Operation characteristics and key technology analysis of high-penetration renewable energy microgrid

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Abstract: With the increasing penetration rate, the strong intermittency and volatility of renewable energy, and the large-scale use of power electronic devices, the safe and stable operation of microgrids has been seriously affected. This paper analyzed the impact of high-penetration renewable energy on power system flow distribution, power quality, operating status, relay protection, etc. And specifically studied several specific keys to improve the operating stability of the microgrid including high-penetration renewable energy.

1. Introduction
Promoting the development of renewable energy is an inevitable way to satisfy human energy needs and live in harmony with nature. Chairman Xi Jinping emphasized at the 75th United Nations General Assembly: China's CO₂ emissions will strive to begin decrease before 2030, and strive to achieve carbon neutrality by 2060. This requirement will further promote the rapid development of renewable energy in China, and the penetration rate of renewable energy in the grid will also continue to increase.

Microgrid is an inevitable product of the development of renewable energy and distributed power sources. It is a way to efficiently use renewable energy [1]. It is composed of the distributed power supply, energy storage unit, load and control device based on certain topological structure of network, and connected to the grid through the switch devices, it can realize the effective management of all kinds of power source, and has the advantages of realizing the local consumption and nearby supply of renewable energy, improving the voltage of power network access point, reducing transmission line loss, delaying the investment of power network upgrade and expansion, and improving the reliability and economy of power supply for users. However, the power supply means, operation characteristics and fault characteristics of microgrid will be very different from the traditional power supply and distribution network. The access of micro-grid will have a great impact on power flow distribution, active/reactive power distribution, power quality and relay protection of the power grid. Especially as the penetration rate of renewable energy continues to increase, the impact on the safe and stable operation of the power grid will also increase [2-3]. Therefore, it is of great significance to study and analyze key technologies for stable operation of high-penetration renewable energy microgrids.

2. Impact of increased renewable energy penetration rate on system operation
At present, the overall penetration rate of renewable energy in China is low. The large-scale access of renewable energy has not fully exposed the impact of the traditional power generation, transmission, transformation and distribution system, and the state has formulated a series of measures to prevent the power grid shock and instability caused by the fluctuation and intermittency of renewable energy, such
as the proportion of renewable energy like photovoltaic and wind power connected to the power grid should be strictly set; wind power generation base implements wind and thermal power bundling policy, etc. [4] However, eventually, renewable energy will eventually replace traditional energy, and the penetration rate of renewable energy will continue to increase, which will have a serious impact on the safe and stable operation of the entire power grid.

2.1 Influence of current distribution
When the penetration rate is low, the output of renewable energy is less than the local load and is completely absorbed. The microgrid is equivalent to a pure energy-consuming load for the traditional grid, and energy always flows unidirectionally from the grid to the load. With the large-scale integration of renewable energy, the penetration rate continues to increase, and when the generated electric energy cannot be absorbed inside the microgrid, the microgrid is no longer a load for the traditional grid, and there is a two-way interaction with the power grid, which makes the traditional power grid change from the single power radiation mode to the multi-power network terminal mode [5], and affected by factors such as sunshine intensity and wind energy resources, the microgrid operation mode need to change frequently, which makes the power flow distribution of the power grid extremely complicated.

2.2 Influence of power quality

2.2.1 Influence of voltage. After the microgrid is connected to the power grid, the voltage at the grid connection point and nearby areas is not only affected by factors such as power source, load size and nature, transmission line impedance and distance, but also closely related to the operating status of the microgrid. The output status of distributed power sources such as photovoltaics and wind power are affected by factors such as wind speed, cloud obscuration, time and other factors, which have greater volatility and intermittent. When the penetration rate is low, and the electricity generated by the microgrid is greater than zero and less than the local load, the input power of the large grid to the grid connection point is reduced, which helps to improve the static stable voltage of the distribution network, but the grid connection point voltage will be slightly increased; when the penetration rate is high, the greater the reverse input power of the microgrid, the more easily the voltage at the access point is affected by the output of distributed power sources in the microgrid, resulting in larger waves, and overvoltage may occur [1]. To meet the requirements of different loads, the distributed power sources in the microgrid are often put into or separated from the large power grid, which can easily cause system voltage fluctuation and flicker. In addition, due to the small capacity of the microgrid itself, when its energy reserve is insufficient or the reactive power compensation cannot meet the system requirements, it will also cause voltage fluctuations and flicker [6].

