A Brief Introduction to the Research on Carbon Neutrality in Power System

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Abstract:—In 2021, the carbon neutral target was officially included in the Chinese government work report, and the term carbon neutral has also begun to enter the public's field of vision. This article summarizes the research on carbon neutrality. Firstly, the article introduces the basic concept of carbon neutrality. After that, the article described the impact of carbon neutrality on the energy and power industries. Finally, from the perspective of the power system, this article introduces some solutions to achieve the goal of carbon neutrality in the new power system. This research provides some references for exploring the realization path of carbon neutrality.

1. Introduction
At the General Debate of the 75th UN General Assembly on September 22, 2020, Chinese President Jinping Xi proposed that China will strive to achieve carbon neutrality by 2060 [1]. Since then, national leaders have repeatedly mentioned the goal of carbon neutrality on various important occasions, and the goal of carbon neutrality has also been formally written into the government work report. Carbon neutrality has become one of the current hotspots, and the understanding and knowledge of carbon neutrality has also attracted the attention of many researchers. Many research results related to carbon neutrality have emerged one after another.

This article briefly summarizes the research on carbon neutrality. The article first describes the basic concept of carbon neutrality. Secondly, the article analyzes the development prospects of the energy and power industries in the context of carbon neutrality. Finally, considering the development direction of the power system, the role of the new power system in China's carbon neutrality program is introduced.

2. The concept of carbon neutrality
At the 75th UN General Assembly in 2020, 121 countries around the world pledged to reach the carbon neutral goal by 2050. China has also made commitments to increase national control, adopt more tough and effective policies and measures, and strive to achieve carbon peaking by 2030 and carbon neutrality by 2060.

In 2021, at the ninth meeting of the Central Finance and Economics Commission, General Secretary Jinping Xi proposed that achieving carbon neutrality is a broad and profound economic and social systemic change [2]. China will incorporate carbon neutrality and carbon peaking into the overall layout of ecological civilization construction, strive to build a low-carbon, safe and efficient new energy system, strive to control the total consumption of fossil energy, improve energy utilization efficiency, carry out actions to replace renewable energy, deepen the reform of the power system, and build a new power system with the theme of new energy.
The first step in reaching the carbon neutrality goal is to achieve the carbon peaking goal, which is a prerequisite for carbon neutrality. Carbon peak \([3]\) means that carbon emissions reach the highest peak in history, after which carbon emissions will enter a phase of gradual decline. Carbon peak is a precondition for carbon neutrality. The earlier the peak time, the lower the pressure to achieve carbon neutrality. At the same time, the higher the peak level, the greater the difficulty required to achieve carbon neutrality, and the higher the technical requirements. China’s goal is to achieve a carbon peak in 2030, and some developed countries such as the United Kingdom have already achieved this goal in the 1890s \([4]\). Therefore, China has fallen behind for decades in this regard.

In order to stabilize the global temperature rise at the level of 1-2°C, it is necessary to reduce global net greenhouse gas emissions. When greenhouse gas emissions are close to zero, the amount of greenhouse gas emissions and absorption will reach a balance. This balance is called neutralization or net zero emissions \([5]\). China aims to be carbon neutral by 2060, a decade behind developed countries.

By analyzing the definition of carbon neutrality, it can be found that the realization of carbon neutrality is divided into two aspects, one is to reduce carbon dioxide emissions, and the other is to increase carbon dioxide absorption. Emission reduction refers to the reduction of carbon emissions in the production and operation of industries such as industry and transportation. While the main measure to increase absorption is to increase greening and planting areas.

There are still many challenges in the process of achieving carbon neutrality. Because carbon neutrality is not just a scientific and technical issue, it is a test of market economic management and a challenge to institutional design and public policies. In order to achieve carbon neutrality, the way of life and production at all levels of society will be completely changed, resulting in long-term and far-reaching impacts.

3. **The impact of carbon neutrality on the power industry**

In 2019, China emitted 11.3 billion tons of carbon dioxide \([6]\). Among them, the carbon emissions of the power industry are about 4.2 billion tons, more than one-third of the total. Therefore, in the process of achieving the goal of carbon neutrality, the energy and power industry will assume the most important and responsible main force.

