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Assessment method for the prevention effectiveness of $PM_{2.5}$ based on the optimization development of coal-fired power generation

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Abstract. A large number of combustion of coal is easy to lead to the haze weather which has brought a lot of inconveniences and threat to people's living and health in E&C China, as the dominant power source of China, the coal-fired power generation is one of the main sources to the haze. In this paper, the contribution of the combustion of coal and development of coal-fired power generation to the $PM_{2.5}$ emissions is summarized based on the analysis of the present situation, the mechanism and the emission source of $PM_{2.5}$. Considering the peak of carbon emissions and the constraints of atmospheric environment, the quantitative assessment method of $PM_{2.5}$ by optimizing the development of coal-fired power generation is present. By the computation analysis for different scenarios, it indicates that the optimization scenario, which means the main new-installed coal-fired power generation is distributed in western and northern China, can prevent the $PM_{2.5}$ effectively for both the load center and coal base regions of China. The results of this paper not only have reference value for the optimized layout of coal-fired power generation in the "13rd fifth-year" power planning, also is of great significance to deal with problems that the atmospheric pollution and climate warming in the future .

1. Introduction

In recent years, the haze weather occurs quite often in eastern and central China (E&C China), which brings a lot of inconveniences and threat to people's living and health. $PM_{2.5}$ is the most important and harmful component of the haze weather, thus how to reduce the $PM_{2.5}$ emission become a major challenge of the air pollution. Coal is the dominant energy in the China, and a large number of utilization of coal is easy to lead to the $PM_{2.5}$. According to the statistic of China's National Bureau of Statistics, the total amount of coal consumption in 2013 amounted to 2.475 billion tons, which accounts for 59.4% of total primary energy consumption and this proportion is far higher than the world average level (30%). A large amount of dust, carbon dioxide (CO_2) and nitric oxide (NO_x) are produced by the combustion of coal, which become one of the main sources of $PM_{2.5}$. Therefore, it is of great significance to control the $PM_{2.5}$ during the coal utilization to realize the prevention and improvement of air pollution.

Coal-fired power generation (CFPG) is the main consumer of coal in China, although the technologies such as dust removal, desulfurization and denitrification have been promotion a lot in power industry, but considering the large coal utilization in the power industry, there is still a large space of emission reduction with different methods. In the meanwhile, the coal combustion in the other industries is also contributes a lot to the air pollution, such as the coal burning scattered. Therefore, to control the $PM_{2.5}$ pollution, it is not only need to reduce the emission for CFPG, but also need to control the pollutants emission in other industries.

In this paper, we summarized the contribution of the coal combustion to the $PM_{2.5}$ emissions based on the analysis of the present situation, the mechanism and the emission source of $PM_{2.5}$. Considering the peak of carbon emissions and the constraints of atmospheric environment we present a optimization model of the CFPG development and give the quantitative assessment method of the $PM_{2.5}$ emission of CFPG. In view of the new trend and characteristics of the CFPG development, we designed different developing scenarios based on the optimization model of the CFPG, and assessed the $PM_{2.5}$ emissions of CFPG quantitatively for each scenario, then give the suggestions for the development of the CFPG in the future. The results of this paper have reference value for the optimized layout of CFPG in the “13rd fifth-year” power planning, also is of great significance to deal with problems that the atmospheric pollution and climate warming in the future.

2. Analysis on the formation mechanism and emission source of $PM_{2.5}$

2.1. Present situation of $PM_{2.5}$ pollution

According to the data published by the Ministry of Environmental Protection of China, there is only 3 cities (Lhasa, Haikou, Zhoushan) achieve the secondary standard of the air quality on the list of the 74 cities which have been implemented the new air quality standards in 2013 (74 cities). During the whole 2013, the air quality of the 74 cities could achieve the standard only within 221 days averagely, which means the standard-reaching rate is only 60.5%, and the yearly average $PM_{2.5}$ concentrations is 72μg/m^3, which is 2.1 times of the limit value for the secondly regions. The ratio of primary pollutants and the average concentrations of $PM_{2.5}$ of the 74 cities in 2013 are shown in Figure 1.

