Risks Analyses and Control Measures of Deep Peak Shaving for the 1000MW Ultra-Supercritical Unit

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Abstract. Influenced by economy, policy and other aspects, it is often necessary to carry out deep peak shaving at low load for large-capacity thermal power units in order to flexibly adapt to the power supply demand of power grid. Safety risks increases obviously in deep peak shaving operation, but it can be lowered to a minimum through reasonable operation adjustment to ensure the safe operation of units. Based on the operation experience, the potential safety risks of deep peak shaving for the 1000MW ultra-supercritical unit are analyzed, and the corresponding control measures are worked out.

1. Introduction
With the slowdown of China’s economic growth in recent years, the mismatch between the increasing speed of social electricity load and that of generator assembly capacity has become increasingly prominent. At the same time, UHV power transmission and new energy power generation are developing rapidly. The traditional coal-fired power industry is being impacted unprecedentedly, and the utilization hours are decreasing year by year. Under this situation, on the one hand, the state actively promotes the structural reform of the supply side, and resolutely shuts down some old units with high energy consumption and pollution. On the other hand, domestic ultra-supercritical units have also carried out a large-scale flexibility transformation and conducted deep peak shaving tests in order to enable the units to operate steadily in a larger load range and meet the needs of rapid peak shaving of the power grid.

2. Risks analyses of deep peak shaving
The boiler equipment type of the 1000MW ultra-supercritical coal-fired unit in Taizhou Power Generation Co., Ltd. of China Energy Group is HG-2980/26.15-YM2, which adopts the arrangement of Π-shaped arrangement with single furnace, reverse double tangential circle combustion, MPM burner + SOFA burner + biased peripheral air burner, vertical upward film water wall of inner threaded tube, start-up system of circulating pump and primary reheating. The characteristics of the steam turbine are condensing type, supercritical type, primary intermediate reheating, single shaft, four cylinders and four exhaust, double back pressure, condensing type and eight stages regenerative extraction type.

When the unit is in normal operation, its control mode is CCS with primary frequency modulation input. The load could be regulated by using AGC, and the load range is from 550 MW to 1000 MW.
When the unit is in deep peak shaving, the unit load should be reduced to 400 MW. Under this low load condition, there are some problems worth to be considered and solved in actual operation, such as the instability of boiler combustion, the over-temperature of local water wall, the over-standard of environmental protection parameters, the blockage and corrosion of air preheater, the fluctuation of boiler feed water, etc.

2.1. The instability of boiler combustion with low load
With the reduction of unit load, the heat load in furnace decreases, the combustion condition of pulverized coal becomes worse, the combustion stability and anti-interference ability decrease. If abnormal conditions such as coal quality deterioration and coal mill tripping occur, it is easy to cause combustion instability, even boiler fire extinguishing.

2.2. The over-temperature of boiler water wall
The boiler adopts the combustion mode of reverse double tangential circle. As shown in Figure 1, it is easy to form a "hot wall" in the middle of the front wall of the water wall, which results in the high temperature of the water wall in this area. In deep peak shaving, the phenomenon of water wall over-temperature is more likely to occur because the heat load of the boiler is relatively more concentrated.

![Figure 1. Reverse double tangential circle combustion](image)

2.3. Over-standard NOx emission in boiler flue gas
The selective catalytic reduction (SCR) method is adopted in the denitrification of boiler flue gas. SCR process is to inject diluted ammonia evenly into the flue gas generated by coal-fired boilers. The flue gas containing ammonia is placed in a reactor with special catalysts (such as V_2O_5-TiO_2). Under the
catalytic action of catalysts, nitrogen oxides and ammonia in flue gas are converted into nitrogen and water to reduce the emission of nitrogen oxides. The main reactions are as follows:

\[ 4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \]
\[ 6\text{NO} + 4\text{NH}_3 \rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \]
\[ 6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O} \]
\[ 2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O} \]

When the denitrification system is in normal operation, the flue gas temperature at the reactor inlet must be above 310 °C. In deep peak shaving, if the flue gas temperature is too low, the catalyst performance will decline, and the NOx content in the flue gas will rise, which will easily cause excessive emissions, at the same time, it will also cause catalyst blockage and permanent damage [1].

2.4. Blockage and corrosion of air preheater

When the unit is in deep peak shaving, the efficiency of denitrification will decrease due to the decrease of flue gas temperature. The unreacted NH₃ in the denitrification system with the escaped ammonia (NH₃), SO₃ in the flue gas and steam will form ammonium bisulfate condensate (NH₃+SO₃+H₂O→NH₄HSO₄) [2]. At a certain temperature, ammonium bisulfate presents a high viscous liquid state. After condensation, ammonium bisulfate easily adheres to the surface of heat exchanger elements of air preheater, adheres to fly ash particles in flue gas, blockages the passage of heat exchanger elements of air preheater, reduces the flow area of air preheater, and increases the resistance of air preheater, thus causing the blockage of air preheater. Under low load conditions, the possibility of low temperature corrosion of air preheater is greatly enhanced by the reduction of exhaust gas temperature of boiler.

