# The Reliability Improvement Strategy of Medium Voltage Distribution Network Based on Network Frame Optimization

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***Abstract*—Shanghai power grid is committed to building a world-class distribution network, and improving the reliability of power supply is one of the core objectives of the construction and modification. In this paper, the statistics and analysis of blackout events are carefully made, optimization method is proposed aimed at the present network frame. Then contrast the reliability of the network frame before and after optimization through the calculation of a medium voltage distribution network. The optimized scheme has proved that the whole grid power supply reliability is obviously improved after the optimization. Research findings in this paper can provide certain reference for the modification, planning and construction of the distribution network.**

***Index Terms*—world-class distribution network, reliability, grid optimization, distribution network planning**

## I. Introduction

Distribution network is an important link between power grid and users in power system. It is a key link to ensure power supply. The development of economy and society relies more and more on electricity. The demand for power supply capability and reliability of power grid is also increasing [1]-[5]. There are many factors that affect the reliability of distribution network [6]-[10], and they can be divided into external factors and internal factors. External factors include meteorological conditions, equipment maintenance, project implementation, management factors. Internal factors mainly include grid structure, equipment level and so on. External factors such as maintenance scheduling time and management methods have been greatly improved through lean management, so the grid structure is an important factor affecting the reliability of power supply. The influence of the grid structure on the reliability of power supply is mainly reflected in whether the grid can make up for or minimize the blackout scope of the fault section and the blackout time of the non-fault section when the fault occurs. In this paper, according to the “Power Supply Reliability Evaluation Rules for Power Supply System Users” (DL/T836-2012), the annual power supply reliability index of regional power grid is analyzed, and the ideas and methods for improving power supply reliability in the future are put forward from the aspect of grid optimization.

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## II. Blackout Statistics

The statistical results of an annual power outage in a distribution network are shown in Table I. Among them, 576 (57 + 519) were planned blackouts, accounting for 66.67%; 35 (4.05%) were planned from user applications; 253 (29.28%) were caused by fails.

TABLE I. BLACKOUT EVENTS STATISTICS

| Category | Planned maintenance | Planned construction | Internal fault | User application |
|---|---|---|---|---|
| Numbers | 57 | 519 | 253 | 35 |
| Proportion /% | 6.60 | 60.07 | 29.28 | 4.05 |

According to the relevant provisions of “Regulations for the Evaluation of Power Supply Reliability of Power Supply System Users” (DT/L 836-2012), the formulas for calculating the average outage time (AIHC-1) of users are as follows:

$$\text{Average power outage time}=\frac{\sum \text{Power failure time per household}}{\text{Total number of users}} \quad (1)$$

Power supply reliability ratio (RS-1) formula:

$$\text{Power supply reliability ratio}=(1-\frac{\text{Average power outage time}}{\text{Statistical time}})\times 100\% \quad (2)$$

In the planned power outage, if the connection between overhead lines is insufficient, there are crossing cables, lack of power supply points, and the number of users between post load switches is too large, etc., it will lead to difficult line division or inflexible line transfer, and more users will be stopped, and the power outage range will be expanded. If the power network is not properly connected, the power failure area may be expanded, the fault finding is difficult, and the time for handling the accident is extended, which will affect the number of households and reliability.


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## III. Reliability Calculation of Different Grid Structures

Distribution network connection mode adopts single power radiation connection, ring connection, sectional connection and n-1 main and standby connection [11].

The radiation wiring of single power source is shown in Fig. 1. The advantages are economy, short power distribution line, small investment, and convenient connection when new load is added. The disadvantages are long time, large range and poor power supply reliability after fault occurrence [12]. For this connection mode, the spare capacity of the line is not considered, that is, each outgoing line (main line) is fully loaded, and in case of failure, the load cannot be transferred. In general, the fault rate of distribution transformer is very low, so it is not considered in actual analysis. When bus fault occurs, all the users are affected, and the average shutdown time is the average repair time of the bus. Failures such as tripping are also rare in the normal operation of the circuit breaker. The most likely fault is the circuit breaker reject when the line fault occurs. Therefore, this fault should also be considered.

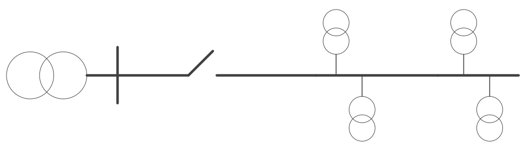

Figure 1. Single source model.

As shown in Fig. 2, there are two power sources in this connection form, which are taken from two bus lines of the same substation or different bus lines of the substation. Normally, open-loop operation is adopted. In normal operation, each line shall have a margin of 50%. However, due to the low degree of automation, once the line or equipment failure occurs, the load transfer needs operation maintenance personnel, and the outage time is also quite long.