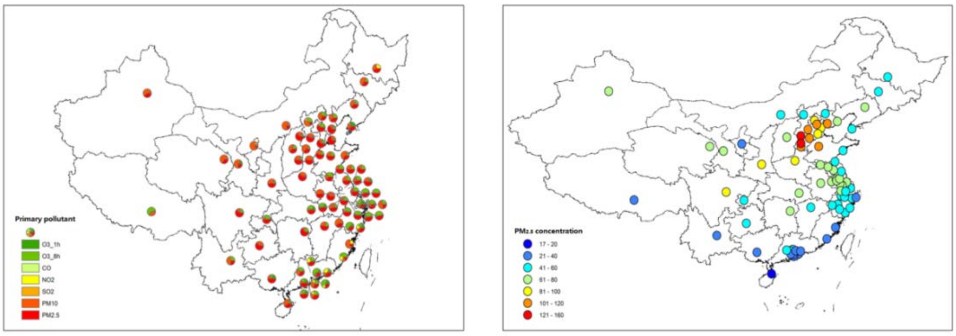

Figure 1. The ratio of primary pollutants and the average concentrations of $PM_{2.5}$ of the 74 cities in 2013 (g/m^3).

It indicates from Figure 1 that the concentration of $PM_{2.5}$ changes greatly in different geographical position, and usually the concentration is higher in the urban, and the regional distribution of $PM_{2.5}$ present much stronger in some megalopolis and big cities as the center. In the Beijing-Tianjin-Hebei region, there are 11 cities listed in the top 20 of the 74 cities mentioned above, and 7 cities in the top 10. For the Beijing-Tianjin-Hebei region, the Yangtze River Delta region and the Pearl River Delta region, which are the most developed regions in China, the population accounts for 24% of China, the consumption of coal accounts for 43% of China, but the land only accounts for 8% of China, so the unit area pollutant emissions is nearly five times of the average value.

2.2. Formation mechanism and emission source of $PM_{2.5}$

The emission source of $PM_{2.5}$ is very complicated, in terms of $PM_{2.5}$ produce process, one source is directly by the pollutant emission, which is called primary particulate matter (PPM). The main component of PPM are carbon, organic carbon and soil dust, etc., which arises mainly from the burning of fossil fuels and biomass fuel, and also from the industrial manufacture, the mineral processing, the construction, and farming, etc.; the other source is the complex which is formed by the condensation of gaseous pollutants discharged from various sources or by heterogeneous chemical reaction, which is called secondary particulate matter (SPM). The main component of SPM are semi volatile organic compounds and ammonium sulfate, nitrate, etc [1]. Among them, the SPM have greater contribution to the formation of $PM_{2.5}$ [2].

For the emission source of $PM_{2.5}$, there are some controversies in the current academic circle. Take Beijing as an example, the Atmospheric Physics of Chinese Academy of Sciences thought the combustion of coal, motor vehicles and industrial production are the main sources of $PM_{2.5}$ pollution [3]. The Environmental Department of Peking University thought the contribution of $PM_{2.5}$ was 35.8% by the motor vehicle emissions and 19% by the coal burning [4]. The Carnegie Center for Global Policy thought the contribution of $PM_{2.5}$ by the motor vehicle emissions is more than 1/4 [5].

3. Optimization model of CFPG development and its assessment method of $PM_{2.5}$

3.1. Improved optimization model of CFPG development

Traditional optimization model of CFPG development is based on principal that the total cost of power supply is lowest during the whole planning period, there the total cost includes the investment and operation cost of the power source and grid, and make the external environment cost as internalization. The optimization analysis not only consider the factors such as the power flow and target market of the CFPG in the future, but also take the following factors as the constraint conditions: power balance, balance of coal supply, supply ability of water, environmental carrying capacity, transport capacity of coal and power market space, by means of the mixed integer programming to get the optimal solution of the install capacity of the CFPG and its delivery power flow [6]. With the action of the air pollution prevention has been gradually strict in China, the optimization of the traditional fossil energy consumption must be the significant step of the whole adjustment of China's energy structure, as development of the CFPG is closely related to $PM_{2.5}$ emissions reduction, so the improved optimization model of CFPG development is mainly adding the constraints of the $PM_{2.5}$ emission and the peak installed capacity of CFPG on the basis of the traditional model, as shown in Figure 2.

