Prediction of outlet air temperature of direct air condenser based on BP neural network

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Abstract. At present, the dynamic parameter monitoring technology of the direct air cooling system is relatively weak. According to the study of outlet air flow temperature characteristics, this paper proposes a direct air condensing unit outlet air flow temperature prediction model based on BP neural network for studying dynamic parameters of direct air cooling units. The historical data of each factor is collected from the on-site DCS system. After the data is preprocessed, the BP neural network is used to establish the air temperature prediction model of the air condenser. Finally, the model is validated by the data that does not participate in the training. The model can predict the outlet air temperature of the air condenser under different working conditions, providing a basis for the next step of developing dynamic parameter monitoring technology, and also provide a reference for the cleaning cycle of the air condenser.

1. Preface

With the continuous development of the power industry, many large-capacity and high-variable thermal power generating units have been built in recent years, which not only consumes a large amount of primary energy but also consumes a large amount of water resources. The distribution of water resources in China is uneven, and many areas in the north are seriously deficient in water. The air-cooling technology of air-cooling unit with air as the cooling medium has become the core technology of thermal power generation in coal-rich and water-deficient areas and the necessary technical measures for water-saving and emission reduction of thermal power plants with its remarkable water-saving advantages. The direct air cooling unit provides air cooling turbine exhaust through the fan, which greatly saves water consumption and operating cost. Direct air cooling system has advantages of no intermediate medium and secondary heat transfer, improving heat exchange efficiency, small heat transfer area, no need for large cooling tower, small floor space, relatively low initial investment, and flexible operation. More and more countries have recognized it and used the system [1, 2].

In the aspect of air-cooled dynamic parameter monitoring, some researches have been carried out on the temperature field or flow field of air-cooled islands [3-5]. Some focus on numerical simulation research, and some focus on mechanism and experimental research, but there are few studies on the dynamic monitoring of air-cooled island temperature field and flow field variables. Zhihua Ge et al.[6] used infrared technology to monitor the air temperature field of the air condenser, and Xu Tie [7] targeted the existing air-cooled island temperature. There are few measuring points, and it is impossible to monitor the temperature change of the temperature field of the entire air-cooled island. It is proposed to use wireless temperature sensor to collect the temperature data of the air-cooled island
temperature field. Liao Guangming et al. [8] used the “one-wire system” to monitor the temperature of the air condenser. Field distribution.

In this paper, a 2×300MW direct air condenser of a gangue power generation company is studied. The relevant historical data is collected from the power plant DCS for modeling. For the convenience of analysis, the data is firstly normalized and preprocessed, and then through the network training, the prediction model of the outlet air temperature is obtained, and the outlet air temperature of the air condenser under different working conditions can be predicted so as to facilitate the reasonable arrangement of the position and quantity of the air condenser temperature measuring point, which can also be used as a reference for the cleaning cycle of the air condenser.

2. Structure of direct air condenser
A 2x300MW unit of a gangue power generation company uses a direct air condenser, which passes the heat from the steam exhaust of the turbine through an air-cooled radiator, and condenses the steam exhaust from the steam through the heat exchange between air and steam. Steam turbine exhaust. It is guaranteed that the turbine will operate at low back pressure. Its cooling medium is ambient air. The process flow is that the steam exhaust of the steam turbine is led to the outdoor air condenser through the coarse exhaust pipe, and the axial cooling fan sends the air out of the outer surface of the radiator [9]. The air-cooling condenser of the 2×300MW circulating fluidized bed direct air-cooled generator set adopts SPX single-row tube technology. There are 24 air-cooled radiators in a single unit, divided into 6 columns each with 4 cooling units. The second cooling unit of each row is steam-water counter-flow type, the other is steam-water down-flow type, and the angle of radiator tube of air cooler is nearly 60°. It is an isosceles triangle (Λ type) structure, and an axial fan is arranged under each cooling unit. The fan has 6 blades, the diameter of the fan is 10.363m, and the area of a single cold zone is about 800,000 square meters. The structure of the condenser is shown in Figure 1 and 2:

![Figure 1. "Λ" structure.](image)

![Figure 2. Schematic diagram of the downstream and counter current structure of an air condenser.](image)

3. BP neural network
Back Propagation (BP) is a one-way propagating multi-layer forward network. The system solves the learning problem of hidden unit connection rights in multi-layer networks. It is the most widely used neural network model.
The central idea of the BP neural network algorithm is to adjust the weight to minimize the total network error. The basic principle is gradient steepest descent method and gradient search technology is used to minimize the error mean square between the actual output value and the expected output value of the network.

When multi-layer networks use BP learning algorithms, they include the first two stages of propagation. In forward propagation, the input values propagate forward layer by layer, up to the output layer. Nodes are only affected by the previous node. If the output layer does not receive the preset value, it goes to backpropagation and inversely calculates the difference (the difference between the expected output value and the actual output value) on the connection path. By modifying the weight of the neuron, the goal of minimizing the difference is achieved.

Figure 3 is a typical BP network structure diagram showing a network structure with only one hidden layer, the different layers are completely interconnected, and the same layers are not connected to each other. There is only one input and output layer, and each layer has many nodes.

In the figure, ‘i’ denotes the neuron number of the input layer, ‘j’ denotes the neuron number of the hidden layer, and ‘k’ denotes the neuron number of the output layer.

