Research on the Development and Index System of Smart Distribution Network in China in the Future

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Abstract: The goal of "Carbon peaks & Carbon neutrality" is not only the requirement of ecological civilization construction, but also a clear requirement for high-quality economic development. In order to achieve the goal of "Carbon peaks & Carbon neutrality", China is facing the simultaneous transformation and upgrading of economic structure and energy structure. With the advance of China's modernization, the power grid will continue to play the role of "bridge" and "link", and China's future distribution network will become the key to development. Building a smart distribution network is the demand of building a new power network, and also the requirement of transformation and upgrading to the energy Internet. This paper analyzed the main driving factors and paths of distribution network evolution and development in developed countries, put forward the functional orientation and main characteristics of China's future smart distribution network development based on the main needs of regional economic development, rural revitalization, Carbon peaks & Carbon neutrality and new power network in China's future distribution network development, and designed the index system of future smart distribution network based on its main characteristics, so as to guide the future development direction of distribution network.

Keywords: Carbon peaks & Carbon neutrality, power grid, smart distribution network, index system of future smart distribution network

1. Introduction

Under the guidance of General Secretary Xi's new energy security strategy of "Four Revolutions and One Cooperation", the energy and power industry grounds its work in the new development stage, implements the new development concept, and actively integrates and serves the new development pattern. The goal of "Carbon peaks & Carbon neutrality" is not only a requirement for ecological civilization construction, but also a clear requirement for

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high-quality economic development. After the goal was put forward, the ninth meeting of the Central Committee of Finance and Economics clearly pointed out that "a new power network based on new energy should be built".

Under the new situation, as an important component of the power network, the power grid will continue to serve as a "bridge" and "link", facilitate the production and consumption of new energy, enhance all-around service capability and stimulate new development momentum [1]. The construction of a new power network will further promote the upgrading of the power grid to the energy Internet, especially to create a new pattern of power grid development on the distribution network side, so as to serve the economy and society in the direction of higher quality, better efficiency and better structure.

Building a smart distribution network in the future is a part of building an energy Internet, a concrete implementation of the requirements of the new power network in the allocation of power resources, and a specific demand for the transformation of power final users to "producers and consumers". Distribution network construction is facing a range of new challenges, such as diversified load development, the rapid development of distributed generation, personalized user demand, such as a series of physical structure, control mode and business demand. A large number of new loads brought about by the deep integration of energy, transportation, industry and other industries, such as electric vehicle charging piles and park integrated energy systems, are connected to the distribution network. Users have certain supply and demand adjustment capabilities, which put forward new requirements for the power supply guarantee capability of the power grid. Distributed new energy with intermittent and random output is connected in the distribution network on a large scale, which further increases the uncertainty of power supply and further reduces the measurable degree, thereby bringing new challenges to the regulation and management of the distribution network. With the new changes in supply and demand, the demand for smart distribution network in the future is getting stronger and stronger.

To build a smart distribution network is to build a new logic and new direction for the evolution and development of distribution network. The function of distribution network is no longer limited to meet the electricity demand of users, but also to meet the all-round needs of users for sale. As the micro-grid, integrated energy system, virtual power plant and other local power units can achieve regional self-balancing play an increasingly important role in power supply, the value of power grid will develop from the original power supply to the direction of power supply guarantee and power regulation, and the future development of distribution network and the index system guiding the development of distribution network will achieve greater results.

2. Evolution path of distribution network in developed countries

There are three main driving factors in distribution network development in developed countries, namely, technological innovation driving factors, ecological environment driving factors and economic and social driving factors. Emerging technologies of informationization, intelligence and digitalization represented by artificial intelligence, quantum communication, mobile communication, Internet of Things and blockchain connect supply side, demand side, energy storage and intelligent response, thereby shifting power users in the power industry from simple users to "producers and consumers", and urging them to participate in the interaction of power network more actively. With the development of energy and power approaching the boundary of ecological environment carrying capacity, over 120 countries and regions around the world have put forward the goal of carbon neutrality. A large number of distributed power sources such as distributed solar energy and wind energy, as well as new energy-using equipment such as electric vehicles and energy storage, are connected to the power grid, which promotes the distribution network to be active, localized, synergistic, market-oriented and intelligent; with the modernization of society and the change of production technology and lifestyle, electricity is becoming the main energy of various industries, and its connection with economic and social development is becoming more and more profound. The demand for economic and social development has also become the main driving factor for the development of distribution network in developed countries.

