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Peak capacity analysis of coal power in China based on full-life cycle cost model optimization

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Abstract. 13th five-year and the next period are critical for the energy and power reform of China. In order to ease the excessive power supply, policies have been introduced by National Energy Board especially toward coal power capacity control. Therefore the rational construction scale and scientific development timing for coal power are of great importance and paid more and more attentions. In this study, the comprehensive influence of coal power reduction policies is analyzed from diverse point of views. Full-life cycle cost model of coal power is established to fully reflect the external and internal cost. Then this model is introduced in an improved power planning optimization theory. The power planning and diverse scenarios production simulation shows that, in order to meet the power, electricity and peak balance of power system, China's coal power peak capacity is within 1.15 ~ 1.2 billion kilowatts before or after 2025. The research result is expected to be helpful to the power industry in 14th and 15th five-year periods, promoting the efficiency and safety of power system.

1. Introduction

Nowadays, China is in a critical period for energy and power reform. Renewable energy has experienced a rapid development stage, which is expected to be the main supply of incremental energy demand by 2030 [1-3]. At the meantime, energy abandon and excessive supply of power generation arise. Considering the coal is main energy resource in China, coal power has a fundamental role to power system. So the rational construction scale and scientific development timing for coal power are of great importance to the power system efficient and safety [4-5].

In 13th five-years and the next period of time, the new norm characteristics of economic development in China become increasingly obvious [6]. A series of issues are to be further investigated, one of which is the reasonable peak scale of coal power capacity [7-8]. A series of policies for coal power control are draw up by National Energy Board within these two years. Research for coal power development has also been carried on in power planning area, especially for power grid with high penetration of clean energy. Reference [9] introduces MIP (mixed integer programming) method in solving the power supply and power grid planning scheme. The minimum investment and running cost is objective function. A two-stage robust power expansion planning theory is proposed. Reference [10] makes low-carbon concept in power planning theory, fully reflecting the external environmental cost

Technology Research Project of State Grid Corporation of China: Global Electricity Market Space Prediction Technology Model in medium and long term of coal power. A method of probabilistic model to solve the diverse objective power grid coordination planning model is proposed in reference

[11], with the coordination of all kinds of power generation. Reference [12] discusses the methods and path of power planning in China's power industry, based on the UHV power transmission technology. Reference [13] presents an innovative methodology for identifying optimum investment strategies in the power industry. It examines results including, among others, the impact of oxy-fuel technology on CO2 emissions prices, and the specific cost of electricity production.

In this paper, the status and development trend of coal power is concluded firstly in chapter 2. The comprehensive influence of coal power capacity reduction, as proposed by National Energy Board, is analyzed in chapter 3. In chapter 4, full-life cycle cost model of coal power is established and to be considered in the power planning theory. Therefore, the peak capacity and reasonable timing of coal power is optimized in chapter 5.

2. Status and development trend of coal power

As of the end of 2016, the total installed coal generation capacity is 943 million kilowatts, accounting for 57.3% of the total generation capacity in China. The annually average utilization hours of power generation equipment and coal generation equipment were reduced from 3769 hours and 4329 hours in 2015 to 3785 hours and 4165 hours respectively, which were the lowest level since 1964. The main reasons include the competition of clean energy generation, the uncontrolled construction of new coal generation, as well as the drastic fluctuation of power demand. As a result, the operating efficiency of coal generation continued to deteriorate, leading to serious risk of vicious competition.

At the same time, China has large-scale approved coal generation projects beyond the oversized coal generation capacity stock. As of the end of 2016, China has approved the coal generation projects more than 300 million kilowatts, based on the research and investigation of the coal power project pre-state, construction progress and so on. In order to define the real progress of each project, five building nodes are put forward as follows.

- Step 1:Pouring the first party concrete on the main plant foundation cushion;
- Step 2:Boiler steel structure hoisting started;
- Step 3:Boiler plate girder hoisting completed, the main plant is build to the top, the turbine platform is paid security;
- Step 4:Boiler water pressure test is completed, the steam car cover is complete;
- Step 5:Experimental operation is completed for generation.

