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Operation optimization of high back pressure series extraction steam heating unit under multivariate factors

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Abstract. In order to study the economic changes of the high back pressure heating unit when the actual operating parameters deviates from the design value, a high back pressure heating unit in series with the extraction steam heating units is taken as an example. The effects of the high back pressure unit electric load, the heat network circulating water flow and the heat network return water temperature on the economic indicators of the high back pressure heating unit and extraction steam heating unit are analyzed. The results show that the thermal consumption is increased by about 126.95 kJ.(kW.h)$^{-1}$, and gross coal consumption rate is increased by about 4.86 g.(kW.h)$^{-1}$ when the electric load of the high back-pressure unit is decreased by each 5 MW. The weighted heat consumption of the heating units of is reduced by 59.62 kJ.(kW.h)$^{-1}$ When the heat network circulating water flow reduced by 1500 t.h^{-1} and the temperature difference between inlet and return water of heat network increased by 4.8 °C.

1. Introduction

The high back pressure steam turbine has the advantages of simple thermal system, low investment cost, mature technology, no cold source loss and large heating area. However, this technology has poor flexibility in electric load and heat load adjustment. Once the heating area is changed, the heating load can be only increased by increasing the circulating water flow of the heat network or raising the external heating temperature of the heat network, which will cause a certain deviation between actual operating parameters of the heating unit and the design value[1-3].

In order to analyze the economic indexes of a high back pressure heating unit in series with extraction steam heating units under different working conditions, the reasons influencing the economic efficiency of heating units were determined. In this paper, the effects of the electric load of the high back pressure unit, the circulating water flow and the return water temperature of the heat network on the economic indexes of the high back pressure unit and extraction heating unit in the whole plant are tested and calculated. Based on the economic change of the heating unit under different working conditions, the energy saving potential of the whole plant is explored, which provides the basis for the energy saving optimization of the whole plant heating units for the cogeneration enterprises with multiple high back pressure units in series with extraction steam heating units.

2. Analysis method of energy saving optimization

In this paper, unit 2, unit 3 and unit 4 heating units in a power plant is used for testing and analysis. Unit 2 is a high back pressure heating unit. Unit 3 and unit 4 are extraction steam heating units. The heat network circulating water is first heated by the condenser of unit 2, and then heated by the exhaust steam of unit 3 and unit 4 in the heat exchanger of the first station of the heat network. This study analyzes the energy saving effect and operating income of the three heating units in the plant by calculating the economic indexes under different electric loads of unit 2, different circulating flow of heat network and different outlet temperature of heat network first station. The main parameters of the three heating units are shown in table 1.The flow chart of the thermodynamic system is shown in figure 1.

Table 1. The main parameters of three heating units.

Item	Unit 2	Unit 3	Unit 4
Rated power(MW)	131	312	312
Rated steam flow($t\cdot h^{-1}$)	466	957	957
Main steam pressure(MPa)	13.24	16.67	16.67
Main steam temperature(°C)	535	538	538
Vacuum(kPa)	45.9	4.9	4.9

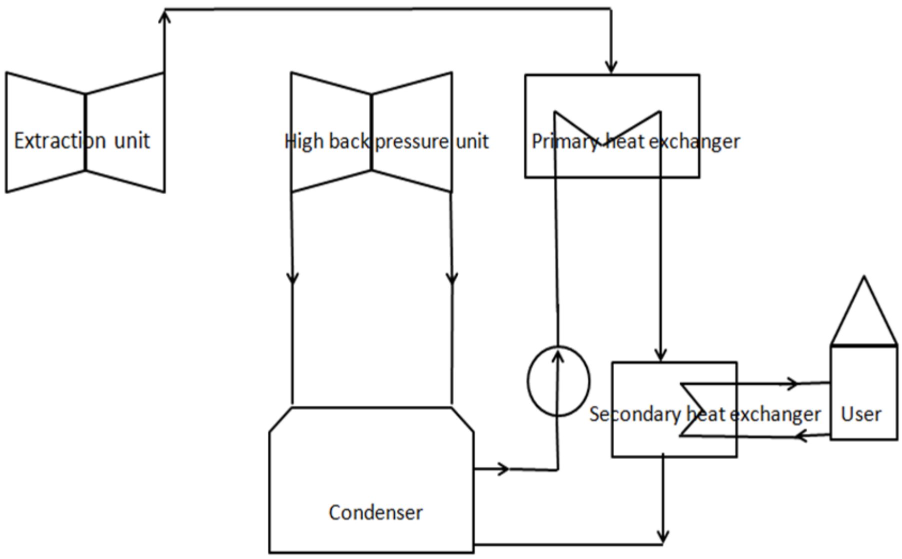

Figure 1. Flow chart of high back pressure series extraction heating system.