2.1 Europe

The wide access of distributed new energy in Europe and the significant changes in load forms such as electric vehicles and energy storage have provided great power for the transformation and development of its distribution network, and its mature power market mechanism offers market-oriented regulation. Subsidy incentives also exist in the early stage of new energy development in Europe, but with the gradual evolution of subsidy mechanism, the electricity market becomes more mature, and the degree of renewable energy participation in the electricity market in European countries is getting higher and higher. At present, the European medium-and long-term market, spot market and balanced market coordinate with each other to cope with the impact of wind power and photovoltaic volatility on the power network [2-3]. Meanwhile, Europe's efficient interconnected power grid is linked to the unified power market, and cross-border transmission is convenient. Renewable energy can be allocated in a wider range, and the relationship between supply and demand can be flexibly adjusted.

In order to better promote the development of distributed renewable energy, Europe also proposed to build a widely interconnected low-voltage microgrid group to realize inter-regional energy allocation, and Germany planned to build a honeycomb-type widely interconnected low-voltage microgrid group in the future. Energy interaction and interconnection are realized between honeycombs through medium-voltage distribution network. Based on the cooperative control within and between honeycombs, the energy management system can realize efficient and reliable utilization and consumption of renewable energy, providing the possibility for energy to completely replace fossil energy.

2.2 United States

Different from Europe's vigorous development of clean energy, the United States has gone through several disputes between "traditional energy" and "clean energy" in energy policy. During the Obama administration, the *Clean Power Plan* was signed, while the Trump administration directly announced its withdrawal from the Paris Agreement, pushed traditional fossil energy and improved energy efficiency, took the "energy-led" route, and took a negative attitude towards clean energy development. The Biden administration announced its return to the Paris Agreement, proposing to cut carbon emissions by at least half by 2030 and achieve its goal of net zero emissions by 2050. In order to achieve this goal, the Biden administration announced a USD2 trillion "new infrastructure plan", including allocating USD 174 billion for the transformation to electric vehicles.

The development of the American distribution system focuses on intelligent management of load side, emphasizing the integration of distribution network, communication and information technology. Its purpose is to stimulate the energy of technological innovation in the whole society, mobilize the third party except public utility managers and consumers to participate in the construction and operation of the smart distribution system, create new market value through information solutions, replace and delay the use of new equipment by information technology, and realize the allocation of assets and the integration of traditional equipment with its very high performance-price ratio. This kind of information solution will cross the boundaries of public infrastructure enterprises, and make a fundamental change in the integration mode between distribution system operators and power consumers. It is hoped that smart distribution systems can provide an incentive environment to promote cooperation between electricity consumers and third-party assets, and use grid facilities to control costs and improve the reliability of power supply. By sharing the data information of power grid in real time, and using high-speed, advanced distributed control and e-commerce to achieve real-time data interaction, users can change the power consumption pattern anytime and anywhere and then intervene in the operation of the power grid, improve the asset utilization rate of the system, achieve the goal of energy saving and emission reduction, and provide a profitable opportunity and platform for realizing the cooperation between supply and demand of power. The demand response resource capacity of the United States in 2017 was 31.508 million KW, Accounting for about 4.2% of the maximum load. Major market-oriented power grid operators conducted load shedding through emergency demand response projects and solved the problem that the market price of electricity reaches the prescribed upper limit or the reserve capacity of the system is insufficient, realize the safe and stable support of the power grid, or call energy storage and all kinds of users during noon to participate in peak shaving and frequency modulation services through valley filling demand response, thus improving the utilization efficiency of photovoltaic power generation [4].

