AGC optimization of supercritical heating unit

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Abstract. A 330MW supercritical coal-fired unit, the unit undertakes the task of industrial steam supply all year round, with a rated steam supply flow of 250t/h. Due to the poor heat storage capacity of the unit and the large industrial steam supply of the unit, the unit is not performing well in the AGC-PROPR mode, Periodic large fluctuations in main steam pressure affect the safety of the unit, AGC performance indicators do not meet the requirements, and this unit is often evaluated by the power grid. In order to improve the AGC adjustment performance of the unit, increase the conversion circuit of heating load and electric load, improve the logic of steam turbine main control, boiler main control and fuel main control, and optimize the PID parameters in a targeted manner. Through optimization, the main steam pressure of the unit does not fluctuate greatly, and the K1, K2, K3 indicators meet the requirements.

1. Introduction
In China, most of the supercritical cogeneration units have a capacity of 330MW, most of which are used for heating and heating in winter, and a small part is used for industrial heating.

Because the heating unit extracts part of the steam from the intermediate pressure cylinder to supply the heat load, the extracted steam does not fully perform work in the intermediate pressure cylinder, resulting in a mismatch between the electrical load of the unit and the boiler load. Therefore, in the AGC-PROPR mode of supercritical units with high heating load, the AGC regulation performance often does not meet the requirements[1-2].

The AGC-PROPR mode is an automatic power generation control mode that unconditionally undertakes to adjust the power. When the unit is in the AGC-POROP mode, the AGC command changes frequently, which requires high adjustment performance of the unit.

According to the regulations of 《Implementation Rules for Grid-connected Operation Management of Power Plants in North China》, AGC adjustment performance indicators include adjustment rate (K1), adjustment accuracy(K2), response time(K3), Comprehensive index of regulation performance(KP).

The adjustment rate K1 can be expressed as:

\[ K_1 = \frac{V_i}{V_N} \]  

In the formula, \( V_N \) is the standard adjustment rate, The unit is MW/minute, The standard regulation rate of supercritical unit is 1.5% of rated power. \( V_i \) is the i-th adjustment rate of the unit.

The adjustment accuracy K2 can be expressed as:
\[ K2 = 2 - \frac{\Delta P_i}{\Delta P_N} \]  

(2)

In the formula, \( \Delta P_N \) is the allowable deviation of adjustment, The allowable deviation of adjustment is 1% of rated power. \( \Delta P_i \) is the i-th adjustment deviation of the unit.

The response time \( K3 \) can be expressed as:

\[ K3 = 2 - \frac{t_i}{t_N} \]  

(3)

In the formula, \( t_N \) is standard response time, The AGC response time of the thermal power unit should be less than 1 minute. \( t_i \) is the i-th response time.

The comprehensive index of regulation performance \( K_P \) can be expressed as:

\[ K_P = K1 \times K2 \times K3 \]  

(4)

2. Problem analysis

After the unit was put into AGC-PROPR mode, the AGC performance index was unqualified for a long time, the adjustment rate index \( K1 \) was less than 1 for a long time, and the adjustment accuracy index \( K2 \) did not meet the requirements. Figure 1 shows the trend of the main parameters of the unit during a period of time before unit optimization.

2.1. Main control performance of steam turbine

It can be seen from Figure 1 that the adjustment rate of the \( t_2 \) section is small and the adjustment accuracy is low, indicating that the ratio and integral of the main control PID of the steam turbine are not strong enough, which leads to the fact that the speed control valve of the steam turbine is not fast enough to meet the rapid change in the AGC-PROPR mode. The main control logic of the steam turbine contains the differential feedforward of the load command. When the unit frequently changes load, the differential feedforward of the load command will play a counter-adjustment effect, which is not conducive to the unit to make adjustments quickly following the AGC command.

2.2. Boiler main control performance

It can be seen from the change trend of the main steam pressure that the main steam pressure in the \( t_2 \) section has an obvious upward trend, and the main steam pressure deviation reaches 2 MPa.
When the AGC command increases rapidly, the turbine quickly opens the speed regulating valve to increase the steam intake, but the opening of the speed regulating valve will cause the steam pressure to drop[3]. At this time, the boiler needs to respond quickly to compensate for the change in steam pressure. However, the boiler response of this unit has a relatively large lag, which leads to large fluctuations in steam pressure. The fluctuation of vapor pressure in $t_1$ section is relatively stable, so the AGC performance index of $t_1$ section is much better.

2.3. Fuel main control performance

It can be seen from Figure 1 that the fuel response is very slow, no matter it is $t_1$ or $t_2$, there is no intersection between the fuel quantity curve and the fuel command curve, and the change of fuel quantity cannot keep up with the change of fuel command. This unit is equipped with a positive pressure direct blowing pulverizing system. The formation of pulverized coal has to go through the processes of coal conveying, coal feeding, and coal grinding, so the fuel response is slow. Moreover, it can be seen from Figure 1 that the change trend of the fuel quantity command is too smooth, and there is no sharp turning point, which shows that the generation of the fuel command is also slow.

3. Optimization method

3.1. Heating load-electrical load conversion

Due to the need for the unit to extract part of the steam from the exhaust steam of the intermediate pressure cylinder for the heating load, this part of the steam does not perform any work, which will inevitably cause a mismatch between the generator load and the boiler load.

At this time, if the coordinated control is still based on the original load command, it will inevitably cause an imbalance between the energy of the boiler and the energy demanded by the steam turbine [4], which will lead to the imbalance of the unit load, pressure, temperature and other parameters. Not only will it affect the safety of the unit, but it will also fail to meet the needs of the AGC-PROPR mode for rapid load changes. Therefore, it is very necessary to convert the extraction steam heating flow into power generation load.

