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Thermal Economy Analysis of External Steam Cooler Based on BP Neural Network

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Abstract: Based on 600MWultra supercritical reheat system, the thermal economic calculation model of ESC (external steam cooler) is established. The BP neural networkis introduced to meet the limitations of the traditional algorithm. Nine inputs and tow outputs are determined from unit parameters. More than 1000 sets of related data sets are got from traditional model, which were used as training data to form a general ESC thermal economy model. The results of the study show that the energy saving effect prediction of ESC is better than the outlet feedwater temperature effect. The thermal economy is related to the superheat of the heater which ESC located. The final feedwater temperature is related to the unit efficiency. With the increase of the feed water temperature of the ESC inlet, the efficiency of the unit becomes U-shaped, so the deviation of the prediction result is relatively large.

1. Introduction

With the rapid development of thermal power units, high parameter ultra supercritical (USC) units have become the mainstream of the industry [1]. Because of the high temperature of reheated steam, the superheating degree of extract steam at all levels after reheating is high and heat loss is large. Adding ESC (external steam cooler) can greatly reduce the superheating degree of extraction steam, reduce the heat exchange loss, increase outlet feed water temperature and improve the thermal economy of the unit [2].

Although the ESC has been widely used in power plants, there is no systematic and perfect analysis and evaluation of its thermal economy. From the current research, it is mainly divided into two methods based on mathematical model and knowledge-based research [3 ~ 8]. The research based on mathematical model can be divided into equivalent heat drop method, heat balance method and matrix method etc. It is difficult to establish an accurate and relatively simple mathematical model to describe the energy-saving effect of the ESC in different capacity units because the factors that affect the energy-saving effect of the ESC are diversity, complexity and nonlinearity. Knowledge-based classification method especially combined with neural network is popular to use experience knowledge to judge energy-saving effect. However, the rationality of knowledge-based is also limited.

In this paper, BP neural network is introduced to establish a general calculation framework for the thermal economy of the ESC. The main steam pressure, temperature, unit back pressure and unit capacity that affect the effect of the ESC are analyzed, and the calculation framework is applied to the economic calculation of a specific unit.

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2. Thermal economy calculation model of thermal system

According to the position relationship with the main water flow, the ESC can be arranged in series or parallel, which can reduce the superheat between the extraction steam and the feed water and the irreversible loss. The series ESC has higher economy compared with the parallel. The feature of using the external series steam cooler system is that the extraction superheat can span several extraction energy levels, so that it can be used for higher energy levels. In this study, a typical ESC is used in the regenerative system, which is installed at the first stage extraction after reheating with the maximum superheat.

The thermal system diagram of the unit before and after adding external steam cooler is shown in Fig. 1 and Fig. 2. The ESC of No. 3 HP (high pressure) heater is located at the outlet of No. 1 HP heater. Firstly, extraction steam of No. 3 HP heater enters the ESC to heatthe high temperature feed water. After the superheat is reduced, the steam enters the No. 3 HP heater to heat the lower temperature feedwater. Then the superheat of the No. 3 heater's extraction steam is significantly reduced. At the same time, the enthalpy rise of the feedwater is increased, which is helpful to reduce the heat exchange temperature difference in the boiler, reduce the irreversible loss, and improve the efficiency of the boiler.

In this study, a typical 600MW primary reheat ultra-supercritical unit is selected as the research model. The thermal calculation software is used to simulate the thermal system. We can get the heat consumption value of the conventional system and the ESC system under the design conditions, and the difference of the two. After adding an ESC, the locally changing thermal economy is [9]:

$$\delta\eta_i = \frac{\Delta H_0 - \Delta Q_0 \eta_i}{H_0 + \Delta H_0} \quad (1)$$

The change of the unit's thermal economy is [10]:

$$\Delta b_b = -b_b \delta\eta_i \quad (2)$$

Here,H_0refers to the change of equivalent enthalpy drop of new steam after adding ESC(kJ/kg). Q_0refers to the heat absorption of hate system (kJ/kg).$b_b$refers to coal consumption rate of power generation of conventional unit (g/Kwh)·

