Power unit load system modelling research based on BP neural network

Ruicai Si1,3, Songhan Wang1, Xiwen Liu1, Jia Li1, Chi Zhou1 and Baoju Li2
1Jilin Province Electric Power Science Research Institute Co., Ltd, Changchun, 130021, China;
2State Grid Jilin Province Electric Power Co., Ltd, Changchun, 130021, China
Email: 18686405023@163.com

Abstract. A thermal power unit is a very complex non-linear multi-variable control object. It has the characteristics of strong coupling, large inertia, large delay and time-varying parameters. The traditional mathematical model is difficult to describe the non-linear characteristics among the parameters of the unit, and it is difficult to meet the control requirements of unit load, main steam pressure and so on. Based on the more advanced BP neural network modeling method, the mathematical model of the operation of 600MW thermal power unit under low, medium and high load is established by using the actual operation data on site. The method used is novel, and the simulation analysis shows that the model also has a strong engineering practice.

1. Introduction
At present, thermal power generation is still the main way of generating electricity. The thermal power unit consists of three major systems: water vapor, combustion, and power generation. Each system contains multiple subsystems. These subsystems work together to complete the functions of the unit. Because these systems are more complicated, the thermal power unit has many problems such as strong coupling, large inertia, large delay, and changing parameters with time. The mathematical modeling of thermal power units also faces many difficulties. Traditional unit models usually use mechanism modeling or linear modeling method, but the simplified linear model obtained by this method cannot cope with large-scale variable load and variable operating conditions.

With the rapid development of science and technology, some intelligent algorithms emerge at the historic moment. Neural network algorithm has a very powerful ability to express the nonlinear mapping, which provides a new way of thinking and method for the research of nonlinear system modeling[1]. BP neural networks are widely used. Some people use it to model the low-temperature waste heat power generation system, and through the research and analysis of the experimental data, it is found that the turbine speed matches the working fluid evaporation pressure, which can make the system reach the maximum power output[2]. The BP neural network can also be applied in the turbine governing system[3], and can also predict the wind speed in a short period of time[4]. The simulation results prove that the prediction effect is better.

In this paper, the thermal power system load system is modeled by using BP neural network. Compared with the traditional modeling method, it has self-learning and self-adaptive ability, and the fault tolerance is also very strong. The simulation results also show that the error between the output...
value of the network and the output value of the actual model is within the allowable range, and the BP neural network can effectively approximate the thermal power unit model.

2. BP neural network algorithms

2.1. Neural network characteristics

Neural network is a large-scale parallel distributed processor composed of simple processing units, which has the characteristics of storing experience and knowledge and making it usable. Neural network is similar to human brain in two aspects. One is that neural network acquires knowledge by learning from external input. The other is that the connection strength of interconnected neurons, also known as synaptic weights, is used to store and acquire knowledge. The basic processing unit of the neural network is the neuron. There are three basic elements in the neuron model: connection weight, summation unit and activation function[3]. The synapses of biological neurons are equivalent to the connection weights in the neuron model. The connection weights represent the strength of the connections between each neuron. The positive weights represent the activation between neurons and the negative weights represent the inhibition between neurons. The summation unit is the sum of all input signals multiplied by the corresponding weights. The activation function can be mapped nonlinearly to limit the output of neurons to (0,1) or (-1,1) intervals.

2.2. BP neural network algorithms

A BP neural network is a feedforward neural network trained according to the error back propagation algorithm. It generally has multiple layers of neurons, which can be understood as a multilayer perceptron (MLP). Multilayer perceptron consists of input layer, output layer and several hidden layers. It emphasizes that the neural network is a multi-layer neuron structure. BP neural network emphasizes that the learning algorithm of the network is error back propagation. Usually, multi-layer perceptrons use error back propagation algorithm when adjusting connection weights, so we regard them as the same network. The hidden layer of BP neural network has one or more layers. The general three-layer BP neural network topology is shown in Figure 1.

![Figure 1. Typical BP neural network structure.](image)

3. BP neural network model of thermal power unit

Because of the delay of fuel quantity B and the opening degree of the main control valve, the main steam pressure and the output power N of the unit are related to the fuel quantity at the current time and the opening degree of the main valve control valve, the fuel quantity at the previous time and the opening degree of the main valve control valve, and the value of the main valve control valve itself at the previous time. In the process of modeling, the amount of fuel, the opening of the control valve, the
main steam pressure and the output power of the unit at the first few moments should be taken as the input of training BP neural network.

For BP neural network main steam pressure model, the input layer can be selected as \( B(k) \), \( B(k-1) \), \( \mu(k) \), \( \mu(k-1) \), \( P(k) \), \( P(k-1) \), \( N(k) \), \( N(k-1) \) and output layer as \( P(k) \), while for BP neural network output power model, the input layer can be selected as \( B(K) \), \( B(k-1) \), \( \mu(k) \), \( \mu(k-1) \), \( P(k) \), \( P(k-1) \), \( N(k-1) \) and the output layer as \( N(k) \).

