Real Time Operating Parameters Optimization of Thermal Power Units Based on Deep Learning Method

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Abstract. Based on big data analysis, for the actual operating data, the method of dividing non-uniform working conditions was studied to obtain typical data of different working conditions. The traditional sliding pressure curve is only a shortcoming of the single value function of the load. Convolution neural network is applied to build a nonlinear model of load, main steam temperature, reheated steam temperature, ambient temperature and main steam pressure. And then, the real-time optimized value of the main steam pressure is obtained. After verification, the model is proved to be satisfactory in both precision and regularity. Finally, the main steam pressure optimization model is applied to the actual 300MW thermal power unit, and closed-loop control is performed. The results prove that the application of real-time main steam pressure optimization can effectively reduce the energy consumption of the unit, and have higher energy saving potential at different ambient temperatures.

1. Introduction
In my country's energy structure, thermal power generation is still dominant and cannot be changed in the short term\([1]\) \([2]\). Among the thermal power units in my country, the coal consumption for power generation is uneven, and the gap exists. In fact, the main steam pressure is not a single-valued function of load, but a complex function related to various factors such as load, condenser vacuum, and circulating water flow. The variable working condition characteristics of the main and auxiliary steam turbine are studied. Many researchers have done a lot of work. Among them, Reference \([3]\) adopted an improved krill swarm optimization algorithm, with the main steam pressure as the target. At the same time, the recovery state network was used to establish the prediction model. Finally, the operation curve of turbine slide pressure was optimized. In literature \([4]\).

There are generally two methods for the modeling of thermal power units and running state reconstruction \([5]\): traditional theoretical model methods and statistical data analysis methods. The traditional theoretical model is used to analyze the characteristics of the thermal equipment and system. Large data technology refers to the ability to quickly obtain valuable information from various types of data in order to solve the shortcomings in traditional research methods\([6]\).

2. Working condition division for historical data
There are many problems in domestic units, such as participation in peak regulation, large range variation of unit load and variety of coal samples. Since the operation data on power plant units are multi-parameter and a large number of data, it is almost difficult to find the data with the same working condition and meet the requirements of data mining. It is difficult to meet the data mining requirements. The current working condition division methods mainly include equal width method, equal frequency method and clustering algorithm and so on\([7,8]\).
Fuzzy C-means clustering algorithm (FCM, Fuzzy C-Means) was first proposed by Dunn and then developed by Bezdek. The basic steps of FCM: (1) First, the number c of sample division classes and the initial clustering center are determined. The initial membership matrix and weight coefficients of samples belonging to different categories are introduced. (2) Then, according to the principle of determining the minimum distance, each sample is assigned to one of the c categories. The cluster center and membership matrix to adjust each sample category are continuously iteratively calculated. (3) Finally, the sum of squared distances within the class with membership weighting is minimized. Furthermore, the classification of the sample points is determined to achieve the purpose of automatically classifying the sample data [8, 9].

According to the one-year mass data stored in the SIS system database of a 300MW thermal power unit of a power plant, five boundary parameters with strong energy consumption sensitivity are selected to determine the working conditions: The load, main steam temperature, circulating water flow rate, circulating water inlet temperature, and reheated steam temperature are used to divide the working conditions. This article chose to divide each parameter into 10 groups, the results are as follows[9,10].

The results of load C-means clustering algorithm to divide the working conditions are shown in Fig 1.

It can be seen from the figure that the final division results of the five operating boundary parameters of the power plant units are not uniform. When the fuzzy C-means clustering algorithm is used to divide the five operating boundary parameters of the power plant unit, the membership of each sample point to all the class centers is calculated. The classification of the sample points is determined, so that each parameter is divided into 10 groups of similar working conditions. According to the concentration of the sample, the size of the working interval is automatically adjusted. The traditional clustering algorithm's shortcomings such as hard division and instability are overcome with this method, which has a better division effect.

3. Optimization of main steam pressure based on convolution neural network

3.1. Modeling process

Convolution neural network[13, 14] is a feed-forward neural network. It uses a series of convolution
layers and down sampling layers to build a multi-layer network to simulate the layer-by-layer processing mechanism of the human brain to perceive visual signals, thereby extracting multi-level features. The basic structure of the network consists of the input layer, the convolution layer (C), the down sampling layer (S), the fully connected layer (F), and the output layer. Convolution layer and down sampling layer can be multiple.

