Multi-scenario Analysis of Thermal Power Units Emission Reduction Considering Optimal Cost-effectiveness

Kuan Zheng 1*, Qiuli Zhao 1, Shumei Shen 2, Fuqiang Zhang 1, Mi Zhou 3

1 State Grid Energy Research Institute Co, Ltd, Beijing 102209, China
2 North China Electric Power University, Beijing 102206, China
3 State Grid University, Beijing 100192, China
*Corresponding author’s e-mail: zhengkuan@sgeri.sgcc.com.cn

Abstract. This article is guided by the most cost-effective emission reduction program, according to the statistics of different unit types installed in 2015, including the operation of each unit, the decommissioning period and the relevant policies and regulations that the country has now clearly defined. This article analyzes the coal-fired emission reduction scenarios and forecast the thermal power generation reductions in 2020 and 2030. It verifies the superiority of the emission reduction scheme and provides a reference for the next step of technology and equipment development.

1. Introduction
In response to the frequent haze pollution in the eastern and central parts of China, all industries have started to reduce emissions. As an important source of conventional pollutants, electric industry is a key sector for combating haze [1]. In 2018, China's electric industry consumed 2.12 billion tons of coal, accounting for 53.9% of the country's total coal consumption. Sulfur dioxide, nitrogen oxide and dust emissions totaled 1.08 million tons, 1.03 million tons and 0.25 million tons respectively, accounting for about 15%, 9% and 4% of the nation's sulfur dioxide, nitrogen oxide and dust emissions. With increasing emphasis on issues such as climate change, energy security, and environmental protection, China is paying more attention to cutting emissions [2]. On December 2, 2015, the Ministry of Environmental Protection, the National Development and Reform Commission and the National Energy Administration jointly issued the Notice on Comprehensively Implementing the Work Plan for Ultra-low Emissions and Energy-saving Reconstruction of Coal-Fired Power Plants. It was required that by 2020, all coal-fired power plants with reformation conditions should achieve ultra-low emission and accelerate the reformation of ultra-low emission of coal-fired generating units. As the world's largest power producer and consumer, China's exploration and realization of the maximum emission reduction in the power industry will play a decisive role in China's ability to control haze.

2. Development status of thermal power industry emission reduction technology
Electric industry has achieved excellent results in ultra-low emissions. The thermal power units have also made major breakthroughs in emission reduction technologies such as dust removal, desulfurization, and denitrification [3]. At present, taking the ultra-low emission as the core, China's coal-fired power plants emission reduction technology has a diversified development trend.
As to dust removal technology, in addition to wet electrostatic precipitator, low-temperature electric dust removal, rotating electrode electric dust removal, high-frequency power supply, electric dust removal, ultra-clean electric bag composite dust removal, bag dust removal and other technologies have also been rapidly developed. In addition, a number of new electrostatic precipitator technologies such as dust agglomeration technology, flue gas quenching and tempering, isolation rapping, partial power-off rapping, pulse power supply, and three-phase power supply have also been applied in individual power units [4]. As to desulfurization technology, on the basis of traditional empty tower lifting technology, there are double pH cyclic desulfurization technology, composite tower desulfurization technology, etc. [5]. At present, the mainstream desulfurization technology in China is limestone-gypsum wet desulfurization technology. If high-efficiency wet desulfurization technology is adopted, the desulfurization design efficiency can exceed 98%, meeting ultra-low emission standards of SO₂. The denitrification technology is mainly divided into two types: generation source control and flue gas denitrification technology. At present, one of the most mature and practically effective denitrification processes is SCR denitrification technology. As ultra-low emissions become the new normal, SCR ultra-low emission technology and full-load denitrification have become the focus of technical research, and one of the important directions for future development.

3. Multi-scenario setting

3.1. Basic idea

As mentioned above, the goal of China's thermal power plant emission is to meet ultra-low emissions standards, and there are various technology to achieve the goal. Based on a cost-effective optimization method, this paper established serval the below process to calculate different thermal power plant emission reduction schemes. The process of the emission reduction plan is shown in Figure 1.
3.2. Thermal power structure setting
According to the existing installed capacity of different unit types, the operation status of each unit and the relevant national policies and regulations, this paper set the target scenarios for coal-fired power plants in 2020 and 2030. The scenario installation structure is shown in Table 1. Among them, the high scenarios mean that more small capacity units would be replaced by large capacity units, which is used to stress the effect of structural emission reduction.