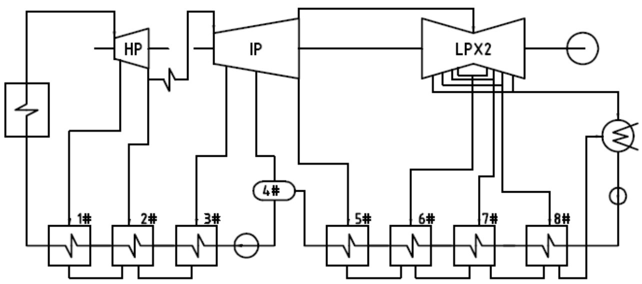

Fig. 1 Conventional thermal systemdiagram

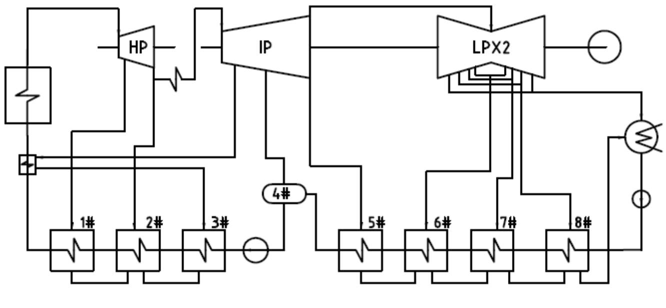

Fig. 2 Thermal systemdiagram with ESC

Although the thermal economic value can be calculated, in the actual process, the thermal economy of the ESC will also change with the unit load changing. To calculate the unit thermal economy increasedby addingESC, it must be calculated according to the parameters of the specific unit design conditions. The changes of mainsteampressure, temperature, reheat steam pressure, temperature, unit back pressure and other parameters will affect the thermal economy of the ESC. The calculation process and required parameters are also relatively large. The calculation process of the heat balance method is complicated and has many parameters. The accuracy of calculation with empirical formulas is low.

In view of the complexity and limitation of the traditional mechanism model in the calculation of thermal economy, this study uses neural network to establish the thermal economy model of the external steam cooler to calculate the heat consumption value of the external steam cooler under different working conditions.

3. BP neural network model of thermal economyof external steam cooler

3.1 Building BP neural network

According to the analysis above, we hope to get the difference of heat consumption and the final feed water outlet temperature of the unit under the current operation condition with or without ESC during the thermal economy evaluation. So these two parameters are output. The ESC steam side pressure, temperature, NO.3 HP heater steam side inlet pressure and outlet feed water temperature are the basic input of the model. In addition, the main steam pressure and temperature, reheat steam pressure and temperature as well as the back pressure of the condenser are alsoconsidered as input parameters. The influence of theseto unit thermal economy will be studied later.

In this study, nine inputs and two outputs BP neural network are constructed. Six nodes are selected in the hidden layer. Using 1000 sets of calculation data of a 600MW power plant, the BP neural network model of ESC thermal economy is trained, and another 100 sets of data is randomly selected for verification. Parts of samples are in Tab.1.

Main squared error is shown in Fig.3.

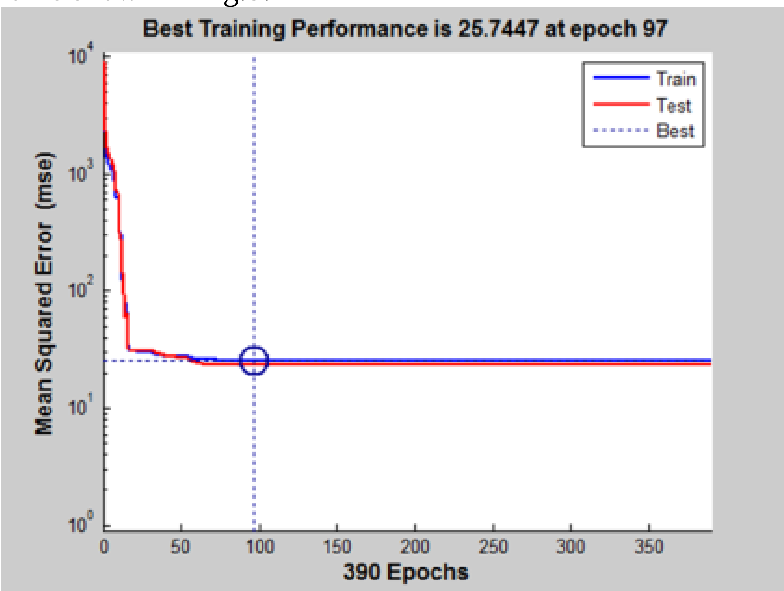

Fig. 3 Comparison of error curves before and after training

It is shown that after training this BP neural network have good convergence, and the predicted value and the design value fit well. The neural network model has high prediction accuracy for ESCthermal economy difference, and can be used to retrieve ESCthermal economy difference with different parameter.

3.2 Results and discussion

Using this model to predict the predict value of 100 data groups, and comparing with the actual operation value, the curvesfromFig.4 to Fig.5are obtained.

Fig.4shows the comparison of predict value and the calculation value of the feed water temperature at ESC outlet. It shows that this two are very close. The maximum difference is about 5.2℃, and the maximum prediction deviation is only 1.7%. The prediction effect is general.