2.2.2 Influence of frequency. The renewable energy power generation equipment in the microgrid is connected to the power grid (or diesel generator set) through power electronic conversion devices, and most of them do not have the primary frequency regulation capability. When the grid load is reduced, the inverter can maintain the grid voltage and frequency basically unchanged and quickly stabilized by limiting the power to be consistent with the grid, but when the load rate of the power grid increases or the renewable energy output fluctuates greatly due to weather changes, the grid frequency will produce large fluctuations, and the maximum amplitude of the fluctuations is directly related to the penetration rate. In addition, the operating status of renewable energy power generation equipment is affected by the control strategy and energy characteristics of the microgrid, and switching action often occurs, which may cause the frequency to exceed the limit of the grid [7].

2.2.3 Influence of harmonics. Harmonics are generated in the power system due to the existence of nonlinear loads. Harmonics have many hazards, such as reducing the transmission capacity of the line, increasing the loss of equipment such as transformers, accelerating the aging and damage of the equipment, causing the malfunction or refusal of the relay protection device, and interfering with the
communication equipment and lines. The development of microgrid and new energy power generation technology has largely benefited from the development of power electronic devices and technologies. Power electronic devices are typical non-linear loads and have been widely used in microgrids. In the microgrid, most of the renewable energy and energy storage loads are connected to the grid through power electronic converters; in addition to the device itself, the power electronic inverter can also generate harmonic current related to the carrier frequency and the switching frequency of the device in PWM (pulse width modulation) technology; in addition, distributed power sources such as photovoltaics and wind power are connected to the grid, and their output is affected by natural conditions, which are intermittent and fluctuating, and will also inject large fluctuating harmonics/interharmonics into the grid. It will increase the harmonic fluctuation and noise of the whole system. With the increase in penetration rate, the types of electronic and electronic devices and devices have become increasingly complex, making the grid topology and parameters become uncertain, the source and propagation characteristics of harmonics have become more complex, and the interference of harmonic analysis noise has become larger, which increases the difficulty of harmonic recognition and processing.

2.3 Influence of operating characteristics
In the high-penetration renewable energy microgrid, the intermittent, random and weak support characteristics of renewable energy output such as photovoltaic power generation and wind power generation are more prominent, and the power conversion, control strategy and dynamic characteristics of the distributed power supply based on the power electronic converter interface are quite different from those of the traditional AC synchronous generator, which have a great impact on the operation characteristics of the power grid. The key to the stability of the high-penetration microgrid system is the change of active and reactive power injected into the system during operation. Under disturbance action, the output frequency of traditional generators is determined by the rotor speed of the generator and is controlled by a governor; the amplitude of the output voltage is controlled by the excitation control system or adjusted by reactive power compensation. The output voltage and frequency of the power supply based on the power electronic converter interface is not directly related to the primary energy, and it depends on the power flow control strategy of the converter interface. On the other hand, when the distributed power supply based on the power electronic converter interface responds to load fluctuations, it is limited by the energy source and the DC side capacitor energy of the power electronic converter. The inertia is much smaller than that of the traditional rotating electrical machine. The barrier of the converter decouples the wind turbine from the electrical frequency, so that the renewable energy equipment presents a universal zero inertia or weak inertia. Therefore, in the case of large disturbances, for renewable energy that has weak tolerance to sudden changes in frequency and voltage and generally does not participate in the frequency and voltage regulation of the grid, it is prone to chain disconnection, forming a vicious circle, intensifying the sudden change, and causing serious shock damage to the system and even collapse. Finally, photovoltaic, wind, energy storage and other equipment are connected to the bus through the power electronic interface, which can achieve fast and flexible power control, resulting in large differences in transient time scales between power sources in the microgrid. Therefore, when the microgrid is externally disturbed, there are not only a microsecond-level electromagnetic transient process, but also a millisecond-level electromechanical transient process and a second to minute-level slow dynamic/medium-long-term dynamic process, making the microgrid dynamic characteristics very complicated.

