



Research on Price Mechanism of Gas-Fired Power Generation in China

Jing Bai¹, Rui Zhao¹, Jianjie Xue¹, Ling Wang¹, and Peiwen Wang²(✉)

¹ State Grid Beijing Electric Power Co., LTD., Dispatching Center, Beijing 100031, China
zhaorui_78@sina.com

² Beijing Tsintergy Technical Co., LTD., Beijing 100084, China
wangpw@tsintergy.com

Abstract. As an important support for optimizing the energy structure, gas-fired power generation units play an important role in achieving the “carbon neutralization and carbon peak” goal and building a new power system. In view of the survival status of gas-fired power generation units, this paper analyzes the price formation mechanism and viability of gas-fired power generation units in China from the perspectives of cost and income. According to the degree of gas-fired power generation units participating in market transactions in various places, based on the formation of gas prices, the construction of the power market, and the current electricity price mechanism, this paper analyzes the relationship between the generation cost and income guarantee mechanism of gas-fired power generation unit, and further discusses the mechanism of gas-fired power generation unit participating in the spot power market, so as to provide theoretical reference and support for gas-fired power generation unit participating in market transactions in the future and promote the coordinated development of the gas-fired power generation industry and the power industry.

Keywords: gas-fired power generation unit · natural gas price marketization · gas electricity linkage · power market

1 Introduction

With the proposal of the “carbon neutralization and carbon peak” goal and the growth of energy demand in the future, as important power support to optimize the energy structure and improve the atmospheric environment, gas-fired power generation units play an important role in building the new power system. Under the background of power market reform, how to reasonably design the relevant mechanisms for gas-fired power generation units to participate in market transactions is an important topic for future research. At present, China’s inherent resource endowment of rich coal, poor soil, and little gas increases the cost of gas fuel. At the same time, the proportion of domestic gas turbine assembly machines is limited. In addition, the current electricity price mechanism is difficult to ensure that gas-fired power generation units obtain reasonable profits.

The survival of gas-fired power generation units is highly sensitive to three factors, namely, electricity price, generation hours, and fuel cost. Among them, the electricity

price mainly includes the net price, market-oriented transaction proportion, and market-oriented transaction price; the generation hours are related to the supply and demand of power generation and consumption in each region; the fuel cost mainly depends on the fuel price and the unit coal or gas consumption. At present, gas-fired power generation units are faced with the following three key issues when participating in the power market transaction. Firstly, China's natural gas resources are mainly concentrated in the northwest, central, and South China Sea areas, but the gas market is mostly in the economically developed eastern and southeast coastal areas. The natural gas industry has high investment and intensive technology, resulting in high development and transmission costs and greatly increased power plant operating costs. Secondly, China has not fully mastered the core technology of gas-fired power generation. Finally, the current electricity price mechanism in China can hardly guarantee the recovery cost of the gas-fired power generation units.

In order to solve the above contradictions, in 2017, the National Development and Reform Commission and the Energy Administration issued the Opinions on Accelerating the Utilization of Natural Gas, which proposed to improve the marketization of gas-fired power generation prices. In June 2018, the National Development and Reform Commission issued the Opinions on Innovating and Improving the Price Mechanism for Promoting Green Development, proposing to give full play to the lever regulation role of the environmental protection electricity price mechanism. In addition, with the advancement of China's power market-oriented system reform, [1–3] put forward relevant policy suggestions such as constitutional reform and optimization of subsidy mechanism by exploring the reform of China's gas-fired power generation pricing mechanism. [4–5] explore the decisive factors of natural gas pricing and the design of corresponding management modes. [6–8] explore how to rationalize the dual-track natural gas price system and puts forward suggestions.

Based on the formation of natural gas prices, the construction of power markets, and the current electricity price mechanism, and combined with the specific survival of existing units, this paper firstly analyzes the participation of gas-fired power generation units in the power market and the relevant mechanism of gas-fired power generation prices in China at this stage; secondly, it analyzes the relevant relationship between the cost and benefit guarantee mechanism of gas-fired power generation, and analyzes the linkage between primary side energy and market side transactions; finally, in view of the current situation of the problem that gas-fired power generation unit participates in the market, which leads to difficulties in survival, the relevant solutions are proposed, which provide theoretical reference for the relevant mechanism of gas-fired power generation unit participating in market transactions in the future.

