Reliability Assessment on Typical Connection Modes of High Reliability Demonstration Area

Kang Wei¹, Hu Po¹, Gao Shan¹, Zhao Yang¹, Wang Zijun³

*Corresponding author’s e-mail: 505386064@qq.com
State Grid Hebei Economic Research Institute, Shijiazhuang, Hebei,050000 China;

Abstract: In the process of construction and modification of distribution, choosing connection modes is a key link of network construction and plays a pivotal role in distribution network. In this thesis, firstly, the distribution network frame and its present situation in demonstration area is analyzed, and the shortcomings in present network are designed; After using the features of advanced distribution network frame in international metropolis for reference, the experience is concluded and four kinds typical connection modes which suit for demonstration area are designed; The characteristics and the scope of application of every typical connection modes are analyzed, the modification scheme according to the present distribution network frame in demonstration area is illustrated. Finally, the examples are taken as cases to illustrate that these typical connection modes are of high power supply reliability. With the constant rise of the require of power supply reliability, the connection modes in demonstration area will be widely used and extended gradually.

1. Introduction
With the rapid development of national economy and the improvement of people's living standards, the require of power supply reliability is getting higher and higher. Improving the reliability of distribution network can benefit the quality of power supply and reduce customers' loss. The selection of connection mode of distribution network frame plays an important role in improving the reliability of power supply. At present, there are many studies on connection modes of distribution network and they have gained some achievement. Ge Shaoyu, et al. [5] provides corresponding guidance for the construction of high-voltage distribution network by listing various connection modes of urban high-voltage distribution network and comparing them from the angle of reliability and economy. Ma Xiufan, et al. [8] analyzed various connection modes of distribution network in detail, pointed out the operation modes and evaluated those connection modes. Xie Xiaowen, et al. [9] analyzed the reliability, economy and adaptability of various connection modes of medium voltage distribution network and showed the reliability index results. However, the reliability of the above connection modes of distribution network is generally less than 99.999%. With the position of power in China's energy structure becoming increasingly prominent, people put forward higher requirements for power supply reliability. Therefore, it is urgent to study the typical connection modes of distribution network with high reliability.

In order to meet the needs of rapid economic development, Pudong Company intends to build a "world-class" modern distribution network in the core area of Pudong (hereinafter referred to as the demonstration area), which is in line with the international development of Pudong New Area, in order to comprehensively improve the power supply level. Therefore, based on analyzing the characteristics
of the advanced distribution network frame at home and abroad, four typical connection modes and corresponding transformation schemes are proposed in view of the present situation of distribution network in the demonstration area. Thus, the reliability of power supply in the demonstration area can be effectively improved and eventually be higher than 99.999%. This will create an experimental precedent for Shanghai Company and even the State Grid Company to build modern distribution network.

2. Analysis of Current Situation of Distribution Network Frame in Demonstration Area

2.1 Current Situation of Distribution Network Frame in Demonstration Area

In order to build a high reliability distribution network in the demonstration area, we should start with the existing network frame, solve the weakness and optimize the frame, so as to improve the power supply capacity and adaptability of distribution network.

At present, the connection modes in the demonstration area include substation transmission to switching station, substation transmission to single ring, switching station transmission to single ring and so on. In the demonstration area, there is also the phenomenon that the single ring (large ring) powered by substations are sent to the next level of ring network (small ring). In addition, although the 10kV cable network in the demonstration area basically meets the requirements of "N-1" check, most of the ring incoming lines come from the same power station, which does not meet the first-level double power standard. The total outage of the upper power station will lead to the total power loss of the ring network. Before the realization of distribution automation, the failure of the cable trunk ring will lead to a complete outage of the primary circuit. The outage time depends on the time of fault location and the time of dispatching and isolating fault points. In the demonstration area of 10kV overhead line, the connection mode is sectional linked and the main problem is that the overhead line is less sectionalized and have fewer liaisons.

For 220 kV power supply, the main problems in the demonstration area are the shortage of power supply points in the north of the demonstration area, the heavy load of some stations during the peak period, and the tight interval of 35 kV outgoing lines. In 110 (35) kV high-voltage distribution network, some stations in the demonstration area come from different buses of the same 220 kV substation; some 35 kV substations have tight 10 kV intervals; some 35 kV switching stations have no sectional switches, and no load transfer can be carried out in the switching stations. In 10 kV medium-voltage distribution network, problems are large overhead line segment capacity but fewer liaisons, type III distribution station built according to the old standard does not conform to the current technical principles; and there are some non-standard phenomena such as overhead line transmission to type III distribution station, box transformer and other atypical wiring.