From more than 100 years, the power system has mainly used fossil energy as its energy source. Under the background of carbon neutrality, new power systems will replace traditional power systems. In terms of planning, operation and safety management, the technology of the traditional power system has matured and has a high level, and the power supply has reached a reliable guarantee. Under the carbon neutral policy, the power system structure will be transformed from a high carbon emission power system to a deep low carbon or zero carbon emission power system. The mechanical electromagnetic system is mainly transformed into power electronic equipment, the deterministic controllable continuous power supply is transformed into uncertain random power supply and fluctuating power supply, and the high rotational inertia system is transformed into a weak rotational inertia system.

In order to vigorously promote the transformation of the power system, the power sector and government agencies need to coordinate development and security to ensure the continuity and reliability of power supply. At the same time, the flexibility of the new power system will be enhanced, the ability to optimize the allocation of resources will be improved, and the efficient coordination between the source and storage of multiple energy sources will be realized. The new power system will effectively solve the uncertainty and randomness of renewable energy, and realize its intelligence and friendliness.

4. **Solutions for carbon neutral power grids**

4.1 **Basic characteristics of new power system**

The main solution for grid carbon neutrality is to build a new type of power system. The new power system should have the following four basic characteristics.
The first feature is extensive interconnection \[7\]. By forming a strong interconnection network platform, the new power system can fully reflect the advantages of the interconnected power grid and obtain the benefits of complementary seasonal differences. Wind power, photovoltaic, hydropower and thermal power are mutually adjusted to realize the sharing of various resources for power generation.

The second point is intelligent interaction \[8\]. The new power system integrates the current communication technology and power technology, and the purpose is to realize the intelligent interaction between information. It has changed the traditional configuration method, from a plan-based, one-way control to a highly aware, two-way interactive way to achieve intelligence and efficiency.

The third point is flexible regulation \[9\]. Renewable energy actively suppresses fluctuations in output and improves the quality of power generation. It can be used as a reliable power source with adjustability and controllability to improve active support performance. The power grid can adjust the peak and frequency in time, realize flexible and flexible control, and prevent the power grid from fluctuating greatly due to disturbance. The new power grid must be able to ensure multi-energy complementarity and meet the needs of renewable energy development. Electricity users are not only consumers of electricity, but also producers of electricity. Strengthen the construction of active distribution networks.

The fourth point is safe and controllable \[10\]. To achieve coordination and synchronization of voltages at all levels, a new generation of control systems must be constructed to prevent the risk of system failures and the risk of power outages in large areas, effectively.

4.2 Challenges of new power systems

In the future, the structure of the power system will undergo great changes, mainly in clean power supply, electronic grid and diversified loads. In this context, with the increase in the proportion of renewable energy in the power system, the power system is also faced with diversified operation modes, probabilistic power balance, blurred source and load boundaries, bidirectional current, complex energy coupling, and flexible resources. Scarcity and many other challenges.

The diversification of operation modes \[11\] means that there are great uncertainties in sources and loads, the operation modes will be more diversified and decentralized, and the power system form will undergo great changes.

Probabilization of power balance \[12\] means that part of the load balance is borne by renewable energy, and the power balance changes from deterministic to probabilistic.

The fuzzification of the source load boundary \[13\] means that with the emergence of distributed energy storage and demand-side demand response, production consumers appear, and the source load boundary becomes more blurred.

The bidirectional power flow of the power system \[14\] means that on the ring network tie line, since there are power generation and electricity consumption at both ends, the tie line power flow flows to that side according to which side generates less electricity and consumes more electricity.

The energy coupling \[15\] refers to the coordinated transformation of various energy forms such as electric energy, heat energy, cold energy and gas.

5. Construction method of new power system

5.1 Digital twin grid

Digital twin technology \[16\] is an emerging digital information technology, which promotes the omnidirectional perception technology of power grid construction, but also improves the network connection speed and stable operation ability. By establishing the connection between real space and virtual space, this technology realizes real-time perception of the state of equipment or system in real space. This technology guides device or system decision-making by feeding back data carrying instructions. Through some series of calculations and operations in the virtual space, the self-decision and self-evolution capabilities of the power grid can be increased. The technology has completely changed the
traditional power supply mode and formed a new digital smart grid construction and operation mode.

