Influence of the Access of Distributed Generation on the Distribution Network System of Inner Mongolia Power Grid and Countermeasure Analysis

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Abstract. Solar energy resource is highly rich in Inner Mongolia regions, and the customers utilized electric are scattered in the vast grassland. Thus, the distributed generation with its unique performance and high quality, has been developed rapidly in recent years. However, the large-scale distributed power supply has brought many unpredictable impacts when they are accessed to the distribution network, even seriously affecting the safe and stable operation of the distribution network. In this work, the technical barriers caused by distributed power generation to the grid-connected have been explored. In addition, the constraints and key influencing factors of distributed generation on distribution network have also been analysed and a safe and stable operation strategy to access distributed photovoltaic power supply into the network has proposed. The results here could provide a theoretical guidance for the rapid formulation and optimization of the distributed power accessing into grid network in Inner Mongolia power grid.

1. Introduction
With the issues of energy shortage and environment protection, the distributed power generation (DG) has attracted more attention for its advantages of green, economy, recycling and improving reliability of power grid all over the world [1]. At present, a series of regulations and policies to promote DG development has been promulgated by China Government. Thus, the scale of DG access in the distribution network is rapidly expanded. However, lots of technical difficulties have appeared in the development of DG as well as the utility of the power system to meet the increased DG accessing scale [2]. Generally, the integration of DG into the power grid will change the internal structure of the power grid, so that the traditional single-power radial network structure will become the multi-power form. The randomness of DG makes the quality, network loss and fault current distribution be significantly changed for the distribution network power. For instance, if the local DG permeability direction exceeds 20%, it will have a great impact on the power grid and it is difficult to match grid interconnection standards in time [3]. Some research groups have also conducted in-depth research on the planning and operation mode of distribution network systems incorporated with DG. They found that the planning and operation mode of traditional distribution networks is no longer applicable, and the control and network scheduling between power supply and network must be re-coordinated [4]. Furthermore, although DG accessing could be helpful for the network structure that the traditional large capacity and high voltage were embedded distribution environment, the intermittent power...
supply pressure caused in the distribution system has seriously restricted its development and application. Moreover, when the generation power and loss of the embedded power generation system are too large, the power transmission may not be able to transfer or return to the embedded power network, which will lead to overvoltage and reversed current, and thus the corresponding power transmission and loss will be greatly increased [5].

Solar energy is an ideal and renewable clean energy that no pollution emits to the atmospheric environment. The solar energy resource is highly rich in Inner Mongolia with an annual average sunshine hours of about 2600–3200 hours. Considering the vast grasslands in Inner Mongolia and the scattered distribution of a large number of pastoral users, the traditional supply capacity of power grid is not enough to meet with the requirement of daily production and life for a large number of grassland herdsmen. Therefore, the solar and wind energy are generally used in Inner Mongolia. The installed capacity and the electricity generation of photovoltaic generation in Inner Mongolia is located at top proportion of the China. By the end of 2018, the photovoltaic installed capacity reached 9.45 million kilowatts (of which 9.12 million photovoltaic power stations) in Inner Mongolia Region, accounting for about the country's PV installed total of 5.42% and a 9th rank of the country [6]. With an increasing number of photovoltaic DG connected to the distribution network in Inner Mongolia regions, new challenges have aroused in policy, technology, and management. The detailed researches have been carried out on the equipment overload, the control of load voltage, and power quality [7]. Nevertheless, few researches focus on the specific DG access scheme, which is very required to instruct the actual work of power enterprises at the grass-roots level. Therefore, it is necessary enhanced to analyze and study the interaction and restriction between DG power supply and distribution network via adopting new technology and tactics to guide enterprises in Inner Mongolia Region to access DG.

Xilingol League is located in the middle of Inner Mongolia region, with a land area of 203000 km² and the total grassland area of 197000 km². There are 118 villages in Xilingol League, which have built 112 village-level photovoltaic power stations [8]. Here, based on the situation of DG in Xilingol League, the effect of DG accessed on power grid and network loss have been investigated. We have analyzed the restriction conditions of photovoltaic DG there, as well as the important influence on isolated island reverse transportation, fault location and voltage fluctuation of distribution network. Furthermore, it is proposed the optimized operation mode and strategy of DG, to implement in the practical construction. The present investigation will provide a easily and safe operation policy to ensure the personal safety of users, to reduce the threat to the damages of lines and equipment, and to optimize the quality of power supply to users, and thus to build well the construction framework to guide DG accessing for the enterprises in Inner Mongolia Region.

