SUITABLE METHODS FOR NEUTRAL GROUNDING OF XINING'S DISTRIBUTION NETWORKS

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ABSTRACT

Xining PSC and Siemens PTI recently completed a comprehensive study on optimization of neutral grounding in the distribution networks of Xining, capital of Qinghai Province, People's Republic of China.
Presently, all 35 kV and 10 kV networks are operated with isolated neutral due to damages of equipment caused by ground faults in the past when resonance grounding was applied.
In face of significant network expansions expected in the near future, suitable methods for neutral grounding had to be analyzed and individually proposed considering network characteristics such as dimensions and structure as well as share of overhead lines and cables.
The selection will be the basis for further distribution automation applications and a significant increase of supply reliability performance.

INTRODUCTION

The neutral treatment or grounding scheme has an impact on major characteristics of electrical networks such as ground fault current level, protection concept, network operation, grounding requirements, inductive interference and overvoltages during ground fault. Selection of the suitable grounding method hence requires consideration and optimization of different aspects for each partial network.
State Grid Xining Power Supply Company (Xining PSC) is operating the sub-transmission and distribution networks of Xining city in Qinghai province, People's Republic of China. Those 110 kV, 35 kV and 10 kV networks will significantly expand in the next years. The electricity peak demand is expected to increase from 1.4 GW presently to 2.0 GW in 2020. Also, some ground fault events happened in the past which caused destructive overvoltages.
Given this background, Xining PSC set up a project to analyze and propose suitable methods for neutral grounding for the scenarios 2016 and 2020 with focus on the 10 kV level. This paper summarizes the results of selected study tasks that were as follows:

- Comparison of neutral grounding schemes and applications worldwide
- Calculation of capacitive ground fault currents for 2016 and 2020 scenarios
- Weak point analysis of existing methods and evaluation of future network developments as well as operational targets
- Development of recommendations on either continuation of existing neutral grounding methods or modification of those.

PRINCIPAL COMPARISON OF NEUTRAL GROUNDING SCHEMES

Overview

The treatment of the neutral does not affect the behavior of the network under normal load conditions. However in case of a line to ground fault the behavior of the network depends decisively on the method used for neutral grounding.
Basically, the following alternatives for the neutral grounding in a medium voltage distribution network are possible (Figure 1):

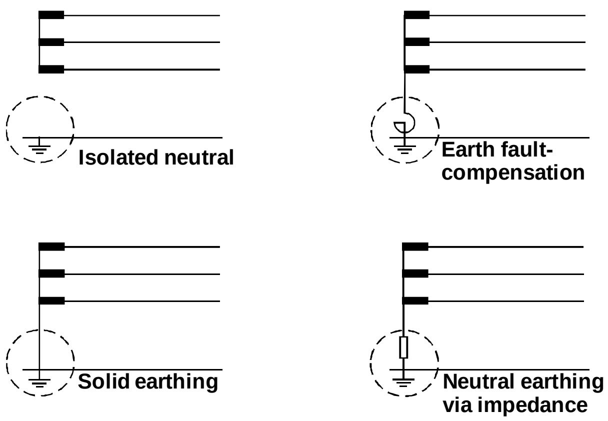

Figure 1: Typical neutral grounding schemes

Isolated neutral

The line to ground fault current is equal to the capacitive ground fault current I_{ce} of the interconnected network.

Ground fault compensation (resonance grounding)

The capacitive ground fault current is neutralized by an inductive ground fault current generated by a reactor, (Petersen coil) connected between system neutral and ground. Compared with reactive low impedance grounding this reactor has a relatively high reactance. Depending on the tuning of the system the resultant ground fault current is of a low magnitude.

Grounding via impedance

High impedance neutral grounding
The line to ground fault current is equal to the geometric sum of the capacitive ground fault current and an ohmic contribution through a neutral resistor.
Low impedance neutral grounding
The line to ground fault current is a short circuit current, which is limited by a neutral impedance (resistor or reactance) to a level well above the capacitive ground fault current.

Solid neutral grounding

The line to ground fault current is a short circuit current in the range of the 3phase fault current.

Further differences and characteristics

Besides the level of ground fault current, the neutral grounding alternatives differ with respect to:

- level of transient over-voltages
- level of power frequency over-voltages
- duration of over-voltages
- fault duration
- method to detect fault location
- type and setting range of protection
- equipment for neutral treatment
- possibility of continuous operation under fault conditions
- danger of failure enlargement

In resonance-grounded networks, high (displacement) voltages of neutral point can even occur during normal operation due to unbalanced line-to-ground capacitances. (Figure 2). .

