The Core Control Strategy Adapted to Different AGC Control Modes for Ultra-supercritical Once-through Furnace Unit Burning Lignite

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Abstract. As for the once-through unit using lignite, in order to meet the AGC requirements of load change, the coordinated control strategy of unit was optimized. The control strategy was optimized mainly from the aspects of steam temperature control and steam pressure control. In order to control the mid-temperature stability, strategy of using feed water and coal to correct the mid-temperature at the same time was adopted, and the feed water flow was revised by desuperheating water. Different measures including variable parameter control of turbine, rapid coal adding to improve the main steam pressure, and feed-forward adjustment of primary air pressure were taken to improve the delay of main steam pressure, and also shortens the starting time of pressure when changing load. When the unit was put into AGC control, according to the different load changing characteristics of the two modes of BLO and BLR, the variable parameters of the coordinated feedforward of each subsystem were modified. And it is necessary to dynamically adjust the correction factor according to the load fluctuation, in order to reduce disturbance of important parameters such as furnace pressure, main steam pressure, main steam temperature, etc. The application results of the control strategy in the power plant show that the optimized control logic can meet the load regulation requirements of different AGC modes for the lignite burning unit, and the steam temperature and steam pressure control effect is good in the process.

Keywords: AGC; Coordinated Control System; Once-through unit; Lignite; Control Strategy.

1. Introduction
With the development of social and the improvement of society's requirements for power quality, the quality requirements of the power grid for AGC regulation have gradually increased. The "Implementation Rules for the Management of Auxiliary Services for Grid-connected Power Plants in North China" and "Implementation Rules for the Management of Grid-connected Operation of Power Plants in North China" (referred to as the "Two Rules") promulgated by North China Power Grid on the quality of unit coordinated control Higher requirements. The "two rules" quantitatively evaluate the unit's adjustment quality KP from the adjustment rate K1, adjustment accuracy K2, response time K3, etc[1-3].
The adjustment indicators are defined in detail in the two rules. 

Adjustment rate

\[ K_1^j = 2 - \frac{v_N}{v_j} \]  

(1)

Adjustment accuracy

\[ K_2^j = 2 - \frac{\Delta P_j}{\text{allowable adjustment}} \]  

(2)

Response time

\[ K_3^j = 2 - \frac{t_j}{\text{standard response time}} \]  

(3)

Adjustment performance for each AGC action

\[ K_p^j = K_1^j \times K_2^j \times K_3^j \]  

(4)

In the formula, \( v_N \) is the standard adjustment rate of the unit; \( v_j \) is the actual load change rate of the \( j \)th adjustment of the unit; \( \Delta P_j \) is the deviation of the \( j \)th adjustment of the unit, and the allowable adjustment deviation is 1% of the rated active power of the unit; \( t_j \) is the \( j \)th response time of the unit, and the AGC response time of the thermal power unit is 60s. \( K_p^j \) is a comprehensive index to measure the \( j \)th load regulation process of the unit.

The main modes used in AGC automatic adjustment are the normal adjustment mode with base point (BLR) and the strict base point sub-mode (BLO). When the BLO mode is put into operation, the AGC load command changes mainly by large changes, and the number of load changes is relatively small; and when the BLR mode is put into use, the AGC load command changes mainly in small continuous changes, and the load changes frequently. Therefore, for the coordinated control of the unit, a fixed set of coordinated control strategies cannot adapt to the control characteristics of the two AGCs at the same time [4-5].

In recent years, the rise in coal prices, the reduction in the number of available hours of power plants, and the introduction of market electricity prices have all resulted in the compression of power plants’ profit margins. For lignite producing areas such as Inner Mongolia and Xinjiang, it is also reasonable for the operation of power plants to use lignite as a fuel or to burn lignite as a fuel for new units and the transformation of old units. Lignite itself has the characteristics of high moisture, high volatile content, low calorific value, and easy to spontaneous combustion. The use of lignite as fuel in power plants saves operating costs. However, for the operation of the unit, the use of lignite will directly lead a large delay time to main steam pressure and main steam pressure. The delay of steam temperature increases and the response capacity of unit load decreases [6-8].

In order to improve the economy of the AGC assessment in the two rules, increase the variable load rate of the unit, and the investment of the BLR mode, all give higher requirements for the control of the main steam pressure. And the characteristics of high moisture and low heating value of lignite caused a large inertia of the pressure response for the steam. For the coordinated control system, the response of the turbine valve to the load is relatively fast, so the core and difficulty of the coordinated control is the control of temperature and pressure.

