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Build New Power System to Promote Carbon Neutrality

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Abstract

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Keywords

carbon neutralization new generation of power system renewable energy

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Abstract: Under the carbon peak and carbon neutrality goals, the supply and demand of China's power system will continue to grow in the next 40 years. Firstly, this study comprehensively analyzes China's power grid system under the goal of carbon neutrality. In the future, wind power and solar power will gradually become the main power supply, which brings new tasks and challenges to the power grid to absorb the renewable energy. On this basis, the general idea and principles of building a new generation of power system are expounded. Then, the basic structure and form of the new generation of power system are analyzed. Due to the continuous expansion of long-distance transmission scale and the imbalance of resources and load in the future, the new generation of power system still has the remarkable characteristics of reverse distribution between the power supply and the load. Therefore, its basic form is still composed of large power grids and is effectively supplemented by distributed power system. In addition, the flexible regulation of resources is important for the safe operation of the power grid, and the power market operation mechanism should guide multiple subjects to participate in the construction of the new generation of power system. Finally, the phased implementation strategy of building a new power system for carbon neutrality is proposed, which plays an important guiding role in building the new power system and achieving carbon neutrality. **DOI:** 10.16418/j.issn.1000-3045.20220329001-en

Keywords: carbon neutralization; new generation of power system; renewable energy

1 General situation of China's power grid system under the goal of carbon neutrality

At present, China has built the world's largest power system. In 2020, China has reached the total electricity consumption of 7.5 trillion kilowatt-hours and the installed capacity of 2.2 billion kilowatts [1]. The supply and demand of China's power system will continue to grow in the future, and the role of power grid in ensuring the balance between the supply and demand will be increasingly prominent [2], which is manifested in the following aspects. (1) The power demand will keep growing. With the economic growth, industrial upgrading, and improvement of people's living standards, per capita electricity consumption will also rise. Meanwhile, to achieve the carbon peak and carbon neutrality ("dual carbon") goals, China shall implement electric energy substitution in the industry, construction, and transportation fields, so as to achieve a higher level of electrification to support the peak consumption of coal, oil, and natural gas. The combined action of the above factors will make China's electricity consumption keep growing in the future (Figure 1). As estimated, China's total electricity consumption will reach over 15 trillion kilowatt-hours in 2060, doubling that in 2020. (2) The installed capacity will keep increasing. As estimated, China's installed capacity will be 6 billion to 8 billion kilowatts in 2060, reaching about three times that in 2020.

In recent years, China has vigorously developed non-fossil energy, especially renewable energy such as wind power and solar power. In 2020, the total installed capacity of wind power and solar power in China reached 535 million kilowatts, accounting for 24.3% of the total installed capacity. The wind and solar power generation reached 727.5 billion kilowatt-hours, accounting for 9.5% of the total power generation [3]. Under the goal of carbon neutrality, wind power and solar power will gradually become the main power supply, which will lead to the heavy task of absorbing renewable energy in the power grid. The installed capacity of wind power and solar power is expected to reach over 4 billion kilowatts in 2060, and that of conventional hydropower and nuclear power 500 million kilowatts and 300 million kilowatts, respectively. The non-carbon power will reach installed capacity of around 90% and the power generation over 85% of the total power generation.

Energy resources are unevenly distributed in China. The north and northwest regions are rich in coal, wind energy, and solar energy resources, while the southwest region is rich in hydropower resource, forming a basic power allocation pattern of power transmission from west to east and from north to south. In 2020, the capacity of power transmission from