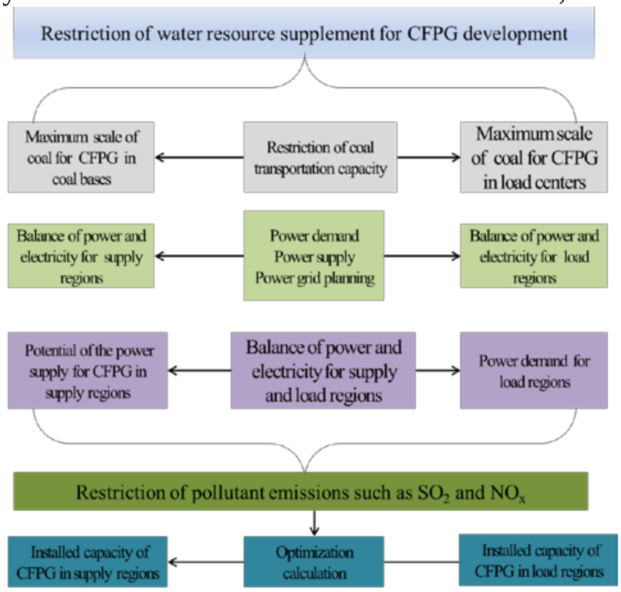

Figure 2. Improved optimization model of CFPG development

According to the action plan to combat air pollution released by State Council of China in September 2013, the $PM_{2.5}$ concentration will reduce by 25%, 20% and 15% respectively in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region and the Pearl River Delta region in 2017. If this target accomplished, the $PM_{2.5}$ concentration will reduce by more than 30% for the three regions above in 2020.

At present, the per capita electricity consumption is still low in China, the demand of electricity will continue to increase for a long time though the present growth rate has slowed down. Considering the double constraints of the conventional air pollutant and the CO_2 emission, the installed-capacity peak of the CFPG is expected around 1200GW in 2030. According to the action plan mentioned above, the new added CFPG will be the main built in western and northern China (W&N China), and the electricity will be supplied through the interregional transmission to the load centers such as the Beijing-Tianjin-Hebei region, the Yangtze River Delta region and the Pearl River Delta region.

3.2. Assessment method of $PM_{2.5}$

As a large coal consumer, the power industry is undoubtedly one of the main sources of $PM_{2.5}$ pollution. Take CFPG as example, the contribution to the $PM_{2.5}$ is from 2 parts: one is the direct emissions (called primary $PM_{2.5}$), the other part is the sulfate and nitrate which are generated from the emissions of SO_2 and NO_x in the atmosphere (called secondary $PM_{2.5}$). According to the related research results [7, 8], 10% of the $PM_{2.5}$ emission of the CFPG comes from the primary particle emitted directly, 50% comes from secondary particle converted from the SO_2, and 40% comes from secondary particle converted from the NO_x, as shown in Figure 3.

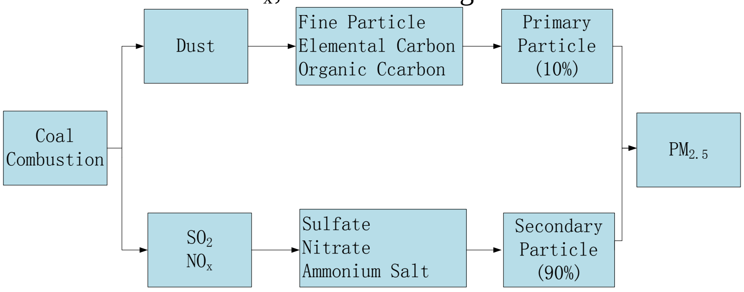

Figure 3. Component analysis of $PM_{2.5}$ for CFPG

The emission of $PM_{2.5}$ can be calculated from the equation (1) [2]:

$$E_{PM_{2.5}} = E_{PM_{2.5}\text{-Primary}} + E_{PM_{2.5}\text{-Secondary}} \tag{1}$$

there the $E_{PM_{2.5}\text{-Primary}}$ is generated from the coal combustion directly, which is dependent on the quality of the coal which mainly includes the ash proportion, the fly-ash ratio and the efficiency of dust removal, it can be calculated by equation (2):

$$E_{PM_{2.5}\text{-Primary}} = C_{coal} \times \eta_{ash} \times \eta_{FAR} \times \eta_{AP} \times (1-\eta_{AR}) \tag{2}$$

there C_{coal} is the consumption of the coal, η_{ash} is the ash proportion of the coal, η_{FAR} is the fly ash ratio, η_{AP} is the proportion of $PM_{2.5}$ to the ash, η_{AR} is the dust removal efficiency.