The total heat absorption of boiler unit 2, unit 3 and unit 4 of the heating units produces both electricity and heat. Both electricity and heat are economically profitable for sale, and the cost is the heat absorbed by the boiler feed water which is supplied by the fuel burned in the boiler. When calculating and analyzing the economy of a heating unit, in addition to adopting the heat consumption rate for comparative analysis, the paper analyzes the boiler heat absorption at the time of profit and per unit profit from the perspective of business operation and [4-5].

3. Test and analysis of the whole working condition of high back pressure series steam extraction heating unit

3.1. Test and analysis the effect of the electric load on the economy of unit 2

When designing the blade profile of a steam turbine, the inlet angle of the steam flow is the optimum one under the rated operating condition, and the impact loss of the blade is the smallest and the efficiency of the cylinder is relatively higher. When the electric load of unit 2 rises from 100 MW to 125 MW, the index changes are shown in table 2.

Table 2. Main indexes of unit 2 machine active power change.

Item	Unit 2	Unit 2
Load(MW)	125.15	100.0
Vacuum(kPa)	26.874	24.120
Heat consumption(kJ.(kW.h)$^{-1}$)	10109.72	10538.56
Thermal efficiency(%)	35.61	34.16
High-pressure cylinder efficiency(%)	81.20	77.68
Middle-pressure cylinder efficiency(%)	91.48	90.48

The heat consumption of unit 2 is 428.84 kJ.(kW..h)$^{-1}$ when the electric load is 125 MW, and the efficiency of high pressure cylinder and medium pressure cylinder is increased by 3.52% and 1% compared with 100 MW, respectively. This shows that the power capacity of unit 2 is improved when the electric load is increased from 100 MW to 125 MW.

3.2. Test and analysis of the effect of unit 2 electric load on the economy of the whole plant

When the electric load of Unit 2 rises, the steam inlet of the turbine increases, the back pressure of the exhaust steam of the low pressure cylinder rises, and the temperature of the circulating water of the condenser rises. Therefor the steam extraction of units 3 and 4 can be extruded, the heat absorption of the boiler decreases when the electrical load of adjacent unit remains unchanged, and the economy of the unit increases. At the same time, the efficiency of the cylinder will change and the power of the turbine will also increase. When the electric load of unit 2 rises from 100 MW to 125 MW, the main economic indexes of the whole plant are shown in table 3.

Table 3. Main indexes of heating units in the whole plant when the active power of unit 2 changes.

Item	Unit 2 100 MW			Unit 2 125 MW		
Unit	Unit 2	Unit 3	Unit 4	Unit 2	Unit 3	Unit 4
Load(MW)	100.00	297.16	300.44	125.15	299.51	307.61
Extraction steam flow(t·h^{-1})	/	134 .73	133.90	/	117.79	123.62
Vacuum(kPa)	24.120	5.709	5.426	26.874	5.532	5.355
Temperature of circulating water supply (°C)		63.20			65.3	
Sale of heat(GJ·h^{-1})		1429.40			1448.42	
Generating capacity of 1 tons of standard coal(kW·h)	2478.06	2897.55	2934.37	2583.18	2934.77	2964.88
Heat consumption(kJ·(kW·h)$^{-1}$)	10538.56	9012.86	8899.75	10109.72	8898.54	8808.17
Absorb heat of three heating units gain per yuan per hour(kJ·h^{-1})		21380			21250	

The higher the electric load of unit 2, the higher the back pressure of unit 2 condenser, the higher the temperature of circulating water supply for unit 2, which can reduce the amount of steam extraction for of unit 3 and unit 4. The heat of the low-pressure cylinder exhaust of unit 2 is completely taken away by the circulating water, and the loss of the cold source is zero. The electricity load has no effect on the heat consumption of unit 2. However, when the electric load of unit 2 is increased by 25 MW, the back pressure rises by 2.754 kPa and the circulating water supply temperature rises by 2.1 °C. The extraction steam of unit 3 and unit 4 reduces by 27.62 t·h^{-1}. The heat consumption of unit 3 and unit 4 can be reduced by 114.32 (kW·h)$^{-1}$ and 91.58 kJ·(kW.h)$^{-1}$. The weighted heat consumption of unit 2, unit 3 and unit 4 can be reduced by 115.27 kJ·(kW.h)$^{-1}$ and the economy of the whole plant can be improved.

3.3. Calculation and analysis of operating profit of unit 2 heating unit with active power change

In order to understand the operation economy of the whole plant heat supply unit intuitively, the generation income and heating income during operation of units 2, 3 and 4 are calculated, taking the boiler efficiency of 90% and pipeline efficiency of 99%.