In summary, for lignite-fired units, how to optimize the coordination Control System of the unit to adapt to the variable load requirements of different AGC modes, and ensure the control effect of steam temperature and steam pressure, have an important meaning.
2. Unit temperature control

2.1. Intermediate point temperature control strategy
For supercritical once-through boiler units, the intermediate point temperature is an important parameter in the conversion process of the boiler's dry and wet modes. It is also an important parameter that characterizes the boiler's thermal load, and it's also a leading signal for the operator to control the superheated steam temperature. In the process of load change, on the basis of ensuring that the intermediate point temperature can be controlled within a reasonable range, the main steam temperature can be well maintained by adjusting the temperature reduction water.

For the control of the intermediate point, the commonly used strategies include two control strategies: "coal feed correction by midpoint" and "feedwater flow correction by midpoint". The main difference between the two control strategies is the control effect on the main steam temperature and main steam pressure. The control strategy of "coal feed correction by midpoint" has better control effect on steam pressure, but the control effect on steam temperature is relatively poor; while the control strategy of "feedwater flow correction by midpoint" is beneficial to the main steam temperature control, while the control of steam pressure is relatively poor [9-10].

In this strategy, the intermediate point temperature is used to simultaneously correct the coal flow and feed water flow rate, which can simultaneously guarantee the control effect of steam temperature and steam pressure, as shown in Figure 1. According to the operation manual of the boiler, the set value of the outlet temperature of the separator corresponding to different loads and pressures can be given, and the actual temperature is calculated by PID, and the intermediate point temperature is outputted to control the corrected coal amount. Since the feedwater responds faster than the coal to the correction of steam temperature and vapor pressure, the intermediate point output coal command can be multiplied by the correction coefficient and a certain inertia time and converted into the feedwater correcting command, which is superimposed on the setpoint value of the feedwater master control.

![Figure 1 Control strategy of the intermediate point temperature](image-url)
2.2. Correction of desuperheating water in main control of water supply

When the unit turns to dry mode, the main control object of the once-through boiler is changed from the water level control of the separator to the water-to-coal ratio control. However, due to the location of desuperheating water is the outlet of the economizer, when the main steam temperature rises and the desuperheating water flow needs to be increased, the feed water flow before the economizer remains stable at this time, but the amount of water entering the economizer is reduced, resulting in an increase in the intermediate point temperature, and the main steam temperature rises. At this time, the control of desuperheating water will further increase the flow of desuperheating water, which will further deteriorate the quality of steam temperature regulation.

In the common control of water supply, the adjusted amount used in conventional control is the feed water flow before the economizer. In order to optimize the temperature control effect, part of the desuperheating water flow will be subtracted from the adjusted amount, as shown in Figure 2. After optimization, when the desuperheating water flow increases, the feedwater main control will increase the part of the feedwater flow by increasing the output of the feedwater pump, to compensate for the influence of desuperheating water flow extraction on the temperature of the intermediate point. So this measure keeps the unit’s intermediate point temperature and main steam temperature stable.

![Figure 2 Correction of desuperheating water flow to feed water control](image)

3. Pressure optimization based on lignite combustion characteristics

Because lignite has the low calorific value and high moisture content, compared with bituminous coal, the response of steam temperature and steam pressure after coal’s adding is more lagging. Therefore, the improvement of the control effect for main steam pressure is the key to coordinated control.
3.1. Variable parameter control of steam turbine main control  
During the load increase process of the unit, when the load command is given, the adjusting valves quickly respond to maintain the load increase. And because the amount of supplemented coal has not yet reflected on the heat, the opening of the adjusting valves in the early stage of the load increase will consume the boiler’s heat storage. Therefore, the control of the turbine’s valve position must not only consider the demand for load control, but also need to take into account the impact on the pressure.

The control of the turbine in this control strategy adopts variable parameter control. When the load deviation is within a certain range, the proportional parameter of the turbine’s load control PID is reduced to slow down the action of the control valves, to alleviate the influence of the valve opening on the steam pressure. When the load deviation increases, the proportional parameter of the turbine’s load control PID is gradually increased to ensure the control demand for the load.

3.2. The control of the fuel feedforward in the process of load variation  
When the load of the unit changes greatly, the pressure starts slowly. Therefore, it is necessary to optimize the pressure control during the load variation process, with optimization of fuel feedforward and boiler PID parameters.

