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Comparison and Analysis of Three Different Power Generation Methods under the Context of Dual Carbon Goals

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Abstract: *Traditional thermal power generation is characterized by mature technology, wide application, and high carbon emissions. Under the context of dual carbon goals, there is an urgent need for technological innovation in decarbonization. This paper aims to systematically analyze and compare three power generation methods, namely coal-fired power generation by steam turbines, power generation by natural gas turbines and fuel cell power generation. An outlook for future power generation technologies is presented at the end.*

Keywords: *Carbon Neutrality, Carbon Peak, Fuel Cell, Coal-fired Steam Turbine, Natural Gas Turbine*

1. Introduction

In recent years, under the background of the "dual carbon goals", the Chinese government has formulated corresponding policies to promote carbon emission reduction in the power industry. In 2016, in the "13th Five-Year Plan for Controlling Greenhouse Gas Emissions", the State Council for the first time proposed quantitative targets to be achieved by 2020, including reducing the CO_2 emissions from power supply of large power generation groups to less than 550gCO_2/(kW·h); in the same year, the "13th Five-Year Plan for Electric Power Development (2016-2020)" clearly required that "by 2020, the installed capacity of gas-fired power generation should increase by 50 million kW to more than 110 million kW, accounting for more than 5% of the national total; On September 12, 2014, the NDRC issued the Action Plan for Energy Conservation, Emission Reduction and Upgrading and Transformation of Coal Power, which sets out the plan for the "orderly development of LCVC power generation" and "strictly implementing the industrial policy of LCVC power generation, focusing on the planning and construction of LCVC power generation projects in major coal-producing provinces and regions and large coal mining areas, which in principle should be based on local consumption and integration, rational planning of construction scale and schedule." It is forbidden to establish conventional coal power projects in the name of LCVC power generation. The best comprehensive utilization mode should be realized according to the utilization values of LCVCs such as gangue, slime and washed coal. Gangue used for power generation should have a calorific value not less than 5020 kJ (1200 kcal)/kg. If gangue is used as the main fuel, the base calorific value of the fired fuel should not be higher than 14640 kJ (3500 kcal)/kg. In principle, supercritical circulating fluidized beds of 300,000 kilowatts and above should be used when possible. And whenever possible, LCVC power generation projects should consider the demand of surrounding industrial enterprises and residents for concentrated heating."

Coal power is characterized by high carbon emissions per calorific unit (0.308kgCO_2/MJ) and a low comprehensive energy utilization rate (33-36%). According to the National Bureau of Statistics, China's total power generation will reach 10 trillion kWh in 2030[1], an increase of 28.2% compared to the current total generation (7.8 trillion kWh).

In recent years, more efficient and environmentally friendly new power generation methods, including power generation by natural gas turbines and fuel cell power generation, have attracted the attention of more and more researchers. Combustion power generation refers to using gas turbines to convert heat energy in combustible gases (including natural gas) into kinetic energy and then into electrical energy, which has a comprehensive energy utilization efficiency of about 38%, and carbon emission of 0.407kgCO_2/MJ for each calorific unit. The fuel cell is a new type of energy conversion device that can directly convert the chemical energy of fuel into electricity. This method has a power generation efficiency of 35-60% and can achieve zero carbon emissions when using hydrogen as the

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feedstock.

With the above emerging power generation technologies, the power industry is expected to achieve carbon emission reduction. However, no one has yet conducted a systematic analysis of these technologies. As such, this paper aims to systematically analyze and compare three power generation methods, namely coal-fired power generation by steam turbines, power generation by natural gas turbines and fuel cell power generation from various aspects including carbon emission, power generation efficiency, economic efficiency, technical feasibility, relevant policies and regulations, etc., so as to provide a reference for related research and industrial development.

2. Coal-fired Power Generation

2.1 Overview of the current situation of Coal-fired Power

In China, coal-fired power generation has undergone more than 40 years of development and reform, with its industrial scale increasing on an annual basis. According to the latest data from the National Bureau of Statistics, China's annual coal consumption has reached 4 billion tons, of which 2.1 billion tons are consumed by thermal power generation, accounting for 53% of the annual total.

