Economic Optimization Analysis of Condensate System Operation

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Abstract. In view of the high power consumption of the condensate pump in a power plant, based on the historical operation data, this paper uses the field test to adjust the operation mode of the condensate system, improves the control logic of the condensate system, and optimizes the fitting curve of the pressure of the condensate main pipe and the internal pressure of the deaerator, effectively solves the problems of poor economic performance of the condensate system.

1. Introduction
Frequency conversion technology can reduce the power consumption of equipment without changing the efficiency of equipment. When a new thermal power plant is built, the auxiliary equipment with high power consumption is often equipped with frequency conversion device to reduce the power consumption of equipment. However, in the actual operation of thermal power plants, some frequency conversion devices do not play an energy-saving role. In view of the above phenomena, this paper takes the operation data of condensate water system of a power plant as an example, and on the basis of field test, through optimizing the operation mode of condensate water system and other measures, effectively reduces the power consumption of condensate pump and improves the operation economy of condensate water system.

2. Equipment general situation
A power plant is equipped with two condensate pumps with 100% BMCR capacity manufactured by Changsha Pump Works Co., Ltd. The condensate pumps are equipped with frequency converters, and the operation mode is one-drag and two-hand switching. The automatic control mode of condensate system is that the frequency converter tracks the pressure of condensate and the deaerator inlet valve group tracks the water level of deaerator.

Table 1. Summary of relevant parameters of condensate pumps

| No. | Item                | Value       | No. | Item                | Value       |
|-----|---------------------|-------------|-----|---------------------|-------------|
| 1   | Model               | C720II-4    | 1   | Model               | YSPKKL630-4 |
| 2   | Inlet pressure      | 9.5kPa (a)  | 2   | Voltage             | 6kV         |
| 3   | Outlet pressure     | 3.0Mp      | 3   | Frequency           | 50Hz        |
| 4   | Outlet volume       | 1685t/h    | 4   | Power               | 2000kW      |
| 5   | Efficiency          | 84.1%      | 5   | Efficiency          | 93.8%       |
| 6   | Speed               | 1480r/min  | 6   | Speed               | 1489r/min   |
| 7   | Cavitation allowance| 4.2m       | 7   | Power factor        | 0.85        |
3. Existing problems
Since commissioning of the power plant, the deaerator water inlet valve group has been partially open for a long time, and the power consumption of condensate pump is obviously larger than that of the same type of equipment. In view of the above situation, the historical operation data of the power plant under typical load conditions are collected and sorted out as shown in Table 2.

| Item                                      | 660 MW | 600 MW | 540 MW | 480 MW | 420 MW | 330 MW |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|
| Deaerator water inlet main valve opening(%) | 40.2   | 43.4   | 44.1   | 42.6   | 45.3   | 37.8   |
| Deaerator water inlet auxiliary valve opening(%) | 99.65  | 99.13  | 0      | 0      | 0      | 0      |
| Condensate flow(t/h)                      | 1510.5 | 1400.1 | 1250.7 | 1130.6 | 950.3  | 800.8  |
| Condensate pump current(A)                | 176.3  | 147.1  | 109.6  | 93.8   | 74.7   | 62.2   |
| Input Switching Voltage(kV)               | 6.2    | 6.2    | 6.1    | 6.1    | 6.0    | 6.0    |
| Speed of condensate pump(1t/m)            | 1455   | 1364   | 1237   | 1160   | 1098   | 1040   |
| Condensate Pressure(Mp)                   | 2.55   | 2.30   | 1.92   | 1.75   | 1.60   | 1.55   |
| Internal pressure of deaerator(Mp)         | 1.20   | 1.09   | 1.00   | 0.90   | 0.80   | 0.63   |

In Table 2, when the unit is between 50% load and 100% load, the main valve opening of deaerator intake is basically maintained at about 45%; the auxiliary inlet valve of deaerator is only open at 90% load of the unit, and closed at other load intervals; in low load intervals of the unit, the pressure of condensate is relatively high, and the current of condensate pump is relatively large.

