The Key technologies for the construction of resilient distribution networks under the background of smart grids

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Abstract: When the power grid faces sudden extreme events, large-scale blackouts have caused huge economic losses. At the same time, under the development of smart grid, the research of resilient distribution network has received more extensive attention. This article introduces the connotations and concepts of resilient distribution networks in the context of smart grids, and expands the connotations of resilient grids. In addition to the resilience of physical strength under extreme disasters, it also proposes market resilience under the laws of market economy and normal operation mode. This article also introduces several key technologies for improving the resilience of power grids, including intelligent self-sensing power reserve system, adjustable flexible load, source-grid-load-storage coordinated control system, online intelligent diagnosis of power cables, and Operation and maintenance, describes the principles and functions of these technologies in building resilient power grids. The article describes from the perspectives of prevention before disasters and recovery when disasters occur.

1. Introduction

The development of human civilization is the development of high energy consumption. The energy structure changes drastically. Human activities have brought huge impacts on the environment and climate. In recent years, extreme natural disasters have occurred frequently. The existing power distribution network failed to take into account the operating conditions under harsh conditions in the early stage of construction. At the same time, the role of users in the power grid is becoming more and more complex. Resilience building has received wider attention. Power system resilience refers to whether the power grid can reduce the loss during the failure process and return to the normal power supply state as soon as possible in the case of a major disaster (such as hurricane, earthquake). The resilient grid in the context of intelligence should be a grid that can actively respond to disasters to ensure critical loads and restore the system to normal functions as soon as possible.

2. Intelligent self-sensing energy storage and power backup system

2.1. Intelligent self-sensing power reserve system

The smart energy storage backup system relies on the development of energy storage technology, unified information platform development, and renewable energy access equipment hardware system[1]. The intelligent energy storage and backup system includes energy storage technology,
intelligent transmission and distribution technology, and online operation and maintenance technology. It uses cloud platform for online detection and monitoring to collect battery data and load data, and uses big data algorithms, genetic algorithms and other algorithms to analyze and process the data to realize the self-learning and prediction of the system, thereby adjusting the charging and discharging of the battery and the state of backup power, so as to extend the life of the battery, improve safety and economy.

2.2. The role of smart energy storage and backup systems on resilient grids

2.2.1. The intelligent power reserve system increases the stability of the power grid
Energy storage promotes the consumption of distributed renewable new energy. The energy crisis and environmental situation have promoted the vigorous development of new energy. The massive access of distributed energy has threatened the stable operation of the power grid. The intelligent power reserve system compensates for the volatility of renewable energy. It can be stored at the peak of power generation and compensated for discharge at the valley. This can increase the utilization rate of renewable energy from 30% to 60%[2]. The existence of the intelligent power reserve system also improves the high voltage and low voltage ride-through capabilities of wind turbines and solar generators, protects the safe operation of the units, improves power generation efficiency and power quality, and increases the resilience of the grid.

2.2.2. Intelligent power reserve system improves grid power quality
The system can dynamically respond to the load of the grid, participate in peak regulation, reduce the capacity increase pressure of the grid during peak hours, and the intelligent reserve power system can also provide stable reactive power, and can restore the voltage in the event of a disaster, thereby increasing the resilience of the grid. The inverter of the system offsets the harmonics generated by the harmonic DG access through the compensation operation, thereby improving the power quality and ensuring the power supply balance of the system[3].

2.2.3. Intelligent power reserve system improves the stability of the power supply market
In recent years, with the drastic changes in decentralization and energy structure, the stable operation of the power grid is facing huge challenges, and the requirements for power supply stability are increasing year by year. For example, since 2020, the reliability rate of power supply in downtown Shanghai has achieved the "five nines" "(le more than 99.999%) breakthrough, reaching 99.9998%, which means that the actual use probability of standby power is extremely low[4]. On the grid side, the cost of investment in the power regulation market is getting higher and higher. Under the constraints of the market economy, the long-term stable operation of the power market needs to reach a new balance[5], and the activation of the standby power supply by the intelligent reserve power system is reduced. It reduces the cost of electricity and power auxiliary regulation, and improves market stability.