The United States is actively developing the construction of distributed renewable energy microgrid integrating fossil fuel power generation. Microgrid demonstration projects in the United States are widely distributed in regions, diversified in investment subjects, diverse in structure and rich in application scenarios, which are mainly used to integrate renewable distributed energy, improve power supply reliability and provide support services for power grids as a controllable unit. Since 2008, nine microgrid demonstration projects have been built in five years, distributed in eight States. By integrated management of distributed energy in microgrid, the peak load of distribution feeder or substation can be reduced by at least 15%, thus reducing the capacity of distribution equipment by about 25% and the capacity of power generation equipment by 10%. In 2010, the U.S. Department of Energy and General Electric jointly invested about USD4 million to develop a microgrid energy management system, which provides a unified control, protection and energy management platform for devices in the microgrid, and coordinates the control of interconnected components in the microgrid to achieve the highest operating efficiency and minimize operating costs. In 2019, 546 new microgrid projects were deployed in the United States, setting a new record for the annual installation of microgrids. Distributed fossil fuel power generation accounted for 86% of the microgrid in the United States. In 2020, the U.S. Department of Energy proposed in its microgrid goal that the cost of developing a commercial mode (the installed capacity of microgrid does not exceed 10MW) is competitive compared with the non-integrated mode (UPS power supply plus diesel generator mode), and put forward specific goals: ① Reduce the load outage time by 98%; ② Reduce carbon emissions by 20%; ③Enhance system energy efficiency by 20% [5-6].

3. China's demand for building a future smart distribution network

development of distribution network is directly related to China's future power production and consumption mode, and needs to meet the national regional development strategy, rural revitalization strategy, "Carbon peaks & Carbon neutrality" goal and the construction of new power network.

3.1 Demands of regional development strategies

Improving the comprehensive utilization efficiency of energy is the inherent requirement of promoting the optimization and adjustment of regional industrial structure. The structural problems of China's industry bias and energy consumption bias towards coal have not been fundamentally changed. In the new mechanism of regional coordinated development, ecological environment co-protection and governance, industrial innovation synergy and so on, it is urgent to adhere to the dual control degree of total energy consumption and intensity, upgrade high-efficiency and energy-saving equipment in traditional industries such as energy, develop energy efficient utilization technologies, develop circular economy and adjust industrial structure. Meanwhile, efforts should be made to deepen the supply-side structural reform, eliminate backward production capacity with high energy consumption and low efficiency, enhance the added value of industries, improve the overall optimal allocation of energy and resource utilization efficiency, improve the green and low-carbon production and lifestyle, make the urban and rural environment more beautiful and livable, and promote the modernization, greening and intelligence of urban construction.

Stimulating green, low-carbon, new industries and new formats is a vital engine to drive the vitality of regional economic development. China is faced with the problems of poor industrial structure, slow growth of new kinetic energy and insufficient development vitality. Further develop and build a new power network with new energy as the main body, build a smart distribution network in the future, and promote the coordinated development of energy internet such as solar energy, wind energy, hydrogen energy, microgrid and multi-energy complementarity with smart cities and parks, which will provide powerful new kinetic energy for regional economic development [7].

Continuously improving the power supply service capacity is a crucial business card to build the comprehensive competitiveness of regional development. Electric power industry is not only the basic industry of national economy, but also a public utility with wide influence. Optimizing the electric power business environment can stimulate the vitality of market players, increase convenience for the people and give full play to the multiplier effect. Under the background of "carbon peaking and carbon neutrality ", it is urgent to adhere to the development concept of circular economy and green environmental protection, use energy technology, information technology and digital technology to promote the digital transformation of marketing, innovate the operation mode of service channels, actively explore new business models such as energy efficiency monitoring and analysis, energy custody and customer-side energy storage, continuously optimize the power business environment, and create a good platform for the optimization and upgrading of regional industries and coordinated development.

3.2 Demands of rural revitalization

Promoting rural electrification is a powerful means to build a modern rural industrial system. The rural revitalization strategy expresses the needs to promote the revitalization of rural industries and promote the integration and development of rural industries, and proposes higher requirements for the power grid to help build a modern rural industrial system. The power grid should empower the development of rural industries, promote the construction of all-electric agricultural products processing, use electricity as energy in cooking, heating, lighting, refrigeration and hot water supply, install energy efficiency monitoring and smart home control equipment, promote the construction of all-electric homestays integrating accommodation, catering, leisure and entertainment, and realize the full coverage of smart electric homestays in the whole village [8]. Electrification is adopted to promote industrial integration, such as electrification transformation of agricultural greenhouses, construction of high-matching multi-span arch sheds, and addition of internal and external sunshade, wet curtain fan cooling, rollover window ventilation and other systems. Environment-aware IoT equipment is deployed to monitor and collect measurement data in real time, and upload them to the smart energy management platform through the edge IoT agent final, so as to accelerate the transformation of functions, formats and mechanisms of rural industries, promote the development of characteristic industries, cultivate new service industries, enhance the integration of primary, secondary and tertiary industries, and help rural revitalization.

