The Influence of Grid-connected Distributed Generation on the Power Supply Reliability of Distribution Network

Haonan Niu¹*, Shenjie Wang¹, Na Pan¹, Zhichao Peng² and Xing Liu¹

¹State Grid Tianjin Binhai Power Supply Company, Tianjin, 300450, China
²State Grid Tianjin Electric Power Company, Tianjin, 300010, China
*Corresponding author’s e-mail: haonan.niu@tj.sgcc.com.cn

Abstract. This paper analyzes the typical distribution network structure and the operating characteristics of distributed generation (DG). By analyzing the impact of grid-connected DG on equipment such as reclosing and spare power automatic switching, we calculate the power supply reliability indexes after the DG is connected to the grid under various operation modes such as reclosing, spare power automatic switching, de-sequencing distributed energy and islanding. Finally, the results of the reliability indexes can provide the theory and data for planning and improving the operating mode of grid-connected DG.

1. Introduction

With the increase of user load year by year and the utilization of new energy, more and more DG especially the clean energy is connected to the distribution network[1]. When a large number of distributed energy sources are connected to the grid, the reliability of the system may be reduced if they are not coordinated with each other[2-3]. Currently, once the grid system is disturbed, all DG will be generally removed from the system to restore the system to its original structure. It will seriously affect the safe and stable operation of the grid system[4]. Therefore, researching the influence of grid-connected distributed energy on the power supply reliability of distribution network is very important.

The grid-connected DG can change the power flow distribution and operating mode of the grid system. There are several significant advantages as follows:

- DG can increase the reserve capacity of the grid. It has the functions of peak shaving and load balancing.
- DG can reduce the need for new large-scale power plants, saving the investment of power plants and transmission equipment.
- DG will bring power production closer to the load, reducing the network losses of power transmission[5-6].
- DG allows to operate in an island mode with load. When the grid system fails, DG can continue to supply power to the part load. This can reduce the scope of power outages and improve the power supply reliability[7].

However, the positive effects of DG is not easy to be achieved in practice. It requires that the DG have high operational reliability and can be scheduled arbitrarily[8-9]. When the restrictions cannot be met, the access of DG will cause many adverse effects on the power distribution system[10-11].
2. Model parameters and Methods
When calculating the power supply reliability of the grid, multiple indicators are generally used to describe the reliability level from multiple sides[12].

2.1. Power supply reliability index
Currently, the most widely used indicators such as SAIDI (System Average Interruption Duration Index), SAIFI(System Average Interruption Frequency Index), MAIFI(Momentary Average Interruption Event Frequency Index). The calculation formula as follows:

\[ SAIDI = \frac{\sum U_i N_i}{\sum N_i} \]  
\[ SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \]  
\[ MAIFI = \sum D_i \lambda_i \]

Where \( U_i \) is the average annual outage times of the load point \( i \); \( N_i \) and \( \lambda_i \) are the user number and the user outage rate respectively; \( D_i \) is the operation times of blackout equipment; \( R \) is the collection of system load points.

In this paper, the power supply reliability index is calculated by the method of FMEA (Failure Mode and Effect Analysis) after DG is connected to the grid. By searching the state of each element, all possible system statuses are listed. Then it analyzes all the states of the system according to the appropriate failure judgment criteria and finds out the set of failure modes of the system. Finally, we get the comprehensive results of the reliability index of the load point and distribution system.

2.2. Typical 10kV distribution network model
Figure 1 is a typical distribution network structure including DG. DG1 is connected to the 10kV bus of the distribution substation through the step-up transformer T1 and line L2, thereby connecting to the grid. The grid and DG1 maintain the power balance of the substation load together. AP1 is the backup power for load A. When the distribution network is operating normally, the BL1 is disconnected. When the distribution network fails, BL1 is closed and AP1 is enabled to supply power to load A.

![Figure 1. Schematic diagram of distribution network with DG.](image)

3. Results & Discussion
In order to simplify the analysis process, the calculation example only considers the line faults, excluding planned power outages, overloads and other component faults.
3.1. Traditional distribution network with the backup power supply
Before DG is connected to the grid, the traditional distribution network is a radial network. The lines generally use three-phase one-time reclosing and some substations or important loads may use the spare power automatic switching devices.

