Modeling and Control Optimization of Denitrification System of 600MW Thermal Power Unit

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Abstract. In order to solve the problems of outlet flue gas NOx concentration fluctuation and exceeding the environmental protection standard of a 600 MW thermal power unit, a denitrification automatic control strategy based on Smith's estimation and intelligent feedforward was adopted for optimization. The practice indicates that the new control strategy can not only effectively reduce the fluctuation of NOx concentration, but also effectively reduce the use of ammonia flue gas aiming at the problems of large delay and multiple interference sources in denitrification system. The field application proves the validity of the method.

Keywords: Denitrification, ammonia spraying, optimal control.

1. Introduction
In recent years, a series of environmental standards and documents have been issued and implemented in China. High requirements for NOx concentration control in outlet flue gas of pyroelectric denitrification system are put forward. The denitrification control system is characterized by nonlinearity, large delay and multiple interference sources and so on. The current domestic large thermal power unit of the SCR denitrification control system has poor automatic effect which make the operation performance of the whole denitrification system is obviously affected[1],[2]due to the incomplete control strategy design, undefined control goal, field measurement conditions and other problems. A 600 MW thermal power unit denitration control system uses the traditional PID control. In practical operation, NOx concentration in flue gas of denitrification system often fluctuates greatly and exceeds environmental protection requirements, and the consumption of ammonia flue gas is relatively large, so the operation performance of the whole denitrification system is obviously affected. Therefore, the control strategy of the original denitrification automatic control system needs to be adjusted. By designing a new denitrification control technology based on Smith estimation and intelligent feedforward, the original control strategy was optimized to ensure that the NOx concentration emission was within the controllable range.
2. The denitrification control technology based on Smith's estimation and intelligent feedforward

The denitrification control technology based on Smith's estimation and intelligent feedforward was adopted according to the characteristics of SCR denitrification process. Add Smith estimator controller in the traditional cascade PID control loop and adopt the comprehensive intelligent feedforward technology of burning, coal quality, load change and other interference sources to ensure the feedforward signals are not only related to unit load, but also related to current NOx concentration and variation trend. Under the premise of ensuring the stability of the system, the speed of adjusting the opening of the ammonia valve is effectively accelerated, so as to effectively suppress the dynamic deviation of NOx under various disturbances.

The realization of the scheme requires accurate modeling and overall optimization of the control system. First, the dynamic characteristic model of denitrification system is obtained through modeling test. Then the denitrification control strategy based on Smith's estimation and intelligent feedforward was adopted in the DCS system of the unit to effectively control the NOx concentration of SCR outlet.

2.1. Acquisition of model of denitrification system

The above denitrification control strategy based on Smith's estimation and intelligent feedforward requires the establishment of denitrification dynamic characteristic model. The specific modeling methods for the denitrification control system of this power unit are as follows [3].

2.1.1. Establish the dynamic characteristic model of the NOx concentration in the outlet flue gas of SCR denitrification device

The SCR denitrification device is to control the amount of ammonia so that the NOx concentration in the flue gas can be deoxidized in the SCR reactor so that the NOx content in the outlet flue gas can meet the standard requirements. For the control system of SCR device, the controlled variable is the concentration of NOx in the outlet flue gas of SCR device, and the amount of ammonia injection is the control variable in the control system. The model is shown below.

\[
W_1(s) = \frac{NO_{out}(s)}{U(s)} = \begin{cases} 
-2.12 & \text{if } \text{330MW}\text{loadpoint} \\
-1.57 & \text{if } \text{540MW}\text{loadpoint} \\
\frac{1}{(1+45s)^2(1+62s)^2}e^{-190s}\text{if } \text{330MW}\text{loadpoint} \\
\frac{1}{(1+32s)(1+50s)^2}e^{-150s}\text{if } \text{540MW}\text{loadpoint}
\end{cases}
\]

2.1.2. Establish the dynamic characteristic model of NOx concentration in flue gas at the entrance of SCR device comparing to NOx concentration in flue gas at the outlet of SCR device

One of the main disturbance factors influencing NOx concentration in the flue gas at the outlet of SCR device is the concentration of NOx in the flue gas at the entrance of SCR device. The SCR denitrification device is to control the amount of ammonia so that the NOx concentration in the flue gas can be deoxidized in the SCR reactor so that the NOx content in the outlet flue gas can meet the standard requirements. For the control system of SCR device, the controlled variable is the concentration of NOx in the outlet flue gas of SCR device, and the amount of ammonia injection is the control variable in the control system. The model is shown below.

\[
W_2(s) = \frac{NO_{out}(s)}{NO_{xin}(s)} = \begin{cases} 
0.32 & \text{if } \text{330MW}\text{loadpoint} \\
0.28 & \text{if } \text{540MW}\text{loadpoint} \\
\frac{1}{(1+86s)}e^{-78s}\text{if } \text{330MW}\text{loadpoint} \\
\frac{1}{(1+72s)}e^{-70s}\text{if } \text{540MW}\text{loadpoint}
\end{cases}
\]
2.1.3. **Apply multi-model switching application.** The model integrity of the denitrification system is increased by identifying the model of denitrification system and introducing the disturbance variables that have influence on the controlled variables. Conduct model identifying according to the unit under different load parameters and obtain models at other load points by linear interpolation method to implement multi-model switching application and optimize the control of SCR ammonia injection based on advanced control algorithms such as Smith estimation, etc.