2.2 Comparison of Advanced Distribution Network Frames in Metropolitan Areas at Home and Abroad

To build a "world-class" modern distribution network, we need to learn from the advanced international experience, collect the advanced experience of major cities, compare the advantages and disadvantages of various parties and analyze them, and extract the experience suitable for the transformation of distribution network frame in the demonstration area. In this paper, Tokyo, Singapore, Hong Kong, Paris and other metropolises are taken as examples for analysis, as is shown in Table1-2:

| Distribution network frame | advantage | disadvantage |
|----------------------------|-----------|--------------|
| Loop power supply mode of 22kV cable and parallel operation | Single ring structure is clear and simple; single cable fault has no effect on users | Reliability is lower than that of loop power supply from the same bus, bus failure leads to total shutdown |
| Main and Standby Wiring | User dual access; single | When busbar failures occur in |
of 22kV Cable

substation or cable failure can instantaneously restore power supply (4s)

substations, only part of the load can be transferred, and the channel requirements are high.

| 6.6kV 4-segment 2-liaison power supply mode | Single ring has clear and simple structure and low investment. | Multi-loop switch with single access has low reliability |
| 6.6kV Overhead 6-segment 3-liaison | Clear section, narrow power failure scope; high line load rate; low investment | Long power failure time in line fault section |

| Tab.2 Distribution Networks frame in Singapore, Hong Kong and Paris |
|------------------|------------------|------------------|
| Distribution network frame | advantage | disadvantage |
| Singapore: Petal reticular structure, parallel operation | High reliability: important users satisfy N-2; good scalability: new power supply area can be extended through contact switch | High investment; high reliability requirement for protective equipment |
| Hong Kong: Strengthened N-supply 1-standby, parallel operation | High reliability: when a single line fault occurs, it has no effect on users; when the main line fault is transferred to standby, the power supply can be quickly restored. | High investment; the whole distribution network should be equipped with circuit breakers and longitudinal differential protection, secondary protection is complex. |
| Paris: Double ring and triple ring, multi-segment network | High reliability: when the cable is faulty, it will be powered by another cable; distribution transformer with double access | High investment, redundant line equipment and low utilization rate |

It can be seen that the main trend of distribution network planning and development in advanced international areas is to strengthen the planning and construction of medium and low voltage distribution network, to strengthen the construction and management of medium voltage distribution network, to improve the load transfer capacity, to simplify the high voltage distribution network and to meet the requirements of customer power supply reliability, which is the basic starting point and foothold of network planning and construction. Setting corresponding criteria at the stage of power network planning make the grid structure meet the requirements of specific reliability and at the same time enhance the connection between stations and sections, so as to improve the response ability to emergencies.

2.3 Draw lessons from experience

It is obvious that the current basic network frame and the reliability of power supply in the demonstration area need improvement compared with the distribution network frame of the international advanced metropolis. The shortcomings of the current network frame in the demonstration area are summarized as follows:

1) Some substations have higher warehouse consolidation rate.
2) The upper power supply of switching station comes from different buses of the same substation.
3) Power supply of ring network comes from different buses of the same substation (switching station).
4) There are few switch stations and 10 kV storage space is tight.
5) The distribution automation is difficult to configure because the large ring covers the small ring.
6) The 10kV distribution network frame can not meet the "N-1" check under overhaul condition.

To this end, by comparing the advantages and disadvantages of the above-mentioned metropolitan areas, the experience for the transformation of distribution network structure in demonstration areas is extracted as shown in Table 3.
Tab. 3  Distribution Networks modification experience

| City Name | Reference from experience |
|-----------|---------------------------|
| Tokyo     | Ring power comes from different power stations; Ring capacity, number of users, sectional capacity and power supply radius are strictly controlled. |
| Singapore | Increasing the tie-lines between the Single Ring in the Demonstration Zone |
| Hong Kong | Increase the tie line between single ring; Control the capacity of ring network |
| Paris     | Double ring is preferred in the demonstration area |

Looking at the planning and development of urban power grids in advanced regions in the world, we can see that solid distribution network frame and flexible load transfer capability are the foundation of modern distribution network. To this end, the distribution network in the demonstration area will build a world-class distribution network with high reliability by drawing lessons from international advanced experience and combining them with its own current situation.

3. Typical connection modes of different land use in demonstration area

Based on the international advanced experience, considering the current situation of the region, this paper puts forward four kinds of target connection modes as the goal of grid transformation, which can strengthen the network frame and improve the reliability of power supply. Four target connection modes can be flexibly applied to different scenarios. While taking into account environmental adaptability and feasibility of implementation, they can standardize the network frame and provide more powerful support for standardized operation and automated deployment of distribution network.

