Research on reducing NOx emissions during start-up period of ultra-supercritical 1000MW unit

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Abstract. Due to the limitation of boiler operating condition, the NOx emission from coal-fired power plant will exceed the standard during the start-up period (the initial stage of grid connection). According to the specific situation of 1000MW ultra-supercritical coal-fired unit in Taizhou Power Generation Co., Ltd. of China Energy Group, this paper analyzes the NOx emission and the reasons for exceeding the standard in the start-up period of the unit. In order to solve this problem, this paper puts forward several measures to reduce NOx emission during unit start-up.

1. Introduction

In recent years, with the reduction of annual utilization hours of thermal power unit, the number of unit start-up and shutdown increases year by year, the NOx emission of the unit often exceeds the standard after the start-up and grid connection[1]. Taking the 1000MW ultra-supercritical coal-fired unit of Taizhou Power Generation Co., Ltd. of China Energy Group as an example, this paper analyzes this problem and puts forward feasible measures to reduce the NOx emission during the start-up of the unit.

The boiler of the 1000MW ultra-supercritical coal-fired unit in Taizhou Power Generation Co., Ltd. of China Energy Group adopts П-type layout with single furnace, reverse double tangential circle combustion mode, MPM burner + SOFA burner + biased peripheral air burner, internal thread tube vertical rising membrane water wall, circulating pump start-up system, and primary intermediate reheat, is equipped with two steam driven induced draft fans and one standby electric induced draft fan. In the denitrification part, Selective Catalytic Reduction (SCR) technology is adopted. During normal operation of the unit, NOx emission concentration is controlled within 50 mg/Nm³.

2. Analyses of NOx emission and over standard reasons during unit start-up

The unit was started once in March and April 2020 respectively. The NOx emission of the unit after grid connection is shown in Table 1. The data comes from the hourly mean value of relevant CEMS data on the environmental protection website.

| NOx average concentration (mg/Nm³) | Over limit time (min) |
|------------------------------------|-----------------------|
| Mar. 482.669 | Apr. 376.260 | Mar. 50 | Apr. 15 |
It can be seen from Table 1 that during the two start-up periods, the unit did not meet the emission standard for more than 4 hours at the initial stage of grid connection.

2.1. Mechanism of NOx production
NOx produced in the process of pulverized coal combustion can be roughly divided into fuel type, thermal type and fast type according to different forming conditions. In the total emission of NOx, the proportion of fuel type NOx is more than 75%. The mechanism is that nitrogen compounds in fuel react with oxygen to form NOx. The main factors affecting fuel type NOx are the intrinsic characteristics of coal combustion and the excess air coefficient in the combustion process.

2.2. NOx emission data correction
According to relevant provisions of GB13223-2011 standard, NOx emission data shall be converted according to 6% oxygen content of flue gas:

\[
\text{NOx}_{O_2=6\%} = \text{NOx}_{\text{MEASURED VALUE}} \times \frac{15}{21-O_2_{\text{MEASURED VALUE}}} \tag{1}
\]

Where:
- \(\text{NOx}_{O_2=6\%}\) is the NOx emission concentration after conversion of flue gas oxygen to 6%, mg/Nm\(^3\);
- \(\text{NOx}_{\text{MEASURED VALUE}}\) is the actual measured NOx emission concentration, ppm;
- \(O_2_{\text{MEASURED VALUE}}\) is the actual measured O\(_2\) concentration in flue gas, %.

2.3. Analysis of NOx emission exceeding standard
In the start-up period of the unit, the excessive air coefficient of the boiler increases the oxidizing atmosphere in the combustion area of the furnace and the conversion ratio of NOx emission data becomes larger. In addition, the low flue gas temperature at the SCR inlet causes the denitrification system unable to be put into operation. Those are the two main reasons for the excessive NOx emission.

When the unit is started, the amount of coal required is less, while the air volume is controlled greatly. The increase of the excess air coefficient of the boiler means that the oxygen content in the flue gas increases, the oxidizing atmosphere in the furnace increases, and nitrogen compounds are more easily oxidized to NOx. In addition, according to the conversion formula of NOx emission, when the oxygen content in the flue gas is greater than 6%, the conversion value will be greater than the actual value. The more oxygen content is, the greater the conversion value is, as shown in Table 2[2]. However, the oxygen content in flue gas of the unit before grid connection has generally reached more than 12%, resulting in further increase of NOx emission after conversion.

Table 2. Measured value of NOx corresponding to different flue gas oxygen content.

| Oxygen content of flue gas (%) | Conversion factor | Converted value (mg/Nm\(^3\)) | Measured value (mg/Nm\(^3\)) |
|------------------------------|------------------|-------------------------------|-----------------------------|
| 11                           | 1.50             | 50                            | 33.3                        |
| 12                           | 1.67             | 50                            | 30.0                        |
| 13                           | 1.88             | 50                            | 26.7                        |
| 14                           | 2.14             | 50                            | 23.3                        |
| 15                           | 2.50             | 50                            | 20.0                        |
| 16                           | 3.00             | 50                            | 16.7                        |
| 17                           | 3.75             | 50                            | 13.3                        |
| 18                           | 5.00             | 50                            | 10.0                        |
SCR can be put into operation only when the flue gas temperature at the inlet is higher than 310 °C. If the flue gas temperature is too low, the catalyst performance will decline. The unreacted NH$_3$ in the denitration system will generate ammonium bisulfate condensate (NH$_3$ + SO$_3$ + H$_2$O → NH$_4$HSO$_4$) [3] with the escaping ammonia (NH$_3$) and SO$_3$ and water vapor in the flue gas. After the cold condensation, it is easy to adhere to the surface of the heat exchange element of the air preheater and the fly ash particles in the flue gas, and block the heat exchange element channel of air preheater. After the unit is connected to the grid, it needs more than 4 hours of loading process so that the flue gas temperature can meet the requirements. Before that, SCR cannot be put into operation, resulting in NOx emission exceeding the standard.