2.4 Influence of relay protection
The integration of high-penetration renewable energy microgrids into the distribution network has changed the structure and trend of the power grid, and has greatly changed the operating characteristics and fault characteristics of the entire system, making the system protection face new challenges. The main reasons include: distribution. The output of renewable energy is intermittent and fluctuating, which increases the difficulty of protection setting. There are multiple power sources such as synchronous motor type, asynchronous motor type, and inverter type in the power grid, and their short-circuit currents...
vary greatly. The protection methods usually used are also different. For example, power electronic devices are limited by withstand voltage and overload capacity, and the short-circuit current is up to twice the rated current, which makes the fault detection method and protection principle based on the increase of current may fail; There are two-way short-circuit currents inside the power grid, and the equivalent power supply capacity on both sides of the fault is quite different. The fault current is related to the equivalent power supply capacity; the microgrid can operate in two modes of islanding and grid-connected, and often switch between these two modes, but the short-circuit current is quite different in these two modes; compared with the traditional power grid, the micro-grid has small capacity, low inertia, and high fault removal time requirements, and the two requirements are inconsistent; due to natural conditions and control strategies, renewable energy needs to switch frequently, so that the topology of the microgrid is also changing during operation [3] [13]. The above situation leads to the misoperation and rejection of the traditional "three-stage relay protection", which depends on the over current time limit, and the reliability of the system becomes lower.

3. Key technologies of high penetration microgrid

Safe and stable operation is the bottleneck for the development of high-penetration renewable energy microgrid systems. To adapt to the development of high-penetration renewable energy, the following key technologies should be focused on research.

3.1 Precise prediction technology

The root of the impact of renewable energy on the operation of the grid lies in the uncontrollability, intermittent and volatility of energy. If accurate forecasting of renewable energy and grid load can be achieved, the system control strategy and power electronics operating conditions can be adjusted in advance to reduce the impact of renewable energy and grid disturbances on the operating characteristics of the grid. At present, although many studies have been carried out at home and abroad, the overall prediction accuracy is 80% to 90%. To a certain extent, the forecast of the trend of renewable energy power changes, but the prediction of renewable energy fluctuations caused by atmospheric turbulence and cloud cover needs to be further improved in accuracy. In power forecasting, it is necessary to fully integrate economic and meteorological information, and use advanced big data processing methods to deeply analyze the changing laws and patterns of renewable energy, grid load, etc. to further improve the prediction accuracy [14], which is beneficial to the stable operation of power grid.

3.2 Reasonable configuration of energy storage technology

Energy storage equipment is an essential part of the future power grid. Reasonably configure energy storage methods and capacity for high-penetration renewable energy microgrids, and give full play to the role of energy storage equipment, which can effectively suppress and smooth the volatility and intermittency of renewable energy power generation, provide inertial reserves for the system, and improve system power schedulable, reactive voltage support and fault traversal capability. By combining with the grid-connected inverter, it can participate in the frequency and voltage regulation of the whole power grid, so that the anti-disturbance and stability of the power grid can be enhanced.