In China, most power plants operate based on the above technologies. According to the TRL table introduced by NASA in the 1970s, coal power technology in China is clearly at level 9 - operation and evaluation.

2.2 Relevant Policies and Regulations

With the passage of time, the shortcomings (environmental pollution from carbon emissions) of coal-fired power generation have become increasingly apparent. Since 2014, the annual utilization time of coal-fired power units has remained below 5,000 hours, a historical low that indicates overcapacity. To address this issue, China has gradually introduced relevant policies since 2016. In the Opinions on Promoting Supply-Side Structural Reform and Preventing and Resolving the Risk of Coal Power Overcapacity (hereinafter referred to as the Opinions), issued in 2017, the central government pointed out that, during the 13th Five-Year Plan period, China would stop or delay the construction of coal power plants, and phase out some existing plants to reduce excess capacity. According to the Opinions, by 2020, the total installed capacity of coal power in the country should reach about 1.1 billion kilowatts. It is not difficult to see that with the changes in the general environment, the traditional coal power industry is facing pressure and challenges on all sides and is in urgent need of transition from previous high-speed development to high-quality development.

2.3 Installed Capacity

Table 1: Total all-caliber installed capacity of power equipment in China from 2017 to 2021

Year	2017		2018		2019		2020		2021	
Annual total	Absolute value (10,000 kW)	Growth rate	Absolute value (10,000 kW)	Growth rate	Absolute value (10,000 kW)	Growth rate	Absolute value (10,000 kW)	Growth rate	Absolute value (10,000 kW)	Growth rate
All-caliber total installed capacity	177703	7.60%	189967	6.90%	201066	5.84%	220058	9.45%	237692	8.01%
Total installed capacity of thermal power	110604	4.30%	114367	3.40%	119055	4.10%	124517	4.59%	129678	4.14%
Total installed capacity of hydropower	34119	2.70%	35226	3.24%	35640	1.18%	37016	3.86%	39092	5.61%
Total installed capacity of nuclear power	3582	6.50%	4466	24.68%	4874	9.14%	4989	2.36%	5326	6.75%
Total installed capacity of grid-connected wind power	16367	10.50%	18426	12.58%	21005	14.00%	28153	34.03%	32848	16.68%
Total installed capacity of grid-connected solar power	13025	68.70%	17463	34.07%	20468	17.21%	25343	23.82%	30656	20.96%

Source: National Energy Administration

Table 1 shows the total all-caliber installed capacity of power equipment in China from 2017 to 2021. As can be seen from the table, the total installed capacity increased from 177703 GW in 2017 to 237692

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GW at the end of 2021, indicating an overall upward trend with a growth rate of around 4%, which is lower than that of all-caliber power equipment. According to the technology maturity table introduced by NASA in the 2070s, China's coal power technology is clearly at level 9 - operation and evaluation. The proportion of the total installed capacity of thermal power equipment to that of all caliber power equipment decreased from 62.3% in 2017 to 54.6% in 2021, while that of clean energy increased from 35.7% to 43.2% over the same period.[5] As can be seen, despite a still growing total capacity, that of thermal power equipment is growing at a yearly decreasing rate, while that of clean power equipment is seeing substantial and ever faster growth year by year.

3. Natural Gas Turbine Power Plants

3.1 Overview of the Current Situation of the Natural Gas Turbine Power

To reduce environmental pollution caused by traditional coal power, the Chinese government has set its sights on low-carbon and efficient natural gas turbines. However, for now, gas turbines can't be applied on a large scale in China, making it extremely difficult for gas power to subvert the dominant position of traditional coal power. Furthermore, although gas for the production of industrial electricity is generally cheaper in China, there is the undeniable truth that the low prices are made possible by substantial state subsidies, without which it would be difficult for related power plants to maintain profitability.[1] For example, at the beginning of 2020, natural gas prices fell to a record low of RMB 1.4 per cubic meter, but on July 9 of the same year, during a video conference held by the National Development and Reform Commission to discuss measures for the incoming summer peak, it was stated that: "although the document regulating this year's prices of natural gas for residential use has been issued, such prices should be raised by 20% over the prescribed prices, while the price control for natural gas for commercial use should be relaxed in an orderly manner", indicating that under China's current national conditions, natural gas turbines are still facing a lot of difficulties as a cleaner alternative power generation option.

