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Analysis and Suggestion on Neutral Grounding Mode for Shanghai Distribution Network Considering Power Supply Reliability

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Abstract. The demand for reliable power supply in large cities is the major concern for both consumers and company, and power outages have uprising influence on economic losses and social impacts. With the continuing growth of underground cable ratio in Shanghai, the medium-voltage distribution network structures are experiencing changes. The choice of grounding method has considerable impact on operation safety and system reliability. It is crucial to carry out in-depth and systematic analysis on different grounding modes. This paper analyzes the technical route, insulation coordination, protection configuration and system reliability for neutral grounding mode for Shanghai distribution network with regard to the development status and safety requirements of urban medium voltage distribution grid, providing effective technical principles and engineering proposals for system planning and safe operation.

1. Introduction

With accelerated economic development mode transformation and industrial restructuring in China, Shanghai's strategic position has become increasingly prominent. Important users such as high-tech, high value-added industries and high-precision manufacturing enterprises keep expanding, resulting higher demands for life quality and electrification of residents, and economic losses and social impacts caused by power outages are growing. Higher requirements are placed on power supply capacity, reliability and quality. The development of urban power grids is facing unprecedented opportunities and challenges [1].

Shanghai power grid has a higher cable rate causing system has a large capacitance current in single-phase ground fault. Therefore, the ratio of low-resistance in neutral grounding mode is relatively high.

By the end of 2017, the proportion of low-resistance in 35kV distribution network neutral grounding mode has reached 86.5%, the arc suppression coil accounted for 11.0% and the ungrounded accounted for only 2.5%. While in 10kV distribution network, it is 50.5%, 33.3% and 16.2% accordingly as shown in figure 1.



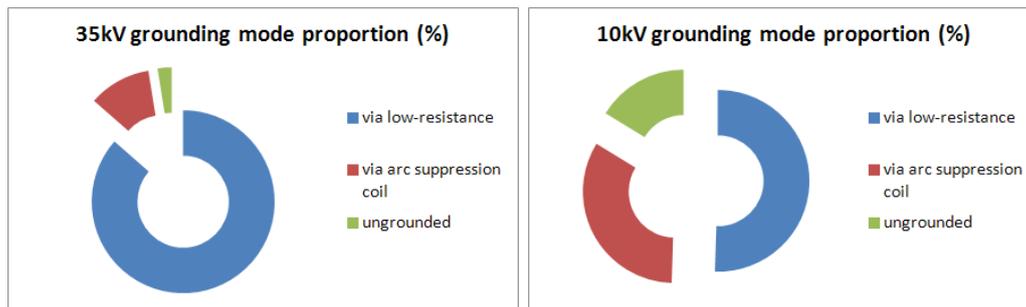


Figure 1. The proportion of low-resistance, arc suppression coil and ungrounded in 35kV and 10kV distribution network neutral grounding mode.

With the continuing growth of underground cable ratio in Shanghai, the medium-voltage distribution network structure will have to undergo major changes. We are facing problems like, what kind of grounding method will be adopted in Shanghai, how to ensure the operation safety and system reliability, and what is the difficulty for engineering transformation, etc, as shown in figure 2. It is crucial to carry out in-depth and systematic analysis to improve safety, reliability and economy of the Shanghai distribution network.

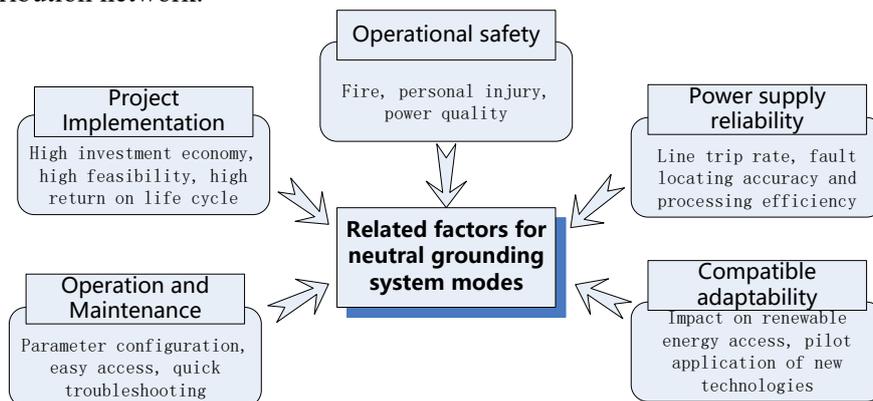


Figure 2. Related factors for neutral grounding system modes.