2.5. Volume fluctuation of boiler feed water

Boiler feed water is supplied by two steam-driven feed water pumps. In normal operation, the flow rate of the two feed water pumps is greater than the minimum flow rate of the pump, and the recirculation regulating valve automatically keeps closed. When the unit load is gradually reduced to the deep peak load, the boiler feed water will be reduced to less than the sum of the minimum flow of two feed water pumps. If the feed water pump recirculation control valve opens automatically at this time, the feed water will be greatly reduced. In addition, in the process of load reduction, the false water level may occur due to the change of main steam pressure, which will cause the high water level of the high-pressure heater to withdraw from operation and disturb the water supply.

3. Control measures of deep peak regulation

When the unit is in deep peak shaving, its 400 MW working condition is lower than the minimum load of the unit in normal operation. Therefore, relevant control measures should be taken in advance to avoid or reduce the possible risks.

3.1. Improving boiler's low load steady combustion ability

3.1.1. Reasonable arrangement of grinding group operation mode. Boiler grinding groups from bottom to top are A, B, C, D, E and F grinding groups respectively. Under the condition of low load, the total coal quantity decreases. If more than three grinding groups are maintained, the coal quantity of each grinding group is on the low side, which will lead to large vibration of the grinding group and possibly damage the equipment.

We arrange the operation of three lower grinding groups A, B and D. A grinding group is equipped with plasma combustion aids that other grinding groups do not have, which can make the pulverized coal at the exit of A grinding group burn more fully. The simultaneous operation of B and A grinding groups can make the lower flame of the boiler more centralized and stable. If the C grinding group is put into operation, the boiler's heat load is too concentrated, which will cause overheating of the lower water wall of the boiler, and there are potential safety hazards. When the E or F grinding groups are
put into operation, the large distance between the A and B grinding groups may lead to unstable combustion and even the dangerous condition of extinguishing. Therefore, the D grinding group is chosen as the third running grinding group, which can achieve better combustion conditions of the boiler. At the same time, the C grinding group is in the state of being ready to start at any time, so that it can be quickly put into operation when the operation of the grinding group trips.

3.1.2. **Reasonable arrangement for warehousing.** In order to ensure the combustion stability of the boiler under low load conditions, A and B grinding groups arrange to add high calorific value coal (SHENHUN 2). However, if all grinding groups burn high calorific value coal, the total coal quantity is not high, which will lead to large vibration of running grinding group. Therefore, the D mill group should store low calorific value economic coal (2:1 YINNI to SHENHUN 5000) to increase the total coal quantity. The specific indicators of coal types are shown in Table 1.

| Types of coal | Calorific value (kilocalorie) | Total moisture Mt (%) | Volatile compounds Vdaf | Total sulfur Stad (%) | Ash content Aad (%) | Ash fusion temperature St (°C) |
|---------------|-------------------------------|-----------------------|-------------------------|----------------------|--------------------|-------------------------------|
| SHENHUN 2     | 5211                          | 14.2                  | 29.19                   | 0.35                 | 16.5               | 1450                          |
| SHENHUN 5000  | 4878                          | 13.2                  | 28.15                   | 0.47                 | 21.2               | 1450                          |
| YINNI          | 3318                          | 40.4                  | 39.75                   | 0.08                 | 4.02               | 1230                          |

3.1.3. **Rational setting of speed of mill separator.** The ignition temperature of pulverized coal flow decreases with the decrease of pulverized coal fineness. At the same pulverized coal concentration, the finer the pulverized coal, the larger the surface area of the combustion reaction, the smaller the thermal resistance of the pulverized coal itself, and the easier the pulverized coal burns. Therefore, on the premise of ensuring no vibration of the coal mill, the rotating speed of the rotating separator of the coal mill should be increased as much as possible to reduce the fineness of the pulverized coal.

3.1.4. **Reasonable allocation of secondary air valves.** When the load is low, the circumferential air opening should be appropriately closed to reduce the ignition heat of pulverized coal. At the same time, the auxiliary windshield corresponding to the running mill should be suitable, and it should not be too large or too small [3]. It can close the air opening around the running mill to 30%, the secondary air opening of the non-running mill group to 5%, SOFA and COFA air valves to 70%, the secondary air pressure and furnace differential pressure to maintain about 300 Pa, and the burner swing angle to 70%-80%. The opening of SOFA and COFA air valves is adjusted according to the NOx at the outlet of the furnace, the secondary air pressure and the differential pressure of the furnace.