The digital twin of the power grid \[17\] is essentially the data closed loop of the power supply system. The power grid system realizes the monitoring, diagnosis and control of the power grid through data identification, accurate state perception, real-time data analysis, model scientific decision-making and intelligent and accurate implementation. This is the role of the digital twin. This technology can improve the efficiency of grid resource allocation and optimize operation. In terms of power grid construction, digital power grids and physical power grids are planned and constructed in parallel. During the build phase, importing data is continuous. During operation, the digital grid model is used to map the physical grid for full data management. For the grid that has been built and operated for many years, through the full deployment of IoT facilities and the digital modeling of the grid, a digital dual grid can be built and managed.

In terms of power grid operation management, the accuracy and timeliness brought by IoT sensing technology, correct decision-making and intelligent control can optimize the operation and management of physical power grids \[18\]. The optimized physical power grid and digital power grid can gradually form an endogenous development model of deep learning and self-optimization through iteration.

5.2 Flexible solution
The development and evolution of new power systems are affected by many factors, such as technological maturity, energy prices, and social development stages. The evolution path of the power system is highly uncertain. The global sensitivity method considering the uncertainty of the path evolution depth can be used to study the evolution path of the power system.

The basic idea of the global sensitivity method is to comprehensively consider various uncertain factors affecting the path, detect various parameters, extract a large number of data samples, and use each set of data as a series of boundary conditions for the power system evolution model. Then, the model generates a large number of evolution paths, and further statistics and analysis are based on different influencing factors. The global sensitivity method exploits the flexibility factor \[19\], embeds it in the traditional system, and analyzes its role in the system evolution. The flexibility factor includes a number of flexibility-related uncertainty factors in the power system evolution model, as well as flexibility resources and flexibility balance.

In the power system evolution, the flexibility resources that need to be invested include the improvement of thermal power generating units, various energy storage types, such as lithium batteries, compressed air energy storage, pumped water storage, etc., as well as load transfer and load shedding. In terms of hydropower, it is considered to be the "three-level" form with the maximum output, minimum output and expected output, with sufficient climbing ability. Energy storage modeling and regulation according to user needs take into account both power and energy regulation. The modeling framework considers the flexibility of each link, and reflects the flexibility of each link of the system on the hour-level time scale and the sky-level time scale. The whole system is modeled as a multi-node system, which can consider the regulation and balance of the system in space.

5.3 Integrated energy system
The interconnected integrated energy system \[20\] is a means to solve the current contradiction between low energy utilization efficiency and environmental protection. The use of an integrated energy system not only promotes the quality and efficiency of energy use, but also promotes low-carbon development of society.

An integrated energy system refers to an integrated system of energy production, supply and consumption formed through the overall optimization of all aspects of "production, distribution, utilization and storage" of various energy sources in the process of planning, operation and trading. The integrated energy system has good performance in terms of economy, safety, low carbon and high efficiency.

The integrated energy system includes various energy sources such as electric energy, heat energy, natural gas, etc., which can realize the mutual adjustment and complementarity among the energy
subsystems, and make the operation of the integrated energy system more convenient and efficient. In addition to supplying electricity through the grid, the integrated energy system also provides gas and heat to the load to meet the various energy needs of the load. Integrated energy systems generate electricity and heat through combined heat and power (CHP) during the transmission of electricity from the grid, gas and heating grids. Integrated energy systems connect electricity and gas networks through electrical (p2g) technology. The integrated energy system realizes the heat exchange of electric energy through air conditioner, water cooling unit or other equipment. When the supply and demand of various energy sources are unbalanced, the dynamic balance of system energy is achieved through the charging and discharging of energy storage devices (electrical storage, gas storage, thermal storage, etc.). Therefore, fully understanding the characteristics, and scheduling optimization on this basis is very important, it make the system more efficiency.

6. Conclusion
With the repeated mention of the carbon neutral target, carbon neutral has become a hot word and has attracted a lot of attention. This article summarizes the research progress of carbon neutralization. Through the description of the basic concepts of carbon neutrality, the article draws out the impact of carbon neutrality on the energy and power industries. Finally, this article analyzes many power systems and sums up some solutions for the new power system to achieve the goal of carbon neutrality. This research provides reference and guidance for the construction of a new carbon-neutral power system.

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