3.2 Relevant Policies and Regulations

Table 2: Some of the gas power-related policies introduced by China in recent years

S/N	Name	Issued by	Time of promulgation
1	The 13th Five-Year Plan for Electric Power Development (2016 - 2020)	National Development and Reform Commission, National Energy Administration	November 2016
2	The 13th Five-Year Plan for Natural Gas Development	National Development and Reform Commission	December 2016
3	Several Opinions on Promoting the Innovation and Development of Gas Turbines by Relying on Energy Engineering	National Development and Reform Commission, National Energy Administration	June 2017
4	Notice on Lowering the Reference Station Prices of Natural Gas for Non-residential Use	National Development and Reform Commission	August 2017
5	Opinions on Accelerating the Utilization of Natural Gas	Thirteen ministries	August 2017
6	Plan for Realizing Clean Heating during Winter in Northern China (2017 - 2021)	National Development and Reform Commission, National Energy Administration	December 2017
7	Three-Year Action Plan to Fight Air Pollution	State Council	July 2018
8	The Catalogue for Guiding Industry Restructuring (2019 Edition)	National Development and Reform Commission	August 2019
9	Implementation Plan on Accelerating Capacity Building for Natural Gas Reserves	National Development and Reform Commission	April 2020

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To achieve "carbon neutrality" and "carbon peaking" as soon as possible, in recent years the national and local governments have gradually issued corresponding policies formulated to reduce the cost of gas turbine power generation and expand the scale of the industry.[2][3] Some of these policies are listed in Table 2.

Despite those policies, currently, the natural gas power industry in China is still facing significant economic pressures. At present, in terms of on-grid prices, natural gas power is still rather expensive compared to traditional coal power. In normal times, natural gas power plants can still maintain some profitability thanks to relevant policies. However, when gas consumption is at a peak and natural gas prices start to increase during winter, maintaining the original on-grid prices would lead to losses for natural gas power plants.

3.3 Installed Capacity

In recent years, due to the increasing emphasis on energy conservation and environmental protection, China urgently needs a more environmentally friendly way of generating electricity to replace some of the high-emission coal power. As a result, natural gas power generation is gradually becoming more and more widely known. Compared with traditional coal power, natural gas power generation has the advantages of higher energy conversion efficiency, lower power consumption rate, and less pollutive emissions. Due to these, China's market for gas power generation has grown tremendously. According to incomplete statistics, from 2012 to 2018, the installed capacity of natural gas power in China increased from 37.67 to 83.75 million kW, and the power production of which increased from 110.3 to 215.5 billion kWh. Despite these, its only accounts for 4.4% of the total full caliber installed capacity of power plants in the country, and 3.1% of the national total 0f power production (as shown in Figure 1).