4. Optimization measures

4.1. Theoretical basis

4.1.1. Similarity law of fluid machinery
According to the similarity law of fluid machinery, the relationship between flow Q, head H, shaft power P and speed n of condensate pump is as follows:

\[
\frac{Q_1}{Q_2} \propto \frac{n_1}{n_2} \quad \frac{H_1}{H_2} \propto \left(\frac{n_1}{n_2}\right)^2 \quad \frac{P_1}{P_2} \propto \left(\frac{n_1}{n_2}\right)^3
\]

Formula (1) shows that as long as the speed of the condensate pump changes, the flow rate, head and shaft power of the condensate pump will change accordingly. After installing frequency conversion device, the condensate pump can change from constant speed operation mode to variable speed operation mode. On the premise of keeping the outlet flow of condensate pump unchanged, as long as the outlet pressure of condensate pump is reduced, the power consumption of motor of condensate pump can be reduced.

4.1.2. Concept of "equilibrium point"
Under high load of the unit, the deaerator water inlet valve group is fully open, and the condensate outlet pressure changes with unit load. When unit load drops to a certain area, deaerator inlet valve group should participate in flow control in order to maintain condensate outlet pressure greater than the minimum safety requirements of condensate miscellaneous users. The load turning point of deaerator water inlet valve group from fully open state to throttle state is called equilibrium point. When the unit load is below the "equilibrium point", the outlet pressure of the condensate pump maintains a certain value, and the condensate flow rate of the unit is satisfied by adjusting the deaerator water inlet valve group. When the unit load is above the "equilibrium point" load, the deaerator water inlet valve group is in full open position, and the condensate flow demand of the unit can be met by increasing the speed of the condensate pump.
4.2. Optimization process
According to the similarity law of fluid machinery and the "balance point" rule, the deaerator water inlet valve group is fully opened through field test adjustment, throttling loss is reduced, and power consumption of condensate pump is reduced. During the test, the AGC is removed, the boiler combustion is adjusted, and the load of the unit is maintained stable; the pressure of the condenser pump converter is automatically put in, and the water level of the deaerator is automatically put in; the opening of the deaerator water inlet auxiliary valve is controlled manually by the operator; the opening of the deaerator water inlet main valve is adjusted gradually by setting the pressure bias to reduce the pressure of the condensate. The adjustment results are shown in Table 3.

Table 3. Data after optimization of condensate system test

| Item                        | 660 MW | 600 MW | 540 MW | 480 MW | 420 MW | 330 MW |
|-----------------------------|--------|--------|--------|--------|--------|--------|
| Deaerator water inlet main valve opening(%) | 99.51  | 99.82  | 99.22  | 98.96  | 99.11  | 42.20  |
| Deaerator water inlet auxiliary valve opening(%) | 99.65  | 99.13  | 99.61  | 99.21  | 99.14  | 0      |
| Condensate flow(t/h)        | 1508.5 | 1401.6 | 1248.1 | 1128.3 | 949.5  | 798.8  |
| Condensate pump current(A)  | 148.6  | 125.3  | 97.2   | 80.4   | 60.5   | 51.3   |
| Input Switching Voltage(kV) | 6.2    | 6.2    | 6.1    | 6.1    | 6.0    | 6.0    |
| Speed of condensate pump(r/min) | 1367  | 1292   | 1178   | 1118   | 1008   | 954    |
| Condensate Pressure(Mp)     | 2.14   | 1.93   | 1.71   | 1.50   | 1.29   | 1.25   |
| Internal pressure of Deaerator(Mp) | 1.20  | 1.10   | 1.00   | 0.90   | 0.80   | 0.63   |

Considering the limitation of the cooling water pressure of the low pressure cylinder seal of the unit, the minimum outlet pressure of the condensate pump of the unit is determined to be 1.25 Mp. From Table 3, it can be seen that the main and auxiliary valves of deaerator are fully open in the unit load range of 60% to 100%, which eliminates the throttling loss of deaerator water inlet valves.

5. Optimization results
5.1. Economic advantage
Comparing the data in Table 2 with that in Table 3, the data in Table 4 can be obtained. From Table 4, it can be found that the current of condensate pump has obvious changes before and after the test optimization. The maximum decrease of current is 27.7A, and the average decrease current of 6 test conditions is 16.74A.