According to the statistics, 170 million kilowatts have been started construction. It should be emphasized that there are 62 million kilowatts whose investment has been completed more that 80% .If all the approved coal generation complete the construction, the coal power installed capacity in China will exceed 1.2 billion kilowatts by 2020. In the background of recent electricity demand level, the overall and structural excess of power capacity will deteriorate further.

As a result, Premier Li Keqiang clearly put forward in this year's government work report that "eliminate, stop and ease more than 50 million kilowatts of the coal generation capacity to prevent the collapse of coal power overcapacity risk, to improve the efficiency of coal industry, to offer development space for clean energy". At the meantime, ‘energy development 13th five-year planning (2016-2020)’ is proposed to control the coal power installed capacity within 1.1 billion kilowatts.

3. The comprehensive analysis of coal power capacity reduction

Overall, China's long-term power demand growth will gradually stabilize, the power market space is limited. The traditional thinking of power capacity such as ‘installed race’ is inadvisable. The coal power capacity reduction is important to the promotion for power system efficiency and the development for clean energy. At the same time, a series of problems in power system has to be solved properly in short term, such as low efficiency of UHV transmission lines, insufficient power supply threat in localized area etc..

3.1. Benefits

Firstly, coal power capacity reduction is a way to reduce power supply redundancy, promoting power system efficiency. Based on a further studies of the average utilization hours of coal power generation equipment mentioned above in a provincial point of view, the provinces with high coal generation capacity such as Guangdong, Henan and Zhejiang have lower utilization hours of coal generation. The regional power surplus is obvious. Scientific control of the production scale, as well as the optimization to the operation mode for stock units, is essential. According to the power balance and production simulations analysis, it is expected that the average utilization hours of coal power in 2020, such as Shanxi, Zhejiang and Henan, will increase more than 400 hours if strictly controlling the scale of coal production.

Secondly, coal power capacity reduction can alleviate the serious situation of fog haze in the eastern part of China. At the meantime, it guarantees the realization of non-fossil energy development target in 2020. In 13^{th} five-year period of China, the role of coal generation is gradually transferred from energy supplier to capacity supplier, in order to give priority to clean energy. It also provides auxiliary and technical support for the efficient utilization of clean energy. Considering that China's energy strategy has shifted from rigid supply to reasonable control, and the total energy consumption in 2020 is controlled by 4.8 billion tons of standard coal, the estimated non-fossil energy consumption in 2020 is about 15.4% by production simulation results. In the medium and long term, under the condition of strict control of the coal generation capacity scale, the power market space in central China and east China during the 14^{th} five-year period is more than 60 million kilowatts. The power gap can be fed by new energy sources in the north and west China, as well as the hydro-power in the southwest China. It is also an important path to achieve low carbon emissions level and improve the proportion of non-fossil energy consumption.

3.2. Threats

Firstly, coal power capacity reduction involves the supporting generation of transmission lines. The shortage scale of supporting coal power generation leads to lower utilization of UHV AC&DC channels. During 2016~2020, a number of UHV AC and DC transmission lines will be put into operation. Taking Jiuquan~Hunan UHV DC transmission line for example, the current approved supporting coal power is 6 million kilowatts, including 2 million kilowatts from power system. The scale of wind and solar power generation is 7 million kilowatts and 2.8 million kilowatts respectively. If there are no other supporting measures, the utilization hours of transmission line is reduced from 6000 hours down to 5500 hours according to the production simulation analysis. Meanwhile, the expected internal rate of return on investment is expected to reduce about 2 percentage points.

Secondly, higher requirement for safe and stable operation of power is put forward, because more new energy generation is needed for high utilization efficiency. For one thing, technical standard of new energy access is higher. The power grid in west and north China is relatively weak, and the short-circuit capacity is small. Therefore the transient over-voltage phenomenon caused by DC transmission line commutation failure is more severe. For another, the reduction of routine operation units will lower system equivalent moment of inertia, affecting the dynamic stability. The last point is the reduction of effective power balance provided by transmission lines. The rotating reserve capacity is to increase.