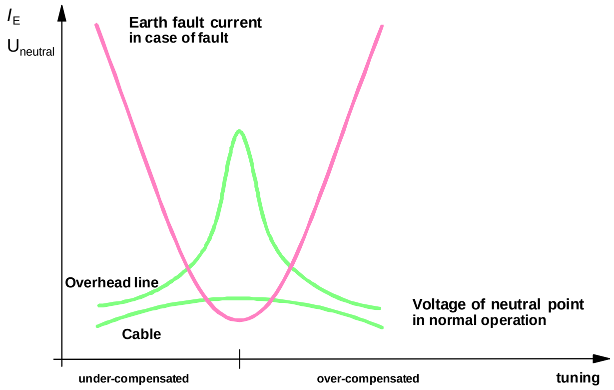

Figure 2: Effects of Petersen coil tuning

These are depending on the level of unbalance, damping conditions of the network and de-tuning of the Petersen coil. Typically, the unbalance in pure cable networks is significantly smaller than in networks with high share of overhead lines

CHARACTERISTICS AND CHALLENGES OF XINING'S DISTRIBUTION NETWORKS

Xining PSC is a city utility in the Northwest of China. It is part of Qinghai PSC. The area of supply is 466 km^2 (Figure 3). There are 1,120,000 customers in Xining.
In 2016, the peak demand of 1,370 MW is fed almost completely from the overlaying 330 kV and 110 kV grids. The Xining city network consists of 31 110 kV substations. There are 860 km of 110 kV lines, 170 km of 35 kV lines, and 2,470 km of 10 kV lines, of which 55% are cables.
According to 13th Five Year Planning of Xining grid, the peak demand will increase to 2,000 MW in 2020. During the next four years, 11 new 110 kV substations will be in operation. With respect to lines, the 35 kV line length will remain unchanged, and the 110 kV and 10 kV line lengths will increase by 170 km and 570 km respectively.

Figure 3: Geographical view of Xining network

Due to the network expansions and the high reliability requirements, more and more cables will be used in the near future. Based on the Xining city network configuration, any ground faults that occur on cable sections are nearly always permanent ground faults which must be located and cleared. For ground faults that occur on overhead lines, it is not easy to find the fault location with isolated neutral.
In order to improve the conditions from the point of view of power supply for customers and operation for the utility, new neutral treatments for the different types of Xining's distribution network are needed.

PRESENT AND FUTURE CONDITIONS

Analysis of existing methods

All 110 kV feeders are equipped with auto-reclosers. About 3-4 temporary ground faults occur per week that are cleared via auto-recloser switching actions.

For 35kV and 10kV networks, ground faults are noticed via zero-sequence voltage detection. No further devices for identification of fault-affected feeder and fault localization are available. Therefore, feeder sections have to be switched off one-by-one until the faulty feeder is found. Then, operating staff is checking the feeder manually on site until the fault location is found. Due to this time-consuming method, fault duration often exceeds 2-3 hours.

110 kV networks

The prevailing neutral grounding concept is low-impedance neutral grounding. For this purpose, all neutrals of 330/110 kV auto transformers as well as 110 kV neutrals of 110/35/10 kV transformers are directly grounded. The expected ground fault currents strongly depend on the fault location. Maximum values (e.g. 40 kA) occur close to primary substations whereas minimum values (e.g. 3.0 kA) occur at the end of long feeders. In 2020, the total line length is expected to increase by about 20 %. For both 2016 and 2020 scenario, some substations show higher ground fault currents than 3phase fault currents.

35 kV networks

The neutral grounding concept applied is either isolated neutral or resonance grounding. All Petersen coils are currently offline due to overvoltage effects occurred in the past. Capacitive ground fault currents are in the range of few Ampères only for each partial network.

In some partial networks with common Petersen coil, the zero-sequence systems of the networks are coupled. This has no negative effects during normal operation. In case of a ground fault, however, both partial networks are coupled resulting in transient overvoltages and displacement voltage in all feeders of the interconnected network. This leads to an increasing risk of double ground faults and large-scale outages in consequence. Ground fault currents in 2020 are expected to remain unchanged as there will be virtually no changes in the networks.

10 kV networks

The neutral grounding concept applied is either isolated neutral or resonance grounding. All Petersen coils are currently offline due to overvoltage effects occurred in the past. The capacitive ground fault current varies between about 120 A and few Ampères at substations with overhead line feeders only. So, the level of ground fault current strongly depends on size of the partial network and share of cable. Although the total line length is expected to increase by more than 20 % in 2020, the range of capacitive fault current will remain unchanged due to similar size of the new partial networks.

When all Petersen coils are switched off for a partial network, grounding systems of substations and ring main units must be capable to cope with the total capacitive fault current.

OPTIMIZATION

Measurements for resonance curve analysis

For selected 35 kV networks and 10 kV networks with available Petersen coils, the individual resonance curves should be determined. The measurements will provide valuable information on total capacitive ground fault current I_{CE} and resistive part I_{Ω} thereof. An example for a recorded resonance curve is given in Figure 4. Based on the results, the suitability of existing Petersen coils as well as the effectiveness of the coil controller for optimum setting is validated.