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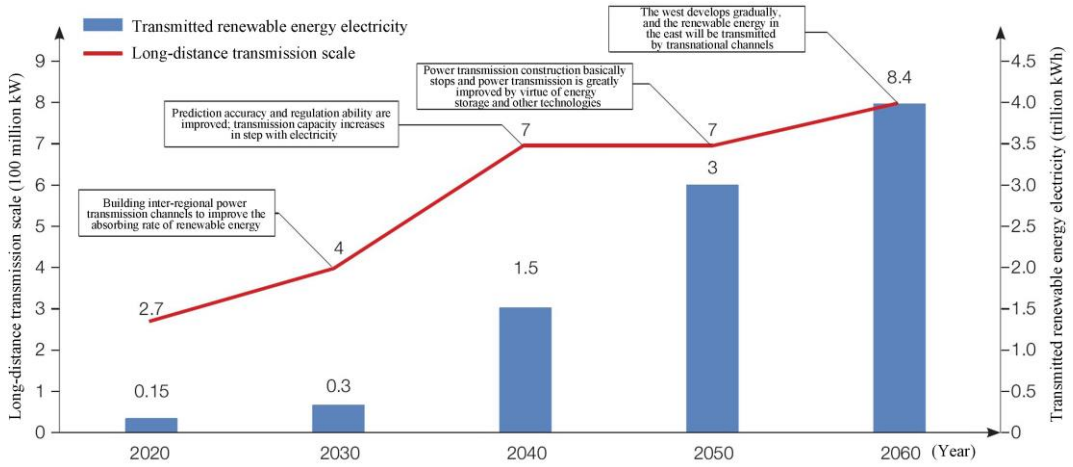

Figure 1 Needs of long-distance transmission capacity from 2020 to 2060

west to east reached 270 million kilowatts [4]. As estimated, 81% of China's hydropower resources [5,6], 86% of wind energy resources, and 96% of solar energy resources are distributed in the west and northeast regions. In the future, about 2/3 of total electricity will be consumed in the eastern and central regions ①. Considering the development of distributed renewable energy, it is still difficult for the central and eastern regions to achieve power self-sufficiency in the short and medium term, and the power supply and load will not change fundamentally. Accordingly, the long-distance energy transmission function of power grid will be further strengthened in the short and medium term. However, as the development difference between the east and the west will be gradually balanced in the long term, there will be several urban clusters in the northwest region including Xinjiang as the land channel connecting the Eurasia along the Belt and Road, which may reduce the demand for energy transmission from the west.

2 General idea and principles for building a new power system

General idea: China should deeply implement the concept of innovative, coordinated, green, open, and shared development, and actively build a new power system to achieve the "dual carbon" goals. The role of power grid as a hub platform in optimizing energy and resource allocation should be given full play to promote the coordinated development of load and storage. The capacity and flexibility of the power grid to absorb renewable energy and diversified load should be improved to steadily promote trans-provincial long-distance clean power transmission. Efforts should be made to build a safe and reliable alternating current synchronous power grid with a reasonable scale and clear structure, improve the digital and intelligent allocation of power grid, and develop new models and forms such as integrated load and storage, micro-power grid, and DC power grid. These measures will provide strong support for ensuring economic and social development and promoting the low-carbon energy transition.

Development principles: (1) Adhering to the system concept for overall optimization. The allocation of resources should be optimized with China taken as a whole to promote the coordinated development of load and storage and improve the overall efficiency and economical efficiency of the power system. (2) Adhering to safety, reliability, and reasonable structure. In view of the bottom line of security, it is required to build a safe and reliable layered power grid with a reasonable scale to enhance the disaster resistance and emergency support of electricity, especially the capacity of dealing with new risks, such as high-proportion renewable energy instability and network attacks. (3) Adhering to clean, low-carbon, and green building. The priority should be given to eco-environment protection in the building of a new power system. The potential of load-side and new-type energy storage technologies should be stimulated to form a new pattern of coordinatedly absorbing renewable energy and meet the demand of large-scale and high-proportion sustainable development and utilization of renewable energy under the goal of carbon neutrality. (4) Adhering to innovation and digital upgrading. Efforts should be made to promote scientific and technological innovation, transformation, and upgrading and improve the digitalization of the power grid. Internet+ intelligent power grid should be built to strengthen system integration and optimization, improve dispatching and operation modes, and increase the efficiency of power systems. (5) Adhering to the combination of long-term and short-term objectives and making breakthroughs after

① Wind and Solar Energy Resource Center, China Meteorological Administration. China Wind and Solar Energy Resources Bulletin 2020.

establishment. It is necessary to eliminate ivory-towered "dynamic" carbon reduction, fully understand the complexity, persistence, and systematization of the "dual carbon" goals, so as to gradually upgrade the modern power system in a gradual and steady way.