3. Source-network-dutch-storage friendly coordination and interaction system

3.1. The connotation definition of the source-network-dutch-storage friendly coordinated interaction system
The source-network-load-storage coordinated control system is such a system, which can realize the aggregation and coordination optimization of distributed generator (DG) energy storage system, controllable load, electric vehicle, etc. through advanced information and communication technology and software system, Can show external output power, participate in grid operation, provide auxiliary services, and participate in the control communication system of the power market[6]. The coordinated control system will be an information communication system that aggregates controllable distributed energy or active user networks in a direct centralized control manner. The system includes control
objects, on-site edge computing equipment, software cloud platforms, large power grids and important critical loads. The structure of the system is shown in Figure 1.

Source network load storage resilience plan

3.2. The mechanism of the source-grid-load-storage coordinated control system in improving grid resilience

In the context of smart grids, power grids have the characteristics of self-healing, toughness, stability, safety, diversification, environmental protection, and high efficiency and economy. The smart grid requires friendly interaction and coordination between source-grid-load-storage. In the event of a disaster, autonomy and load recovery can be done. The resilience of the power grid can be improved from four aspects: planning, prevention, restoration, and brittleness reinforcement. The effect of the coordinated control system on the resilient distribution network is mainly reflected in the restoration level. After an accident occurs, the system can use the source network load storage resources in the system to restore the outage load, forming a closed-loop autonomous network, quickly recovering important loads and reducing losses.

3.3. Key technologies for the development of source-network-load-storage coordinated control system

3.3.1. Multi-energy flow intelligent complementary Multi-energy flow intelligent complementary control technology

The control objects of the source-net-load-storage coordinated control system are complex and diverse. Energy Internet is the coupling of multiple energy networks, including complementary coordination and security control between network energy flows. Multi-energy flow intelligent complementary control technology is the key to realize the coordination and optimization of DER's high-demand power output system. This is also the focus and difficulty of the challenges faced by coordinated control.

At present, multi-energy flow complementary control technology mainly focuses on control strategy and control technology. Control strategy mainly refers to the optimal scheduling model and control model of multi-type energy generation; control technology mainly refers to non-traditional control strategy and control strategy based on digital signal processing[7]. Models include neural network control, predictive control, power grid self-healing automatic control technology, Internet remote control technology, fuzzy control technology, access port control technology, etc.
3.3.2. Smart Metering Cloud Big Data Analysis and Processing Technology
The AMI advanced metering architecture is the key to realizing smart information automation of the power grid. Smart metering technology is the basis for the source-grid-load-storage coordinated control system to monitor, operate and control DG and controllable loads[8]. Under the technical framework of the smart grid, cloud information processing technology will be organically combined with big data technology. Big data information processing technology can compare and analyze multiple users on the basis of accurate analysis of users' energy consumption habits, provide users with comprehensive energy utilization optimization schemes, and guide users to coordinate energy use. Cloud big data technology undertakes the functions of data aggregation, analysis, and transmission, and plays an important role in connecting various technical modules.

3.3.3. Information and Communication Technology and Internet of Things Technology
The core connotation of the source-network-load-storage coordinated control system is "aggregation coordination" and "communication" to achieve the effect of accumulating more. The source-network-load-storage coordinated control system aggregates a large number of DERs, and conducts real-time collection and operation management of electricity consumption information from the user side with fine management granularity. The operation of the source-network-load-storage coordinated control system includes the source-network-load-storage coordinated control system power trading platform, monitoring platform, operation management and regulation platform, etc. The operation of the entire system relies on information communication technology and Internet of Things technology. Support can ensure the smooth flow of information and business[9]. So as to achieve the balance of energy flow and realize the aggregation and deployment of electric energy on the load side. Big data can predict the situation of load and new energy, thereby increasing the data processing speed of the source-network-load-storage coordinated control system and improving the stability of system operation.