The SO_2、SO_3、NO_x emitted from the CFPG are the main sources to form the secondary $PM_{2.5}$, which can be calculated by equation (3-5).

$$E_{PM_{2.5}\text{-}SO_2} = C_{coal} \times \eta_{SO_2} \times \eta_{PM_{2.5}\text{-}SO_2} \tag{3}$$

$$E_{PM_{2.5}\text{-}SO_3} = C_{coal} \times \eta_{SO_3} \times \eta_{PM_{2.5}\text{-}SO_3} \tag{4}$$

$$E_{PM_{2.5}\text{-NOx}} = C_{coal} \times \eta_{\text{NOx}} \times \eta_{PM_{2.5}\text{-NOx}} \tag{5}$$

The secondary $PM_{2.5}$ generated from the CFPG is the summation of the three results above:

$$E_{PM_{2.5}\text{Secondary}} = E_{PM_{2.5}\text{SO}_2} + E_{PM_{2.5}\text{SO}_3} + E_{PM_{2.5}\text{NOx}} \quad (6)$$

4. Assessment of the prevention effectiveness of $PM_{2.5}$ considering different development scenarios of CFPG

4.1. Scenarios design

By the end of 2013, the total installed capacity of all power generations in China is 1247 GW, and the installed capacity of CFPG is 862 GW, accounted for 69.2%. The total electricity consumption is 5.32 million GWh, CFPG contributes 3.95 million GWh which accounted for 74.2%. According to the equations presented in Section 3.2, the total emissions of SO_2, NO_x and $PM_{2.5}$ of all CFPG in China in 2013 are 5.8 million tons, 8.10 million tons and 6.4 million tons respectively. According to the action plan mentioned in Section 3, the proportion of CFPG in China will remain around 60% by 2020. Considering the different roadmaps, two development scenarios of CFPG are designed in this paper.

Scenario 1: the uniform growth of the CFPG. During the "twelfth five-year" period, the average annual growth of the CFPG in China is 5.9%, the growth of the coal bases in W&N China such as Shanxi, Shaanxi, Gansu, Inner Mongolia, Ningxia and Xinjiang is 7.2%, and the growth in E&C China is 5.6%. According to this calculation, the total installed capacity of the CFPG in China is 1200GW in 2020, and 25.3% is in W&N China while 46.4% in E&C China.

Scenario 2: optimization development of the CFPG. Although the CFPG is still the main power supply in China in the future, while considering the new circumstance that the growth of the economic and power demand has slowed down, and the environment restriction is more and more strict, the utilization time of the CFPG must decrease. With the prompt development of renewable energy, the pressure of the peak regulation of the power system will increase, and the CFPG will be changed into the main source of the capacity supply from the current source of the electricity supply. Considering the coal and renewable energy are mainly distributed in the W&N China, the CFPG will develop to westwards and northwards. Therefore, in this scenario, 80% of the new installed CFPG will be located in the W&N China and 20% is located in eastern and central load center. According to this calculation, the total installed capacity of the CFPG in China is 1197GW in 2020, and 39.3% is in northern and western China while 32.8% in E&C China.

Considering the proportion of the unit composition of CFPG in different regions, and the emission performance of the dust, SO_2 and NO_x for different units, also some other factors such as the coal quality and conditions of pollutant diffusion conditions, the emissions of $PM_{2.5}$ for CFPG in W&N China and E&C China with Scenario 1 in 2020 and with Scenario 2 in 2020 are calculated by the assessment method mentioned in Section 3.2. The results are shown in Table1.

Table 1. Emissions of PM2.5 of CFPG in different regions of China

Scenario analysis		Installed capacity of CFPG (GW)	SO_2 (10^4ton)	NO_x (10^4ton)	Primary $PM_{2.5}$ (10^4ton)	Secondary $PM_{2.5}$ (10^4ton)	Total $PM_{2.5}$ (10^4ton)
Present situation	**E&C China**	356.57	262	369	28	260	289
	W&N China	217.01	251	293	17	210	227
Scenario 1 in 2020	**E&C China**	568.98	358	486	35	351	386
	W&N China	405.89	422	493	29	353	382
Scenario 2 in 2020	**E&C China**	392.62	371	424	25	311	337
	W&N China	470.42	489	572	30	368	398

4.2. Comparative analysis

According to the calculated result above, it shows that the emissions of $PM_{2.5}$ are increasing since 2013 to 2020 in all the regions because the installed capacity of the CFPG still increases during this period, while the growth speeds are different obviously in the different scenarios. As shown in Figure 4, the emission of $PM_{2.5}$ with Scenario 2 is 490,000 tons less than that with Scenario 1 in the E&C

China, which means the prevention of $PM_{2.5}$ in the E&C China is effective by means of moving the layout of CFPG westward and northward; while for the W&N China, although the new added installed capacity of the CFPG with Scenario 2 is much more than that with Scenario 1 because of the layout of CFPG moving westward and northward, the emissions of $PM_{2.5}$ for both scenarios are almost the same. The reasons for this phenomenon are that the adding units of CFPG in W&N China are the more-developed units with lower pollutant emissions, and the emissions have to meet the increasingly stringent policies of environment protection.