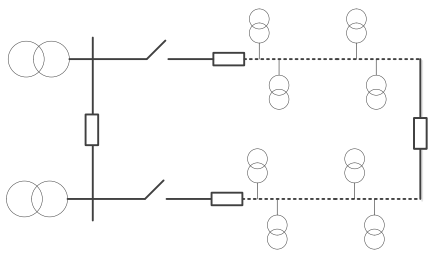

Figure 2. Ring model.

The sectionalized contact connection is shown in Fig. 3. The line is segmented by installing sectionalized switch on the main line, and each segment has a contact line connected with other lines. When a fault occurs in any line, the power supply of the other line is not affected, and the fault range of the line is reduced to the minimum. In the connection mode, the line shall have sufficient reserve capacity. Compared with the loop connection mode, the sub-section connection mode improves the utilization rate of feeder, but it increases the line investment due to the need to establish contact lines with others. This connection mode can be applied in large parts of the city network, and the contact line can be connected nearby. However, it should be noted that the connection should be established between the outgoing lines of different substations or different buses of the same substation.

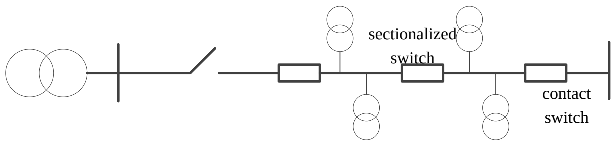


Figure 3. Segmented contact model.

As shown in Fig. 4, the main and standby connection mode of “n-1” is connected to a ring network by a line. Among them, one line serves as a common spare line. Under normal circumstances, it runs without load, while other lines can run fully. When a fault occurs in an operating line, the backup line can be put into operation through line switching. With the difference of “N” value, the operation flexibility, reliability and the average load rate of the line are different. Generally, the “3-1” and “4-1” modes are ideal, with the total line utilization rate of 66% and 75% respectively. The mode wiring above “5-1” is relatively complex, and the operation is also complicated. At the same time, the length of the contact line is relatively long and the investment is relatively large, and the utilization rate of the line load flow is not obvious. The advantage of “n-1” main and standby connection mode is higher reliability of power supply and higher theoretical utilization rate of line. This method is applicable to areas where the load is saturated and the network is built according to the final scale.

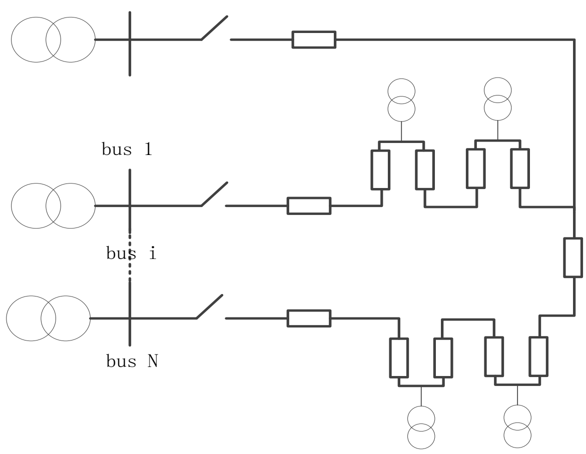


Figure 4. N-1 main and standby model.

For the above four typical networks, the network equivalent method of reliability analysis of distribution network is applied to calculate the system reliability index under the condition of the number of users such as the equal load capacity. The component reliability parameters used in the calculation are from the actual operation records of China's power distribution system, as shown in Table II, and the calculation results are shown in Table III. In Table II, SAIFI (system average compensation frequency index) represents the average power outage frequency index of the system. SAIDI (system average duration index) refers to the system average duration of power outage. ASAI (average service available index) represents the average power supply availability indicator.

TABLE II. THE RELIABILITY PARMAMETER OF ELEMENT

| Element | Failure rate (time/ year) | Recovery time (hours/time) |
|---|---|---|
| Bus | 0.03 | 12.38 |
| Circuit breaker | 0.007 | 6.3 |
| Transformer | 0.003 | 15 |
| Line | 0.029 (time/km/year) | 5.62 |

TABLE III. THE RELIABILITY AND ECONOMY OF DIFFERENT CONNECTION MODES OF POWER DISTRIBUTION NETWORK

| Connection mode | SAIFI | SAIDI | ASAI | Coefficient of investment |
|---|---|---|---|---|
| Single source | 3.5012 | 15.03 | 99.851 | 1 |
| Loop | 2.8367 | 8.812 | 99.924 | 1.15 |
| Sectionalized contact | 2.5522 | 7.238 | 99.973 | 1.2 |
| N-1 | 1.5321 | 6.671 | 99.996 | 1.5 |

Through the analysis of different distribution grid structure, the reliability from low to high is single radiation connection mode, loop connection mode, segment connection mode and n-1 connection mode.