3.4. Summary
The source-grid-load-storage coordinated control system is a cloud-based control system. Its application scenario is the reformed market of the electricity market. It is still in the theoretical and demonstration application stage. There is no large-scale and mature market operation mode at home and abroad. The currently operating source-network-load-storage coordinated control system demonstration project has a small installed capacity, along with energy storage technology, multi-energy flow intelligent complementary control technology, smart metering cloud big data analysis and processing technology, information communication technology and the Internet of Things. With the development of technology, the application of large-scale source-grid-load-storage coordinated control system will play a greater role in new energy consumption, power grid controllable load regulation, and power grid peak and frequency modulation. Establishing a scientific market cooperation mechanism on the basis of game theory can realize the stable development and operation of the source-network-load-storage coordinated control system.

4. Intelligent diagnosis and intelligent operation and maintenance of power cables.

4.1. On-line monitoring and intelligent diagnosis of power cables
The guarantee of the critical load requires accurate monitoring and diagnosis of the power supply on the critical load side. By installing a power cable monitoring device with the ability to monitor partial discharge and ground current at the node, the fault condition of the cable is monitored, and the fault is reported and visualized. The detection system can make corresponding measures and treatment plans for the failure. The monitoring system should include three system levels, including the partial discharge monitoring subsystem, the high-voltage cable metal sheath circulation monitoring subsystem, analysis and diagnosis and safety early warning system.
4.2. Analysis, diagnosis and safety early warning system of power cable monitoring data flow
According to the partial discharge information and circulating current information of the distribution network, a model of the hidden dangers of the information to the cable safety is established, and the relevant indicators of the resilient distribution network are established. Analyze the laws of monitoring data and fit the characteristic values of power grid security and resilience. In this way, the state curve of the normal operation of the system is simulated, the corresponding warning boundaries and parameters are drawn, the actual monitoring data is compared with the expected curve and the constant virtual warning threshold, and the alarm and response strategies are made after a certain range of the threshold is exceeded. Perform in-depth learning on a large number of distribution network partial discharge and circulation monitoring data, further discover the characteristics of ensuring the resilience of the distribution network, and continuously optimize the algorithm for determining the expected curve and the constant virtual warning threshold.

4.3. Intelligent operation and maintenance
According to the monitoring data of the subsystem, the operation and maintenance platform provides the fault location, fault level, fault type, etc. of the system, and provides corresponding maintenance suggestions, predicts the consequences of the fault, and sets up solutions for different fault levels and fault conditions in advance, to guide the maintenance operations of offline operation and maintenance personnel. In this way, the number of offline on-site inspections by maintenance personnel is reduced, which not only reduces the labor costs of offline operation and maintenance, but also improves work efficiency. At the same time, it also promotes the construction of resilient grids and keeps pace with the development of new infrastructure and smart grids[11]. The intelligentization of energy and electricity is the direction of future grid construction, and the fault detection system will be the underlying support for the realization of smart grids.

4.4. Summary
The source-grid-load-storage coordinated control system is a cloud-based control system. Its application points to the reform of the electricity market. It is still in the stage of theory and demonstration applications. There is no large-scale and mature market operation mechanism at home and abroad. The coordinated control system demonstration project has a small capacity. With the development of energy storage technology, multi-energy flow intelligent complementary control technology, smart metering technology, information communication technology and Internet of Things technology, large-scale coordinated control system applications will be used in new energy consumption, to play a greater role in power grid peak and frequency modulation. Establishing a scientific market cooperation mechanism on the basis of game theory is the key to industrialization.

5. Conclusion
The resilient construction of smart grids requires the combination of smart energy storage and power backup systems, flexible adjustable loads, digital operation and maintenance, and source-grid-load-storage coordinated control systems, and unified management of on-site equipment through edge computing. When the power grid suffers a disaster, the detection system on the key node of the cable will work to automatically detect the disaster area and form a number of regional autonomous micro-grids. At this time, for areas not affected by the disaster, according to the state of the internal source network load storage, the external support and power released are calculated, and the microgrid control unit can provide power support to the paralyzed microgrid. The master control of the source-grid-load-storage coordinated control system calculates the power that can be released and the support that each microgrid in the area can provide, so as to evaluate the ability to restore power to the disaster-stricken grid. When the capacity exceeds the critical Load, the critical load of the disaster can be restored, which has the effect of quickly restoring the outage load. If the capacity is lower than the critical load, it will be restored according to the preset recovery level of the critical load to reduce losses and achieve the best effect.
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