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Analysis of the Path to Build a New Power System for the Guangzhou Power Grid

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Abstract:
Since the beginning of the modern era, countries have begun to study how to develop without further damaging the environment. For the power industry, a new type of power system must be built to reach carbon peak and carbon neutral. The paper focuses on Guangzhou city as an example, and starts from the current situation of the power system in Guangzhou, analyses the various indicators of the power system such as the number and location of the converting stations in Guangzhou. Besides, the paper analyses the existing problems includes pressure on optimization and transformation of energy structure, low level of intelligence in smart grids and so on. The article also summarizes a variety of key technologies for building a new type of power system. In addition, the paper puts forward a brief method of building a new type of power system in Guangzhou, which provides a reference for the further development of Guangzhou City.

Keywords: Carbon Peak , Carbon Neutral, Low-carbon Technologies, New Power Systems, Power System Planning

1. Introduction

Since the Industrial Revolution in the 1860s, greenhouse gases (mainly carbon dioxide) produced by mankind's extensive use of fossil fuels (coal, oil, natural gas) have led to global warming, which in turn has triggered climate change, such as extreme weather and rising sea levels. To address these global challenges, the international community has begun to strengthen co-operation to reduce carbon emissions. To avoid further deterioration of the climate, China has put forward the concepts of carbon peaking and carbon neutrality. Achieving carbon neutrality means that the country and society will gradually shift to a green and low-carbon economic model, which will help promote the development of new energy industries, improve resource efficiency, and reduce dependence on fossil energy. The goal of carbon neutrality has become an important commitment by countries to combat climate change, demonstrating their willingness to contribute to global environmental governance. China, as one of the world's top two countries in terms of population, has a crucial impact on the climate. China is the world's largest carbon emitter, and the introduction of carbon peaking and carbon neutrality targets demonstrates China's strong commitment to combating climate change, as well as being an important strategy for promoting its

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own economic transformation and realising green development. For the power industry, this challenge becomes the construction of a new type of power system. The new power system is characterised by a high proportion of new energy, a high proportion of power electronics and a low moment of inertia. Specifically embodied in: the volatility and uncertainty of renewable energy generation on the power side increase, and gradually become the main source of power consumption [1]. Grid sideWith large-scale new energy access, the utilisation rate of transmission channels of the grid has increased, but system stability is also subject to more challenges.On the user side, user loads are diversified and controllable, and load management requires more intelligence and flexibility The core objective of the new type of power system is to achieve cleaner, more efficient, and more intelligent power, to support large-scale renewable energy access and to achieve carbon peaking and carbon neutrality. It is upgraded on the basis of the traditional power system, integrating advanced information and communication technology, energy management technology and multiple energy forms [2]. This paper will take Guangzhou, one of the largest cities in China, as an example, and start from the current status of the Guangzhou power grid by combining data indicators, followed by analysing five representative key technologies, and finally combining the current challenges and future development directions to analyse how Guangzhou can build a new power system.