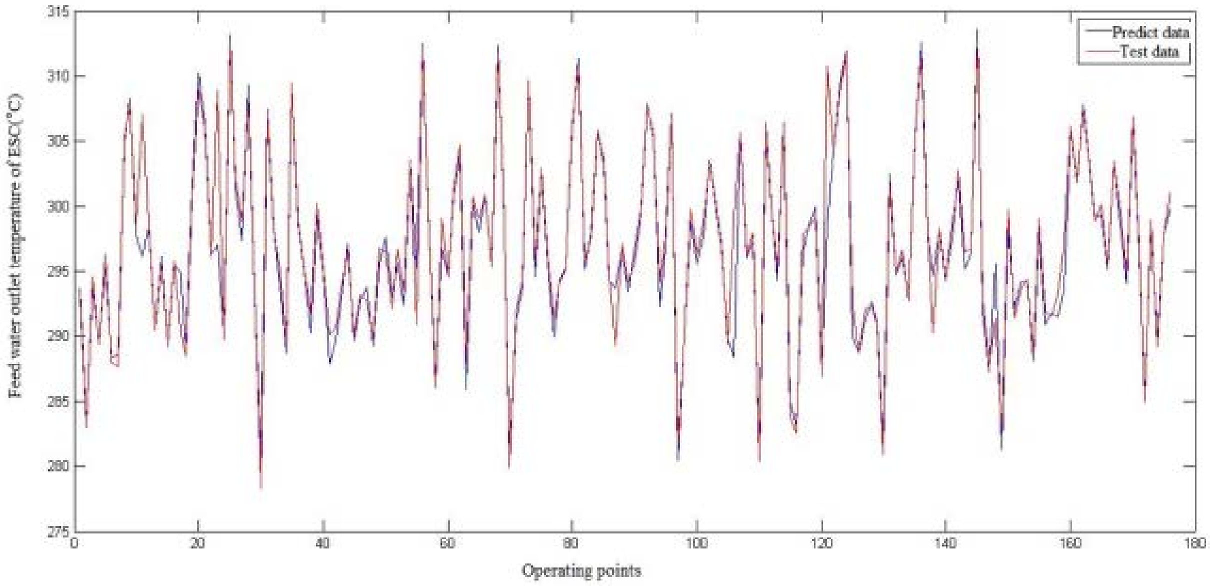

Fig. 4 Comparison of predict value to calculation value of outlet feed-water temperature of ECS

Fig.5 shows the comparison between the predict value and calculation value of the thermaleconomy of ESC. It can be seen that the prediction effect is good. And the error ratevissmaller than Fig.2, the maximum positive deviation of heat consumption difference is 3.61KJ, and the maximum negative deviation is -10.2KJ. This prediction accuracycan also meets the engineering needs.

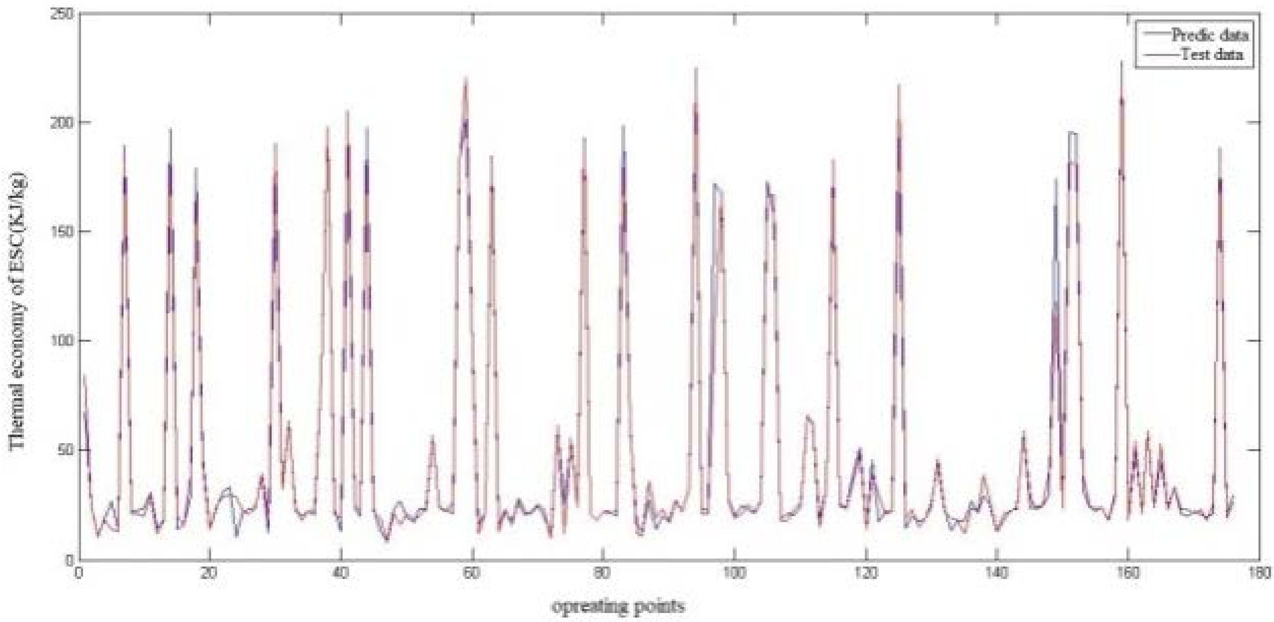

Fig. 5 Comparison of predict value to calculation value of thermal economy of ESC