2. Investigation on the key technologies and strategy of DG power supply to access the distribution network

2.1. Strategies for the islanding effects

Nowadays, the voltage level of photovoltaic DG in Inner Mongolia power grid ranges from 220 V to 10 kV, and the multi-point accessing mode is generally used in several photovoltaic power generation. Considering most of DG are not included in the real-time monitoring of the dispatching departments at all levels of the company, the operation of circuit breakers during fault conditions or network maintenance may produce isolated island once DG is connected to the power grid [9]. Actually, a small-scale and low-density DG power connection generally does not produce islanding effect. However, in the concentrated high density DG photovoltaic grid-connected regions, when the capacity ratio of distribution network reaches a certain proportion, the islanding effect should be given more prominence. Due to the large-scale access of photovoltaic DG, a conventional switching equipment may lead to the lack of the effective protection monitoring. As a result, the installation of the corresponding anti-island devices, such as a novel anti-islanding switch and inverter, has been imperative when the DG was incorporated into the distribution network (Figure 1a). Moreover, the
electricity generated by photovoltaic power stations is direct current (DC) while 220 kV transmission lines generally transport AC power in grassland area. Thus the photovoltaic power generation cannot be directly integrated into the grid. Here, an inverter has been connected to the grid which could transmit DC to the surrounding power grid. In this project, only one main transformer is supplied for 220 kV lines. Meanwhile, in order to avoid islanding, the circuit breaker is sent out by the connected PV power station during the operation of the main transformer protection. In addition, in terms of the special circumstances further measures have been taken to guard the hidden trouble caused by islanding effect and reverse transmission. Firstly, we have strengthened the supervision of the safety measures on sites of the maintenance and construction, and strictly implemented the work flow of "power outage, power inspection, hanging ground wire " . Also, the management method of “two votes” has been rigidly implemented. Secondly, the novel back-transmission and back-measures technology have been carried out in the 10 kV of photovoltaic power station meanwhile the anti-island and "check-off gate" have been achieved by using photovoltaic grid-connected inverter. Additionally, in the distribution network side, the necessary effective protection measures have been implemented to improve the safety level of distribution network system.

![Figure 1. (a) DG grid-connected and anti-island device diagram, (b) A schematic of property rights for DG grid-connected system](image)

2.2. The property rights demarcation

The meadow grassland widely distributed and the Herders is sparsely populated in Xilingol League. Thus it is not suitable for the decentralized construction of village-level photovoltaic power station. On considering of this, the sites for 35 kV or 110 kV substations have been chosen to build within 5 km. In such distributed photovoltaic power generation system, it is necessary to consider not only the islanding effect and the hidden danger of back-to-back power transmission, but also it is very important for the maintenance personnel to familiarize and master the characteristics of photovoltaic power generation. However, due to the DG photovoltaic intrinsic features, such as local construction, local consumption, short construction cycle, more scattered sites, a lot of inconvenience and difficulties have been experienced for the operation and maintenance. Therefore, a large number of users will choose to deliver the work to equipment suppliers or local power supply companies. According to the document of GB/T 29319 “Technical Regulations on Accessing PV Systems to Distribution Network”, the property right boundary should be set at the grid-connected switch between the distributed photovoltaic system and the grid, and the relevant enterprise are respectively responsible for the corresponding metering and maintenance. Furthermore, the power company is responsible for the maintenance of the common part of the DG access, including the circuit breaker, isolation switch, cable line, corresponding communication, automation and other facilities of the access part. Meanwhile, the user is responsible for the regular maintenance of its DG photovoltaic system equipment (Figure 1b). Furthermore, power companies and users have been required to pay enough attention to ensure that the device is put into running as required, and the operation is stable and reliable.