2 Analysis of Gas-Fired Power Generation Units Participating in the Power Market

The profitability of gas-fired power generation units is affected by three factors: electricity price, generation hours, and fuel cost. According to the degree of China's gas-fired power generation units participating in the market, this paper divides them into three

Table 1. Summary of changes in the natural gas sales price (CNY/m³)

| Year | | 2013 | 2014 | 2015 | 2021 | 2022 |
|-------------------------|----------------------|------|------|------|------|------|
| Natural gas sales price | | 2.67 | 3.09 | 2.51 | 2.64 | 2.27 |
| Heating/cooling | Six areas in Beijing | 2.67 | 3.09 | 2.60 | 2.82 | 2.45 |
| | Other areas | - | - | 2.36 | 2.58 | 2.21 |

types: Not participating in the market, Participating in the medium and long-term market, Participating in the medium and long-term and spot markets, and studies them from the aspects of the income and the price mechanism of gas-fired power generation unit participating in the market.

2.1 Not Participating in the Market

The price of natural gas in Beijing consists of gate station price, gas distribution price, and gas purchase loss. Wherein, the gate station price fluctuates on the basis of the benchmark gate station price; the gas distribution price is determined by Beijing municipality on its own, which is composed of “permitted cost + reasonable income”; the gas purchase loss is reflected by the difference between supply and sales. Table 1 shows the change in natural gas sales prices in Beijing from 2013 to 2022.

It can be seen from Table 1 that the overall change range of gas prices in Beijing from 2013 to 2022 was not large. For peak shaving units, the gas consumption of gas units for start-up and shutdown is at least 80000 m³ for hot start-up and shutdown. According to the electricity price of 2.27 CNY/m³ in 2022, the fuel cost for one start-up and shutdown is 181600 CNY. In the two detailed rules and regulations of North China, the peak shaving compensation for gas and thermal power units for one start-up and shutdown is 260 CNY / MW based on the unit capacity. The peak shaving capacity for one start-up and shutdown converted from “two driven by one” and “one driven by one” working conditions is calculated as half of the capacity of the whole set of peak shaving units. Therefore, the peak shaving compensation for one start-up and shutdown is calculated based on the capacity of class F gas-fired power generation unit of 390MW, up to 101400 CNY. Only by successfully once start-up and shutdown, the peak shaving unit compensated by a certain amount, and the subsidy for the peak shaving unit is insufficient to make up for the cost. To sum up, under the current peak shaving compensation or electricity price mechanism of gas-fired power generation units, most of the gas-fired power generation units undertake public welfare and regulatory tasks, and the economy is poor.

2.2 Participating in the Medium and Long-Term Market

1) Market participation of gas-fired power generation units in Tianjin

The price of natural gas in Tianjin consists of gate station price, pipeline natural gas

Table 2. Summary of changes in the natural gas sales price (CNY/m³)

| Year | 2013 | 2014 | 2015 | 2016 | 2017.9 | 2017 | 2018 |
|-------------------------------|------|------|------|------|--------|------|------|
| General industry and Commerce | 3.25 | 3.65 | 2.77 | 3.07 | 2.66 | 2.91 | 3.12 |
| Central heating | 3.25 | 3.25 | 2.37 | 2.67 | 2.26 | 2.51 | 2.72 |
| Year | 2019 | 2019 | 2020 | 2020 | 2020 | 2021 | |
| General industry and Commerce | 2.63 | 3.17 | 2.71 | 2.52 | 3.07 | 2.62 | |
| Central heating | 2.23 | 2.88 | 2.42 | 2.23 | 2.78 | 2.33 | |

sales price, and wholesale price. The change in natural gas sales price in Tianjin from 2013 to 2021 is shown in Table 2.

It can be seen from Table 2 that the sales price of natural gas also rises due to the fluctuation of gas prices in the heating season every year. In addition, in 2019, the power generation cost of gas-fired power plants in Tianjin was about 0.4162 ~ 0.5734 CNY / kWh, and that of coal-fired power plants in Tianjin was about 0.2385 ~ 0.3711 CNY / kWh. High gas prices are one of the reasons why most users still choose coal as their main consumption energy.

2) Market participation of gas-fired power generation units in Jiangsu

In 2013, Jiangsu Province implemented gate station price management of natural gas, and divided natural gas into two parts: stock gas and incremental gas. In 2019, the price of natural gas gate stations in Jiangsu Province was the highest, which was 2,020 CNY/thousand cubic meters, about 343 CNY/thousand cubic meters higher than the national average gate station price. In the same year, the power generation cost of gas power plants is about 0.4434 ~ 0.6038 CNY / kWh, and that of coal power plants is about 0.2525 ~ 0.3865 CNY/kWh. The high price of gas is one of the reasons why most users still choose coal as their main source of energy.