2. Analysis on fault events in urban distribution networks at home and abroad

2.1. Fault Case

Case 1: At 14:49 on October 12, 2016, the 275kV “Chengbei Line 3L” cable in the “Xinzuo Substation” of Saitama Prefecture, Japan, was overheated and caught fire, igniting other five transmission lines in the same cable channel in “Xindong 26”.



Figure 3. Fire scene with power failure in Tokyo.

The accident caused power loss in lower level “Nalima Substation” and “Fengdao Substation”, affecting 590,000 users in 7 regions of Tokyo. After the fault occurred, the load was transferred to nearby substations with same voltage level and the power supply was restored around 16:30 on the same day, as shown in figure 3.

Case 2: At 22 o'clock on November 19, 2018, a malfunction occurred at “Gaoxin Jinye No. 1 Road” and “Zhangbawu Road” cross-cables in Xi'an, causing power loss in several areas of high-tech zone, affecting at least 34WW load and 14,000 users, as shown in figure 4. On November 21, another fault point was found during test delivery, resulting power restoration delay. It was not until 13:30 on November 22 that the power loss area was completely restored.



Figure 4. Cable tunnel fire scene in Xi'an.

Case 3: From August 17 to 18 in 2014, three cables attached to the 35kV secondary bus line at one 220kV substation in Shanghai failed in a short period of time one after another. After the event, combined with the trip line fault recording, relay protection and switching action analysis, it is found that when the C-phase of the No. 1 cable is grounded on the 17th, the single-phase fault grounding protection did not operate due to the fact that the 35kV secondary bus line is grounded by arc suppression coil. The voltages of the other two phases increased, causing insulation damage No. 2 and 3 cables. The insulation completely broke down at weak point within two days, as shown in figure 5.



Figure 5. Cable insulation damaged point.

2.2. Fault Analysis

From the preliminary analysis of the above three cases, we can know: first, with the development of the city, the cable rate is continuously rising and the resources of the transmission channel are becoming increasingly tense. The single-circuit failure is tend to cause a chain reaction, resulting fault expansion. After that, the physically adjacent lines in the same channel are likely to have different power supply topology, service partitions and voltage levels, which make the system unable to meet the single fail-safe criterion as N-1, and the accident is difficult to recover in a short period of time.

Third, the line with cable segments should not continue to operate with fault. Especially for the case where there are overhead lines, cable lines and even hybrid lines on the bus, it is not advisable to use the arc-suppression coil grounding method, in terms of overvoltage and fault expansion.

Then, the power cable having neutral point ungrounded that is allowed to operate with fault should not share the channel with line voltage above 110kV, and those lines with neutral points ungrounded should be modified. The continue operation under faulty circumstance is prohibited. For urban power grids with high load density, high cable-forming rate and strong user sensitivity, the power users' requirements for power supply reliability are met by strong power grid structure and flexible scheduling control, rather than continuing operation with fault.

3. Analyses on Neutral Grounding System in Shanghai Medium Voltage Distribution Network Characteristics

3.1. Analyses on selecting principle for medium voltage distribution network neutral grounding system

The neutral grounding method of the medium voltage distribution network in Shanghai is divided into ungrounded mode, low resistance grounding mode and resonant grounding mode (ie, arc suppression coil grounding). According to the relevant standards and literature, for the selection of neutral grounding method, the magnitude of ground fault capacitor current is a critical reference factor.

For systems having large proportion of overhead lines, the ground fault capacitor current is relatively low and the resonant grounding method can be adopted. For systems having large proportion of underground cables, the ground fault capacitor current is relatively high and the low-resistance grounding method should be adopted. It should be pointed out that the hybrid line of the Shanghai medium voltage distribution network is equivalent to the overhead line. The neutral point is grounded through arc suppression coil, allowing operation with faults [2].

With the accelerating process of urbanization in Shanghai, the cable rate of urban power grids has increased year by year. The practical application scenarios of the medium voltage network grounding system present following characteristics:

(1) The cable dominated network has a large grid-to-ground capacitor current, so the arc-suppression coil grounding method is difficult to meet the increasing arc-extinguishing requirements of capacitive current.

(2) The cable lines are less affected by external conditions with fewer transient ground faults but generally permanent faults. The use of arc suppression coil grounding has difficulty in faulty line selection, decreasing power supply reliability manual fault detection.

(3) The process of manual trial pulling makes all the feeders on the bus bar re-charging repeatedly, especially for those lines with cable segments, the insulation damage cannot be recovered, which is most likely to cause insulation degradation and total failure.