Accelerating the development of distributed energy is the inherent requirement of helping to build a modern rural energy system. The rural revitalization strategy clearly requires that efforts should be made to build a clean, low-carbon, safe and efficient rural modern energy system, and promote the continuous upgrading of rural energy consumption, production and resource utilization. The power grid should improve the access level of new energy, enhance the consumption capacity of new energy in rural areas, convert waste into renewable energy for residents' life, production and operation, form a rural modern energy system with coordinated development of biomass energy, solar energy and electric energy, encourage and accelerate the development of new energy sources such as wind power and photovoltaics, comply with rural energy demands, solve the problem of local consumption, and realize the benefits of rural new energy, and address the problem of unbalanced and insufficient development of clean energy in rural areas.

Strengthening the construction of rural power supply service capacity is an inevitable requirement to improve the happiness of rural residents. The rural revitalization strategy stresses that it is necessary to improve the system and mechanism of urban-rural integration development, deepen the reform of agriculture and rural areas, establish and improve the policy system of equal exchange and two-way flow of urban and rural elements, promote more flow of elements to rural areas, and enhance the vitality of agricultural and rural development. Power supply service is to meet the practical needs of new power supply users in rural and urban areas, provide power services considering economic differences and reliability differences, monitor the mode and status of energy operation, ensure safe supply, and conduct intelligent regulation and control to provide scientific decision support for users' refined energy demand, guide users to integrate load resources and effectively participate in peak shaving, frequency modulation and standby of power grid, provide a platform for flexible loads such as electric vehicles to effectively interact with power grid, and provide personalized, intelligent and interactive energy service.

3.3 Demand of implementing "Carbon peaks & Carbon neutrality" to build a new power network

To achieve the goal of "Carbon peaks & Carbon neutrality", measures should be taken to speed up the construction of a new power network. According to the goal, combined with the preliminary arrangement of relevant state departments, the installed capacity increment from 2020 to 2030 is mainly non-fossil energy power generation. Due to the phenomenon of "large installed capacity and small power consumption" of new energy installed capacity, in order to ensure the safety of power supply, the installed capacity of coal power and gas power still sees certain growth, and the energy storage scale is rapidly increased. Driven by the demand for renewable energy with a high penetration rate, a high proportion of power electronic equipment and a high-speed growth of multiple loads, distributed microgrid and micro-energy network should be developed in a coordinated manner, so as to consume and utilize new energy with the lowest cost, maximum strength and highest efficiency.

The safe and reliable operation of urban energy requires that energy development will be shifted to centralized production and extensive access to distributed resources. According to the natural endowment of urban resources and the temporal and spatial characteristics of load, new energy is either developed centrally on a large scale at the sending end and transported to the urban load center at a long distance, or developed locally and distributed in the urban load center and directly transported to the final users. Centralized development will depend on the transmission capacity of large power grids, which requires large power grids to have higher flexibility and support capacity for new energy sources. Wide access to distributed resources will depend on the innovation of the urban distribution system. The urban distribution system will no longer be the traditional passive system with radial and unidirectional power flow. Instead, it is transformed into a "power exchange system" integrating power collection, power transmission, power storage and power distribution, and small power networks in a single area can operate on isolated islands or interconnect, which has an impact on the structure and safe operation of the whole urban distribution system.

Improving the consumption capacity of distributed resources requires the wide application of energy storage technology on the load side of source network. With the development and improvement of various energy storage technologies, the application scenarios of energy storage technologies will be more extensive. In the future, smart distribution network needs large-scale allocation of network-side energy storage to effectively solve the contradiction between the limitation of traditional expansion mode and the increasing load demand, and further improve the utilization rate of network resources and facilities; meet the large-scale configuration of load-side energy storage, effectively improve the ability of distributed energy access and accident response on the user side, further improve the reliability of power supply, and meet the power quality requirements.