4. Neural network modeling and analysis

4.1. Selection of model variables

This model is based on a unit of the air-cooling condenser of the test unit. At present, there is 16 temperature measurement points in one unit of the air-cooled condenser of the unit. This set of measurement system is installed after the unit is put into operation. Although the outlet air temperature of the air condenser can be monitored, the position of the measuring point is fixed, the measuring point distribution distance is large, and it is equidistantly arranged, and can not fully reflect the change of air cooling temperature. Further research is needed. The location and number of measuring points and the connection between software and hardware is not very good, it will cause poor communication. The arrangement of measuring points is shown in Figure 4:
There are many factors affecting the outlet air temperature of the direct air condenser. Refering to Lijun Yang [10] for the analysis of the performance evaluation of the direct air condenser and the actual operation of the power plant to determine the unit load, exhaust pressure and exhaust steam temperature. The condensate temperature, ambient temperature and axial fan speed are the input variables of the BP neural network. These six variables can be obtained through online monitoring of the system. The output temperature is based on the currently measured outlet temperature. By analyzing the output data, the position of the measuring point is unreasonably arranged, the output value difference between some adjacent measuring points is not large, so the average value is selected to represent the temperature of this area, and the typical temperature values are collected one by one. It is finally determined that the nine effective outlet air flow temperatures are the output variables of the model.

4.2. Data Processing and Model Construction

The unit and variation range of each variable are different. In order to shorten the network training time and improve the training accuracy, the established sample needs to be preprocessed by the formula (1) to normalize the data. The raw data is linearly transformed to map the result to $[0, 1]$.

$$x_n = (x - x_{ll}) / (x_{ul} - x_{ll})$$  \hspace{1cm} (1)

Where $x_n$ is the normalized value of the variable $x$, $x_{ll}$ is the lower limit of the variable, and $x_{ul}$ is the upper limit of the variable $x$.

According to the actual working condition of the direct air condenser, combined with the selection of the above model variables, the nodes of the input layer are composed of the parameters of the unit load, the exhaust steam pressure, the exhaust steam temperature, the condensate temperature, the ambient temperature and the axial fan speed. Since there is only one outlet air temperature parameter, the number of nodes in the output layer is 1. Only one hidden layer is set in the network. According to the Kolmogorov theorem [12], if the output layer of the 3-layer neural network is $n$ nodes, the hidden layer should be $2n+1$ nodes. Therefore, the number of hidden layer nodes in this network is 13. The implicit layer neuron transfer function of the network is a S-type tangent function: \( \tan \text{sig}(n) = 2 / (1 + e^{-2n}) - 1 \), and the output function of the network's output layer is a linear function \( \text{purelin}(n) \). The training function of the network is \( \text{trainlm} \), and the learning function of the network is \( \text{learngdm} \). The target error is set to 0.001 during training, and the maximum number of iterations is set to 15000 through multiple experiments.

4.3. Model training and verification

The input parameters for the prediction model are the same, but the nine different measurement points have different output results due to different positions. Therefore, this prediction uses nine different measurement points as the output parameters of the nine models, meaning nine are established. The prediction model respectively predicts the change in the outlet temperature at which the nine output points represent the position. Since the computing mechanism and modeling ideas are the same, this paper takes one of them as an example to model.

After determining the BP network structure and initial parameters, According to using the Simulink toolbox of MATLAB software, the actual data of the six input parameters is used as the input signal of the network, and the outlet air temperature data of the air condenser is used as the output signal. After normalization, the network training is started. The training performance curve of the network, the comparison curve between the training output and the actual output, and the relative error curve of the training process are respectively shown in Figure 5, Figure 6 and Figure 7.
Figure 5. Training performance curve.

Figure 6. Comparison of training output versus actual output.

Figure 7. Relative error curve of the training process.

Figure 5 shows the calculation based on the mean square error performance evaluation function (mse). After the iterative 5624, the training error of the BP network has reached the preset error of 0.001. From Figure 6, the trend of the actual output and the predicted output can be seen. Consistently, as can be seen from Figure 7, the errors in the sample training process are all concentrated in ±4% fluctuations, most of which are within ±2%. It shows that the dynamic response of the whole training process is very good and can meet the requirements.

After the network training, the test samples composed of 100 sets of data that did not participate in the training are used to further test the predictive power of the network. The test sample is imported into the trained BP neural network. The comparison between the predicted output and the actual output of the test sample is shown in Figure 8. As can be seen from Figure 8, the predicted value and the output value are not only consistent, but also have many parameters and even overlap. Figure 9 is a graph of relative error. As can be seen from Figure 9, the relative errors of 100 detected sample points are all distributed around ±8%, and most of them are concentrated within ±4%. It is proved that the prediction result of the prediction model is more accurate. It can provide reference value to the operation of the unit to a certain extent.
Figure 8. Comparison of test output and test sample.

Figure 9. Relative error plot of the inspection process.

5. Conclusions
In this paper, the BP neural network is used to establish the forecast model of outlet air temperature of the direct air condenser, and the actual data is used to verify the validity of the model. The built model has the following advantages:

1. The BP airflow network can be used to establish a direct air-cooling condenser outlet air flow temperature prediction model, and it can accurately predict the change of the outlet air temperature in a certain area under variable operating conditions.

2. The predicted value can be used to optimize the number of measuring points and position of temperature sensor (The position can be changed from time to time based on the predicted result) of the direct air condenser outlet air temperature in the next step, according to the predicted next working
condition, the temperature in this area is compared with the actual value now, and if the difference is large, it will need to be measured frequently. If the difference is small, the number of measuring points can be reduced appropriately. At the same time, it provides certain guidance for antifreeze, energy saving and consumption reduction in winter.

3. After optimizing the measuring point, according to the comparison between the predicted value and the actual value, it can also make a preliminary judgment on the operation of the air condenser and the unit, and provide a certain reference for the cleaning cycle of the air-energy condenser.

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