3. Measures to reduce NOx emission

3.1. Reduction of secondary air volume and oxidizing atmosphere in furnace

When the secondary air volume is lower than 25% of the rated total air volume, the protection action will be triggered, resulting in the boiler flameout. In order to have a sense of psychological safety, the total air volume of the boiler will remain large during the unit startup process, reaching about 1600t/h before grid connection. Therefore, the total air volume of the boiler can be reduced properly when the stable combustion of the furnace is satisfied.

During the start-up period of the unit, the opening of the three-layer SOFA damper at the upper part of the furnace is not large, and the auxiliary damper of the shutdown mill is put into automatic operation, which results in the increase of air volume in the combustion area at the lower part of the furnace. In order to reduce the oxidizing atmosphere in the combustion area, the three-layer SOFA damper can be fully opened, and the auxiliary damper of the shutdown mill can be manually closed[4].

3.2. Increase of SCR inlet flue gas temperature

There are two factors that affect SCR inlet flue gas temperature, i.e. flue gas heat generated by boiler combustion and inlet water temperature of economizer.

The more fuel the boiler has, the more flue gas it has. Under the condition of ensuring the coal with high calorific value of mill A at the bottom, the coal with relatively low calorific value can be added to the rest of the grinding silos to increase the total coal quantity and flue gas quantity. In addition, when the boiler turned state (wet state to dry state), grinding groups A, B and D operated, and the furnace flame was relatively lower. According to the field analysis, before the boiler turning state, when mill A and mill B are in operation, the furnace combustion is stable and the fire detection signal is normal, and mill E can be started to turn state. Meanwhile, the CD layer oil gun is hot standby. In this way, once the combustion of mill E is unstable and the flame detection signal is weak, the oil gun at the corresponding angle can be put into combustion support rapidly. When mill A, mill B and mill E are operated to turn the state, the furnace flame can be raised and the flue gas temperature can be further raised.

In the process of unit startup, the increase of fuel quantity means the increase of unit load. Therefore, it is necessary to optimize the start-up operation[5], and increase the unit load as soon as possible, such as arranging warm-up in advance, arranging the impulse of steam pump and steam induced draft fan when the main engine is running, and heating the steam inlet of high-pressure heater and low-pressure heater when the main engine is running at high speed.

When the inlet water temperature of economizer increases, the heat absorption of economizer can be reduced and the exhaust gas temperature of boiler can be increased. There are two ways of water entering the economizer, one is the water supply through the deaerator and high-pressure heater, the other is the boiler circulating water after the heat is absorbed by the furnace water wall and pressurized by the boiler water circulating pump. Therefore, when the boiler water circulating pump is running, the outlet regulating valve shall be kept at 80% or more open, the hot water recycling quantity shall be increased, and the inlet water temperature of the economizer shall be increased.
Before boiler ignition, open the heating regulating valve from auxiliary steam to deaerator as much as possible to keep the temperature of deaerator above 150 °C. Increasing the temperature of boiler water supply is conducive to the ignition and stable combustion of boiler. In addition, the high-pressure heater #2 can be put into operation as early as possible after ignition, which can further improve the feed water temperature.

After the hot cleaning of the boiler, the boiler does not need to be discharged. However, since the main steam source of auxiliary steam is from the adjacent unit, and the heating steam source of deaerator and the steam source of shaft seal are from auxiliary steam, the external steam source will cause the water level of hot well to rise continuously, which may submerge the air extraction port of condenser, thus affecting the vacuum. The boiler is required to discharge hot water from time to time and supplement the water supply with relatively low temperature to control the water level of hot well, which also reduces the cost water temperature at the inlet of the coal feeder. Therefore, in the process of boiler hot cleaning, the set value of hot well water level should be lowered in advance to keep a lower water level. In addition, under the condition of satisfying the operation conditions, the gland seal steam source shall be switched to the high-pressure cylinder for exhaust as soon as possible, and the heating steam source of deaerator shall be switched to the fourth stage extraction of the main steam turbine to realize the self-supply of the unit.

4. Conclusions
This paper analyzes the causes of NOx emission exceeding the standard during the start-up of ultra-supercritical unit. Some methods are put forward, such as reducing the total air volume properly, closing the air valve in the combustion area, adjusting the type of coal for bunkering, changing the operation mode of the mill group when the boiler is running, reasonably arranging the start-up of the auxiliary machine, increasing the temperature of the water supply, controlling the low water level of the condenser and realizing the self-supply of steam as soon as possible, which can be used for reference for the similar unit to reduce the emission of NOx during the start-up process.

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