New situation and countermeasures for power grid safety under the background of new power system construction

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Abstract. The new power system is an important carrier for building a new energy system and serving the "dual carbon". The power grid is a hub platform for energy conversion, utilization, transmission configuration, and supply-demand docking, and is a key link in building a new power system. A profound understanding of the development characteristics of the new power system is of great significance for grasping the changes in the essential features of safety management. The new power system has undergone significant changes in terms of power generation, user side, and overall system characteristics, posing many challenges to the supply and demand, network, and institutional mechanisms of security governance. It is necessary to pay attention to sufficient power supply, strengthen network security guarantees, establish and improve relevant institutional standards, and ensure high-quality economic and social development with high-level security.

1. Foreword

Carrying out green energy transformation, implementing clean energy power substitution and supply, and developing new power systems are the main driving forces for achieving China's carbon peak and carbon neutrality strategic goals[1]. Building a new power system with new energy as the mainstay is the foundation, key, and core to achieving carbon peak and carbon neutrality. Structurally, the new power system is a system dominated by new energy sources; From the perspective of links, the new power system is an integrated and coordinated system of "source grid load storage intelligence"; From a morphological perspective, the new power system is a system that deeply integrates large systems, distributed systems (microsystems), and develops together; From a governance perspective, the new power system is an open system that integrates and promotes marketization and rule of law; From a characteristic perspective, the new power system is a safe and controllable, economically efficient, green and low-carbon, open and shared, and digitally intelligent system.

The new power system has undergone profound changes in its own structure and characteristics, and is highly interactive with external systems to form a complex giant system form. The main contradiction of its safety issues has gradually evolved from system stability to diversified issues including power production, system operation, equipment safety, and unconventional event response.

2. Analysis of characteristics of new power system

The new power system is an important carrier for building a new energy system and serving the "dual carbon" goals, and it is an important task that the power industry shoulders.

From the perspective of power generation, new energy will gradually become the main source of installed capacity and electricity. In 2023, State Grid Corporation of China's operating area will add 220 million kilowatts of wind and solar new energy installed capacity. It is expected that by 2030, wind power, solar power and other new energy installed capacity will surpass coal-fired power and become the largest power source; By 2060, the proportion of electricity generation is expected to exceed 50%, becoming the main source of electricity. The high proportion of new energy has more obvious characteristics of randomness, intermittency, and volatility, and the "tidal" operation of the power system has become the norm, which puts higher demands on system regulation and power supply.

From the perspective of users, terminal energy consumption is highly electrified and there will be a large number of electricity "producers and consumers" emerging. It is expected that the electrification level of terminal energy consumption in China will increase to around 35% and 70% by 2030 and 2060. With the rapid development of diversified loads and energy storage, many electricity users are both consumers and producers of electricity. It is expected that by 2060, the adjustable

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load scale will reach 15% of the maximum electricity load of the power grid. It is necessary to further mobilize the potential of load side regulation to support the safe and stable operation of the system.

From the perspective of the power grid, the development of the power grid will form a pattern dominated by the large power grid and the coexistence of multiple power grid forms. The AC/DC hybrid power grid remains the dominant force in optimizing the allocation of energy resources. At the same time, microgrids, distributed energy, energy storage, and local DC power grids will develop rapidly, and will be interconnected, complementary, symbiotic, and coordinated with the power grid. The increasingly complex structure of the power grid makes fault prevention difficult, and higher requirements are put forward for the grid's new energy consumption capacity, multi DC input capacity, and transmission and distribution network coordination ability.

From the perspective of the overall system, the operating mechanism and balance mode of the power system will undergo profound changes. The power system will transition from a mechanical electromagnetic system dominated by synchronous generators to a hybrid system dominated by power electronic devices and synchronous machines. It will gradually shift from real-time balance of source and load to incomplete real-time balance of source grid load storage interaction. It is urgent to rebuild the cognitive, control, and fault defense technology system.

3. Analysis of security risk situation

3.1. Extreme climate change exacerbates supply-demand imbalance

Under climate change, the uncertainty of source and load has increased, and the lack of weak power support capacity for safe and reliable alternative foundations after the sharp decline in new energy generation output has further worsened the balance of power supply and demand. The large-scale grid connection of intermittent renewable energy power will pose a threat to the power system's ability to maintain peak shaving, stable power supply, and safe operation[2]. Under weather conditions such as cold waves, extreme heat, and extreme drought, the output of new energy and fuel supply are severely affected[3]. Coupled with factors such as unexpected load growth, supply security is facing greater threats, which can easily lead to supply-demand imbalances and result in large-scale power rationing or wheel shutdowns. For example, the "2.15" power outage in Texas, USA in 2021 resulted in a significant increase in electricity load due to extreme cold wave weather[4]. Conventional units, mainly powered by gas, experienced a decrease in output due to a shortage of primary energy. At the same time, due to low wind speeds and freezing conditions, the average output of wind power with an installed capacity of 25 gigawatts was less than 4 gigawatts, causing a power shortage. The "8.28" power outage in Brazil in 2013 resulted in continuous drought in the northeast region, which was in a state of power shortage. After the system was disconnected, the supply-demand imbalance was exacerbated, leading to almost complete load stoppage in the northeast. Moreover, climate risks may bring greater uncertainty to the energy market, and severe fluctuations in the energy market can have profound impacts on the real economy[5].