3 Basic structure and form of the future power system

3.1 Long-distance transmission will keep expanding

The withdrawal of fossil energy generating units will aggravate the reverse distribution of power generation resources and load centers. In view of the great power gap in the east, it is necessary to perform large-scale inter-regional power dispatching [7].

Under the goal of carbon neutrality, large power transmission channels across provinces and regions will be further increased. It is estimated that the scale of cross-provincial transmission channels will reach 700 million to 800 million kilowatts in 2060, which will be significantly higher than that (270 million kilowatts) in 2020. The trans-provincial power transmission will reach about 3 trillion kilowatt-hours, mainly from the non-fossil energy. The main power flows from the northeast, northwest, and southwest to the east and central regions.

3.2 Large power grids will still be the basic structure of power systems

The renewable energy generation is closely related to meteorological conditions. In view of geographical differences in China, the interconnection of large power grids can improve the resource sharing capacity. Meanwhile, as renewable energy is gradually becoming the main power supply, it will be hard to ensure the security of local power supply under unfavorable meteorological conditions such as continuous rainy days. Large power grids are required for realizing large-scale mutual complementation, thus improving system reliability and ensuring power supply security.

Under the goal of carbon neutrality, large power grids are still the basic form of the power system. Large power grids and large markets can coordinate the allocation of resources across China, achieve cross-regional complementation, and improve the reliability of power supply. Meanwhile, they can ensure seasonal complementation and regulate wind, light, water and fire energy to realize cross-regional compensation, thus fully sharing various power generation resources and making them mutually reserved.

3.3 The distributed power system will provide effective compensation and combine with large power grids to form the basic form of the power system

Wind energy and solar energy, with low density and wide distribution, are suitable for distributed development and utilization. In the future, with large-scale and distributed access of wind power, photovoltaic power, stored energy, and flexible load, the electricity market will be diversified and the electricity transmission will be transited from unidirectional transmission to interactive and flexible transmission of stored power. The dispatching mode of the traditional power system shall also be changed accordingly [8].

Under the goal of carbon neutrality (Figure 2), distributed power system and large power grids are compatible, supporting and complementing each other to ensure the safe and stable operation of the power grid. The distributed power system, being close to users, plays a prominent role in ensuring the power supply for important facilities in central cities, supporting high-quality development of county-level economy, serving green development of industrial parks, and solving power problems in remote areas. The flexible and proactive distributed power system can support diversified open access and two-way interaction of power sources and loads and promote efficient local absorbing of distributed renewable energy. Relying on advanced measurement technology, modern information communication, big data, and Internet of Things, the distributed power system will have panoramic perception. Based on large-scale supercomputing capability and artificial intelligence technology, distributed power system can intelligently control operation, improving operation efficiency of the system and optimizing the allocation of resources.

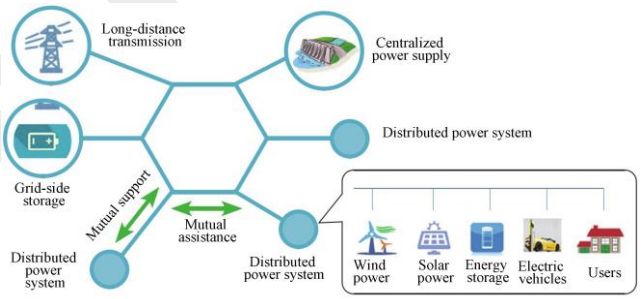

Figure 2 Schematic diagram of future power grid

3.4 The flexible regulation ability of power system will be significantly improved

Under the goal of carbon neutrality, the access of high-proportion capacity of power generated with renewable energy will pose a huge challenge to the operation of the power grid. Power generation with renewable energy fluctuates greatly and is poorly matched with load curve, and even completely opposite in some periods. Wind power generation is low at peak load, and photovoltaic power generation is almost zero at the evening peak. The large-scale development of new energy has increased the pressure of power grid on balanced regulation of peak. The traditional power system could not realize real-time balance between power generation and load, which need joint efforts from all parties to improve the regulation ability.