4. Functional orientation of the future smart distribution network

4.1 Functions of future smart distribution network

Both the new power network and the energy Internet are specific requirements for the allocation of energy resources. The construction of the new power network and the transformation of the energy Internet have the same goal and come down in one continuous line. In essence, the function and role of the power grid have undergone qualitative changes, from the previous value concentrated in power supply to the value of capacity reserve, resource regulation and platform advantages to provide more diversified services.

The function of distribution network will give more prominence to capacity reserve. With the development of new energy power supply in a centralized and distributed way, the form of distribution network gradually extends to micro-grid to achieve local balance and large grid to share the role of power service. The regional power self-balance is realized by using technical means such as integration of load and storage of source network and microgrid. First, efforts should be made to effectively reduce the peak shaving pressure of the main network, and use limited regulation resources to achieve higher voltage level, resource allocation and supply and demand balance between more networks; second, in terms of system efficiency, measures should be taken to reduce the long-distance transmission of electric energy and improve system efficiency; third, when the security risks such as frequent extreme weather increase, the power supply capacity to users can be further guaranteed when the main network is impacted. The reserve value of the main network is more reflected in the guarantee and bottom-up function under extreme circumstances and shortage of supply and demand.

The value of distribution network expands towards platform digitalization. With the change of power grid form, new market players such as virtual power plants, load aggregators and microgrid operators will also appear in large numbers. The value of power grid will not only be reflected in energy transmission and control, but also be further highlighted under the new model and new format, including commercial values including enterprise cultivation, technical services, technical consultation and management consultation. The power grid may even runs through the demand of the whole link of the distribution and storage industry chain. Decentralized and marginalized subjects will further realize the observability of the system through the information distribution of the power grid, and the value of data and value-added services based on data drive will increase rapidly. The platform and digital services of the power grid will meet the needs of different subjects in transaction cooperation, operation and management, etc.

4.2 Main positioning of future smart distribution network

Compared with the traditional distribution network, the future smart distribution network has obvious changes in target constraints, system boundaries and supply and demand balance, which will become the main difference from the traditional distribution network. In terms of target constraints, security constraints are the main ones, and diversified constraints of security, economy and environment are changed. Moreover, security constraints and environmental constraints are more rigid, and economic constraints are both the target and the focus of market-oriented means. In terms of system boundary, it changes from relying on high-voltage power transmission to relying on unstable energy resources which are almost difficult to produce and control, such as wind and light, and becomes more dependent on meteorological conditions such as light, temperature and wind speed, and the boundary of energy system extends to resources and environment. In terms of supply and demand balance, the power balance mode has changed from passively relying on main network resources to actively using distributed generation, energy storage and adjustable load to participate in system balance; from unified centralized balance to decentralized autonomous balance of microgrid, park and building.

Future virtual power plants, park (residential) integrated energy systems and grid-connected microgrid will be the main scenarios of future distribution network. In the virtual power plant scene, business entities can realize the coordination and optimization among distributed photovoltaic, energy storage, controllable load and charging piles within their business scope, and realize certain energy interaction functions. They can participate in the operation and transaction of future smart distribution network through the market, and the future smart distribution network is their main transaction object and the main service provider to ensure their standby security and technical consultation and management consultation. The comprehensive energy system of the park can realize the local consumption balance of the park (residential area) by using the nearby local energy resources, and meet the comprehensive energy demand of a certain production and living range; meet the production and living needs through the complementary attributes of multiple energy and the coordination and complementarity among electricity, gas, cold, heat and hydrogen. It has certain energy self-balance and self-sustaining ability, and mainly exchanges energy with the future smart distribution network. In the future, smart distribution network can supply power to users and provide technical services in the form of grid-connected microgrid, and use distributed power supply and energy storage to have certain regional self-balancing capability.

5. Evaluation index of future smart distribution network

5.1 Main characteristics of future smart distribution network

Facing more abundant market players, smart distribution network in the future needs to connect more power service providers, meet users' diversified energy needs and experiences through more service providers, and guide clean and low-carbon energy consumption. It will also be an important physical carrier to realize inclusive services, and its main features will be safety, high efficiency, green and low carbon, interaction and openness, and value sharing.