3.1.5. **Avoiding cold air into the furnace.** During the period of deep peak shaving, the inspection of bottom water seal and slag dredger should be strengthened, and the water level monitoring should be done well to ensure the normal water level of bottom water seal [4]. At the same time, check and close all fire observation holes of the boiler body to avoid the unstable combustion caused by cold air entering the furnace.

### 3.2. Avoiding boiler water wall overheating

Because the boiler adopts the reverse double tangential circle combustion mode, if the tangential circle deviation occurs, the temperature of the corresponding area is easy to rise. At low load, the monitoring of water wall temperature should be strengthened. If it is found that the local water wall temperature increases, the secondary air valve in the corresponding area should be opened to increase the secondary air pressure, reduce the superheat properly, and control the wall temperature within the allowable range.
3.3. Improving the efficiency of denitrification system

When the unit is in deep peak shaving, the activity of catalyst will decrease when the flue gas temperature decreases, which will affect the efficiency of denitrification. Therefore, the flue gas temperature of the boiler should be increased as much as possible.

Before the unit's deep peak shaving test, the frequency of soot blowing of the furnace should be appropriately reduced to a certain extent to weaken the heat transfer effect, so as to improve the inlet flue gas temperature of denitrification system.

When the unit is in deep peak shaving, the normal input of high pressure heater should be ensured, the feed water temperature should be increased as much as possible, the radiation heat absorption in furnace should be reduced, and the flue gas temperature should be increased. At the same time, on the premise of ensuring that the mill group does not vibrate, the coal quantity of D mill group should be increased appropriately, and the burner swing angle should be adjusted to make the furnace flame skewed upward. In addition, on the basis of satisfying the stable combustion in the furnace, the total air volume can be reduced appropriately, and the production of NOx in the original flue gas can be reduced.

3.4. Preventing clogging and corrosion of air preheater

It is necessary to improve the efficiency of denitrification system and reduce the production of ammonia bisulfate. In addition, the soot blowing steam source of the air preheater should be cut from the low pressure steam source of the furnace body to the auxiliary steam ahead of time to ensure that the soot blowing pressure of the air preheater is normal at low load, while the air preheater maintains continuous soot blowing.

Full-open air supply fan recirculation control valve can increase the secondary air temperature at the inlet of air preheater, thereby increasing the average temperature at the cold end of air preheater and reducing the risk of low temperature corrosion of air preheater.

3.5. Reducing the disturbance of boiler feedwater

Under the condition of 400 MW deep peak shaving, the feed water flow of the boiler is about 1740 t/h, while the steam pump recirculation from flow to 680 t/h starts to open automatically, and it opens completely at 460 t/h. In order to avoid disturbance caused by frequent switching of feed water pump recirculation valve at critical flow rate, when the load is reduced to about 500 MW, a steam pump recirculation regulating valve is withdrawn manually and gradually opened to 30%. During the whole peak shaving process, the rotational speed of two steam driven feed water pumps is maintained above 3100 rpm.

With the reduction of unit load, the pressure difference between No. 3 high-pressure heater and deaerator decreases gradually, the drainage of high-pressure heater is relatively poor, and false water level rises easily at low load. If the adjustment is not in time, the withdrawal of high-pressure heater will cause disturbance to feed water and furnace combustion. Therefore, it is necessary to reduce the water level setting value of high-pressure heater in advance, and adjust in time.

4. Conclusions

In this paper, the safety risks of the ultra-supercritical unit in the process of deep peak shaving are analyzed, and the corresponding control measures are formulated, which are summarized as follows:

(1) The operation mode of A, B and D grinding group is adopted, in which A and B grinding group burn high calorific value coal and D grinding group burn low calorific value economic coal, which not only ensures the stability of boiler combustion, but also ensures the operation safety of grinding group. At the same time, it should be checked to confirm that the water seal level at the bottom of the furnace is normal and the boiler fire observation hole is closed, so as to avoid cold air entering the furnace and affecting combustion.

(2) Boiler reverse double tangential circle combustion mode, leading to water wall in the middle of the front wall under low load conditions, easy to overheat. By reducing the intermediate-point
superheat degree, increasing the secondary air pressure and opening the secondary air valve in the over-temperature area, the over-temperature of the water wall can be effectively improved.

(3) When the load is low, the temperature of flue gas decreases, which will lead to the reduction of denitrification effect, blockage and corrosion of air preheater. By reducing the number of soot blowing in the convective heat transfer area, the convective heat transfer of flue gas can be reduced and the temperature of flue gas can be increased.

The main measures mentioned above can greatly reduce the safety risks brought by deep peak shaving, and can provide some reference for the same type of millions of units in deep peak shaving.

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