(4) Due to the difference in operational protection control requirements, effective contact cannot be formed between different grounding systems, which limits the load transfer and also affects power supply reliability.

3.2. Insulation coordination analysis of mainstream neutral grounding system

3.2.1. Ungrounded neutral point system When a single-phase ground fault occurs in a ungrounded neutral point system, the sound phase voltage will rise to line voltage. If it is a permanent ground fault, the sound phase equipment runs for a long time under the line voltage, which is extremely unfavourable for weak insulation equipment such as old cables. At the same time, the ungrounded system is prone to the ferromagnetic resonance overvoltage of the electromagnetic voltage transformer, causing the PT fuse to blow and protect system malfunction. As the system capacitance current increases, the probability of arc grounding overvoltage will also increase. The arc grounding overvoltage can theoretically reach 7.5 times of the phase voltage, which poses a great threat to the insulation of power equipment. In fact, there are many times in the country, the insulation failure of

bus bar equipment or the phase-to-phase flashover accident caused by the arcing grounding overvoltage of ungrounded system.

3.2.2. Resonant grounding system The resonant grounding system compensates the most ground fault current, greatly reducing the probability of resonant overvoltage. However, due to the existence of high-frequency components in the intermittent arc grounding current, the arc-suppression coil is saturated, so the resonant grounding system cannot eliminate arc-grounding overvoltage. In addition, with the development of power load, the required capacity of arc suppression coil will also gradually increase. If the device capacity cannot keep up with load increase timely, the resonance will occur between capacitance and arc suppression coil. According to the recent single-phase ground faults statistics of shanghai in the past years, 27.2% of the faults in 35kV power grid with arc-suppression coil grounding system developed into two-phase two-point ground faults during the processing, which seriously affected power supply reliability.

At the same time, when the capacity configuration of arc suppression coil is unreasonable, it is easy to cause shifting and falsely grounded system neutral point.

3.2.3. Small resistance grounding system The small resistance grounding system can basically eliminate resonant and arc grounding overvoltage. The system overvoltage level is basically equal to higher voltage system. It is not allowed to operate with faults, which is conducive to the safety and stability for old equipment or other weak insulation equipment. According to Shanghai's operating experience, the small-resistance grounding system should also increase zero-sequence current protection and intermittent grounding protection.

3.3. Protection configuration principle of small resistance grounded system

The newly built 110/35kV substations all adopt small resistance grounded neutral point in shanghai power grid. The small resistor is currently connected to the 35kV main lead of 220kV transformer through a grounding transformer. The grounding transformer capacity is determined according to 1000A of grounding current and 10 seconds of flow. For this type of connection, with regard to protection requirements, the current transformer should be placed on both high and low voltage sides of grounding transformer, equipped with double protection on high-voltage side current transformer of grounding transformer. At the same time, The high-voltage side of grounding transformer is equipped with quick-break and over-current protection. The low-voltage side of the grounding transformer is equipped with zero current one stage and two stage protection [3].

Considering that the zero-sequence current protection setting value has difficulty in matching the fuse's melting curve, when the capacity in small resistance grounding system is above 800kVA and that in ungrounded system is over 1000kVA, the transformer should be configured current protection reflecting phase-to-phase fault and zero sequence protection manifesting ground fault.

4. Evaluation and recommendations on Shanghai small current grounding system operation

4.1. Evaluation and analysis on small current grounding system operation

The substation neutral point grounding method transformation, operation and maintenance involve overall planning of substation bus bar with a wide range. At present, when single-phase ground fault occurs in 10-35kV arc-suppression coil grounding or ungrounded system, the manual test-pull method will mainly be used to check the fault point, which can be easily interfered by human factors. When a single-phase ground fault occurs in a small-resistance grounding system, the faulty line is generally tripped by zero-current protection, as shown in table 1. Accordingly, the corresponding fault is checked and processed, but intermittent grounding protection is required [4].

Table 1. Comparison of operation results when single-phase ground fault occurs.

Grounding Method	Troubleshooting method	Advantages
Resonant grounded	Manual test pull	Operation with fault, lower trip rate
Ungrounded	Manual test pull	Operation with fault, lower trip rate
Low resistance grounded	Zero current protection	No overvoltage, accurate faulty line selection

The ungrounded system is easy to generate electric arc when single-phase grounding fault occurs as capacitor current exceeding 10A, causing over-voltage and discharging breakthrough at the weak insulation place of equipment. At the same time, if the arc is not self-extinguishable, it is likely to destroy the surrounding insulation and develop into phase-to-phase short circuit, expanding the accident. The resonant grounding system has a low trip rate, but the fault finding process is complicated. At the same time, due to the rapid development of city power grid, the under-compensated operating state often occurs. After the grounding protection of low-resistance grounding system, the insulation level of substation primary equipment is guaranteed, which reduces the pull-out operation amount and maintenance with increased fault trip rate, proposing higher requirements for the self-healing level of distribution automation system [5].