Also, from the point of view that increasing the peak regulation capability of power system to analyze this phenomenon, the increasing amount of the CFPG unit in the W&N China could guarantee the system accepting more clean power generated from the renewable energy. Which is a big bonus not only for the consumption of the renewable energy in the W&N China, but also for the clean alternative effect to reduce the $PM_{2.5}$ emission in the E&C China. All things considered, the prevention effectiveness of $PM_{2.5}$ for China with Scenario 2 is much better, which also means the optimization layout of the CFPG is of great significance for the prevention of $PM_{2.5}$.

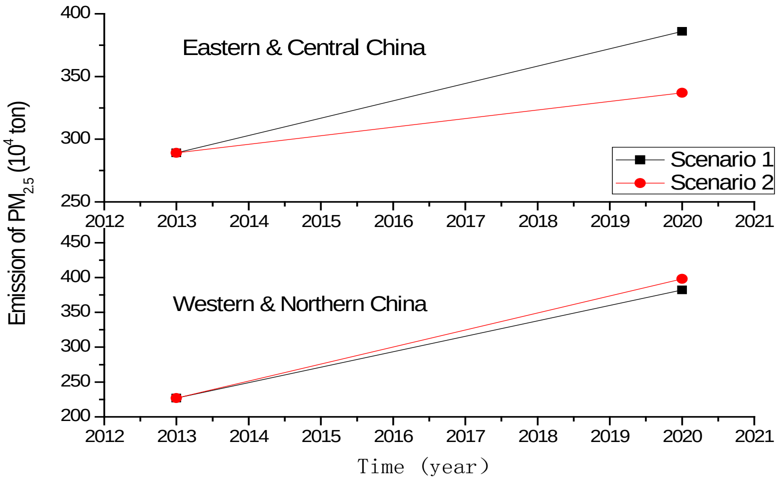

Figure 4. Comparison of $PM_{2.5}$ emissions of CFPG with different scenarios.

5. Conclusion

In this paper, the quantitative assessment method of the $PM_{2.5}$ emissions for CFPG is proposed, the contribution to form the $PM_{2.5}$ of CFPG is analyzed. By the computation analysis for different scenarios, it shows that the optimization development of CFPG with 80% adding CFPG in W&N China and 20% in E&C China contribute a lot for the prevention effectiveness of $PM_{2.5}$ for China. Consequently, as one of the important step of the power industry reform, the optimization development of CFPG can prevent the $PM_{2.5}$ for China and it is of great significance to deal with problems that the atmospheric pollution and climate warming in the future.

References

[1] Xu Lan, et al. 2013 Sources and research status of the air fine particulate matter (PM2.5) *Environmental Protection and Technology* **19(3)** 5-10.
[2] Mo Hua, et al. 2013 Contribution to PM2.5 of Atmospheric Pollutant Emission from Thermal Power Sector and Emission Reduction Countermeasures *Electric Power* **46(8)** 1-6.
[3] Wang Yuesi, et al. 2013 Formation of haze pollution in Beijing-Tianjin-Hebei region and their control strategies *Bulletin of Chinese Academy of Sciences* **3** 353-363
[4] He lingyan, et al. 2005 Determination of organic molecular tracers in PM2.5 in the atmosphere of Beijing *Acta Scientiae Circumstantiae* **25(1)** 23-29.
[5] Wang Tao The contribution of motor vehicle to haze may be undervalued in Beijing.

http://carnegietsinghua.org/2014/02/28/.

[6] Bai Jianhua, et al. 2007 Optimizing research on power transmission scale and target market ofmain coal-power bases *Electric Power* **40(12)** 10-13.

[7] Yue Yong, et al. 2005 Experimental study on characteristics of particulate matter size distribution and trace elements enrichment in emissions from a pulverized coal-fired boiler *Proceeding of the CSEE* **25(18)** 74-79.

[8] Wang Sheng, et al. 2011 Fine particle emission characteristics from coal -fired power plants based on field tests *Acta Scientiae Circumstantiae* **31(3)** 630-635.