Lastly, the local scale of new coal generation, as well as the stabilized power received from UHV transmission lines, is reduced. Some areas may have short-term electricity supply intense. For example, the supporting coal generation is significantly reduced in Ximeng, Mengxi, Shanxi and other places. As a result, the received power of north China is affected. The south part of Hebei province has a power supply gap more than 4 million kilowatts based on the production simulation analysis.

4. Full-life cycle cost model of coal power

Based on the analysis above, it is known that the reasonable and scientific development scale is important to power system. The coal power needs to be included in the optimization process of power system planning with detailed description of the comprehensive cost of coal power units. Therefore, full-life cycle cost model of coal power is proposed in this research.

The full-life cycle cost model of coal power is based on the life cycle evaluation method. It mainly focuses on the environmental cost of the whole process in coal power production. Therefore pollutant discharge and external influence can be quantified. This model considers input-output relationship, technical indicators, emission factors, and related environmental costs.

According to the research areas involved, the full-life cycle of coal power can be divided into three main stages: coal exploit and transportation, coal power generation, other auxiliary processes, as shown in Figure 1. Based on the full-life cycle of coal generation and different stages of expenditure, the cost of coal power in different stages can be analyzed.

- Coal exploit and transportation involves exploit scheme, total scale of production, energy loss during transportation, transportation scheme, distance of transportation, contamination emission during transportation and so on.
- Coal power generation involves power generation process of different power generation technology for energy efficiency and emission factors, the total energy use, the amount of pollutant emissions, pollutant removal efficiency and so on.
- Other auxiliary processes involves the fly ash, waste residue and other waste, the relevant disposal costs and transportation costs, and other possible related costs, such as the occurrence of major environmental accidents, or excessive penalties.

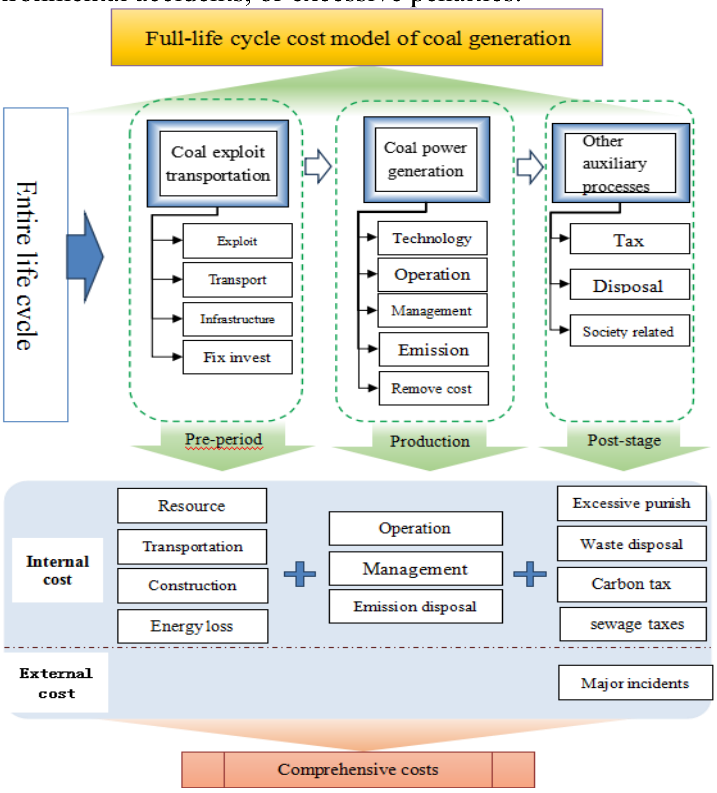

Figure 1. Full-life cycle cost model of coal power.

Based on the effects of these costs on the coal power industry, the cost can be further divided into internal and external costs. The internal cost refers to the part of the cost that can be directly internalized into the coal power industry. Meanwhile, the internal cost can be economized, such as construction cost, transportation cost, resource cost, environmental investment cost, operating cost, management cost, sewage taxes, waste disposal costs, carbon taxes and so on. External costs refer to the additional costs that may have been incurred by the coal power production to the external society. This part has not yet been included in the cost of production and operation, such as the impact of major environmental pollution incidents and their influences on the ecological environment and human health.