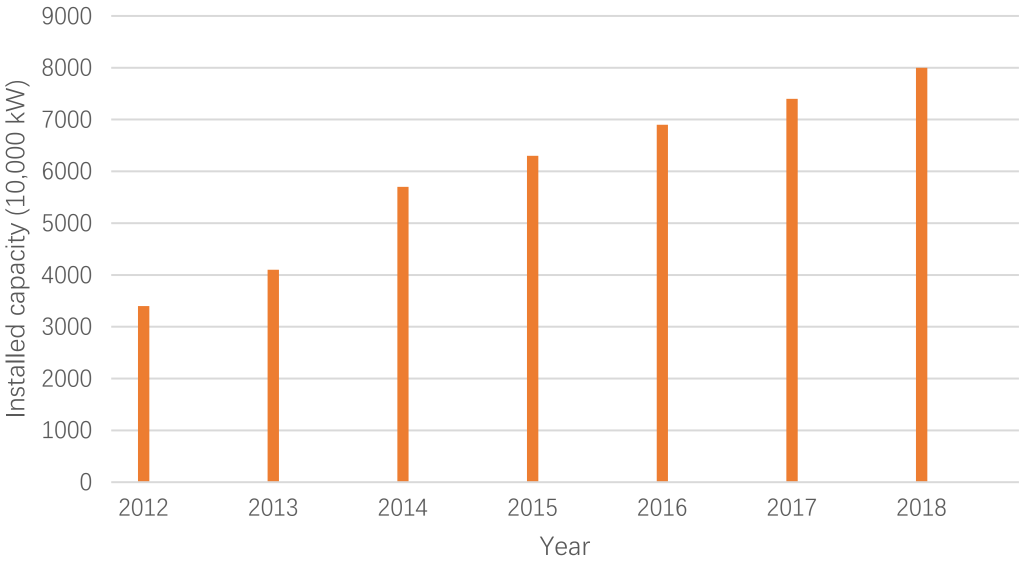

Figure 1: Installed capacity of natural gas power in China from 2012 to 2018[2]

However, in other developed countries, the above proportion can be as high as 30%-35% (US) and 21% (EU). Therefore, in terms of power production and installed capacity, China's natural gas power industry still has a long way to go.

4. Fuel Cell Power Generation

4.1 Overview of the Current Situation of Fuel Cell

With the rise of new energy technologies, one of them - fuel cell power generation has gradually become more popular. As an emerging technology, fuel cell power generation theoretically can achieve an efficiency of up to 80% while having little to no environmental pollution. However, due to the immaturity of this technology, it is currently only used in demonstration projects without large-scale application and promotion. In addition, because the related industry started in China much later than it

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did in the United States and Japan and other developed countries, its development lags far behind those in developed countries. In addition, since China introduced this technology later than developed countries such as the United States and Japan, the development of the related industry in China lags far behind those in such developed countries. Figure 2 presents the global shipments of the technology, fuel cell.

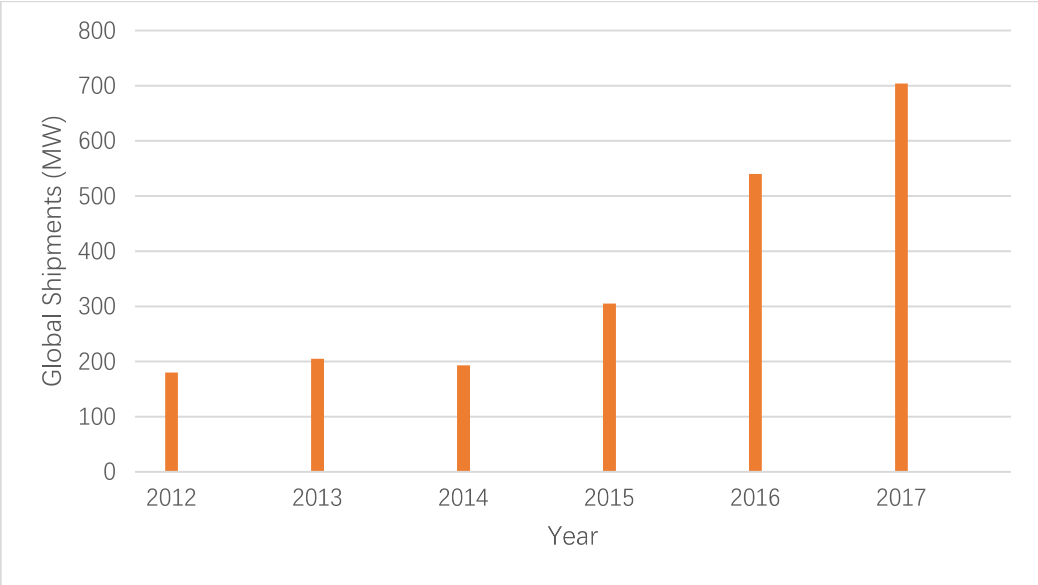

Figure 2: Fuel cell shipments worldwide (2012-2017)[6]

Furthermore, fuel cells also have certain disadvantages of their own. Due to higher equipment costs, the on-grid price of fuel cell power is much higher than those of traditional coal power and natural gas power. At the same time, due to the limitations of technological development, existing fuel cells do not have the best energy conversion efficiency possible, and the service life of related equipment is shorter than that of traditional power generation equipment. Therefore, despite some progress in technological accumulation, fuel cell power can't reach large-scale commercialization and industrialization in the short term.