Since 2019, gas-fired power plants in Jiangsu Province have implemented two price systems: capacity price and electricity price. In terms of capacity electricity price, the price of peak shaving units and 400,000 -level cogeneration unit is 28 CNY/kW· month, that of 200,000-level cogeneration unit is 32 CNY /kW·month, and that of 100,000 level cogeneration units and regional distributed units is 42 CNY /kW·month. In terms of electricity price, the price of peak shaving units is 0.436 CNY /kWh, that of 400,000-level cogeneration units is 0.449 CNY /kWh, that of 200,000-level cogeneration units is 0.484 CNY /kWh, and that of 100,000-level cogeneration units and regional distributed units is 0.469 CNY /kWh.

3) Summary

To sum up, in order to promote the construction of new power systems, ensure the participation of gas-fired power generation units in the market, and improve the natural gas price formation mechanism, how formulating a scientific and reasonable natural gas price is the development direction of the future power market reform.

2.3 Participating in the Medium and Long-Term and Spot Markets

Since November 20, 2016, the gas consumption of non-residents in Guangdong Province has changed from the highest gate station price management to the benchmark gate station price management, and on this basis, the upward fluctuation is not more than 20%, and the downward fluctuation is not limited. Since 2018, Guangdong has actively implemented the time of use electricity price mechanism. In 2018, Guangdong included “gas-fired power plants other than 9E units without heating participation in peak shaving” in the power market transactions, and in 2019, new 9E units entered the market. So far, all gas-fired units in the province have entered the market. In 2020, Guangdong adjusted the net price of gas-fired power generation to appropriately reduce the cost of electricity for the whole society. Specifically, the net price of LNG power plants is reduced by 0.049 CNY/kWh, 0.605 CNY/kWh for 9F and above units within 3500 h (inclusive), 0.63 CNY/kWh for 9E units within 4000 h (inclusive), and 0.64 CNY/kWh for 6F and below units within 5000 hours (inclusive).

In the typhoon season of 2020, Guangdong Province organized a full-month spot settlement trial operation. The province transferred 69 gas units into the spot market, and the gas units entered the open 5–10% spot market. In 2021, except for the price of LNG power plants, the net price of other types of units in Guangdong Province will increase by 0.05 CNY / kWh, and the sales price in the industrial and commercial catalog will be canceled. The power market transaction will be improved. There will be no floating upper and lower limits in the spot market.

3 Income Analysis of Gas-Fired Power Generation Unit in Each Market Development Stage

3.1 Revenue from Electricity Sales of the Gas-Fired Power Generation Unit

According to the above analysis of the power generation cost and electricity price of gas-fired power generation units in each region, the power profit space level of each region can be calculated according to the kWh profit space. kWh profit space (CNY/KWH) P can be expressed as:

$$P = W - K_v - K_f \quad (1)$$

where, W represents the net price (excluding tax), CNY / kWh; K_v represents fuel cost, CNY / kWh; K_f represents fixed cost, CNY / kWh.

Table 3 shows the kWh profit space of gas-fired power plants in each region calculated according to the fixed cost of 0.1–0.22 CNY / kWh. The kWh profit space of gas-fired power plants in Jiangsu is about -0.1678–0.0406 CNY / kWh. According to the calculation of the 400000 units cogeneration power plant with an installed capacity of 780000 kW in Jiangsu, the annual capacity electricity price is 262 million CNY, and the two-part electricity price capacity income of the Jiangsu gas-fired power plant is about 0.0672 CNY / kWh (calculated by 5000 generation hours).

Table 3. kWh profit space of gas-fired power plants in each region (CNY/kWh)

| Region | Gas-fired power plant | |
|---------|-----------------------|---------|
| | Lowest | Highest |
| Beijing | 0.0766 | 0.2338 |
| Tianjin | 0.0926 | 0.2338 |
| Jiangsu | -0.1006 | 0.1078 |

3.2 Revenue from the Heating of Gas-Fired Power Generation Unit

Some thermal power plants or cogeneration thermal power enterprises can obtain heating income in addition to electricity sales. In Beijing, the ex-factory price of the gas power plant from November 15, 2019, to March 15, 2020, is 86.5 CNY/GL. In Tianjin, the ex-factory price of heat sources in gas power plants is about 50–60 CNY/GL. In Jiangsu, the highest gas heating ex-factory price is 7.93 CNY/GL.

3.3 Sensitivity Analysis

Taking Tianjin as an example, based on the power generation hours and electricity price of the Wu Qing power plant in 2020, by adjusting the proportion of different planned power generation hours and market-oriented electricity, the income and profit of units are calculated, and the impact of different market development stages on the income and profit of gas-fired power plants is analyzed.