2. Overview of the Current Power System Situation in Guangzhou

The power system includes the generation system, transmission system, distribution system and the customer side. The Guangzhou Power Grid is located in the centre of Guangdong's main ring network and is the load centre of the South China Grid's west-east power transmission receiving end, with an area of 7,434.4 km2 of power supply, 4.78 million power supply customers, and an estimated population of over 16 million people actually supplied with power.. It is expected that by the end of 2025 there will be 466 substations of 110kV and above in the city, including 11 500kV substations, 89 220kV substations, and 366 110kV substations[3]. For the power transmission and distribution system, Guangzhou's high voltage transmission system mainly includes 220kV, 110kV and some 500kV transmission lines. The ultra-high voltage system is mainly used for long-distance transmission, importing power from power plants or out-of-province power into the Guangzhou metropolitan area. These transmission lines are usually connected to large substations, which are responsible for dropping the voltage to a lower voltage level for further distribution. This part of the 500kV transmission grid is responsible for transporting electricity from within Guangdong Province and other provinces to 500kV substations in Guangzhou, such as the Baiyun 500kV substation. Through these lines, power can be transmitted to Guangzhou from large power plants in the provinces and from hydroelectric power stations such as the Three Gorges etc. The 220kV transmission grid is the backbone of the transmission system in Guangzhou, covering the main areas of the city and distributing the power output from the 500kV substations to smaller substations. For example, there are 220kV substations in Nansha and Tianhe districts of Guangzhou, which are responsible for power distribution within the region. Medium voltage distribution networks with voltage levels of 35kV, 10kV, 6kV, etc. are connected to the output of 220kV or 110kV substations to further distribute power to smaller power users. Most of Guangzhou's urban residential and commercial electricity is usually supplied through a 10kV distribution network. 10kV lines are output from substations and pass through distribution transformers to reduce the voltage to 220V or 380V, which is supplied to residential houses or small commercial facilities. In the main administrative and commercial areas of central Guangzhou, such as Tianhe or Yuexiu districts, power supply relies on the 10kV distribution network from 110kV substations, which serves a wide range of residential and commercial offices as well as small industrial users. Slightly more remote areas of Guangzhou, such as parts of Nansha District, are served by 220kV backbone grids, with extensive 35kV and 10kV distribution grids serving large industrial and port facilities. These more distant areas such as Zengcheng District, and Huadu District rely on 220kV transmission lines for power supply, and distribute power through 35kV and 10kV distribution lines to support large-scale industrial and residential power consumption in the region.

Overall, Guangzhou's grid system is stepped down from ultra-high voltage transmission, sequentially passing through substations, medium-voltage distribution grids, and then low-voltage distribution grids to efficiently transmit power to the consumer side.For the user side, the proportion of natural gas-fired power generation and renewable energy in Guangzhou's electricity consumption has risen significantly up to 2024. According to the plan, natural gas consumption in Guangdong Province is expected to increase by 65.5% between 2021-2025, reaching 4.8 billion cubic metres in 2025 Natural gas is emerging as a key transitional energy source, providing important support for electricity supply. At the same time, the share of renewable energy sources (e.g. solar and wind) in total electricity supply is steadily increasing, with non-fossil energy sources accounting for about 30% of total energy consumption in Guangdong in 2024. Overall, Guangzhou has begun to transition to a new power system, but it still suffers from a low share of renewable energy, a concentration of power sources in remote areas, and little land available in the city for grid construction.

3. Analysis of Key Technologies for Building New Power Systems

2.1 Smart Grid Technology

Smart grid is the core of a new type of power system, which enhances the intelligence of the power system by introducing digital technology to improve power supply reliability, flexibility and energy efficiency. Among them, smart meters combined with remote data acquisition systems can monitor and manage power demand in real time and help users optimize their power consumption behaviour. With smart devices, the power system can dynamically regulate users' electricity demand, cut loads at peak times and ease pressure on the grid. Through synchronous phase measurement units (PMUs), the operating status of the power grid in a wide area can be monitored in real time to ensure the stability and security of the power grid [4].

2.2 Energy Storage Technology

Energy storage is an important technology to solve the problem of intermittency of renewable energy sources by storing power during the low demand of electricity and releasing it during the peak time through energy storage devices to balance the power supply. At this stage, there are three feasible energy storage methods: firstly, for small-scale scenarios, electrochemical energy storage (e.g. lithium-ion batteries, sodium-sulphur batteries, etc.) will be used, which can quickly respond to grid scheduling and balance the short-term fluctuations of the grid. In large-scale, long-term energy storage requirements, generally use physical energy storage (such as pumped storage, compressed air energy storage). Especially it can be used for large-scale wind and solar power regulation. Recently there have also been some new energy storage technologies (e.g. hydrogen energy storage, flywheel energy storage, etc.), such as hydrogen energy storage by converting electrical energy into hydrogen for storage and converting it to electrical energy when needed through fuel cells or generators.