Under the goal of carbon neutrality, the power grid system

should integrate and flexibly regulate the load and power storage. At the power supply side, power supply can be flexibly regulated by pumped-storage and energy storage. Renewable energy generation stations will become system-friendly stations by configuration of energy storage, improvement of power prediction level, and intelligent scheduling and operation. Therefore, they can improve the power supply and mitigate the impact of intermittent and fluctuating renewable energy on the power system. At the power grid side, it is necessary to take into full consideration of inter-provincial resource complementation, regulate resources with the sharing system, give full play to the benefits of the access to large power grids, and flatten the fluctuation of renewable energy generation between different regions. At the load side, new flexible loads such as electric heating, electric hydrogen production, data center, and electric vehicle charging facilities have become important parts of the power system. The market mechanism can be used to change the traditional mode of changing the resource with load, realizing deep integration and flexible interaction of load and power storage.

3.5 There will be a service platform supporting market-oriented operation of electricity

The power market can restore the attributes of power products to the greatest extent, and realize the following functions: allocating resources by market, releasing price signals, reflecting cost characteristics, enhancing demand elasticity, guiding power investment, mobilizing flexible resources of the system, promoting interaction between load and power storage, and guiding multiple subjects to participate in decision-making regarding operation of the system [9]. Under the goal of carbon neutrality, China will form a high-standard market system covering electric energy, auxiliary services, power generation rights, transmission rights, and capacity compensation, which is dominated by medium- and long-term market and supplemented by the spot market.

4 Phased implementation strategy of building a new power system

4.1 Carbon control phase (2021–2030)

In this phase, renewable energy will rapidly develop in western regions such as Qinghai, Ningxia, and Xinjiang. The basically matured long-distance UHVDC technology, immature energy storage technology, and insufficient flexible regulation of the power system will make the transmission and absorption of renewable energy still rely on the construction of trans-regional long-distance power transmission systems. This phase will focus on balancing the resources between the east and the west, building distributed microgrids for integration at the user side, and laying a foundation for the flexible regulation of the power system. It is suggested to build cross-regional power transmission channels such as the Hami–Chongqing, eastern Gansu–Shandong, Jinsha River upper basin–Hubei, western Inner Mongolia–Hebei, Ningxia–Hunan, and Sichuan–Hunan channels. It is estimated that the scale of trans-provincial long-distance power transmission channels in China will reach 400 million kilowatts, increasing by 130 million kilowatts compared with that in 2020. The scale of trans-provincial renewable energy transmission is expected to reach 150 million kilowatts, with the transmission power over 300 billion kilowatt-hours.

As the construction of distributed renewable energy facilities in the fields of ports, railways, highways, and oil fields gradually peak, the original backward distribution network should be improved in terms of perception, control, and intelligence level. In addition, AC-DC microgrids should be extensively developed to accept and absorb distributed renewable energy.

4.2 Carbon reduction phase (2031–2040)

China will gradually realize socialist modernization and become a great modern socialist country in this phase. The power load will be 1.5 times of that at present, and the load will still be concentrated in the central and eastern regions. In this phase, on the one hand, as restricted by the capacity of renewable energy in the east, most of the new loads need to be satisfied by long-distance trans-provincial transmission, and it is expected that the construction pressure of transmission channels will still be large. On the other hand, the transmission channels will be saturated in Hexi Corridor in this phase as restricted by geographical conditions, making it hard to build new transmission corridors in central and eastern regions. It is estimated that the scale of trans-provincial long-distance transmission channels needs to reach 600 million to 700 million kilowatts, and new channels with the scale of 200 million to 300 million kilowatts need to be built.