1) Model 1: Switching station with four power, two main and two standbys

Switching station is the core node of 10kV distribution network in demonstration area. It is of great significance for improving the reliability of power supply to strengthen the inter-station communication and improve the lateral load transfer capability of switching stations. In order to transfer load rapidly and realize horizontal standby and “N-2” without two-way power supply, connection mode schematic diagram of switching station with four power, two main and two standby, is proposed as is shown in figure 1.
The characteristics, advantages, disadvantages and application scope of this wiring mode are as follows:

Characteristic: Each bus bar of switching station reserves one interval for tie-line, which forms hand-in-hand with adjacent switching station and operates open-loop. The diameter of tie-line is the same as that of the incoming line of switching station.

Advantages: High reliability which can reach 99.9991% combined with distribution automation.

Disadvantage: High requirement for the number of warehouses in switching stations; small-scale equipment and special tie-line are needed to increase investment.

Scope of application: It is suitable for areas with insufficient medium voltage interval, limited outlet corridor, concentrated load and high reliability requirements.

2) Model 2: single ring with three power, two main and one standby

In order to make effective use of the existing single ring framework, further optimize the network structure and increase power supply points, by drawing lessons from the design idea of double ring, a tie-line is added between the single ring and the tie-line is located at the important load to realize the single ring with three power, two main and one standby, as is shown in Figure 2.

The characteristics, advantages, disadvantages and application scope of this wiring mode are as follows:

Characteristic: A special line is added to a single ring node, which is connected with the adjacent single ring network and breaks normal operation. For single ring sent by substations, the addition of tie-lines can greatly improve the reliability of power supply. If any section fails, pulling the corresponding section switch and closing the contact switch can transfer the load to the adjacent feeder to complete the transfer.

Advantages: meeting the "N-1" outage requirements; still able to transfer load outward when losing two main power supply, which has high reliability of power supply; flexible operation mode, which can balance load by controlling the contact switch between ring networks; important load nodes can meet the "N-2".

Disadvantages: increased investment because of dedicated tie-lines; the path between interconnected single ring is required to be adjacent due to the cost of laying implementation and
channel constraints; in order to avoid overload after load transfer, the maximum capacity of single ring is further limited.

Scope of application: It is suitable for areas with high reliability requirements, areas with small and medium capacity and single power user concentration, as well as areas where it is difficult to transform into double ring.

3）Model 3: double ring with four power

There are four power sources in the double ring, and there are connections between the adjacent nodes of the ring network, so the load transfer capability is strong and the power supply reliability is high, as is shown in figure 3.

Fig.3 connection mode schematic diagram of double ring with four power

The characteristics, advantages, disadvantages and application scope of this wiring mode are as follows:

Characteristic: Users can get two directions of power supply, which has high reliability. Even if the single ring is reformed according to mode 2, its theoretical reliability of power supply is still lower than that of the double ring. Multiple ring network units can be connected in series in the double ring, which makes the operation more flexible.

Advantages: the grid meets the "N-2" outage requirements, with the highest reliability; operation mode is flexible, which can balance load by controlling the liaison switch between loops; load transfer between stations can be realized when the power supply (substation or main transformer) fails.

Disadvantage: Construction, transformation and operation cost is higher, and channel resources are occupied more.

Scope of application: It is suitable for construction and development land in core area, power supply for important users and high load density and high reliability area.

4）Model 4: Overhead line with four segments, three liaisons, one main and three standbys

In order to meet the "N-2" outage requirement of feeder line, overhead lines should be able to transfer all non-fault load after losing two power sources. If two liaison connection mode is adopted, the load rate of overhead line can not be higher than 50% in normal operation. If three liaison connection mode is adopted, it can not be higher than 66%. Three liaison mode is preferred for overhead lines in demonstration areas, and the number of segments is no less than the number of liaisons, namely four segment three liaison, as is shown in figure 4.
The characteristics, advantages, disadvantages and application scope of this wiring mode are as follows:

Characteristic: While fault occurs in any segment, the load of non-fault section can be transferred to adjacent line through liaison switch. If the load rate is controlled at 66%, the non-fault load can be transferred outward through the other two tie-lines when two power sources are lost.

Advantages: when the upper power supply fails, all load can be transferred; the number of liaisons is large and the operation mode is complex, but combined with distribution automation they can shorten the recovery time; more segments can narrow the power failure scope; low construction, transformation and maintenance cost.

Disadvantages: It is difficult to set up a tie-line, which occupies more channel resources; more liaisons make the operation mode more complicated than that of a single liaison.

Scope of application: It is suitable for the area that overhead lines have been built and the reliability requirement is high.

4. Transformation schemes for network frame

The ultimate goal of the transformation of the network frame in the demonstration area is to form a modern distribution network characterized by "multi-liaison of power supply, gridding of power network and automation of distribution network" with a power supply reliability rate higher than 99.9999%. Under the guidance of this goal, the transformation of network frame in demonstration area should follow relevant technical principles and international advanced experience, and provide effective basic support for distribution automation.