With the deepening of energy transformation, the proportion of renewable energy continues to increase, and the output of hydropower and new energy is highly correlated with meteorological factors, leading to an increase in the instability and uncertainty of power supply. China's electricity demand presents a "double peak" feature in winter and summer, with the winter peak load in northern regions often approaching or exceeding the summer peak, resulting in high pressure to ensure supply during peak load periods.

3.2. The integration of various new entities poses severe challenges to network security protection

Intelligent terminals are widely used, and there is a risk of untrusted access for a large number of heterogeneous terminals. Each power grid has a larger number of heterogeneous intelligent interactive terminals, more ubiquitous network security protection boundaries, and more flexible and diverse business security access requirements. User terminals are at risk of information leakage, illegal access, and being controlled. The rapid development of national and group attack methods, the emergence of new network attack techniques, and the constant emergence of new attack methods such as ransomware and APT attacks have led to an increasing intensity of attack and defense. Combining artificial intelligence, social engineering, and other means to break through boundary protection measures and attack the internal systems of the power grid is becoming increasingly risky, posing a serious threat to traditional boundary protection systems. The weak security protection capability of external entities may lead to the control and destruction of the power monitoring system after network attacks, and in severe cases, it may cause the system to lose stability. The proportion of new energy and distributed power sources is increasing, and wind turbines can be remotely shut down. By breaking through a single wind turbine network, the entire wind farm can be controlled. The smart home business is developing rapidly, with billions of terminals of various types. There is a risk of illegal control of a massive number of smart home terminals, and starting and stopping at the same time will have a serious impact on the safe operation of the power system.

China is still in the stage of industrialization, and the demand for energy and electricity will continue to rise. There is still a strong coupling relationship between economic development and carbon emissions. It is necessary to explore a practical path that ensures the safe and reliable supply of energy and electricity while achieving carbon reduction under sustained and stable economic growth. At the same time, the power system presents the "dual high" characteristics of a high proportion of renewable energy and a high proportion of power electronic equipment. The system's moment of inertia continues to decrease, and its frequency and voltage regulation capabilities are insufficient, posing greater challenges to the safe operation of AC/DC hybrid power grids. In traditional power systems, ensuring power supply is mainly about ensuring the satisfaction of quantity. As long as the installed capacity is sufficient, fuel reserves are sufficient, and the power grid system operates stably, it can basically ensure the safe and reliable supply of power, such as ensuring sufficient coal production capacity, smooth coal transportation capacity, sufficient reserve capacity, and stable and full operation of units. However, under the conditions of the new power system, the guarantee of quantity alone is still far from enough. Due to the inherent defects of randomness, volatility, and intermittency in the output of new energy generation mainly based on wind and solar power, even with a large amount of installed capacity reserves, it is still necessary to estimate the actual power generation based on weather conditions. Therefore, traditional energy evaluation methods cannot be used to evaluate the power supply capacity under new power system conditions.

3.3. The interface and standards for safety management responsibilities in the new power system need to be improved

With the diversified development of new energy, new business models, and new businesses, existing laws and regulations cannot cover the needs of safe development, resulting in a lack of safety supervision, overstepping, and multiple supervision. Experts, scholars, and policy makers around the world are increasingly recognizing the intrinsic connection between energy transition and judicial issues[6]. Lack of safety supervision in equipment manufacturing, planning, construction, operation and maintenance of new energy, new business models, and new businesses such as offshore wind power and electrochemical energy storage. There are no specific regulations or constraints on the safety supervision responsibilities, interfaces, etc. of new energy, new business models, and new businesses in laws and regulations. It is necessary to supplement the safety responsibilities of new grid connected entities, improve the accident level standards, accident investigation, punishment standards, and other related requirements for new power systems. In addition, in recent years, with the diversification of investment entities, the construction of new energy generation facilities (such as photovoltaic power plants, wind power plants, garbage power plants, etc.) and energy storage power plants has experienced a surge. The diversification of investments at the same time has led to the diversification of equity and other situations, resulting in blurred boundaries of safety responsibility subjects, difficulties in dividing safety responsibility subjects, inadequate implementation of safety responsibility systems, and the emergence of ambiguous areas between safety responsibility and safety supervision, which urgently need to be improved.