When the electric load of unit 2 is 100 MW, the generating capacity of unit 2, 3 and 4 is 2478.06 kW·h per ton of standard coal, 2897.55 kW·h per ton of standard coal and 2934.37 kW·h per ton of standard coal, respectively. Based on the calculation of electricity price of 0.349 RBM·(kW·h)$^{-1}$, the gross revenue of three heating units is 2900.18 yuan per ton of standard coal. The total external sales heat of the heating network is 1429.40 GJ·h^{-1}, and the gross profit of heating is 56218.3 yuan based on the heat price 39.33 RMB·GJ^{-1}.

When the electric load of unit 2 is 125 MW, the generating capacity of unit 2, 3 and 4 is 2583.18 kW·h per ton of standard coal, 2934.77 kW·h per ton of standard coal and 2964.88 kW·h per ton of standard coal, respectively. Based on the calculation of electricity price of 0.349 RBM·(kW·h)$^{-1}$, the gross revenue of three heating units is 2960.51 yuan per ton of standard coal. The total external sales heat of the heating network is 1488.42 GJ·h^{-1}, and the gross profit of heating is 56966.43 yuan based on the heat price 39.33 RMB·GJ^{-1}.

For cogeneration of coal-fired units, the indexes that directly judge the economic benefits of generating and heating are the benefits and costs. The benefit is the gross gain electricity and heat per ton of standard coal. The cost is the boiler heat absorption when the power generation and heating income are 1 yuan.

The economy of unit 2, unit 3 and unit 4 is improved when the load of unit 2 increases from 100 MW to 125 MW. Three heating units generate more electricity at 172.85 kW·h by burning 1 ton of standard coal when the external sales heat is stable. Power generation gross profit increases by 60.32 yuan.

The heat absorption of the three heating units for gaining 1 yuan per hour. is 21250 kJ when the load of unit 2 is 125MW. The heat absorption of the three heating units for gaining 1 yuan per hour. is 21380 kJ when the load of unit 2 is 100MW. Compared with the 125 MW and 100 MW of Unit 2, the heat absorption of the boilers of the three heating units decreases 130 kJ per hour.

3.4. Test and analysis of heat supply network circulating water flow change on heating unit economy

The larger the heat network circulation flow, the faster the flow rate, the larger the heat exchanger coefficient, which the heat transfer capacity of the heat exchange station is stronger. However, when the flow rate of primary network is faster, the time that secondary network absorbs heat from primary network is shortened. The heat transfer is going to go down. The greater the circulating water flow rate of the heating network, the energy consumption of the heating network is higher. If the circulating water flow of the heat network decreases, it may not meet the heating demand of the heat exchanger station at the end of the heat network. The change of main economic indexes of heating units in the whole plant is shown in table 4 when the circulating water flow of heat network decreases from 10000 t·h^{-1} to 8500 t·h^{-1}.

The temperature difference between the supply and return water of the heating network is 31.68 °C when the circulating water flow rate of heating is about 10000 t.h-1.The weighted heat consumption of three heating units is 9479.20 kJ.(kW.h)$^{-1}$. The temperature difference between the supply and return water of the heating network is 36.48 °C when the circulating water flow rate of heating is about 8500 t.h-1.The weighted heat consumption of three heating units is 9419.58 kJ.(kW.h)$^{-1}$. The temperature difference between the hot water circulating water supply and the return water increased by 4.8 °C and the weighted heat consumption of the three heating units decreased by 59.62 kJ.(kW.h)$^{-1}$ when the circulating water flow rate of the heat supply network dropped from 10000 t/h to 8500 t/h. The small flow and large temperature difference of the hot network circulating water is more economical.

Table 4. Main indexes of heating unit when heat network variable flow.

Item	Flow rate of heating 10000 t·h^{-1}			Flow rate of heating 8500 t·h^{-1}		
Unit	Unit 2	Unit 3	Unit 4	Unit 2	Unit 3	Unit 4
Load(MW)	120.56	175.53	176.58	120.56	175.53	176.58
Extraction steam flow(t·h^{-1})	/	69.78	93.25	/	76.62	84.09
Vacuum(kPa)	31.190	6.201	5.351	34.413	7.953	7.293
Temperature of circulating water supply (°C)		68.68			70.17	
Sale of heat(GJ·h^{-1})		1265.87			1237.36	
Generating capacity of 1 tons of standard coal(kW·h)	2527.16	2812.17	2873.81	2516.69	2837.75	2908.56
Heat consumption(kJ (kW·h)$^{-1}$)	10333.82	9286.51	9087.30	10376.82	9202.79	8978.74
Absorb heat of three heating units gain per yuan per hour(kJ·h^{-1})		20860			20830	

The heat absorption of the three heating units for gaining 1 yuan per hour. is 20860 kJ when the circulating water flow of heat network is 10000 t·h^{-1}. The heat absorption of the three heating units for gaining 1 yuan per hour. is 20830 kJ when the circulating water flow of heat network is 8500 t·h^{-1}.It shows that the small flow and large temperature difference of the hot network circulating water has more revenue.