| scenarios          | 0.6-10 | 10-20 | 20-30 | 30-60 | 60-100 | ≥100 | Total |
|--------------------|--------|-------|-------|-------|--------|------|-------|
| 2020 basic scenario | 4800   | 3900  | 3000  | 39600 | 45000  | 13700 | 110000|
| 2020 high scenario  | 0      | 1950  | 3000  | 39600 | 45000  | 20450 | 110000|
| 2030 basic scenario | 3500   | 2200  | 2000  | 33600 | 49900  | 17000 | 108200|
| 2030 high scenario  | 0      | 0     | 1000  | 33600 | 49900  | 23700 | 108200|

3.3. Emission reduction technology setting
According to the relevant requirements of the Comprehensive Implementation of the Work Plan for Ultra Low Emissions and Energy Saving of Coal-fired Power Plants, the pace of ultra-low emission reform of existing coal-fired generating units will be accelerated. The eastern region had completed the ultra-low emission reform tasks in 2017. The central region had strived to complete basically by 2018, and the western region would complete by 2020. Therefore, emission reduction technologies in 2020 and 2030 are preferred from ultra-low emission technologies. It is mainly preferred from the following technologies: equalizing effect board, desulfurization efficiency ring, improving liquid-gas ratio zone control, boiler low-nitrogen combustion reform, SCR denitrification device adding new catalyst, low-temperature electric dust removal, wet electric dust removal, and high-frequency power supply.

3.4. Emission reduction regulations setting
In accordance with the relevant requirements of the joint document of the Ministry of Environmental Protection, the Development and Reform Commission and the Energy Administration on the Comprehensive Implementation of the Work Program for Ultra-Low Emissions and Energy Conservation Reform of Coal-fired Power Plants, by 2020, all coal-fired power plants with reformation conditions in the country must strive to achieve normal emission standard (i.e., the emission concentration of dust, sulfur dioxide and nitrogen oxides is not higher than 10 mg/m³, 35 mg/m³, 50 mg/m³ respectively under the condition of 6% of reference oxygen content). Conditional new coal-fired generating units should reach ultra-low emission levels (i.e., the emission concentration of dust, sulfur dioxide and nitrogen oxides should not exceed 5 mg/m³, 35 mg/m³, 50 mg/m³ respectively under the condition of 6% of reference oxygen content). In principle, the newly-built coal-fired power generation project in the country should adopt ultra-supercritical units of 600,000 kW and above, and the average coal consumption for power supply is less than 300g of standard coal/kWh. The 2020 target scenario needs to meet the conventional pollutant emission concentration requirements. In addition to the above requirements, the 2030 target scenario must meet the above requirements for carbon emission peaks.

4. Multiple scenarios analysis
As mentioned above, we can separately derive different structural scenarios in 2020 and 2030, and analyze and summarize the results of the reduction of thermal power units in the country in the future. The emission reduction plan for 2020 basic scenario is shown in Table 2. In the 2020 basic scenario, the emission concentrations of all important pollutants have reached the relevant requirements in the National Full Implementation of the Work Plan for Ultra-low Emission and Energy-saving Renovation of Coal-fired Power Plants. Through the technical reformation of ultra-low emission and other measures, he dust emissions would be reduced to 137 thousand tons, the sulfur dioxide emissions
would be reduced to 785 thousand tons, and the nitrogen oxides would be reduced to 872 thousand tons of nitrogen oxides.

Table 2. Emission reduction plan in 2020 basic scenario

| Technology name | Different unit capacity (10,000 kW) |
|-----------------|------------------------------------|
| Desulfurization technology | 0.6-10 10-20 20-30 30-60 60-100 ≥100 |
| Desulfurization efficiency ring | 3700 1180 |
| Increasing liquid-gas ratio | 590 550 |
| Partition control | 460 2990 |
| Denitrification technology | 670 630 530 3380 4200 1340 |
| Boiler low nitrogen combustion reform | 300 110 |
| New catalyst for SCR | 50 50 40 240 |
| Dust removal technology | Low temperature electric | 323 194 |
| Wet electric | 24 41 260 |
| High frequency power supply | 282 | 3074 |

The emission reduction plan for 2020 high scenario is shown in Table 3. In the 2020 high scenario, the dust emissions would be reduced to 120 thousand tons, the sulfur dioxide emissions would be reduced to 702 thousand tons, and the nitrogen oxides would be reduced to 806 thousand tons of nitrogen oxides.