4.Suggestions for relevant measures

4.1. Deepen the research and analysis of system characteristics, improve the research system and layout of security technology support technology

We should continue to conduct in-depth research in the fields of new energy power prediction, grid connection standards, simulation models, etc., master the operating mechanism, improve the new energy grid connection standards as soon as possible, require new energy to participate in system frequency and voltage regulation, and strengthen the management of new energy sub synchronous harmonics. Accelerate the special research on GIS, explosion prevention of large-scale oil filled equipment, and flexible DC network construction. Establish a normal research mechanism for fault mechanisms, deeply explore key technologies for improving reliability, and enhance the safe operation level of main equipment. Build a "panoramic perception, flexible control, intelligent interaction, main distribution coordination, safety and reliability, and lean management" distribution network scheduling and control system and technical architecture, strengthen the unified scheduling and management of distributed power sources, new energy storage, virtual power plants, etc., and incorporate distributed power sources into the balance of electricity and quantity. Accelerate the construction of a safe and reliable distribution communication network, achieving observability, measurability, adjustability, and controllability of the distribution network.

4.2. Coordinate the development of various power sources and strengthen the construction of supportive power supply systems in key areas in the near future

Adopting forms such as pumped storage, natural gas power generation, new energy storage, and coal-fired power according to local conditions, we will accelerate the construction of power sources, emergency backup, and peak shaving power sources in key cities and critical meteorological disaster zones. In areas with weak power grids, we will build microgrids that can operate independently under extreme conditions, improve the level of isolated grid operation, and expand transmission channels from energy rich areas to load center areas, forming an integrated open and multi energy complementary pattern to ensure sufficient power supply.

4.3. Strengthen the awareness of network security situation, enhance the breadth and depth of network security risk monitoring

The new power system is facing a more complex network environment, and strengthening network information security is currently of paramount importance. With the transformation of the smart grid model, higher requirements have been put forward for the security and interactivity of the power grid security situation protection system[7]. In view of the highly open, interactive and intelligent network characteristics of new business, we will strengthen the top-level design of information network security assurance, strengthen the "horizontal to the edge, vertical to the bottom" protection system, apply trusted computing technology to improve the security immunity of core hosts, optimize the architecture of power management information area and interconnection area, standardize the compliance process of processing links such as collection, release, circulation and sharing, strengthen data and information security defense, and continue to consolidate the network defense in depth of the new power system.

4.4. Establish a power safety standard system with mandatory standards as the main body and recommended standards as supplements

Represented by the new energy active network construction technology group, we will promote the construction of relevant standard systems, promote system integration at lower costs, and play a good role in technology sourcing. Strengthen the top-level design of the construction of new power system standards, improve the safety regulations of new grid connected entities, coordinate the revision of standards and specifications for planning and construction, grid connection, stable operation, network security, emergency capabilities, etc., strengthen the rigid constraints of new entities, and guide various entities to construct and operate according to standards. Adapt to the stable technical standard system of the new power system, enhance the level of autonomy and controllability, and lead the construction of the new power system with innovation.

4.5. Promote the construction of emergency power capacity and strengthen the ability to restore power system operation in extreme emergencies

In the current and future period, traditional power sources are still needed as flexible resources, fundamental guarantee power sources, and emergency guarantee power sources. Only by ensuring the safe and stable supply of the system can a new type of power system be gradually constructed.

Adhere to the equal emphasis on "defense, emergency response, and recovery", improve the emergency response system for pre disaster prevention, disaster warning, emergency response, repair command, and resource allocation, strengthen resource sharing with government departments such as meteorology, water conservancy, and natural resources, explore natural disaster monitoring and forecasting based on the power grid and its operational risks, equipment and its defense capabilities, and users and their guarantee capabilities, construct a power grid meteorological prediction and warning service system, improve the ability to predict and warn of local microclimate and other disaster situations, improve the regional disaster prevention and reduction work mechanism, carry out regular special emergency drills, evaluate the adaptability and pertinence of emergency plans, and dynamically revise plans. According to the different characteristics of disasters, set up several preset points for easy repair in vulnerable areas and around vulnerable users in advance, arrange emergency teams, materials Emergency power generation vehicles, mobile emergency communication systems, and other rescue equipment are deployed in advance to implement precise prevention measures for key areas and targets.

5. Conclusion

The construction of a new power system is a complex and systematic project, which should focus on ensuring energy security, promoting green transformation, adhering to a system concept, strengthening technological innovation, and leveraging the role of the market. The government, society, and energy enterprises should work together, and all links of the power grid, load, and storage should work together. Profoundly grasping the changing laws and governance strategies of security management in terms of supply-demand balance, network security, and institutional mechanisms is the current priority for promoting the steady and orderly development of the new power system.

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