2.3 Extra-high Voltage Transmission Technology

UHV transmission technology is the key to large-scale long-distance transmission in new power systems. UHV transmission technology can transmit power from resource-rich areas (such as hydroelectric power stations and wind farms) to load centres far from the power source (such as large cities and industrial zones). It plays an important role in cross-regional power distribution, effectively solving the challenge of resource imbalance. For example, China's 'West-to-East Power Transmission' project uses UHV transmission to transport abundant electricity resources from the west to economically developed regions in the east. At the same time, UHV transmission technology helps build a strong backbone power grid, effectively improving the stability and reliability of the power system. Through the interconnection of UHV lines, power grids in different regions can realise power mutual aid, and when power supply tension or grid failure occurs in one region, other regions can provide support, so as to guarantee the stability of the overall power supply.

2.4 Flexible DC Transmission Technology

Flexible DC transmission technology is a DC transmission technology based on voltage source converter, which is suitable for accessing renewable energy, multi-port transmission, and interconnection of cross-regional power grids. Flexible DC transmission systems are capable of flexibly controlling active and reactive power, responding to grid fluctuations in a short period of time, and improving voltage stability and power quality. Therefore, flexible DC transmission is suitable for improving weak links in the grid and increasing the overall reliability of the grid. When a line fault occurs, the flexible DC system is able to quickly disconnect the faulty line and maintain power supply, while having good fault isolation capabilities to reduce the impact on other parts of the grid. In urban environments, transmission lines need to minimise the occupation of space. Flexible DC transmission is able to use underground cables for power transmission, which occupies a small area and is suitable for urban environments. In addition, flexible DC transmission allows for tidal flow control and avoids overloading and voltage fluctuation problems on lines in urban grids. Flexible DC transmission systems are particularly suitable for connecting long-distance offshore wind power to the onshore grid. As offshore wind farms are often far away from the power load centre, the long-distance transmission capability and voltage controllable characteristics of flexible DC technology make it possible to transmit offshore wind power efficiently and safely. For some island areas far from the mainland, flexible DC transmission can provide a reliable

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power supply solution. By connecting to the mainland power grid, these islands are able to obtain a stable power supply, reduce dependence on traditional energy sources such as diesel power generation, and promote the development of green energy. Guangzhou, as a coastal city, flexible DC technology can play a very critical role.

2.5 Distributed Power and Microgrid Technology

With the rapid development of user-side distributed photovoltaic, wind power and other energy sources, microgrid and distributed power technology is gradually becoming an important part of the new power system. Microgrid can realise self-regulation and self-recovery, and can operate independently of the main grid, which is especially suitable for power supply in remote areas or special demand scenarios. Through the intelligent scheduling system, distributed power can be effectively integrated into the large power grid to achieve the optimal management of distributed power generation, energy storage and load [5].

3. Current Challenges Facing Guangzhou Power System

3.1 Pressure on Optimization and Transformation of Energy Structure

Guangzhou's power structure is still dominated by traditional fossil fuel power generation, with thermal power occupying a major share and a low proportion of clean and renewable energy. This not only increases the pressure on carbon emissions, but also makes energy security and environmental issues increasingly prominent. Under the global trend of reducing carbon emissions and increasing the proportion of clean energy, how to rapidly realise the transformation of energy structure is one of the primary challenges facing Guangzhou. In particular, how to gradually reduce the dependence on fossil fuels such as coal while ensuring a stable supply of electricity [6].