4.1. Coal exploit and transportation stage

The pre-period cost of coal power generation is modeled as equation 1. C_j^{Pre} is the utilization of coal of type j based on the current power generation technology. S_j is the transportation distance for the coal. c_j is the unit transportation costs. The total cost of coal transportation is proportional to distance, unit cost, supply scale and so on. $F(Q_j)$ is the cost of resource utilization. It is the purchase cost of different types of coal, as well as a function of the amount of coal procurement. C^{ENV} is the pre-environmental costs, including pre-purchase of environmental protection equipment investment, environmental technology costs, pre-environmental disposal costs and so on.

$$C_j^{pre} = \sum_{j=1} Q_j \cdot S_j \cdot c_j + \sum_{j=1} F(Q_j) + C^{env} \quad (1)$$

4.2. Coal power generation stage

C_{ij}^{Gene} is the environmental costs in the process of power generation. $F(Q_j^{ele})$ is the coal power operating costs. $G(l)$ is coal power plant management costs, which is a function of human capital (l). Q_j^{ele} is the power generation by coal of type j. Pi is the total emissions, where λij is the coal power generation efficiency for j-type coal resource, that is, the standard coal consumption of unit power supply. ζij is the pollutant factor of emission type I in the power generation process , which can be evaluated by the proportion of such compounds. And φi describes the pollutant removal rate of emission type I for the power plant environmental protection devices, such as the de-sulfurization and de-nitrification device. ci is the disposal cost of waste per unit and it is a comprehensive variety of coal pollution control costs.

$$C_{ij}^{gene} = F(Q_j^{elc}) + G(l) + \sum_{j=1}\sum_{i=1} P_i \cdot c_i \quad (2)$$

$$P_i = \lambda_{ij}\xi_{ij}(1-\varphi_j)Q_j^{elc} \quad (3)$$

4.3. Subsequent stage

C_j^{post} is the total cost in subsequent stage. $F(Pi)$ is the sewage charge required for pollutant of type i. $F(P_Z)$ is the waste disposal cost, which is the function of the amount of waste generated. $R^{carb}(P_{carb})$ is carbon tax based on the carbon emission amount during generation. The carbon tax is zero before the introduction of carbon tax mechanism. $W(P_W)$ is illegal punishment for excessive emissions and illegal sewage. C^{accid} is the economic losses and compensation costs for coal power environmental accidents.

$$C_j^{post} = F(P_i) + f(P_z) + R^{carb}(P_{carb}) + w(P_w) + C^{accid} \quad (4)$$

4.4. Comprehensive optimization processes

Based on the models mentioned above, the full-life cycle cost model of coal power is introduced into the comprehensive optimization process of power planning. During the planning period, the sum of the power supply costs of the various regions is the smallest. Among them, the cost of electricity includes power generation cost, line costs, power loss and external costs.

Type is the different generation. *Z* is the research areas. *R* is the total planning period. *I, S, F, V, E*, *Φ* means the investment costs, added remaining value of fixed assets at the end of the period, fixed operating costs, variable operating costs, loss of power costs and environmental costs respectively. The energy and electricity power balance, environmental limitation, distributed generation acceptance limitation, unit maintenance arrangement, peak regulation and other constraints are included in the power planning model.

$$\min C_{\mathrm{T}} = \sum_{z\in Z}\sum_{i=1}^{R}[\sum_{t\in Type}(I_{t,i,z} - S_{t,i,z} + F_{t,i,z} + V_{t,i,z})\cdot(1+\gamma)^{-y_i} + \sum_{k\in T_{i,z}}(I_{k,i,z} - S_{k,i,z} + F_{k,i,z} + V_{k,i,z})\cdot(1+\gamma)^{-y_i} + E_{i,z}\cdot(1+\gamma)^{-y_i} + \phi_{i,z}\cdot(1+\gamma)^{-y_i}] \quad (5)$$