Gridding is based on the power supply customers. It divides the power supply jurisdiction into unit grids according to certain standards, so as to realize block transformation and power supply zoning, facilitate grid reconstruction after the accident and reduce the power failure scope.

In the demonstration area, the principle of "multi-liaison of power supply" of medium-voltage network frame should be based on the requirement of relevant technical guidelines for distribution network. The two incoming lines of 10kV all have one-level dual power supply, and the 10kV line has at least three power sources to satisfy the "N-1" under overhaul condition. Under the feasible conditions of field implementation, the network frame is reformed into four typical connection modes. Specific modifications are as follows:

In the financial and trade grid, measures such as adding tie-lines in 35 kV substation, rebuilding 10 kV network frame in the grid and rebuilding substation tie-lines are taken to further improve the reliability of power supply.

General residential land grid transformation can take measures such as transforming the original neighborhood station into 10 kV switching station, increasing the number of tie-lines between switching stations and transforming overhead lines around the grid into multi-segment and three liaisons.

Double ring connection is preferred in the developing areas under construction. Switching stations come from different substations, and special tie-lines are established between the switching stations.
Through the comprehensive transformation of the main frame of distribution network, the grid interior, the grid exterior and the grid equipment, as well as the increase of horizontal liaison for 35kV substation, the demonstration area will greatly improve the capacity of load transfer, reduce the average load rate of the line, and fully realize the "N-1" power supply environment under planned overhaul, so that most customers without dual power supply can obtain power from the non-fault side during power failure and planned overhaul.

5. numerical example analysis

The example in this paper is based on the average annual statistical data of equipment failure in Pudong Power Supply Company from 2008 to 2012. The statistical data of equipment reliability is obtained as one of the input parameters of the calculation.

The outage rate of overhead line faults is 17.6519 times per 100 km year and the repair time is 3.2616 hours per time; the outage rate of cable faults is 3.0371 times per 100 km year and the repair time is 3.9384 hours per time; the outage rate of transformer faults is 1.3809 times per 100 km year and the repair time is 1.4957 hours per time; the outage rate of circuit breaker faults is 0.5602 times per 100 years, the repair time is 4.2772 hours per time.

In addition, the reliability of 35kV power supply side is set according to the failure outage rate of 0.1 times per hundred years and the repair time of 3 hours per time.

The breaking time of the circuit breaker is 0.75 hours when the manual operation is used, 0.5 hours when the three telemetry is realized, and 0 hours when the distribution network automation is realized.

All HV station outlet line models are LGJ70/10, the length is 1 km, the other line models are YJV400, the length of each segment is 0.2 km, all distribution transformer models are S13-400/10/0.4, the size of all loads are 0.3+j0.1.

Through the analysis of the evaluation and prediction of power supply reliability of medium voltage distribution network and the assistant decision-making system, the results of each index of power supply reliability of distribution network after adopting four typical connection modes are compared as shown in table 4.

| Reliability Indicators | before reform | model 1 | model 2 | model 3 | model 4 |
|------------------------|---------------|---------|---------|---------|---------|
| SAIFI (time/Household.Year) | 0.1690 | 0.1243 | 0.0603 | 0.0149 | 0.0516 |
| SAIDI (hour/Household.Year) | 0.1974 | 0.0800 | 0.0664 | 0.0237 | 0.0453 |
| CAIDI (hour/blackout household.time) | 1.1679 | 0.6435 | 1.1012 | 1.5941 | 1.2603 |
| ENSI (MWh/year) | 35.3872 | 0.0960 | 0.5312 | 0.0568 | 0.0871 |
| AENS (MWh/year.household) | 0.0954 | 0.0240 | 0.0266 | 0.0071 | 0.0182 |
| LOSS (billion/year) | 1.0616 | 0.0029 | 0.0159 | 0.0017 | 0.0026 |
| ASAI(%) | 99.9977 | 99.9991 | 99.9992 | 99.9997 | 99.9993 |

The calculation results show that the theoretical reliability of power supply in the demonstration area before transformation is close to the standard of A+ power supply area, and the theoretical reliability of power supply has been further improved after transformation. By adapting the four typical connection modes proposed in this paper, the reliability of power supply can be significantly improved and the reliability rate of power supply can be higher than 99.999%, which means the demonstration area truly achieve the goal of building a "world-class" modern distribution network.

6. conclusion

On the basis of drawing lessons from the structural characteristics of advanced international distribution networks, this paper puts forward four typical connection modes of distribution networks. According to the four typical connection modes, the network frame of the demonstration area is reformed, the structure of the medium voltage distribution network is greatly strengthened, the
connection mode is optimized, and the reliability of power supply is improved. From the results of the numerical example, it can be seen that the typical connection mode is suitable for the construction of distribution network in high reliability demonstration area, which has certain reference significance for the construction of distribution network in other areas.

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