With the accumulation of renewable energy generation data and meteorological data during 2020–2040, the prediction accuracy of renewable energy generation will be greatly improved. On the one hand, with the gradual improvement of the user-side market mechanism, the load and power storage will be deeply integrated and flexibly interacted. Particularly, new flexible loads such as electric heating, electric hydrogen production, data center, and electric vehicle charging facilities will be important parts of the power system in this phase. Therefore, with the same transmission capacity, renewable energy transmission will be greatly increased, and it is expected that trans-provincial transmission of renewable energy will exceed 1.5 trillion kilowatt-hours. On the other hand, distributed renewable energy will gradually be integrated with the living of urban and rural residents and industrial production, forming a pattern dominated by AC system and supplemented by DC system. Meanwhile, the construction of the intelligent power distribution system will also be strengthened.

4.3 Low carbon phase (2041–2050)

It is expected that breakthroughs will be achieved for energy storage technologies in this phase, and the cost of various types of batteries will be significantly reduced. The levelized cost of energy (LCOE) of energy storage systems such as lithium battery and liquid flow battery can be reduced to CNY 0.1–0.2 per kilowatt-hour, and the building scale will be greatly increased. Therefore, smooth inter-regional transportation of renewable energy can be achieved, and the utilization rate of the existing transmission channels will be improved.

As the energy storage technologies will become increasingly mature in this phase, the cost and pressure of new transmission channels will be reduced. In the 10 years of this phase, the scale of trans-provincial long-distance power transmission channels is expected to be maintained at 600 million to 700 million kilowatts, and that of the newly built channels will be less than 50 million kilowatts. The utilization rate of these channels will approach the limit with the development of technologies, and thus the renewable energy transmission will exceed 3 trillion kilowatt-hours.

4.4 Carbon neutrality phase (2051–2060)

In this phase, a great modern socialist country will be basically constructed, with balanced development between the east and the west. There will be several urban clusters developed from logistics hubs in Xinjiang and other northwest regions as the land channels connecting the Eurasia along the Belt and Road, which may reduce the demand and impetus for power transmission from the northwest to central and eastern regions, and enable parts of the northwest to gradually achieve self-balance. It will make the increased demand for green electricity in the central and eastern regions gradually turn to the supply from the northeast and even the power transmission channels from Mongolia and Russia. It is expected that 100 million to 200 million of power transmission channels will be added in this phase, mainly the transnational channels. Finally, the scale of trans-regional long-distance power transmission channels will reach 700 million to 800 million kilowatts, and the renewable energy transmission will reach 4 trillion kilowatt-hours.

References

1 China Federation of Electric Power Enterprises. China Power Statistics Yearbook 2021. Beijing: China Statistics Press, 2021. (in Chinese)

2 Zhou X X, Zhao Q, Zhang Y Q. Development prospect and key technologies of China's energy and power system under the goal of "double carbon". China Power Enterprise Management, 2021, (31): 14–17. (in Chinese)

3 Wang Y, Liu B J. Marching towards a new stage of high-quality energy development—A summary of energy development in the 13th Five Year Plan period. China Electric Power, 2021, (1): 24–27. (in Chinese)

4 Zhang J H. Energy structure and system morphology are facing tremendous changes. Electric Power Equipment Management, 2021, (4): 18–20. (in Chinese)

5 National Leading Group for review of hydraulic resources. General Report on the Review Results of Hydraulic Resources of the People's Republic of China (2003). Beijing: China Electric Power Press, 2004. (in Chinese)

6 Zhou D. The Challenges that China's energy security faces. Sino-Global Energy, 2020, 25 (8): 22. (in Chinese)

7 Lou W, Li M. Study on regional coordination of renewable energy power in China. Energy of China, 2021, 43 (2): 44–47. (in Chinese)

8 Su N. What does the new power system look like? China Energy News, 2021-12-06 (22). (in Chinese)

9 Song Y H, Bao M L, Ding Y, et el. Review of Chinese electricity spot market key issues and its suggestions under the new round of Chinese power system reform. Proceedings of the CSEE, 2020, 40 (10): 3172–3187. (in Chinese)

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