2.3. The power quality
Although there are many kinds of topological grid in distribution network system, at present, most distribution network in Xilingol League are still dominated with radial chain structure (see Figure 2a). When the DG power supply is connected, the voltage will gradually decrease along the direction of feeder power flow, which directly leads to the lower output of each node in the distribution network loop [10]. At the same time, the power output will basically be controlled and supported in the hierarchical distribution network system when the DG power supply is connected. Thus, the magnitude and direction of all kinds of active and reactive power transmitted on the line will be changed, which will also directly lead to the increase of the output voltage of each node in the distribution network. Moreover, due to the change of daily temperature difference in Inner Mongolia where the annual mean temperature is about 4.3 °C with an extreme maximum temperature is 38.7 °C and an extreme minimum temperature of -38.8 °C. The photovoltaic system and their components will be greatly affected by the change of local light irradiation and temperature, and thus the daily generation of electricity usually presents an irregular fluctuation. Furthermore, because a large number of power electronic converters are applied to DG power grid, the frequent switching on and off can easily produce a large number of high and low frequency harmonics and then cause harmonic component pollution to the power grid. Therefore, it is difficult to coordinate the balanced operation with the load of distribution network, and the steady-state voltage will also produce abnormal fluctuation with the fluctuation of power generation on the line. So the limit voltage of the whole distribution network system could be easily exceeded. Moreover, the function and protection range of the relay protector in the circuit are greatly reduced, and then some abnormal states such as protection rejection or delay action may appear when some regional electrical equipment fails [11]. It will further directly affect the user's safe and reliable utilization of electricity. In addition, the output force of photovoltaic power generation changes with the magnitude of solar illumination, and therefore if it is directly superimposed with the magnitude of voltage fluctuation of other system loads, it is likely to cause more voltage fluctuation and flicker directly.

Therefore, when DG is connected to the distribution network, we must consider and effectively control the system voltage fluctuation and harmonic pollution. We have to limit the capacity and position of DG incorporated to ensure the reliability of the power network equipment operation. The DG’s output capacity is adjusted according to the change of load voltage. And the fast response dynamic power compensation device at the DG power station has to be configured to solve the issue of voltage flicker. Also, the harmonic is monitored in real time after DG is connected to the grid which is to detect the input harmonics and restrain the harmonic fluctuation by changing the transformer connection group. If it exceeds the national standard, it is also necessary to adopt the corresponding measures such as adding active power filter device to solve the influence on the power quality.

![Figure 2. (a) Strategy to control voltage fluctuation for photovoltaic DG incorporated power network, (b) Line Fault Location](image-url-here)
Hence, the effective distribution line relay protection measures have to be considered due to the photovoltaic DG accessed distribution network.

In considering of the natural distributive characteristic of DG spread across different Banner counties and gacha grasslands in Inner Mongolia region, it is more difficult to locate the interruption and fault of distribution network. Thus we classify the electrical load system with the same inlet switch as the feeder area, so the fault of all nodes in the same feeder area are similar. Furthermore, for the convenience of fault location when the power grid is running normally, there should be supplied enough load capacity for all the DG power sources incorporated at the same time. When the distribution network fails, the photovoltaic power station will provide fault current to the fault point, which will cause the normal operation line protection failure (mal-operation or rejection) [12]. In this case, the existing protection device will be affected, and the protection setting in traditional distribution network is difficult to meet the requirements. For mal-operation or rejection, it is mainly solved by limiting the amount of injection of short circuit current provided from photovoltaic power station or by installing directional elements on the protective device [13]. First of all, according to the influence of distributed power supply on the protection current, the original single radiation-like is converted into a dual or multi-power structure. It is clearly stipulated in the “Technical regulations of the distributed generation accessed to distribution network in Power Grid of the west of Inner Mongolia region” that when a short circuit occurs on the side of the distribution network, its output from DG to the distribution network should not be greater than 150% of the rated current, and DG should be immediately disconnected from the distribution network.

As we known, if the threshold setting of the current is too high, it would lead to mal-operation or rejection. Thus, we can ensure to prevent the occurrence of mal-operation or rejection by reasonably setting the threshold of the current of the protection equipment. On the other hand, when DG is incorporated into the grid, it is equivalent to the load power supply connected to the opposite side of the grid. Therefore, when the fault occurs, the DG is still connected in the system which can continuously provide current to the fault point eventually, leading to reclosing failure. Further, it is proposed to install directional protection device at the DG power supply end similar to bidirectional metering device, which can ensure the current direction of the original power supply and thus avoid the influence of DG accessing on the protection device. It is very beneficial to accurately determine the fault location (Figure 2b).

2.5. Equipment overload

With the improvement of people’s life quality, all kinds of household appliances have been popularized on a large scale, and the electric load of residents has greatly increased. At present, many distribution lines have been running at full load. Combined with the large-scale construction of electric vehicle charging piles, it is difficult to meet the demand of distribution lines in several regions. In addition, the largest wind power generation is located at Inner Mongolia and thus these DG power supply can meet the demand of local load to some extent and relieve the pressure of power flow transmission. However, because DG power generation is greatly affected by climate, once the output of the power supply drops suddenly in the peak load period after large-scale distributed power supply access, the power flow transfer is difficult to be predicted [14]. And the overload phenomenon of partial line equipment is easy to occur in the case of the operation mode in distribution network is not perfect. In considered regions, the substation with large industrial load has been equipped with SVG reactive static compensation device to achieve local balance of reactive power stratification zones.