Because the BP neural network performs sample learning, the typicality of the sample data has a great influence on the approximation and promotion ability of the model. If the typicality is insufficient, the convergence speed of the model will be reduced and the prediction ability will be reduced, which makes the research difficult. To minimize the impact of sample typicality, the research object of this paper is a 600 MW unit in a power plant. The operation data of the unit under high, medium and low loads are collected from the site. The data are collected every 1 s, totaling 3600 sets of data. These data are divided into three categories according to the different load levels at sampling time, and 1200 sets of data are used to build BP neural network models under different loads. Of the 1200 sets of data, 200 sets were used to test the established model and 1000 sets were used to train the BP neural network model.

All the information needed by BP neural network is obtained from learning samples. The final system modeling effect depends on the number and quality of training samples selected. If the absolute value of net input is very large, the output of neurons will tend to be saturated, the accuracy of weight adjustment will be reduced, and the absolute value of net input should be limited. Normally, the inputs of BP neural network have different physical meanings and should be standardized. So data preprocessing is also very necessary.

In this paper, the input and output data are quantified as standard vectors with deviation and mean of 1. Finally, the output is inversely normalized to the unit of value used for the initial target.

In this paper, a BP neural network with hidden layer is adopted. The number of neurons in the hidden layer of BP neural network is set to 15. The activation function is automatically given by the new function in the MATLAB neural network toolbox. The BP neural network model of thermal power unit is shown in Figure 2 and Figure 3:

**Figure 2.** BP neural network load model.  
**Figure 3.** BP Neural network main steam pressure model.

### 4. A simulation example

After designing the network model, BP neural network is trained by using the principle of error back propagation, and its connection weight is constantly changed to minimize the error between the output value of the model and the output target value of the known training sample. In the model established in this paper, the initial weights of input layer to hidden layer and hidden layer to output layer are...
within the range of [-1,1]. The classical BP algorithm with constant learning rate is used to train the network model. The learning rate of the training of the neural network is set to 0.2, the training goal is set to 0.001, and the training steps are taken to 1000 times. The model takes the historical data of 3600 units of a 600 MW unit and trains them three times according to the different load levels during sampling.

4.1. BP neural network model training of load

(1) Predictive output and error of network under low load

Figure 4. Load forecasting output and error of BP network at low load.

Figure 5. Forecast output and error of BP network for load at medium load.

Figure 6. Output and error of BP network for load prediction at high load.
(2) Predictive output and error of network under medium load
(3) Predictive output and error of network under high load

Figures 4 to 6 show that when the BP model and the actual model have the same input, the fitting error of the sample data of thermal power unit output power is between ±3, the fitting effect is the best at low load, followed by high load and the worst at medium load.

4.2. BP neural network model training of main steam pressure
(1) Predictive output and error of network under low load
(2) Predictive output and error of network under medium load
(3) Predictive output and error of network under high load

Figures 7 to 9 show that when BP model and actual model have the same input, the fitting error of sample data of main steam pressure of thermal power unit under low load is between ±0.01, the fitting error range of medium load is (-0.08, 0.01), and the fitting error range of high load is (-0.04, 0.01). It can be seen that the fitting effect of main steam pressure is the best in low load operation, followed by high load operation and the worst in medium load operation. The main reason is that, under the high and low loads, according to the actual operating conditions of the thermal power unit, the change of the training sample data learned is relatively stable compared with the medium load, and the deviation is small, so the neural network is fitted, the error is small and the fitting effect is much better than the medium load.

Figure 7. Prediction output and prediction error of BP network for main steam pressure at low load.

Figure 8. Prediction output and prediction error of BP network for main steam pressure at medium load.
Figure 9. Prediction output and prediction error of BP network for main steam pressure at high load.

Through simulation, it can be verified that the BP neural network model established in this paper can well fit the non-linear mathematical model between unit load and fuel quantity, turbine valve opening and main steam pressure. The model has high generalization ability and accuracy, and can be applied to the design of predictive optimization controller to meet the needs of engineering applications.

5. Conclusions
In this paper, BP neural network is used to establish the low, medium and high load models of thermal power units. Compared with the traditional single full load modeling method, it can adapt to the operation requirements of thermal power units under different engineering conditions, which has innovative and practical guiding significance. Simultaneously, the simulation results obtained by training a large number of field collected data show that BP neural network is successful in approaching the accurate mathematical model of unit load, and can be applied to the design of predictive optimization controller to meet the needs of engineering applications.

BP neural network can be used not only for the construction of thermal power units, but also for hydropower units and nuclear power units. It is used to guide controller design and make it more widely used.

Acknowledgement
National Key R&D Program of China NO. 2017YFB0902100

References
[1] Tu Xuewei 2009 Modeling of Ultra Supercritical Units Based on Neural Network [D] North China Electric Power University (Beijing)
[2] Wan Zheng, Yao Guangwei 2014 Based on BP Neural Network Modeling of Low-temperature Waste Heat Power Generation System [J] Energy Research and Management 4 29-32
[3] Xie Jin, Chen Qijuan, Li Junyi 2015 BP neural network based-modeling and simulation of hydraulic turbine governing system [J] Water Resources and Hydropower Technology 46(3) 119
[4] Wang Ning 2019 Short-term Wind Speed Prediction Based on Wavelet Packet Dural Network [J] Control and Information Technology 04 1-6 [2019-08-04]