Due to the slow pressure response of the lignite-fired boiler, the main steam pressure can maintain the same slope as the set value during the process of large increase or decrease of the load. But due to the slow pressure rise, the pressure deviation always exists in the process. So it is easy to cause the excessive accumulation of coal in the process, and pressure overshoot after the load changing.

The differential feedforward of the load designed in the control of the boiler is shown in Figure 3. In the process of variable load, the amount of coal is over-regulated to supplement the boiler heat storage consumption in the load changing process. The differential feedforward is proportional to the variable load rate. The logic design of the differential feedforward can meet the pressure control when the load changes. However, after the AGC is put into the R mode, the frequent action of the load will also cause the repeated regulation of the fuel, which is easy to cause the fluctuation of the steam temperature and steam pressure. In order to satisfy the AGC O mode and R mode control at the same time, the derivative feedforward amount is corrected. When the load deviation is small, the differential feedforward coal quantity is corrected by the function to reduce the overshoot of the coal quantity when the load changes. So in the AGC R mode, the chang of load and steam temperature can be satisfied by the change of the static coal quantity and the heat storage of the boiler.

In addition, due to the high moisture content of lignite, the load for low-load stable combustion is higher. Therefore, when the load of the unit is reduced to half load, it is necessary to gradually reduce the overshoot of the feedforward to prevent excessive reduction of coal and water, and it’s carried out in this control logic.
3.3. Optimization of Pressure for the Primary Air
The increase of primary air pressure can quickly increase the amount of pulverized coal entering the furnace, so as to achieve rapid response to load. Therefore, the design logic in this scheme is to increase the feedforward amount of the primary air pressure when the load change exceeds 50MW, to improve the pressure response rate at the initial stage of the load changing. When the AGC is in the R mode, the primary air pressure feedforward limiter is reduced to a certain extent to reduce the disturbance of the furnace pressure caused by frequent load changes.

3.4. Control of Hot Air of Coal Mill
Due to the low calorific value of lignite, the total amount of coal entering the furnace is large, and the coal amount of mill is close to the upper limit. Therefore, a large amount of hot air is required to dry the coal, and the primary air rate is usually between 45% and 45%. One of the major functions of the hot primary air is to dry the pulverized coal and ensure the air temperature at the outlet of the mill. When the load is changed, in order to ensure the response speed of the load, the role of the feedforward overshoot of the primary air pressure should be strengthened. Therefore, compared to the bituminous coal, the output of the primary fan has a greater influence on the mill’s ability and the response of the furnace pressure when the load changes.

In the process of load changing, the hot primary air volume of the coal mill follows slowly, resulting in insufficient response speed of the boiler's thermal load, causing the main steam pressure response time during the load changing to be too long. Adding of the feedforward of the coal amount to the hot primary air is used in the logic. In order to adapt to the R mode of AGC, when the deviation between the command and the actual load is less than 15MW, the derivative is reduced to reduce the disturbance.
4. Application of control strategy

After using the control strategy to optimize the logic of a 660MW ultra-supercritical once-through boiler unit, AGC test was carried out. During the AGC test, the load changes greatly; while in the AGC 48-hour assessment stage, it is mainly the adjustment mode of small load disturbance. It can be seen from the trends in Figure 4 and Figure 5 that the load control and the control of steam temperature and pressure can meet the requirements. The application of this control strategy can meet the requirements of BLO mode and BLR mode in AGC adjustment of lignite-fired units.

![Figure 4 AGC large load change process](image1)

![Figure 5 AGC small load disturbance process](image2)
5. Conclusion
This paper takes lignite-fired once-through boiler units as the object, and aims to adapt to the load changes of different AGC modes. Measures are taken to optimize the Coordinated Control System of the unit. For the control of the intermediate point temperature, a control strategy of simultaneously correcting water and coal is adopted, and the correction of the main feedwater flow by desuperheating water is added to the main feedwater control, which can achieve better temperature control effects. For the large delay characteristics of main steam pressure, control strategies such as variable parameter adjustment in turbine’s control, and feedforward of coal and primary air pressure, are adopted to improve the response rate of main steam pressure. In addition, in view of the differences in the control characteristics of different AGC modes, a dynamically changing load rate is set, and feedforward amount is dynamically differentiated.

The application results in the unit show that, under different AGC modes, this control strategy can meet the load regulation requirements and has a good control effect on pressure and temperature, which can provide a reference for the same type of units.

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