Study on High-precision Grid Outage Region Based on Distribution Network Topology Analysis

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ABSTRACT - Based on the recursion method and the Java language, this paper develops a program for analyzing the distribution network topology diagram and explores various scenarios of power outages. The power line topology analysis can pinpoint the power outage range, providing a solid foundation for power outage information release and distribution network reliability calculation.

1. Introduction
With the vigorous advancement of the new energy security strategy of "energy consumption revolution, energy supply revolution, energy technology revolution and energy system revolution", in 2020, my country put forward the new energy transition goal of "carbon neutrality and carbon peaking" for the first time.² Under the blueprint of the strategic goal of energy transition, my country's power system is gradually developing in the direction of a new power system with renewable energy as the main body. It is worth noting that the distribution network, as the main form of distributed energy access and a key link in improving the consumption of renewable energy, is a strong guarantee for achieving the "dual carbon" goal.

But with the access of distributed new energy sources, higher requirements are put forward for the reliability of the distribution network. The possibility of failure of the low-voltage distribution network during operation is relatively high, and timely and accurate determination of the faulty line section is of great significance to reduce the user's excessive power outage and improve the reliability of power supply.

In order to accurately determine the fault area in time Section, it is necessary to accurately analyze the topology of the distribution network.

2. Distribution network topological structure
The distribution network topology diagram is a file describing the topological structure of a 10kV distribution line. It contains the essential information and topological locations of the power device, such
as the line name, line number, outgoing switch, overhead line, cable, ring network cabinet, switch cabinet, line switch, isolator and distribution transformer.

2.1 Format of distribution network topology diagram
Distribution network topology is stored in XML format. As a markup language used to mark electronic files to make them structural, the XML language is mainly applied in structural data storage.

2.2 Basic structure of distribution network topology diagram

![distribution network topology diagram](image)

1) **Line attribution**
Describe the power line providers and other information.

2) **Voltage level metadata**
Describe the voltage level metadata

3) **Device type metadata**
Describe the metadata of device types connected with each line.

4) **Device information**
Describe the basic attributes of each device on the line. Among them, the voltage level and device type all refer to metadata. It is notable that the ID of the device is critical in subsequent analysis. As Figure 2.

![Figure 2](image)
5) Terminal information
Describe the ConnectivityNode attribute, like, PD_xxxx, refers to the ID number of the Node, and multiple terminals correspond to one Node. The ConductingDevice corresponds to the ID number in the device information; the corresponding relationship may be one-on-one or two-on-one. As Figure 3.

![Figure 3 ConnectivityNode attributes](image)

6) Node information
In Node information, only the Node ID number, i.e., PD_xxxx, is useful. As Figure 4.

![Figure 4 Node information](image)

2.3 Basic analysis of distribution network topology diagram
The XML file can be analyzed by the Jsoup Library in Java. The Nodes and Terminals are mainly used to describe the line topology.

The device information includes the name, status, type, voltage level and other attributes of all devices on the line.

The Terminals part consists of multiple terminals with Terminal ID, name, type, ConductingDevice, and ConnectivityNode. Among them, ConductingDevice is the ID of the device, through which the device corresponding to the terminal can be found, and ConnectivityNode is the ID of Node

The Nodes part comprises multiple Nodes with ID numbers, which is in many-for-one correspondence with the ConnectivityNode in Terminals.

2.4 Analysis of distribution network topology diagram
The Nodes and Terminals are matched according to the ConnectivityNode. Some devices and Terminals are in a one-on-one relationship, while others are in many-for-one correspondence, as shown in the following figure:
Figure 5 The relationship of terminals and node

1) The Terminals are connected to devices in accordance with the ConductingDevice, as shown in the figure below.

Figure 6 the relationship of node terminal and devices
3. Analysis of distribution network topology diagram

3.1 Analyzing the lines into a multiple-way linked list
Nodes with the same Terminal ID are connected to yield a multi-way linked list, representing this line's basic topology, as shown in the following figure.

![Figure 7](image1)

3.2 Analyzing the lines into a tree diagram according to the power supply point
After choosing a power supply point, the multi-way linked list can be analyzed into a tree diagram by the tail recursion algorithm, just like lifting any place of a fishing net to turn it into an umbrella structure, as can be seen below:

![Figure 8](image2)

4. Precise analysis of various outage ranges

4.1 Analysis of a single line power outage
Whether it is a fault power outage or a planned power outage, in most cases, the dispatching department will only tell the power outage time, lines, and positions rather than the accurate power outage range.
Therefore, the precise power outage range can be calculated by analyzing the distribution network topology diagram, thus providing a solid guarantee for releasing power outage information and calculating the reliability of the distribution network.

1) Power supply analysis under the single-break scenario
For a single-break power supply, the root node of the tree diagram can be set as the station switch to generate the tree diagram, and the power outage range is below the leaf node where the breakpoint is located.

2) Power supply analysis of series feeding of interconnection switch through other lines under the single-break scenario
For the series feeding of interconnection switch through other lines under the single-break scenario, the root node of the tree diagram can be set as the interconnection switch to generate the tree diagram, and the power outage range is below the leaf node where the breakpoint is located.

3) Power supply analysis under the multiple-break scenario
For a multi-break power supply, the root node of the tree diagram can be set as the station switch to generate the tree diagram. The power outage range can be calculated by regarding each breakpoint as a single breakpoint and then unifying the results.