## IV. OPTIMIZATION STRATEGY AND APPLICATION

The current status of 10kV overhead network in a certain region is dominated by single connection mode, supplemented by a certain number of multi-segment and multi-connection connection mode. The overhead network has a long line extension and a large capacity of mounting. In addition, there are some K mode stations and P mode stations without piecewise connection, P mode station outbound direct transmission overhead line, substation outbound direct transmission P mode station, user special line or P mode station outbound direct transmission K mode station, which have a direct impact on reliability.

The 10kV overhead grid should form an overhead distribution network with an open-loop operation. The power supply shall be directly supplied by the substation according to the final multi-section three-connection connection mode. If the link switch is missing in the overhead line, the fault in the line will cause the entire line to be cut off. When this line is overhauled, all users on the line will also be cut off. The solution to this problem is to add circuit breakers to the line and to communicate with other lines.

The large number of users on the overhead line causes the user capacity to exceed the rated capacity of the line. The optimization strategy for this problem is as follows: new subsection switch is installed, or the original line is divided by combining with the new substation of peripheral infrastructure construction. After adjustment, the power cut range can be reduced and the number of power cut can be reduced.

In case of cable fault, it is difficult and takes a long time to find fault point. The optimization strategy for this problem is as follows: adding isolation device (sectional-switch) at both ends of the cable, reducing split-bar cable and directly isolating cable telemetry insulation, enhancing the technical means, optimizing wiring of the line. After adjustment, the power failure range can be reduced and the fault processing time can be reduced.

The superior power supply of type K station should be directly from substation or first-level K station. The 10kV output line of the ring website can provide 10kV users with an average single-way mounting capacity of less than 800kVA. The solving strategies of this kind of problem are: changing the type K station to be directly supplied by substation or form the double ring network form of type K station, and the type P station is supplied by type K station, cutting the line when the line segment with the rated capacity exceeding the capacity of the single line.

The total number of the line which power outage occurs more than two times is 116. According to the power grid network frame question classification, after the optimization of the grid structure, the fault of a power failure number can be reduced 194.09 per household, the plan overhaul of a power failure can be reduced 207.53 per household, the plan overhaul of the construction can be reduced 4545.32 per household, the plan overhaul of the apply for power failure can be reduced 310.04 per household. 5256.98 per household can be saved each year, accounting for 19.07% of the total power failure number, and the power supply reliability can be improved 0.0061%.

TABLE IV. LINES WHICH CAN BE OPTIMIZED

| | Number of lines | Proportion /% | Optimal quantity | Newly installed column | Reduce the household |
|---|---|---|---|---|---|
| Repeating power outage | 90 | 49.72 | 116 | 30.59km (cable),<br>23.12km(overhead line),<br>133 (sectional switch),<br>55 (contact switch) | 5256.98 |
| Number of blackouts (⩾6) | 159 | 87.85 | | | |
| Power outage time more than 8 hours (household number⩾6) | 64 | 35.36 | | | |

In total, the new cable needed is about 30.59 km, the new overhead line is 23.12 km, the newly installed sub-section switch is 133, and the connection switch is 55. The household can be reduced 5256.98 hours after the optimization. To complete the construction, some conditional supports need to be satisfied. First, the corresponding grid investment is needed to achieve. Second, it is necessary to have appropriate power point and substation space. Third, the new cable must have channel. Fourth, the new circuit breaker site must have the pole position. Fifth, overhead line connection needs to have overhead channels. The project can be carried out by stages and batches according to the 10kV delivery project of the newly-built infrastructure substation, technical renovation projects and business expansion project.

## V. Conclusion

This paper investigates the basic situation of medium voltage distribution network in a certain area, analyzes the existing problems of medium voltage distribution network from the network structure, and quantifies the factors affecting the reliability of medium voltage distribution network. Based on the analysis of the actual situation of the regional distribution network, the relevant strategies and suggestions for improving the reliability of power supply are put forward according to the distribution network target network framework, which provides a reference for improving the quality of power supply service of the distribution network. It is suggested to continue to promote the construction of distribution network upgrading project, speed up the technical transformation of distribution network equipment, focus on accelerating the transformation of high-loss equipment, old equipment and distribution network optimization, and improve the operation level of distribution network equipment and the reliability and flexibility of the grid.

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