This paper designs the transfer functions $F_1(x)$ and $F_2(x)$ suitable for the unit based on the thermal balance diagram of the steam turbine system. The parameter settings of $F_1(x)$ and $F_2(x)$ are shown in Table 1 and Table 2. $F_1(x)$ is a polyline function composed of 12 points, and $F_2(x)$ is a polyline function composed of 6 points. The increased heating load-generation load conversion logic is shown in Figure 2. The adjustment stage pressure is calculated through two conversion functions to calculate the conversion coefficient, and the conversion coefficient is multiplied by the filtered heating flow to get the converted power generation load.

![Figure 2. Heating load-generation load conversion logic](image-url)
Table 1. Conversion function $F_1(x)$ parameter settings

| $x$ | 5.6 | 6.1 | 7.4 | 8.2 | 9.2 | 10.9 | 12.7 | 14.5 | 16.2 | 18.1 | 19.8 | 21.0 |
|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|
| $y$ | 296 | 325 | 400 | 440 | 500 | 600  | 700  | 800  | 900  | 1000 | 1100 | 1165 |

Table 2. Conversion function $F_2(x)$ parameter settings

| $x$ | 299.7 | 486.0 | 743.7 | 1033.5 | 1109.1 | 1165.00 |
|-----|-------|-------|-------|--------|--------|---------|
| $y$ | 0.20015 | 0.22260 | 0.23172 | 0.23147 | 0.23021 | 0.23102 |

3.2. Optimization of fuel main control

There are two problems in the main fuel control. The first problem is the slow generation of the fuel quantity command, and the second problem is the slow response of the actual fuel quantity.

The main fuel control logic before optimization is shown in Figure 3(a). In the figure, LEADLAG is the lead-lag module, HLLMT is the limit module, DEV is the subtraction module, and SUM is the addition module. The generation of fuel command consists of fuel variable load feedforward (BIR), theoretical fuel quantity corresponding to the main control command of the boiler, and differential feedforward of the main steam pressure command. Differential feedforward is to increase the speed, but the differential value of the main steam pressure command is very small, which cannot meet the requirements of rapid load change.

Figure 3(b) is the optimized fuel main control logic. In order to allow the fuel main control to quickly adjust the fuel quantity according to the pressure deviation, the differential of the main vapor pressure command in the original fuel main control logic is changed to the differential of the boiler main control command. The main control command of the boiler includes not only the control of pressure, but also the differential feedforward of pressure deviation. The fuel main control logic increases the differential feedforward of the main control command of the boiler, which can not only meet the needs of rapid load change, but also meet the pressure deviation. Adjust the amount of fuel in time when it is large.

![Figure 3. Fuel master control logic before and after optimization](image)

In order to allow the actual fuel quantity to follow the fuel quantity command faster, the KP of the fuel main control PID is increased from 0.8 to 1, and the Ti is adjusted from 35 to 25.

3.3. Optimization of boiler main control and steam turbine main control

When the unit is put into AGC-PROPR mode, it is required that the unit can quickly follow the
changes of AGC commands and meet the requirements of adjustment speed, adjustment accuracy, and response time.

Figure 5(a) shows the main control logic of the steam turbine under coordinated control. There are two parts in the formation of the main control command of the steam turbine. One is the power deviation through PID adjustment, and the other is the differential feedforward of the load command and the function feedforward of the load command.

In addition to the inappropriate PID parameters of the steam turbine main control, the inverse adjustment of the load by the differential feedforward is also the reason for the slow adjustment of the steam turbine main control. Figure 4 shows the change curve of the main control of the steam turbine during the load change process of the unit. The circle marked the place where the differential feedforward and reverse adjustment occurs. When the active power cannot keep up with the load command, the main control command of the steam turbine needs to be rapidly reduced. When the command and the AGC command are equal, the main control command of the steam turbine has not continued to decline rapidly, but has a rising trend due to the counter-adjustment effect of the derivative. In order to reduce the anti-adjustment effect of the steam turbine main control differential feedforward, the gain of the differential feedforward is adjusted from 4 to 1.5.

In order to increase the adjustment rate and accuracy of the unit, the KP value of the main control PID of the steam turbine is increased from 0.85 to 0.95, and the Ti value is adjusted from 7.2 to 6.5.

The main control logic of the boiler is shown in Figure 5(b). The formation of the main control command of the boiler is composed of three parts. One is the main steam pressure deviation given by the PID regulator, the other is the differential feedforward of the main steam pressure deviation, the third is to superimpose the function feedforward of the load command of the load after the heating conversion.

In order to improve the regulation performance of the main control of the boiler and reduce the fluctuation of main steam pressure, the KP value of the main control PID of the boiler is increased from 0.7 to 0.95, and the differential output limit of the main steam pressure deviation is changed from ±4 to ±10.
4. Optimization effect
After optimization, the main parameter trend of the AGC-PROPR mode of this unit is shown in Figure 6. The optimized AGC performance has been greatly improved, the main steam pressure no longer fluctuates periodically, the main steam pressure deviation can be controlled within 0.6MPa, and the change speed of the fuel quantity command and the total fuel quantity has been greatly compared with that before the optimization. The K1, K2, and K3 are 1.15, 1.16, and 1.85 after optimization.

5. Conclusion
Taking a 330MW supercritical heating unit as an example, through optimization, the regulation performance of the unit is improved, and the AGC performance indicators meet the requirements, which proves the effectiveness of this optimization strategy.

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