2.6. The power loss of DG accessed in distribution grid

In this part, the influence of DG incorporated into distribution network on the network and power loss have been mainly investigated. As DG are incorporated into the distribution network, the power supply capacity will continue to increase, which can meet the needs of more scattered users. However, as the active power output of photovoltaic power station increases during the day, it is pure active power output with a power factor of 0.98. Thus the reactive power compensation device cannot
effectively carry out dynamic reactive power compensation because of overvoltage protection. The reactive power flows to the photovoltaic power station to support the transmission of active power. Meanwhile, the reactive power of the line will flow in the opposite direction to the power grid when the photovoltaic power station does not generate electricity at night. Therefore, a large number of DG accessed, result in the increase of power loss. Thus the design and construction of the new network architecture will be very important. Because not only the DG amount of power load has a great influence on the network and power loss, but also the installation position of the DG and the overall structure of the power network are related to the network and power loss. Hence, it is suggested that the dispatching management of distribution network should be strengthened in the area of high density access for DG, and the annual operation mode of fine distribution network should be made referenced to the mode of main network. The main way of systemic voltage quality is controlled to optimize the distribution network structure, to rationally plan, to arrange the system network structure, and to reserve the possible additional capacity. Also, the on-load regulator is arranged reasonably in the system, and the power supply on the user side is connected to the system through at least one on-load regulator. The normal, "N-1" and "N-2" operating conditions of distribution network are considered as far as possible, and the direction of power flow transfers after failure is accurately defined.

2.7. The operation and control
Aiming at the countermeasures of DG accessing to distribution network discussed above, we have proposed the key approaches in distribution network construction in Inner Mongolia as follows.

In the early stage of the project, it is suggested that the deep intervention is necessary, and the initial work should be deep and fine engineering. One is to ensure the anti-island devices must be equipped and the other is to ensure that the corresponding relay protection functions must be equipped in the distributed power generation projects. The configuration and selective modes of the protection devices must meet the technical specifications and anti-accident measures of the power network. Also, the grounding mode of DG should be consistent with those on the power grid side, and should meet the requirements of personal equipment safety.

At the preparatory stage before construction, one is to urge the power supply units of the league city to promote the substantive operation level of the owner's project department, and to strengthen the communication and coordination with the production and construction units. It is also proposed to actively publicize the hidden dangers caused by photovoltaic DG to the construction. On the other hand, for the sub-bureau, it is required to be familiar with the operation of the local power grid. It need to make clear the existing risk points and the measures should be taken to ensure the safety of personnel and equipment. Finally, it has to check the regular pre-test records of anti-island devices to ensure it being reliably put into the operation.

In the construction stage of the project, it is to strictly standardize the implementation of the work flow such as "power outage, electricity inspection, and grounding wire" in the construction site. “two-vote” management method should be rigidly implemented. It is also resolutely interdicted for the operation of stopping power transmission by the personnel of the construction unit. After the power is failure, it must use the electrical apparatus according to the regulations to test the possible live lines and equipment one by one. In addition, within the visible range of the construction operation sites, it is necessary to install the ground wire according to the requirements of the construction or the operation rules to ensure the grounding point is reliable and effective. The photovoltaic side should also ground well, and arrange special personnel to verify. Many measures should be taken simultaneously to prevent the isolated island and the reversed power transmission which could lead to the electric shock casualty accident.

In the completion and power transmission stage, the power transmission process must be strictly carried out. After removing all the installed wiring, the power supply of the public power grid must be restored first, and the distributed photovoltaic grid-connected switch is finally operated, so as to prevent the hidden danger caused by the reversed power transmission to the operators.
3. Conclusion
As more and more DG is connected to distribution network system in Inner Mongolia, the structure and operation mode of the power grid could face with great challenges. Investigating the key technology and countermeasures of DG connected power grid can effectively improve the efficiency of DG assess grid for local league and city. In the present work, a detailed investigation have been made on the islanding effect, property rights demarcation, voltage fluctuation, network and power loss, relay protection and fault location of distribution lines, and overload of distribution network equipment in Xilingol League. Finally, based on the construction of the distribution network project, this manuscript has also analysed the important issues that need to pay larger attention from five aspects: the pre-project, the pre-construction, before the construction stage, during the construction process, and the completion acceptance stage. This work will lay a significant basis to well achieve the company's annual distribution network investment with a higher safety and quality.

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