3.5. Analysis of the economics of heat supply unit when the return water temperature of heat network changes

The most obvious change of the heat load is the return water temperature when the heat load of the heat network changes[6]. There are two main reasons for the heat load change. First, the primary network of the heating network is not adjusted after the environmental temperature changes (for example, from February to march). The other is that the primary network is not adjusted accordingly after the secondary network adjustment (for example, from November to January). The most obvious change of the heat load is the return water temperature when the heat load of the heat network changes. There are two main reasons for the heat load change. First, the primary network of the heating network is not adjusted after the environmental temperature changes (for example, from February to march). The other is that the primary network is not adjusted accordingly after the secondary network adjustment (for example, from November to January). The heat absorption of the two network of the heat supply network from the primary network of the heat supply network is reduced as the backwater temperature of primary network increases. Thermoelectric companies sell less heat. The profit of the thermoelectric enterprise was squeezed by the thermal company of the secondary network of the hot network. Figure 2 shows the variation of backwater temperature of the primary heat network.

As shown in Figure 1, the return water temperature is increasing month by month. The return water of the heating south line and the heating north line in February is 53.02 °C and 52.25 °C. The heat exchange with the secondary network of the heating network and the heat exchange capacity of the secondary network and the primary network of the heating network are reduced month by month.

The winter heating is a livelihood project in China. The whole society pays attention to heat supply at the beginning of heating. The secondary heating network generally supplies a sufficient amount of heat. The return temperature of the hot network is relatively low. The ambient temperature gradually increases at the end of the heating period. The heat load of the heating network is gradually decreasing. If the thermoelectric enterprise still adopts the heating mode in the initial stage of heating, the return temperature of the heating network will be high when the heating network is under low load. The heating economy will decline.

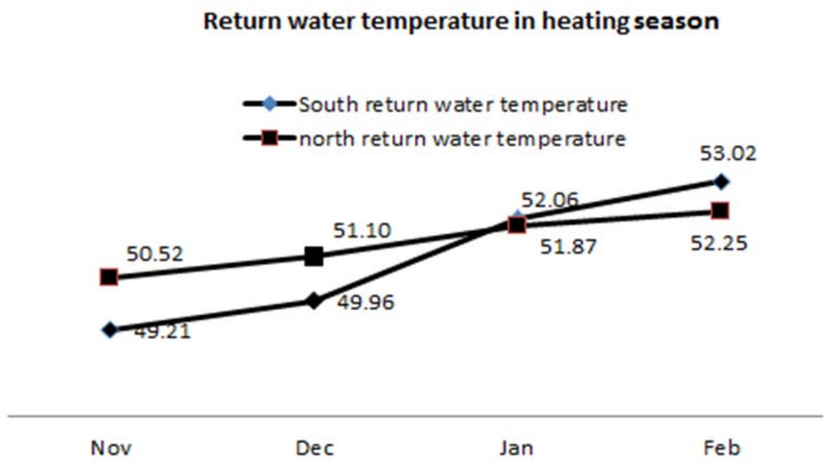

Figure 2. The trend of return water temperature of the heating network 24 hours a day.

4. Conclusions

There is no cold source loss during operation of unit 2 with high back pressure. The higher the electric load of unit 2, the temperature of circulating water supply will be higher. The steam extraction capacity of unit 3 and unit 4 will be cut back. The efficiency of the turbine will be go up. The thermal loss of three units is 634.74 kJ·(kW.h)$^{-1}$ when the load difference of unit 2 is 25 MW. For every 5 MW reduction of power load of unit 2, the thermal consumption of the whole plant increases by about 126.95 kJ·(kW.h)$^{-1}$ and the coal consumption of power generation increases by about 4.86 g· (kW·h)$^{-1}$.

The temperature difference between the circulating water and the return water of the heat network will increase when the circulating water flow of the heat network decreases. The heat consumption and the heat absorption of the three heating units for gaining 1 yuan per hour will decrease with small flow and large temperature difference of the heat network. The heating unit is more economical and profitable.

The water supply temperature of primary network should be timely adjusted according to the return water temperature of primary network in the middle and end of heating period. The purpose is to avoid maintaining the temperature of the primary water supply for a long time which will result in a high return temperature of the heat network. The primary heating network shall be adjusted in time to avoid the waste of external heating energy when the heat load of the heating network changes.

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