3.3 Demand side control technology

The load on the demand side of the power grid contains many temperature-controlled loads such as electric water heaters, refrigerators, air conditioners, and charging loads such as electric vehicles. Short-term slight changes in temperature or charging rate (period) will not affect the comfort and function of users, this kind of load is called controllable load or flexible load, this kind of load can participate in microgrid frequency adjustment. In Europe, controllable load accounts for about 30% of all electricity consumption [15], and this proportion will continue to rise with the increase of electric vehicles. With the development of smart grid technology, grid elements have become fully available, and user load types, capacity, and electricity usage rules have become public. It will be possible to introduce users to the electricity market in the next step, encourage users to participate in power demand response, and realize
the participation in the power grid frequency modulation through controllable load regulation, which has the advantages of large capacity, fast response speed and so on, thus improves the adjustment toughness of power grid.

3.4 Intelligent adaptive relay protection technology
Microgrid relay protection must not only achieve the reliability, selectivity, quick-action and sensitivity required by traditional relay protection, but also meet the requirements of adaptability, that is, the same set of protection strategies can adapt to the islanding and grid connection of the microgrid. It runs in two modes, and when the topology of the microgrid changes, the protection strategy will not fail. Micro grid has the characteristics of multiple operation modes and multiple operation state network structure changes, etc. The research mainly focuses on the intelligent algorithm relay protection system suitable for the current characteristics of micro grid, exploring how to effectively identify the network topology structure and operation state changes, and on the basis of fault feature model and real-time measurement data to explore suitable fault current calculation method, automatically adapt to the operation process of micro power grid structure and the change of the mode, automatic adjustment of related parameters of the protection device. Through the integration of multiple protection methods, centralized protection and local protection cooperate with each other\(^{[16]}\), focusing on special design for PCC points, microgrid buses, feeder lines, distributed power sources and loads. In addition, the existing relay protection devices were upgraded by adding intelligent auxiliary modules to meet the protection requirements of high-penetration micro-grids.

3.5 Modification of traditional generator control technology
Eventually, renewable energy will surely replace traditional fossil energy, but for a long period of time it must be a deep integration and complementary coexistence between these two. At present, in the face of the impact of the access of renewable energy, the main measures are to increase the redundancy factor of the installed capacity of renewable energy and supporting thermal power units. This will not be a long-term solution. Focusing on traditional thermal power units' peak shaving capacity, climbing speed and start-stop time, etc., upgrading the generator sets can improve the support capacity of the renewable energy power generation system, so as to enhance the anti-interference and fast recovery performance of the renewable energy connecting to the grid.

3.6 Planning and design and coordinated control technology of high-penetration renewable energy microgrid
In view of the multi-temporal and spatial distribution characteristics of high-permeability renewable energy and its impact on the grid, the strong intermittent and volatility of renewable energy output, and the large number of controllable load access characteristics, people still need to study the microgrid architecture and composition, distribution network form and structure, distributed power source type and capacity optimization configuration, role and form of energy storage unit, multi-objective and multi-time scale control strategy, system optimized operation and energy coordinated control, scientific and effective relay protection system, etc. At the same time, people also need to carry out research on the active reconfiguration and autonomous operation of the distribution system considering the coordination of electric vehicles, energy storage and renewable energy, and the theory of collaborative optimization in the market environment, so as to give full play to the support of energy storage units and controllable loads, so as to reduce the dependence on traditional generating units and realize scientific management and safe and economic operation of high-permeability microgrids.

4. Conclusion
To ensure the reliability of power supply, China's traditional power plants and power grids are constructed with a large margin, so that when the initial penetration rate of renewable energy is low, it will not have a large impact on the grid. However, as the penetration rate of renewable energy such as photovoltaics and wind power continues to increase, the impact of large-scale renewable energy access
to the grid is no longer just the partial voltage deviation and the local voltage deviation caused by the intermittent and random nature of renewable energy in the early stage of development. Harmonic pollution will also have an important impact on power system peak and frequency modulation strategies, reserve capacity determination, economic operation, relay protection, safety and stability, and many other aspects. This paper analyzes the impact of high penetration renewable energy on grid power flow distribution, main electrical performance indicators and system operation status, and elaborates several key technologies to improve the safe and stable operation of high-penetration renewable energy microgrid systems, hoping to provide reference for the development and research of renewable energy microgrid with high penetration rate.

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