It should be pointed out that there is no single effective technical means to achieve accurate positioning of single-phase small current grounded faults. Therefore, other technical solutions are needed for finding lines with damaged insulation.

4.2. Influence of neutral grounding method on reliability

If the main transformer neutral point is not grounded or passed through arc suppression coil, it can run for a period of time with fault. It can even suspend the accident development through trial pull operation. Although no reliability event is generated, there is a risk of further expansion of the accident. It will not only affect the reliability indicator, but will also lead to serious grid incidents and adverse social impacts.

If the main transformer neutral point is grounded by small resistance, considering the large installation capacity of 10kV line in Shanghai area, the protection difference of line segments cannot be configured. Therefore, once the fault occurs, the K-type station or upper level substation outlet switch will be tripped, resulting feeder fully stopped. It is necessary to manually locate the fault and gradually restore the load afterwards.

Therefore, when the fault handling time is the same and the arc-suppression coil grounding system fault does not expand, the reliability index of arc-suppression coil grounding system is generally better than small-resistance grounding system from the perspective of reliability statistics.

In addition, considering that the main reason affecting power supply reliability in Shanghai at this stage is pre-arranged power blackout, the proportion of it accounting for 80%-90% of the total blackout. Furthermore, the related power grid equipment will also be out of service during the process of transforming into small resistance grounding system. The blackout increase is expected to considering scheduled operations.

4.3. Main problems of grounding system transformation

Since the Shanghai distribution network has three neutral grounding methods, as arcing coil grounded, small resistance grounded and ungrounded system, the requirements for operation, maintenance, protection configuration and material procurement are different, which increases grid operation management difficulty.

The transformation work is of great significance, but the principle should be applied to all lines and substations connected to the foremost transformation object. For the fully insulated overhead lines, the economics and practicability of this principle have yet to be demonstrated, mainly reflecting the following characteristics.

4.3.1. Highly systematic When the substation is rebuilt with new grounding method, the corresponding grounding method and protection configuration of the entire power supply system must be simultaneously transformed. After 35 kV ground systems in 220 kV station is rebuilt to small resistance, the 10 kV ground system in lower 35-110 kV station must be changed to small resistance synchronously, together with the subordinate 10 kV switching station should be modified with zero-current protection function. Otherwise, if a grounding fault occurs in any substation, it may cause to leap-level trip, extending fault range and prolonging troubleshooting time.

4.3.2. Long construction period When the substation is rebuilt with new grounding mode, if the 10 kV switch station connected to it has different grounding protection configurations, it may cause grid disconnection. Power outages are inevitable when transferring loads, and retrofitting a substation may involve multiple switch substations throughout the power supply area. Taking Songjiang Company's 110 kV Liuwu Station and Buxi Station as examples, the lower 10 kV switch substations count as 33 and 29 respectively. Objectively, the workload of 10kV transformation is far greater than that of 110kV.

5. Recommendations

For a substation with all cable outlets, since the capacitor current of grounding fault is relatively large, the low resistance grounding method must be used. For the overhead lines and hybrid lines in the A+ and A type areas, the overhead line entry project should be combined with the cable transformation, and the transition to low resistance grounding mode should be gradually implemented. For a substation with all cable outlets, since the capacitor current of grounding fault is relatively small, the neutral point can be grounded via arc suppression coil. The pilot project of intelligent line selection equipment should be carried out according to local conditions, and the accuracy of fault line selection and positioning can be improved on the basis of stable reliability. The subsequent transition to low resistance grounding mode is accessible when the grid requires modification.

After adopting small resistance grounding method, it is recommended that the A+ and A type areas with high cable rate accelerate distribution automation and self-healing system coverage to ensure system stability. It is also recommended that all power supply companies carry out the investigation and risk analysis of 110/35/10kV cables in the same trench. For the substations with small resistance grounding transformation being planned, but the outlet cable is laid in the same trench with other higher voltage cables, the analysis of failure impact should be carried out in advance. Accidents are classified according to the amount of load loss after failure, and corresponding accident handling plans and operation mode adjustments should be prepared for potential faults and other hazard.

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