Table 4. Data comparison table before and after optimization of condensate system test

| Item                        | 660 MW | 600 MW | 540 MW | 480 MW | 420 MW | 330 MW |
|-----------------------------|--------|--------|--------|--------|--------|--------|
| Condensate pump current before optimization (A) | 176.3  | 147.1  | 109.6  | 93.8   | 74.7   | 62.2   |
| Condensate pump current after optimization (A) | 148.6  | 125.3  | 97.2   | 80.4   | 60.5   | 51.3   |
| Current drop value (A)      | 27.7   | 21.8   | 12.4   | 13.4   | 14.2   | 10.9   |
| Pressure of condensate before optimization(Mp) | 2.55   | 2.30   | 1.92   | 1.75   | 1.60   | 1.55   |
| Pressure of condensate after optimization(Mp) | 2.14   | 1.93   | 1.71   | 1.50   | 1.29   | 1.25   |
| Pressure drop value of condensate(Mp) | 0.41   | 0.37   | 0.21   | 0.25   | 0.31   | 0.30   |

Assuming that this power plant generates 6,000 hours of electricity per year and the price of electricity connected to the grid is 0.40 yuan per kilowatt hour, the condensate pump can save 354,900 yuan per year by calculating the average decline value of condensate pump under six load conditions. The calculation formula is as follows:

\[ W = P \times T = \sqrt{3}UICOS\phi T = \sqrt{3} \times 6 \times 16.74 \times 0.85 \times 1 = 147.87(kW \cdot h) \]
\[ \sum (¥) = W \times T \times ¥ = 147.87 \times 6000 \times 0.40 = 35.49(\text{ten thousand}) \]
At the same time, it can be seen from Table 4 that the decreasing trend of condensate pressure is consistent with that of condensate pump current. The maximum decreasing range of main pipe pressure is 0.41 Mp, and the average decreasing pressure is 0.31 Mp under six test conditions. The decrease of condensate pressure also reflects the reduction of throttling loss of deaerator water inlet valve group, which is beneficial to the service life of deaerator water inlet valve group and pipeline and improves the operation safety of condensate system.

5.2. Improvement scheme of condensate system control

5.2.1. Thermal control logic
Optimize the automatic control scheme of condensate system: the main inlet valve tracks the water level of deaerator, frequency conversion tracks the pressure of condensate, and the setting value of condensate pressure is set according to the field test results.

- Automatic control of water level: Maintain automatic control of water level of main inlet valve of deaerator.
- Automatic control of condensate pressure: Maintain the automatic control of frequency converter main pipe pressure. According to the test data, the interpolation function of condensate pressure and internal pressure of deaerator is given (see table 5), which can make the main inlet valve of deaerator fully open basically (the auxiliary inlet valve needs to be fully opened manually); with the decrease of load, the condensate pressure gradually decreases, and the minimum pressure of condensate is 1.25 Mp (excluding unit start-up and shutdown conditions).

Table 5. The relationship between the pressure of condensate and the internal pressure of deaerator

| No. | Generator power (MW) | Internal pressure of deaerator (Mp) | Recommended values of condensate pressure (Mp) |
|-----|----------------------|------------------------------------|-----------------------------------------------|
| 1   | 700                  | 1.26                               | 2.27                                          |
| 2   | 660                  | 1.20                               | 2.14                                          |
| 3   | 600                  | 1.10                               | 1.93                                          |
| 4   | 540                  | 1.00                               | 1.71                                          |
| 5   | 480                  | 0.90                               | 1.50                                          |
| 6   | 420                  | 0.80                               | 1.29                                          |
| 7   | 330                  | 0.63                               | 1.25                                          |
| 8   | 0                    | /                                  | 1.25                                          |

- Interlocking protection: In the peak shaving process, the main and auxiliary valves of deaerator water inlet water are basically fully opened. In order to avoid destabilization of deaerator water level caused by condensate pump starts power frequency standby condensate pump, DCS logic configuration increases: "When frequency conversion condensate pump starts power frequency standby condensate pump, the water inlet auxiliary valves are fully closed, and the main valve of water inlet water is quickly closed to 40% opening".

- Setting value of standby condensate pump for condensate pressure start is revised to 1.10 MP.

5.2.2. The relationship between the pressure of condensate and the internal pressure of deaerator
Considering the influence of unit back pressure, the corresponding relationship between unit load and condensate flow will change. This paper considers that the condensate pressure tracking deaerator internal pressure is more reasonable than tracking generator power, as shown in Figure 1.
6. Conclusion
Aiming at the problems of high power consumption of condensate pump and large throttling loss of deaerator water inlet valve, this paper optimizes and adjusts the operation mode of condensate system through field test on the basis of analysis of historical operation data. It has been proved that the operation economy and safety of condensate system have been effectively improved, which has certain reference significance for the economic optimization of the same type of condensate system.

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