Table 3. Emission reduction plan in 2020 high scenario

| Technology name | Different unit capacity (10,000 kW) |
|-----------------|------------------------------------|
| Desulfurization technology | 0.6-10 10-20 20-30 30-60 60-100 ≥100 |
| Desulfurization efficiency ring | 3814 2111 |
| Increasing liquid-gas ratio | 282 |
| Partition control | 479 3074 |
| Denitrification technology | 312 527 3377 4205 2327 |
| Boiler low nitrogen combustion reform | 323 194 |
| New catalyst for SCR denitrification unit | 24 41 260 |
| Low temperature electric dust removal | 312 527 3377 4205 2327 |

The emission reduction plan for 2030 basic scenario is shown in Table 4. In the 2030 basic scenario, the dust emissions would reduce 98 thousand tons, the sulfur dioxide emissions would reduce 514 thousand tons, and the nitrogen oxides would reduce 474 thousand tons of nitrogen oxides compared with the 2020 basic scenario.
| Technology name          | 0.6-10 | 10-20 | 20-30 | 30-60 | 60-100 | ≥100 |
|-------------------------|--------|-------|-------|-------|--------|------|
| Current sharing board   |        |       |       |       |        |      |
| Desulfurization efficiency ring |     |       |       |       |        |      |
| Increasing liquid-gas ratio |     |       |       |       |        |      |
| Partition control       | 310    | 330   | 240   | 290   | 4880   | 1660 |
| Boiler low nitrogen combustion reform |       |       |       |       |        |      |
| New catalyst for SCR    | 380    | 410   | 290   | 2930  | 4879   | 2601 |
| Low temperature electric |     |       |       |       |        |      |
| Wet electric            | 30     | 30    | 20    | 190   |        |      |
| High frequency power supply |     |       |       |       |        |      |

The emission reduction plan for 2030 high scenario is shown in Table 5. In the 2030 high scenario, through the technical reformation of ultra-low emission and power structure adjustment, the dust emissions would reduce 105 thousand tons, the sulfur dioxide emissions would be reduced by 547 thousand tons, and the nitrogen oxides would reduce 500 thousand tons of nitrogen oxides compared with the 2020 basic scenario.

| Technology name          | 0.6-10 | 10-20 | 20-30 | 30-60 | 60-100 | ≥100 |
|-------------------------|--------|-------|-------|-------|--------|------|
| Current sharing board   | 4047   | 2158  | 2158  | 2158  |        |      |
| Desulfurization efficiency ring |     |       |       |       |        |      |
| Increasing liquid-gas ratio |     |       |       |       |        |      |
| Partition control       | 122    | 2438  | 146   | 2928  | 4879   | 2601 |
| Boiler low nitrogen combustion reform |       |       |       |       |        |      |
| New catalyst for SCR    | 337    | 217   | 10    | 202   |        |      |
| Low temperature electric |     |       |       |       |        |      |
| Wet electric            |        |       |       |       |        |      |
| High frequency power supply |     |       |       |       |        |      |

5. Conclusions
Overall, China is in an important period of industrialization and urbanization. In the next 20 years, China's electrification level will maintain a relatively fast growth rate. At the same time, power demand growth is significantly higher than energy demand growth, and the power industry's emissions proportion will continue to rise. After 2020, power supply structure adjustment will accelerate, coal power development will reach its peak. Therefore, it can be seen from the analysis in the above scenarios that each thermal power unit basically meets the emission requirements, its reformation will also be greatly changed, and the space for emission reduction will increase significantly.

Through empirical analysis, during the 13th Five-Year Plan period, the thermal power industry still has some space for conventional pollutant emission reduction. After 2030, China's thermal power plant's emission reduction space will be very small. On the one hand, China's power structure transformation is developing fast, and clean energy power generation will replace thermal power to become China's leading power source. The positioning of thermal power will be transformed from "electricity main body" to "capacity main body". As a result, power generation will be significantly reduced and emissions will be significantly reduced. On the other hand, the thermal power unit will have almost completed the ultra-low emission technology reformation by 2020. At that time, the thermal power units can reduce emissions by more than 65%, reduce sulfur dioxide by more than 60%, and reduce nitrogen oxides by more than 50%. By 2030, thermal power plants could reduce costs...
through technological innovation. The retrofit effect of existing ultra-low emission technologies has become saturated. If there are no preconditions for a significant increase in the hidden costs of health or the environment, the thermal power companies will no longer have the incentive to further reduce pollutant emissions.

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