2.2. **Denitrification control technology based on Smith estimation**

The characteristic of Smith control is to estimate the dynamic characteristics of the control object in the basic control process (including the action of disturbance source) in advance, then compensated by the estimator to reflect the regulated quantity of delayed τ to the regulator ahead of time to make the regulator move in advance, so as to reduce the overshoot and speed up the adjustment process. The principle is shown in figure 1.

![Figure 1. Smith estimator principle schematic diagram](image)

\[ R(s) - Set value; Y(s) - regulated variable; G_c(s) - transfer function of the regulator; U(s) - regulator output; Y'(s) - regulated variable after being compensated by the Smith estimator; G_s(s) - Smith estimator transfer function; G_0(s)e^{-\tau} - pure delay control object; G_0(s) - transfer function of control object without pure delay Z. \]

Figure 1. Smith estimator principle schematic diagram

\( G_0(S)e^{-\tau} \) is the transfer function between ammonia injection and NOx concentration at the outlet of SCR denitrification device, that is \( W_1(s) \) or \( W_2(s) \). Pure delay link of \( e^{-\tau} \) have been removed through Smith estimate controller. The regulated variables have been changed to \( G'_1(s) \) object with rapid feature in dynamic process to eliminate the effect of pure delay on control quality of denitrification system. Combined with conventional PID cascade regulator, good control quality can be obtained.

2.3. **Intelligent feed forward and Override control setting**

In a conventional NOx control system, the corresponding proportional or differential signal of the unit load instruction is usually used as feedforward for the ammonia spraying regulator. This feedforward control is independent of the actual NOx inlet concentration change degree, change trend and other operating conditions. Therefore, it is necessary to design intelligent feedforward which is related to the variation trend of unit load and NOx concentration at inlet[4]-[5]. The denitrification control strategy based on Smith estimation and intelligent feedforward is shown in FIG.2. The intelligent feedforward and Override control setting includes the following:

The feedforward and NOx concentration of flue gas in denitrification inlet are designed for variable load forecasting of ammonia injection, oxygen content and combustion rate. The feedforward of NOx concentration of flue gas at ammonia denitrification inlet was calculated through the dynamic model of NOx concentration at the inlet of SCR device to the NOx concentration at the outlet of SCR device. At the same time, use the proportional micro components of load change, unit oxygen content and combustion rate to make the feedforward amount of the ammonia spraying regulator more reasonable.
The unit denitrification system is restricted by the boiler structure. There is a problem of uneven flow field in long and narrow flue of NOx concentration measurement point at the outlet to make a certain deviation between the concentration of NOx in chimney and the concentration of NOx at SCR outlet. The NOx concentration at SCR outlet was compared in real time based on NOx concentration at environmental assessment points. The deviation between the concentration of NOx at the side outlet of SCR A and B and the concentration of NOx in chimney was evaluated. When the cumulative mean exceeds a certain error, the NOx concentration measurement and set value of the controller are intelligently corrected.

The uneven smoke flow field on side A and side B leads to the inconsistency of smoke flow on both sides. By comparing the amount of ammonia sprayed on side A and side B and the concentration of NOx at the inlet, the deviation between side A and side B was estimated, and the amount of ammonia sprayed on side A and side B was intelligently proportioned.

Because the CEMS analyzer needs 10 minutes of purge calibration every 3-4 hours, the CEMS data on the swept side should be override and maintained during the purge time. When NOx concentration changes due to changes in combustion conditions during purge, CEMS data recovery will lead to the fluctuation of the regulating system after the end of the purge. So it cannot be solved simply by measuring and maintaining. The calibration of side A and side B CEMS purge is not synchronous. Side A purge is replaced by side B. Considering the measurement inconsistency of side A and side B, the difference should be superimposed, so as to accurately eliminate the fluctuation caused by the purge calibration.

![Figure 2. The denitrification control SAMA diagram](image-url)
The dynamic compensation of various disturbance factors in denitrification control system is realized by using advanced Smith control algorithm and intelligent feedforward technology. Intelligent feedforward eliminates system fluctuation from the source of reaction, adjusting the feedforward coefficient continuously through the intelligent learning algorithm to make it change with unit working condition, so as to effectively reduce the NOx concentration fluctuation of export.

2.4. Actual optimization effect
The control strategy of the unit was deeply optimized from two aspects: reducing the amount of ammonia spraying and enhancing the control effect of nitrogen oxides on the denitrification side for studying and practicing on optimal control strategy of ultra-low emission denitrification. The closed-loop stability and anti-disturbance capability of the system are greatly improved. In actual operation, NOx concentration at chimney outlet can be effectively controlled below 30mg/Nm3, as shown in figure 3. During the whole process of unit load changing from 300MW to 600MW and then from 600MW to 450MW, the NOx content response in the flue gas at the outlet of SCR device is relatively stable. The dynamic deviation is within ±15mg/Nm3 and converges to the set value in half a cycle, meeting the relevant requirements of national and industrial standards.

![Figure 3. The denitrification control SAMA diagram](image)

3. Conclusion
Denitrification control and implementation plan based on Smith prediction and intelligent feedforward make minor modifications on actual DCS system of power plant can obviously improve the control quality of denitrification system. Practical applications show that this scheme can effectively improve the running performance of denitration system, greatly reduce NOx concentration fluctuation, and significantly reduce the ammonia consumption, achieved good social and environmental benefits and economic benefits.

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