In this paper, five boundary parameters with high energy consumption sensitivity factors, such as load, ambient temperature, main steam temperature, reheated steam temperature and circulating water flow, are selected in the thermal system of the power plant. The main steam pressure of the unit is the optimization goal. A parameter real-time optimization model is established.

First, the load, circulating water inlet temperature, main steam temperature, reheat steam temperature and circulating water flow rate are normalized. The original data is converted to [-1, 1] as the input node. The main steam pressure of the unit is used as the output node. Finally, the regression results are processed with inverse normalization to obtain effective and accurate optimization results. The overall flow chart of neural network modeling is shown in Fig.2.

![The SIS database](image)

**Fig.2** The overall flow chart

The historical data of the unit for one year is preprocessed and the working conditions are divided. 6088 effective working conditions under different working conditions are obtained as the data basis. 5000 sets of data were randomly taken to train the neural network, and the remaining 1088 sets of samples were used to test and predict. Due to the huge amount of data, in order to make the comparison clearer and more obvious, 10% of the training data is taken out. Namely 500 sets of data are displayed as graph. After a lot of testing and comparison, it is finally determined that the input layer is a convolution layer and a hidden layer. Learning rate is set to 0.1, 60 iterations and batch data size is 10. The results and accuracy analysis of neural network training and prediction are shown in Fig. 3–Fig. 6.
The average relative error results of the training and prediction of the convolution neural network are 1.2305% and 0.9011%, and a higher accuracy is achieved. In order to verify whether the model conforms to the corresponding theoretical law, the input parameters (circulating water inlet temperature, main steam temperature, reheat steam temperature and circulating water flow rate) are determined, and the load optimal initial pressure curve under typical load conditions is drawn. Then, the range is changed by an input parameter. The load-optimal initial pressure curve under different boundary conditions is drawn. According to the temperature of the circulating water inlet, the load optimal initial pressure curve is drawn. When the input parameter is selected as a certain value, that is the main steam temperature is 538°C, the reheat steam temperature is 538°C, and the circulating water flow rate is 30000t/h. Then, the inlet temperature of the circulating water is taken as 10°C, 20°C, 30°C. The load is 150MW-320MW under different working conditions. The specific verification regularity process is shown in Fig. 11. The resulting load-optimal initial pressure curve is shown in Fig. 12.

Fig.7 load - optimum pressure curve at different circular water inlet temperature

\(t_{xrw}\) represents the circulating water inlet temperature; \(t_0\) represents the main steam temperature; \(trh\) represents the reheat steam temperature; \(D_{xhs}\) represents the circulating water flow rate; \(Ng\) represents the unit load. It can be seen from Fig. 12 that under the condition that the main steam temperature, the reheat steam temperature and the circulating water flow rate are fixed. The optimal
sliding-pressure operation curve obtained from the initial pressure optimization shows the "fixed-slip" operation mode. During sliding pressure operation, the corresponding point in the optimal initial pressure curve keeps increasing with the increase of the circulating water inlet temperature. At the same time, the corresponding point in the optimal initial pressure curve also increases as the load increases. At higher load intervals, the unit changed at the inflection point from sliding pressure operation to constant pressure operation. As the temperature of the circulating water inlet decreased, the inflection point moved backward. Then it is operated at constant pressure under the rated main steam pressure. This optimal initial pressure potential conforms to the corresponding theoretical law. In the actual operation of the unit, when the ambient temperature is high, the temperature of the circulating water is also high. Therefore, the load point at which the sliding pressure starts is lower than when the ambient temperature is low. The law of the forecast model in this paper is completely consistent with the actual operation. Therefore, the model established by the company not only has high accuracy, but also conforms to the corresponding theoretical law. The real-time value of main steam pressure in actual operation is optimized and guided.

4. Conclusion

Energy saving and consumption reduction is still the key research content of thermal power generating units. This article is based on big data analysis. According to the massive historical data, the working conditions are divided by fuzzy clustering method and typical data of different working conditions are obtained. The main steam pressure model is established based on the deep learning neural network. After verification, satisfactory results have been achieved in accuracy and regularity. Finally, the main steam pressure optimization model is applied to the actual 300MW thermal power unit, and closed-loop control is performed. The results prove that the application of real-time main steam pressure optimization can effectively reduce the energy consumption of the unit. Under different ambient temperatures, there is a higher energy saving potential.

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