In this analysis, the planned electricity revenue is expressed as:

$$I = Q * U \quad (2)$$

where, Q represents the planned power consumption, and U represents the net price.

Medium and long-term trading electricity revenue I_L is expressed as:

$$I_L = Q_L * U_L \quad (3)$$

where, Q_L refers to the medium and long-term market trading electricity, and U_L refers to the medium - and long-term market trading price. Moreover, the medium - and long-term trading price, the growth rate of market-oriented trading electricity, and other influencing factors are $\pm 30\%$ on the basis of the spot mode (the market-oriented trading electricity is 530 million kWh, and the market-oriented trading price is 0.4662 CNY / kWh). The sensitivity analysis results are shown in Table 4.

According to the above results, the income rises with the rise of the market transaction price. Under the premise of 10% market trading electricity growth rate and market trading price of 0.4662 CNY/kWh, the overall income of the Wu Qing gas power plant fluctuates within the range of 734–800 million CNY; under the premise of 10% market transaction price growth rate and market transaction electricity of 530 million kWh, the overall income of Wu Qing gas power plant fluctuates within the range of 793–831 million CNY.

Table 4. Sensitivity analysis of income to market trading electricity and the market trading price

| Income ($\times 10^8$ CNY) | | Market trading price (CNY/kWh) | | | | |
|---|------|--------------------------------|---------|--------|---------|---------|
| | | 0.37296 | 0.41958 | 0.4662 | 0.51282 | 0.55944 |
| Market trading electricity ($\times 10^8$ kWh) | 4.24 | 8.08 | 7.92 | 7.92 | 8.06 | 8.37 |
| | 4.77 | 8.13 | 8.00 | 8.00 | 8.12 | 8.38 |
| | 5.30 | 8.06 | 7.93 | 7.93 | 8.05 | 8.31 |
| | 5.83 | 7.87 | 7.73 | 7.73 | 7.85 | 8.12 |
| | 6.36 | 7.50 | 7.34 | 7.34 | 7.48 | 7.78 |

3.4 Summary

The operation mode of gas-fired power generation units in the Beijing-Tianjin-Hebei region, most units are centralized cogeneration units, while in Jiangsu Province, most units are peak shaving units and distributed units. In terms of electricity price, Jiangsu's gas net price is at a medium level in the whole country, and the net price of gas power generation in the Beijing-Tianjin-Hebei region is higher than that in Jiangsu as a whole. In terms of power generation hours, Jiangsu thermal power generation hours in 2016 were the highest, 5093 h. In terms of fuel cost, the natural gas gate station price in Tianjin is high, while that in Beijing is slightly lower than that in Jiangsu. In general, the overall marketization of thermal power in the Beijing-Tianjin-Hebei region is relatively low, and the electricity price is relatively high.

4 Existing Problems and Solutions of Gas-Fired Power Generation Price Mechanism

In view of the above situation of the gas-fired power generation price mechanism in China, the existing problems are summarized as follows, and targeted solutions are put forward.

4.1 There Are Regional Differences in Gas and Electricity Costs

In recent years, the rise in gas prices has led to an increase in the power generation costs of gas-fired power plants, while the net price is low, resulting in low profits for enterprises. According to the statistics of the China Petroleum Institute of economics and technology, the price of gas purchased by gas-fired power plants is between 2.5–3 CNY/m³. The cost of gas-fired power generation is 0.2–0.3 CNY / kWh higher than that of coal-fired power generation, which has a small competitive advantage. In addition, the gas prices of power plants in some regions are not uniform, and simple treatment methods such as the single gas price system are not conducive to the rational scheduling of the system, which makes it impossible to realize the optimal allocation of resources.

In view of the above problems, if there is a more reasonable net price for gas-fired power generation, it can make up for the cost of gas-fired power generation enterprises

and ensure an appropriate rate of return. The government needs to build a scientific linkage mechanism of gas and electricity prices to ensure the economic operation of power generation enterprises. In the future, we can consider liberalizing the price of natural gas and moving towards full marketization.

4.2 Gas Unit Price Model is Difficult to Unify

Most gas-fired power generation units in northern China are cogeneration. In the heating season, the units operate with the base charge "based on heat fixing", and in the non-heating season, the power grid is used for peak regulation. Most gas units in southern China are conventional power generation, which is used for peak shaving of the power grid and gas grid. A small number of cogeneration units operate year-round with a base charge.

