to approximate function. The size of weight determines the all informations of the neural network. The study process of neural network is a process of amending the weight, which in order to enable the mapping represented by the network be close to the required mapping as much as possible. Back propagation algorithm is a learning method commonly used by multilayer feedforward neural network, which actually is a minimization method with the gradient descent.

Radial Basis Function (RBF) network is proposed by Powell M.J.D in 1985, which is a class of feedforward network taking the function approximation theory as the basic construction. Because the convergence of BP network is slow in function approximation and easy to fall into minimum part, and very incompatibly with the biological context in theory, so in recent years the researchers pay more attention to RBF network. The RBF network is a neural network only containing a hidden layer; the radial basis function is a two-tier network. In the middle layer, it use the radial basis function responding to part to instead the traditional global responded excitation function. These good characteristics of RBF shch the simple struct ure, a fast training process and has nothing to do with the initial value make it was widely applied to the forecast field.

RBF network design include structure design and parameter design. Structure design mainly resolve the problem that how to determine the number of network nodes. Parameter design in general consider the three kinds of parameters including: the data center of basis function , expansion functions and the weight of output node.

According to the method of getting value from data center, the RBF network design methods can be divided into two categories:

The first class method: data centers are selected from the input samples. Generally speaking, the centers in the density area of samples can be more, and the centers in the sparse area of samples can be less; such as the datas itselfs was uniformly distributed, so the centers can be uniformly distributed. In short, the data centers elected should be representative. The expansion constant of radial basis function can be determined by data center, and in order to avoid each radial basis function too sharp or too peace, a selection method is to set all expansion constants of radial basis functions for the use"(6),"

$$\delta = \frac{d_{max}}{\sqrt{2M}}.$$  \hspace{1cm} (6)

The second class method: the self-organization selection of the data center. It often used a variety of dynamic clustering algorithms to autonomously select the data center, and we need to dynamically adjust the location of data centers in the process of learning. The commonly used method is K-means clustering, and its advantage is that it can determine the expansion constants of the hidden points according to the distance of the each cluster center.

we use the second class method to build radial basis function in this paper, shown in Figure 6:

In this picture, $x_i$ is expressed as wind speed and air pressure, and the data output is the output power of wind farm.

The calculated results to the above obtained data using RBF was shown in Figure 7:

We can see from the forecasting maps the absolute mean error of forecasting was about 24%; the maximum error was 41% emerged in where the wind speed changes most violently. This also indicates that the regularity is stronger and the forecasting accuracy is higher in where the wind speed changes gentler; while the regularity is weaker and the forecast accuracy is lower in where the wind speed changes more rapid. Its essence lies in that the imprecision of wind speed forecasting and air pressure forecasting directly passed to the wind speed forecasting. If we want to further improve the forecasting...
accuracy, we need to find the ways to improve the forecasting accuracy of speed and pressure in wind farm.

V. CONCLUSIONS

The technical requirements(try out) of national grid wind farms accessing grid clearly pointed out the need for forecasting the wind farms power. The analysis of time series and the RBF neural network will be introduced into the wind power forecasting in this article. The forecasting of wind power has a great significance to the construction and operation of wind farm. The study Conclusions of the above mentioned wind power forecasting system have:

Time series model is a dynamic model, which has a very good extension to dynamic data, thereby it could avoid the impact of the directly adding “Window” when we strike the statistical properties of dynamic data. For the random and dynamic of wind speed, the method of time series ARMA reflects a larger advantage.

RBF neural network has a very good non-linear learning ability and a advantage in resolving wind power forecasting.

The Changes in the characteristic watery wind make a great difference between the wind power and conventional power. In actual operation, most wind power has anti-peak characteristics. As a consequence, the power system in operation must balance the wind power fluctuations with sufficient standby power supply and peak regulation capacity (the spinning reserve). This not only increases the cost of the entire power system operation, still also bring the hidden dangers to the safe and stable operation in the power grid. In theory, spinning reserve remaining for the wind power are equal with a considerable wind power installed capacity. Therefore, the access to wind power will lead the lower rates of the conventional unit load, and the unit coal consumption to increase.

On the contrary, if the further in-depth study are concentrated on the establishment of this prediction system which are used in the power dispatch center, and the wind electric power are unified into the dispatching plan, then the spinning reserve remaining out of wind power will only be required to meet the forecast error of wind power. As a consequence, the wind power forecast, acted in the city, will increase the rates of the conventional unit load and decrease the unit coal consumption. The wind power forecast will not only improve the economic efficiency, but also conductively make the energy-efficient emission reduction and environmental protection.

In summary, the ARMA-RBF model is not only innovative and pioneering in theory, but also the wind-power forecasting system based on the model has an important practical value and good economic and social benefits.

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REFERENCES