It can be seen from the result that the prediction accuracy of heat consumption difference is always better than that of feed water temperature of ECS outlet. It is believed that the reason for the backward extrapolation of the thermal economy calculation model of the ESC is due to the superheat ofHP heater where the external steam cooler is located. There is an optimal efficiency point under the design condition of the unit. If it deviates from the optimal efficiency point to a certain extent, the heat consumption of the unit will form a U-shaped curve, and the final feedwateroutlet temperature of ESC will also deviate greatly. The negative difference of thermal economy is three times of positive difference. The reason for this is that the optimal point of the unit before adding ESC and after is changed. For this reason, we consider setting the best range to find the uniform law of heat consumption difference and feed water temperature in this range.

4. Conclusion

This study research onthe thermal system of the ESC, establishes the thermal economic calculation model of ESC with BP neural network. The traditional mechanism model has limitations in calculation because of diversity of unit types and the complexity of influence factors. Therefore, this paperproposes a neural network model of ESC thermal economybased on theoretical calculation model. The results reveal the followings.

(1) The input and output parameters of BP neural networkheater model are determined. Inputs: main steam pressure and temperature, reheat steam pressure and temperature, unit back pressure, NO.3 steam temperature, NO.3 feed wateroutlet temperature, ESC steam temperature and pressure. Outputs: ESC feed water outlet temperature， thermal economy of ESC.

(2) The maximum calculation errors of the model's feed water temperature at ESC outlet is 5.2 ℃, the maximum prediction deviation is 1.7%.The maximum positive deviation of heat consumption difference is 3.61KJ, and the maximum negative deviation is -10.2KJ. Thedifference range of thermal economy of ESC is (-10.2KJ, 3. 61KJ).

(3) The heat consumption value of the unit is related to the best efficiency point of the unit, forming a u-shaped curve. If exceeding the optimal efficiency point, the predict result of ESC outlet feed water temperaturewill deviate greatly. The predict result of thermal economy of ESC related to the superheat of NO.3 HP heater which is independent of unit efficiency. The superheat is higher, the energy saving effect is better.

Acknowledgments

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Table.1 The samples of input and output parameters

Item	Main steam Pre.(bar)	Main steam Tep. (˚C)	Reheat steam Pre. (bar)	Reheat steam Tep. (˚C)	Condenser inlet pre. (bar)	NO.3 Heater steam pre. (bar)	NO.3 Heater outlet feedwaterTep.(˚C)	ESCHeating steam Pre. (bar)	ESC Heating steam Tep.(˚C)	Steam turbine heat rate difference	ESC Feedwater outlet Tep.(˚C)
1	247	566	43.81	600	0.1013	76.94	294.0	21.29	485.1	18	299.7
2	247	566	43.81	600	0.1013	78.06	295.0	21.29	485.1	18	300.7
3	247	566	43.81	600	0.1013	59.28	274.8	21.29	485.1	18	282
4	247	566	43.81	600	0.1013	60.2	275.9	21.29	485.1	18	283
5	247	566	43.81	600	0.1013	61.12	277	21.29	485.1	18	284.1
6	242	566	46.37	566	0.049	67.02	283.7	23.72	467	18	287.7
7	242	566	46.37	566	0.049	58.74	273.9	23.72	467	18	278.3
8	242	566	46.37	566	0.049	58.74	273.9	23.72	467	180	278.3
9	242	566	46.37	566	0.049	58.83	274	23.72	467	190	278.4
10	242	566	46.37	566	0.049	59.74	275.1	23.72	467	198	279.5
11	242	566	46.87	566	0.081	81.61	298	20.92	441.8	18	300.4
12	242	566	46.87	566	0.081	82.19	298.5	20.92	441.7	18	300.9
13	242	566	46.87	566	0.081	82.78	299	20.92	441.7	18	301.4
14	242	566	46.87	566	0.081	83.37	299.5	20.92	441.8	18	301.9
15	242	566	46.87	566	0.081	83.96	300	20.92	441.8	18	302.3
16	242	566	46.37	566	0.11	71.13	286.3	17	451.4	180	290.9
17	242	566	46.37	566	0.11	71.13	286.3	18	452	190	291.3
18	242	566	46.37	566	0.11	71.13	286.3	19	452.6	198	291.8
19	242	566	46.37	566	0.11	71.13	286.3	20	453.2	204	292.3
20	242	566	46.37	566	0.11	71.13	286.3	21	453.8	211	292.8