If the success rate of spare power automatic switching and reclosing in transient fault are 90% and 95% respectively, we calculate the system power supply reliability index under different operating strategies, shown in Table 1. Operation 1 means that the reclosing is enabled after a fault. Operation 2 means that the reclosing is not enabled after the fault, but the spare power is turned on. After comparison, it is found that the use of spare power automatic switching can improve the power supply reliability of the power distribution system.

| Operation in the event of the traditional distribution network failure | SAIFI | SAIDI | MAIFI |
|---------------------------------------------------------------|-------|-------|-------|
| Operation 1 | 0.440 times | 1.340 h | 1.610 times |
| Operation 2 | 0.265 times | 0.665 h | 1.785 times |
| Operation 1 and Operation 2 | 0.224 times | 0.724 h | 1.826 times |

3.2. Reclosing strategy after DG is connected to the grid
After DG is connected to the grid, the network will bring the same period issues affecting the use of reclosing and spare power automatic switching. In order to avoid non-synchronous closing, the line L2 generally disables reclosing and adopts manual synchronous closing. For the line L1, the common domestic reclosing strategy as follows:

- **Strategy 1**: Take the method of detecting no pressure on the large energy side and detecting the same time on the small energy side. After the grid is disconnected, because the small system will quickly lose synchronization, the success rate of detection is very low during the same period.
- **Strategy 2**: Disable reclosing.
- **Strategy 3**: Take the method of detecting no voltage on the large energy side and detecting the busbar on the small energy side without voltage. In fact, it is delayed waiting for the small system to crash.
- **Strategy 4**: De-sequencing reclosing. In other worlds, when the system fails, DG1 will be withdrawn first and then the system will be closed.

If the success rate of reclosing in the same period and detecting the busbar without voltage are 10% and 60% respectively. There is no island operation in the system. We calculate the system power supply reliability index and percentage under different reclosing strategies, shown in Figure 2 and Figure 3.

![Figure 2. Power supply reliability index](image1)
![Figure 3. Power supply reliability percentage](image2)
According to the data, the strategy 1-3 are relatively passive, which will reduce the reliability of the power supply of the system. But the strategy 4 can reduce the adverse effects and reach the reliability level before DG1 is connected to grid.

3.3. Operating in island mode
If the line has a permanent failure or reclosing failure, there are two operating modes for DG. They are exit operation and planned island operation (microgrid). Assuming that DG1 can form a microgrid with load A, we analyze several common operating modes as follows:

- **Mode 1**: After the fault occurs, DG1 disconnects from the grid immediately and the line L1 enables reclosing. DG1 can be reconnected to the grid after the distribution network is restored to stability.
- **Mode 2**: The line L1 disables reclosing and DG1 takes part of the local load to form an island (microgrid).
- **Mode 3**: De-sequence reclosing. After the line L1 reclosing fails, DG1 quickly forms an island (microgrid) with load A.
- **Mode 4**: DG1 quickly forms a microgrid with load A. The load outside the microgrid is restored by the line L1 using reclosing.

Assuming that the success rate of forming an island (microgrid) is 85%, we calculated the system power supply reliability index and percentage under the above 4 modes, shown in Figure 4 and Figure 5.

It can be seen from the results that both mode 3 and mode 4 can improve the reliability of power supply. In mode 1, DG1 disconnects from the grid immediately after a fault, so it can't improve the reliability of power supply. In mode 2, due to the line L1 disable reclosing, the local load outside the island (microgrid) continues to lose power, which reduces the reliability of power supply. Therefore, if DG is connected to grid in the form of microgrid and combined with reclosing measures, it can improve the reliability of power supply.

4. Conclusion
In this paper, we analyze the impact of grid-connected DG on equipment such as reclosing and spare power automatic switching through taking a typical distribution network model as an example. The conclusions are as follows:

- The use of backup energy can improve the reliability of the power distribution system.
- DG does not necessarily improve the reliability of power supply, but unreasonable operation will reduce the reliability of power supply of the system.
- If distributed energy is out of operation after a failure, it will not have any improvement effect on the reliability of the power supply of the distribution network.
If DG is connected to grid in the form of microgrid and combined with reclosing measures, it can improve the power supply reliability of load in microgrid. But the power supply reliability of load outside the microgrid must be improved by reclosing measures.

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