3.2 Low Level of Intelligence in Smart Grid

The level of grid intelligence and automation in Guangzhou still needs to be improved, and although smart grid pilots have been carried out in some areas, the wide-scale promotion and upgrading has not yet been completed. The level of grid automation management is limited, the response speed is slow when encountering power emergencies, and the regulation capacity of the grid is also relatively insufficient. As urbanisation advances and power demand continues to grow, the carrying capacity of the grid is under greater pressure. If the degree of grid intelligence is insufficient, the stability of power supply and the ability to respond to disasters or emergencies will be limited. And as the uncertainty on both sides of the power supply and load increases significantly, the question of how to accurately model and forecast the output of power supplies and loads becomes a fundamental issue for planning.

3.3 Renewable Energy Access and Consumption Issues

The utilisation rate of renewable energy such as wind and solar energy in Guangzhou is relatively low. Although there has been some growth in recent years, the scale of renewable energy access is constrained due to the limitations of the grid structure and scheduling capacity. It is difficult for the power consumption system to make full use of these distributed energy sources [7]. How to improve the access ratio of renewable energy in the grid, and effectively solve the consumption problems caused by the volatility of new energy generation is a key issue that must be resolved in the future.

3.4 Renovation and Renewal of Old Power Infrastructure

As a rapidly developing city, Guangzhou has an old power infrastructure in some areas, with aging power supply equipment and outdated transmission and distribution lines posing a risk to the stability and safety of the power supply. Large-scale renewal of old power facilities requires huge capital investment. At the same time, the impact of construction on the city's daily life also needs to be fully considered. The city lacks land that can be used for power construction.

3.5 Continuous Growth of Electricity Demand

Guangzhou, an important city in southern China, has a population of nearly 19 million and is still growing, industrial, commercial, and residential power demand continues to grow, especially in the hot summer season, and the surge in demand for power to the power grid to bring great pressure. How to cope with the continuous growth of electricity demand while maintaining a stable supply of electricity and improving the efficiency of electricity supply and regulation is a long-term challenge for Guangzhou's power system. How to balance the contradiction between development and transformation is one of the current difficulties.

4. Future Direction of Development:

4.1 Development and Promotion of Smart Grids

The smart grid is the core direction of power system development. Guangzhou will focus on promoting the construction of a smart grid in the city in the future to realise automation and intelligent management of the power system. By combining IoT, AI, and big data technologies, smart grid monitors the power flow and load in the grid in real-time, and can precisely control power supply and load adjustment, thus improving the reliability and efficiency of power supply. At the same time, the smart grid can dynamically adjust the electricity load, shave peaks and fill valleys, and reduce power losses. Guangzhou can further introduce smart meters and smart home devices to enable residents to manage electricity consumption more efficiently and provide flexible tariffs to incentivize users to use electricity resources during low peak hours. The smart grid's ability to cope with extreme weather and emergencies will also be significantly improved, allowing it to automatically locate and isolate faults, reduce the impact of power outages, and improve the security and stability of the grid [8].

4.2 Increase the Proportion of Clean Energy Application

Guangzhou's new future power system will rely more on clean energy sources such as solar, wind and biomass. This direction will significantly reduce the city's carbon emissions and support the nationwide goal of carbon neutrality [9]. The city of Guangzhou has high light conditions, making it ideal for the development of photovoltaic power generation. In addition, wind energy resources within the city and offshore can be utilised through technical means, especially offshore wind power projects can be developed. In order to better utilise clean energy, Guangzhou can layout more PV power plants and promote the popularity of distributed PV in residential and commercial buildings. In the future, larger-scale clean energy can also be accessed through extra-high-voltage transmission technology to improve the sustainability of the grid. To ensure stable access of clean energy to the grid, Guangzhou also needs to strengthen the construction of energy storage facilities and intelligent dispatch systems to achieve full utilisation of clean energy and higher power quality.