5. Peak analysis of coal generation development

The power and power flow capacity of China in 2020~2030 is carried out based on the power planning optimization theory, in order to judge the reasonable development scale of coal power. With the gradually highlighted of marginal cost advantage of new energy power, the incremental demand for electricity will be mainly satisfied by the new energy power generation. As a regulated power supply, coal power has the utilization cost lower than the pumped storage, gas units and other energy storage scheme. It is stable and controllable. The voltage and frequency support ability, high technology maturity advantages, as well as its excellent comprehensive technical and economy characteristics make coal power indispensable, especially for power system of high renewable energy access.

In the power planning and production simulations, the main boundaries are listed below.

- After 13th five-years period, China gradually entered the post-industrialization stage. It is expected that China's total social electricity consumption will reach 8.5~9.1 trillion, 9.4~10.3 trillion kwh in 2025 and 2030, which have an average annual growth rate of 3.5%~3.9% and 2.2%~2.5% respectively in 14th five-years and 15th five-years period.
- The actual reserve rate is selected within a reasonable range in accordance with the <power system design manual>. Among them, Hubei, Hunan, Sichuan and other provinces with large proportion of hydro-power capacity, the system reserve rate is higher than that with larger proportion of coal power. Meanwhile, the reserve rate of larger power grid can be reduced. After 2020, with the expansion of the system scale and strengthen network structure, the system reserve rate can be slightly reduced, from 10% to 15% respectively.
- The generation cost is determined by diverse factors. For coal generation, the carbon tax and environmental extra cost is considered in different levels. For hydro-power generation, the undeveloped resource is in Tibet and west of Sichuan province, the per-unit cost is higher than installed capacity. The gas generation cost is depended on the gas resource supply. For renewable energy such as wind and solar generation, double-factor learning curve method is used to predict the per-unit cost, mainly based on the accumulated scale and investment.

The power planning and diverse scenarios production simulation shows that, in order to meet the power, electricity and peak balance of power system, China's coal power development peak is within 1.15 ~ 1.2 billion kilowatts in 2025. The unit average utilization hours will be reduced to about 3700 hours. By 2030, the development and utilization of new energy power generation are significantly increased. The wind power and solar power installed capacity is about 350 to 450 million kilowatts, 300 to 400 million kilowatts respectively. The hydro-power installed capacity is 430 to 450 million kilowatts. The total installed capacity of nuclear power is between 90 million to 110 million kilowatts. Coal power installed capacity reduced to 1.13 to 1.18 billion kilowatts, and the unit average utilization hours is about 3400 hours. After 2030, the average utilization hours of coal will be further reduced.

It should be emphasized that the reasonable scale of coal power is also benefit to the efficiency of new energy development. The north west, north east and middle north of China have severe energy abandon problems in recent years. Based on the power system production simulations, the energy abandon rate can be limited within 5%, as shown in table 1. Therefore, the 1.15 ~ 1.2 billion kilowatts peak of coal power capacity is acceptable.

Table 1. Regional energy abandon rate in 2030.

Energy abandon rate (%)	Wind power	Solar power
North west	4.9	6.4
North east	3.5	9.6
Middle North	4.6	2.3
Total	4.6	5.0

6. Conclusions

Electricity surplus is the key problem to power development nowadays. Therefore corresponding policies are proposed by National Energy Board these years, in order to limit construction scale of coal power capacity. Benefits and threats are concluded in details in this study. Meanwhile, an improved generation and power grid planning optimization model is proposed mainly focusing on the full-life cycle cost of coal power generation. Based on the power planning and diverse scenarios production simulation, in order to meet the power, electricity and peak balance of power system, China's coal power peak capacity is within 1.15 ~ 1.2 billion kilowatts before or after 2025. The reasonable construction timing and limitation is of great importance to the healthy power industry, especially for the efficiency of new energy development. Based on the power system production simulations, the energy abandon rate of north west, north east and middle north of China can be limited within 5%.

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