4.2 Comparison of Different Power Generation Methods

Table 3: Comparative data of three different power generation methods

	Coal power	Natural gas power	Fuel cell power
Feedstock	C (Carbon resources such as coal and coke)	CH_4	H_2, methane, propane and other gas, organic fuel (optional)
Cost	Power generation cost: 0.18 (RMB/kW·h); Cost when reaching end users: 0.454 (RMB/kW·h); Average cost 0.557(RMB/kW·h)	0.406(RMB/kWh); 0.614(RMB/kWh)	Using methane as feedstock: Power generation cost: 0.53 (yuan/kW·h); Equipment cost: 1 (yuan/kW·h); Average cost: 1.53 (RMB/kW·h)
SO_2 (mg·/kWhkW-1·h-1)	400-550	41-51	≈0
NOx（mg/kWhmg·kW-1·h-1）	340-380	50-64	≈0
CO_2（mg/kWhmg·kW-1·h-1）	780-900	300-360	≈0
Carbon emissions per calorific unit	Household induction cooker 0.350 kg/MJ Industrial boiler 0.293 kg/MJ Weighted average 0.308 kg/MJ	Residential gas 0.484 kg/MJ Industrial boiler 0.307 kg/MJ Cyclic power generation 0.542 kg/MJ Weighted average 0.407 kg/MJ[4]	0

Different power generation methods all have their own advantages and disadvantages. This paper introduces the comparative analysis of three different power generation methods, which covers several

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aspects including feedstock, cost, pollutant emission and carbon emission. The specific data are shown in Table 3.

From the data presented in table3, it is not difficult to see that coal power, natural gas power and fuel cell power all have their own advantages and disadvantages. Conventional coal power generation uses more common feedstocks, so its cost is lower than those of the other two methods. However, the problem with conventional coal power is that the emissions it produces are more harmful to the environment, while the other two methods produce fewer emissions in general (under certain conditions, fuel cell power generation can even achieve zero emissions of traditional pollutants). Despite being more environmentally friendly and efficient, natural gas and fuel cell-based power generation methods cannot meet the demand for electricity in today's society. Due to the high price of natural gas in China, despite some support from national policies, natural gas power still shows a disadvantage of being more expensive in China. At the same time, in the context of China's pursuit of dual carbon goals in recent years, another disadvantage of gas power generation - high carbon emissions per calorific unit, becomes more apparent. Under the influence of the above factors, China is moving slowly with the full industrialization of natural gas power generation. On the other hand, fuel cell power generation is a clean power generation method that meets the needs of carbon emission reduction. At the same time, this method is also highly efficient thanks to the direct conversion of chemical energy into electrical energy. However, due to the high cost and short service life of related equipment, fuel cell power generation is still in the stage of theoretical research and demonstration in China as the industrialization of this method cannot be realized right now.

5. Outlooks and Suggestions

Through the above status and data analysis, it is easy to see that in the context of current technology and social development, it is extremely difficult to meet China's electricity demand by relying on any single method. And the solution is to use a combination of different methods. For that, the Chinese government can use different policies (such as reasonable carbon taxes) to promote the development of low-carbon power generation technologies and contain the use of energy-intensive and polluting power generation methods. With the advancement of fuel cell technology, the service life of related equipment is expected to be extended. This change will promote the relevant industrialization process and in turn, bring about the reduction of equipment costs. If these are realized, the cost of fuel cell power generation will be drastically reduced, allowing it to become a significant power generation method in specific scenarios.

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