4.3 Promote the Construction of Distributed Power Systems

Distributed power system is an important development direction for Guangzhou's future power system. Distributed power connects power production directly to the user side, making power supply more flexible and decentralised. For example, distributed photovoltaic power generation systems can be installed on building rooftops, communities, parks and other locations in the city, which not only saves transmission and distribution costs, but also increases the resilience of the grid's power supply. Distributed power systems can help Guangzhou balance power supply during peak demand and avoid overloading large-scale power equipment. During natural disasters or emergencies, distributed power systems can also be used as a backup power source to enhance the security of the city's power supply. In the future, Guangzhou can form several small autonomous power networks through the combination of distributed power and microgrid technology to enhance the self-sufficiency of urban power supply, reduce the dependence on the backbone grid, and provide citizens with more stable and reliable power services [10].

4.4 Strengthen the Application and Research and Development of Energy Storage Technology

Energy storage technology is an important component in the development of Guangzhou's power system, which helps to solve the problem of intermittency and volatility of clean energy generation. In the future, Guangzhou can provide reliable energy storage solutions for the power grid by laying out large-scale battery energy storage systems, pumped storage and hydrogen energy storage. These energy storage systems can store excess power at times of low power demand and release it at times of peak demand, thus balancing supply and demand and shaving peaks and filling valleys. At the same time, energy storage facilities can also provide back-up power in case of emergency to ensure grid stability. Guangzhou can consider building centralized energy storage bases in new development zones and urban fringes, while promoting small-scale energy storage devices and household batteries in commercial and residential areas to further improve the flexibility and emergency response capability of the power system. To meet the growing demand for electricity and the development of new energy sources, Guangzhou should also increase its investment in R&D of energy storage technology, aiming to break through the bottlenecks of cost and efficiency and promote the development of the energy storage industry.

4.5 Digital Transformation and Management Optimization of Power Systems

Guangzhou's new future power system will require a high degree of digital management to achieve more efficient

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energy distribution and use. The digital transformation will rely on advanced technologies such as big data, artificial intelligence, and the Internet of Things (IoT) to comprehensively monitor and analyse all aspects of the power grid. Through smart sensors, smart meters and other devices, Guangzhou's power system can collect real-time grid data, monitor electricity consumption and load changes, and realise remote management and operation and maintenance of power equipment. Data analysis can also help predict fluctuations in power demand and advance power scheduling and load balancing, thus reducing the risk of overloaded grid operation and improving the reliability of power supply. Driven by digital transformation, Guangzhou can develop virtual power plant technology to virtually aggregate small power generation equipment, energy storage devices and adjustable loads distributed in different regions for unified scheduling and management. The intelligent control system of the virtual power plant can respond to the power market demand in real-time and dynamically adjust the power generation output according to the grid load situation to achieve the purpose of peak shaving and valley filling. This management mode not only improves the flexibility of the power grid but also provides a more friendly environment for the access and use of renewable energy. At the same time, digital management can also improve the operation and maintenance efficiency of power facilities. Through equipment health status monitoring, fault diagnosis and predictive maintenance systems, Guangzhou Power Company can detect hidden dangers and take preventive measures in a timely manner before problems arise in equipment, reducing the incidence of faults and improving the reliability of power supply. Guangzhou can further develop a blockchain-based energy trading platform in the future to allow peer-to-peer power transactions between distributed energy users and transparent energy distribution. It also can record and allocate energy through a digital ledger to enhance the convenience and security of power transactions.

5. Conclusion

The paper provides an in-depth analysis of the construction of a new power system in the specific city of Guangzhou. Starting from the current status of the generation side, transmission and distribution side, and the user side of the Guangzhou power system, a review of the existing literature is conducted to draw out the key technologies for further construction of the power system at this stage. The current challenges facing the Guangzhou power system are analysed based on the current situation. Building a new power system is not only a necessary measure to promote the optimisation of the energy structure and ensure energy security but also an important way to achieve carbon neutrality and promote high-quality economic and social development. This transition is of great significance for addressing global climate change and promoting green development. At present, the construction of the power system in Guangzhou at this stage needs further development and improvement. The paper makes a prediction of the development of the power system in Guangzhou. It is expected that this paper can provide a reference for the planning and construction of the new power system in Guangzhou.

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