In order to adapt to the increase of the installed capacity of renewable energy generation in the future, it is necessary to constantly optimize the power supply structure and adopt the two-part price mechanism to determine the net price of gas-fired power generation according to different unit types and demands. The high fuel cost caused by gas price changes is shared according to the market pricing principle so that the relevant power generation enterprises can maintain relatively stable profits. In addition, in coordination with the fixed net price subsidy policy, a dynamic decreasing subsidy mechanism of net price based on the newly installed capacity is formed to encourage the industry to move forward.

4.3 The Current Subsidy Mechanism for Gas-Fired Power Generation is not Perfect

Based on the market participation of existing gas units, it can be classified into three types in Table 5.

It can be seen from Sect. 4.2 that electricity price is one of the important factors restricting gas-fired power generation. It is necessary to establish a differentiated electricity price policy that can reflect energy efficiency and social benefits. Therefore, on the one hand, the peak shaving electricity price or two-part electricity price mechanism can be adopted; on the other hand, the environmental protection cost can be included in the net price of gas-fired power generation, reflecting the environmental protection benefits. At the same time, the linkage mechanism of gas price and electricity price should be established to establish an effective cost transmission mechanism. In addition, a power trading platform can be established to allow gas-fired power plants to sign trading contracts directly with power users and determine the electricity quantity and price through independent negotiation. In view of the trans-provincial and trans-regional electricity transactions, Tianjin adopts the inter-provincial electricity spot trading mode, and the electricity price of gas units has exceeded 2–3 CNY, which alleviates the operating difficulties of gas units and realizes the electricity balance in the regional power grid.

Table 5. Comparison of two-part electricity price, kWh compensation, and capacity market

| | Two-part electricity price | kWh compensation | Capacity market |
|----------------------|--|--|---|
| Definition | The two-part electricity price divides the electricity tariff settlement between the power grid company and the generation side into electricity tariff and capacity tariff. The electricity price compensates for the variable costs of the units participating in peak shaving. The capacity price is determined according to the unit capacity and compensates for the fixed costs of the peak shaving units. | At the initial stage of market construction, gas-fired units may not participate in bidding. The gas-fired power plant shall enjoy the same environmental subsidies as the coal-fired power plant with desulfurization equipment. In other operation periods, the gas and electricity price linkage subsidy policy can be implemented. | The capacity market provides a practical and effective way to ensure the adequacy of power supply and solve the demand for unit cost recovery. |
| Application examples | Since 2019, gas-fired power plants in Jiangsu Province have implemented a two-part electricity price system. At the end of 2015, Zhejiang Province began to trial the two-part net price of gas units, and the set standard of electricity price is only based on the type of unit capacity. In 2022, the gas-fired power generation unit in Tianjin enter the market through bidding at the same stage, and the two-part system will be adopted for price settlement. | After the No. 1439 document, Guangdong Province did not verify the base electricity quantity, and the gas directly participated in the market transaction. According to the gas net price and the coal net price, the actual net electricity quantity was subsidized at a variable cost per kWh. | American PJM capacity market is based on multiple auction reliability pricing models; The capacity market in the UK consists of capacity quota, auction, trade, and other stages. The government guides in the quota and delivery stages and achieves complete market competition in the auction and trade. |

(continued)

Table 5. (continued)

| | Two-part electricity price | kWh compensation | Capacity market |
|-------------------|---|--|-----------------|
| Market conditions | Jiangsu: medium and long term + spot Zhejiang: base + medium and long term + spot Shanghai: base + medium and long term + spot Tianjin: 3500h hourly base + medium and long term | Guangdong: Directly participate in market transactions without checking the base. According to the current net price of 650 CNY / MWh, the electricity consumption within 4100h pricing hours is subsidized. | |

5 Conclusion

Gas-fired power generation unit plays an important role in achieving the “carbon neutralization and carbon peak” goal and building a new power system. Based on the formation of natural gas price, the construction of the power market, and the current electricity price mechanism, this paper analyzes the relationship between the generation cost and the income guarantee mechanism of gas-fired power generation units, and further discusses the relevant mechanism of gas-fired power generation unit participating in the power spot market.

In the future, we should formulate flexible price strategies and incentive policies, and improve the natural gas price formation mechanism based on multiple factors. At the same time, we should promote the linkage mechanism of natural gas and electricity prices and establish a natural gas price formation mechanism that reflects the scarcity of resources and changes in market supply and demand. In addition, different prices are adopted for different users to reduce the intermediate link cost and the price of power generation users, so as to further narrow the gas price gap between power generation users and residential users. Finally, the relevant regulatory authorities should deal with the behavior of not implementing the price linkage mechanism, and gradually improve the dynamic price database and the natural gas price monitoring system based on the big data information network.

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