4) Power supply analysis under the scenario of breakpoints supplied by multiple power supply points
For breakpoints supplied by multiple power supply points, the tree diagram can be generated with each power supply point as the root node. The power outage range can be calculated according to the power supply under the multiple-break scenario, and the final power outage range is the intersection of the results.

4.2 Analysis of the multiple line outage
1) Power outage analysis of two separate lines
For the power outage analysis of two separate lines, the power outage range can be calculated following the steps mentioned in 3.1 and then unifying the results.

2) Power outage analysis of multiple separate lines
The calculating steps of power outage range for multiple lines are the same as those of two separate lines.

5. Precise releasing of the power outage and supply information
After the power outage range is calculated, the distribution transformers in the faulty components can be screened out. Then users’ information under each transformer can be obtained through the ledger. The accurate release of power outage information can be realized by mass texting through the contact information.

6. Distribution network reliability calculation

6.1 Calculating method for distribution network reliability
1) Annual reliability calculation of a single user

$$\text{ASPSD} = \frac{\text{Annual total power outage duration}}{\text{Annual supposed power supply duration}} \times 100\%$$

ASPSD: Annual supposed power supply duration

2) Annual reliability calculation of multiple users

$$\text{NOU} \times \text{ASPSD} = \frac{\sum \text{Annual power outage duration of each user}}{\text{Number of users} \times \text{Annual supposed power supply duration}} \times 100\%$$
NOU: Number of users
ASPSD: Annual supposed power supply duration

Where, the total annual power outage duration of each user, $\Sigma$, is called the number of power outage households. Generally speaking, the number of users is constant, and the annual power supply duration is 8,760 hours. Only when there is a power outage, the number of households is difficult to determine. Therefore, it is necessary to calculate the number of power outage households for each power outage within one year. The number of users involved in each power outage is not as easy to determine as the starting and ending times of power interruption. As a result, the dispatcher will only report the approximate power failure range when a line is partially cut off, including the power supply points and breakpoints, without targeting every user. Usually, the reliability is calculated according to the simultaneous power failure of the whole line. However, this is equivalent to expanding the power outage range, and the calculated reliability is lower than the actual. Therefore, as long as the users involved in each power outage can be pinpointed, the number of households during each power outage can be precisely calculated, thus improving the accuracy of power supply reliability calculation.

6.2 Improving the calculation accuracy of power outage households by analyzing the distribution topology diagram

To accurately calculate the number of power outage households, the information of lines involved in the power outage, the starting and ending times of power outage, the power supply points and breakpoints are obtained from the dispatching department. Then, the power outage duration is calculated using the starting and ending times. Next, through the distribution network topology diagram, the power supply points and breakpoints, the accurate power outage range is calculated, and the distribution transformers are screened out. Then, through the equipment ledger and users’ ledger information, the number of users involved in the power outage transformer, users' nature, and other information are obtained. Finally, the number of users involved in this power outage is calculated by multiplying the figure with the power outage duration.

With the number of households during each power outage, the reliability of each line, each power supply station, each power supply company in each county and other information, even the monthly and annual reliability can be calculated. It provides a solid foundation for accurately calculating the power supply reliability of the distribution network.

7. Conclusion

This article introduces the basic structure of the distribution network topology diagram, and gives the analysis method of the topology relationship, which can parse the topology diagram into a tree diagram. Based on the tree diagram, an accurate analysis of the range of power outages under various conditions is done, based on the power outage Scope analysis provides a method for accurate push of power outage and transmission information. Based on outage scope analysis and distribution network reliability calculation formula, a method to improve reliability calculation accuracy is given. In order to improve the accuracy of power outage and transmission information push A solution is proposed to improve the reliability of the distribution network.

References

[1] Li X, Gao L, Liu JT. The approach to carbon emission quotas of road transportation: a carbon emission intensity perspective[J]. Journal of advanced transportation, 2020, (3): 1-18.
[2] HU Funian, SUN Shoujuan. Fault location of distribution network by applying matrix algorithm based on graph theory[J]. Electric Power, 2016, 49(3): 94-98.
[3] XU Xinmin, MA Zhenliang. A novel algorithm for fault location in a distribution network based on topology division[J]. Electric Power, 2012, 45(5): 20-24.
[4] WEI T, MA Z, SU J, et al. Development and application of distribution network planning calculation and analysis software[J]. Southern Power System Technology, 2016, 10(5): 38-44
[5] WEI Ran, ZHANG Pan, GAO Qiangwei, et al. Simulation analysis of low-voltage distribution network fault diagnosis based on tree structure diagram[J]. Power System Protection and Control, 2021, 49(13): 167-173.

[6] HU Funian, ZHANG Ren, BIAN Xiaoliang. Fault location method of active distribution network based on graph theory[J]. Control Engineering of China, 2021, 28(5): 833-838.

[7] LI Jiawei, WANG Xiaojun, HE Jinghan, et al. Distribution network fault location based on graph attention network[J]. Power System Technology, 2021, 45(6): 2113-2121.

[8] XIAO B, ZHAO D P, JIANG Z, et al. Power supply capability evaluation of urban distribution network[J]. Power Generation Technology, 2018, 39(3): 213-219.