1. Safe and efficient

The safety and efficiency of smart distribution network in the future are mirrored in its regional power self-balancing capability, flexible grid structure. It mainly utilizes nearby and local energy, which is the economy of using energy first. Through the scientific and reasonable standby of public power grid, safety and reliability can be improved.

2. Green and low carbon

The green and low carbon of the future smart distribution network is reflected in being more friendly to new energy sources. It has a stronger carrying capacity for distributed new energy, which is mirrored in its stronger adaptability to the energy consumption mode based on electricity, and stronger access ability to new power facilities such as charging piles for electric vehicles, which can meet the ever-increasing variety of power consumption and the ever-increasing power consumption and load growth.

3. Interactive and open

The interactive and open nature of the future smart distribution network is reflected in the fact that more power service providers can flexibly and freely access the future smart distribution network and flow energy and information through the distribution network

4. Value sharing

The value sharing of the future smart distribution network is reflected in the sharing of the value created by power safety and efficiency among network operation, individual market entities and users, so as to realize the transmission and sharing of value chain in more links. Users and service providers can obtain corresponding benefits by participating in the interaction with future smart distribution network.

5.2 Future smart distribution network index system

According to the main characteristics of the future smart distribution network, the corresponding index systems are set respectively. According to the index system shown in Table 1, specific targets are put forward.

The transmission and transformation capacity exceeding 40% of the maximum load can be called the reserve capacity of the network with regional self-balancing capability, and the newly added reserve capacity per unit asset refers to the ratio of the newly added reserve capacity and the investment amount provided by the public network for the network with regional self-balancing capability.

Power self-balancing capacity refers to the percentage of the maximum load received by the local power grid from the superior power grid to the maximum load consumed by users in the local power grid.

Average power outage time per household refers to the cumulative number of power outage times per household divided by the total number of power supply households = Σ (time per power outage × number of users per power outage)/total number of power supply users.

The proportion of clean electricity refers to the proportion of clean electricity traded by users in the local power grid in the total consumption of electricity.

Distributed new energy carrying capacity refers to the installed capacity of new energy whose maximum new energy output does not exceed the capacity of local power grid.

The growth rate of average household electricity consumption refers to the ratio of total electricity consumption to total households in local power grid and the difference between the same period of last year and the value of the same period of last year.

The index of getting electricity has the same meaning as the World Bank.

Power service providers sell electricity. In a certain area, the electricity obtained by power users from power service providers accounts for the proportion of total electricity consumption.

The proportion of value-added services refers to the percentage of market-oriented income other than electricity sales income of power service providers or power grid enterprises in total operating income.

The income of final power users refers to the income obtained by final power users who do not engage in wholesale and retail of electricity from participating in electricity market transactions or demand response.

Customer service satisfaction refers to the number of users who are very satisfied with the power service provider, which accounts for the proportion of the total number of users.

Table 1 Index System of Future Smart Distribution Network

Level 1 index	Level 2 index
Safe and efficient	New reserve capacity per unit asset
	Power self-balancing capability
	Average outage time per household
Green and low carbon	Specific gravity of clean electricity
	Distributed new energy carrying capacity
	Growth rate of electricity consumption per household
Interactive and open	Obtain power index
	Distribution automation rate
	Electricity sold by power service providers
Value sharing	Proportion of value-added service charges
	Revenue of final power users
	Customer service satisfaction

6. Conclusion

The development of energy and power is facing new situations and challenges that support the simultaneous development of energy structure transformation and economic structure transformation. This paper probed into the development direction of smart distribution network construction in the future, proposed that the function of distribution network should change from the original single power supply to providing safe standby and system regulation, and the value of distribution network should show more platform-based business value, so as to meet the needs of regional economic development, rural revitalization and "Carbon peaks & Carbon neutrality" and speed up the construction of a new power network. According to the development of distribution network, the future smart distribution network will have the main basic characteristics of safe and efficient, green and low carbon, interactive and open, and value sharing. According to these basic characteristics, the evaluation system of future smart distribution network was put forward.

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