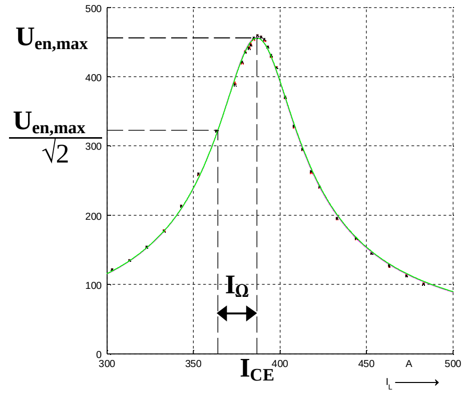

Figure 4: Resonance curve analysis.

Recommended measures for 110 kV networks

Due to the fact that feeding 330/110 kV transformers are auto-transformers, change of method of neutral grounding in one voltage level affects the ground fault conditions in the other level. Therefore, present method of low-impedance neutral grounding cannot be changed.

However, it is recommended to adjust the max. ground fault currents in a way that they do not exceed the corresponding 3phase values. This can be done either by isolating one 330/110 kV transformer’s neutral for substations with 3 or 4 transformers in parallel or installation of neutral grounding reactors at selected transformers. For both options the ground fault currents can be suitably limited. However, isolation level of the transformer neutrals as well as impact on 330 kV network has to be evaluated in advance.

Recommended measures for 35 kV and 10 kV networks

Generally, operation of isolated neutral is not recommended due to transient overvoltages in the healthy phases. In networks with ground fault currents less than 10 A there is the danger of intermittent ground faults and the risk of ferro resonance oscillations in addition.

For networks with low capacitive fault current, high-impedance neutral grounding should be introduced instead. For networks with capacitive fault currents above 45 A (35 kV networks) and 35 A (10 kV networks), resonance grounding is more suitable as practical experiences have shown that self-extinguishing of ground faults in networks with isolated neutral can only be assumed for ground fault currents below 45 A and 35 A respectively [1].
For networks with high cable share, self-extinguishing arc flashes are unlikely. So, there are no advantages of resonance grounding compared to low-impedance neutral grounding.
Table 1 sums up favorable methods of neutral grounding for different types of 10 kV networks and capacitive ground fault currents respectively.

Table 1: Favorable types of neutral grounding

	Type of 10 kV network	
	Networks with overhead line share	Pure cable networks
$I_{ce} < 35A$	**High-impedance neutral grounding**	**Low-impedance neutral grounding**
$I_{ce} > 35A$	**Resonance grounding**	**Low-impedance neutral grounding**

In case of separate partial networks, it is recommended using separate neutral grounding devices, too.
In general, possible measures to avoid significantly high zero-sequence voltages under normal operation could be operation of Petersen coils with slight overcompensation and/or reduction of unsymmetrical conditions for overhead lines.
For the residual ground fault current in case of networks with resonance grounding a value of 60 A can be tolerated. If no data is available, the residual current may be assumed to 10 % of capacitive ground fault current [2]. For the partial networks of Xining, maximum residual ground fault currents are expected to be less than 20 A.
In a first step, the resonance curve should be determined for selected networks (see above).

Recommended fault localization methods

The current method of fault localization by switching of line sections has disadvantages with respect to supply interruptions, duration and efforts for operation staff.
For fault localization in networks with high-impedance neutral grounding or resonance grounding, both transient ground fault relays and the sensitive wattmetric ground fault detection function of modern overcurrent-time relays can be used. There are inhomogeneous practical experiences with both localization methods.
Transient ground fault relays rely on the transient sequence of the ground fault and the detection process cannot be repeated.
On the other hand, for sensitive wattmetric ground fault direction detection, window-type CTs are necessary for all cable feeders. Further, increase of residual current via a resistor connected in parallel to the Petersen coil in case of low capacitive ground fault currents is recommended.
In networks with low-impedance neutral grounding, fault passage indicators should be installed at the transformer stations to support fault localization. Duration for localization can be significantly reduced when remote-controlled indicators are chosen.
Nevertheless, suitability of existing feeder monitoring and fault indication devices with respect to the recommended neutral grounding methods shall be evaluated first.

Ground fault trials

After introducing a new method of neutral treatment to a network, ground fault trials should be carried out in order to verify correct operation of protection devices and fault localization equipment as well as to familiarize operating staff with the new ground fault conditions.

CONCLUSION

Due to significant disadvantages of operation with isolated neutral such as risk of intermittent ground faults and ferro resonance oscillations, change towards alternative methods is recommended.
After selection of pilot networks for the different types of neutral grounding, the following steps are recommended:

- Networks with resonance grounding
  - Re-activation of Petersen coils
  - Measurement of resonance curve and identification of mitigation measures, if applicable
  - Selection of suitable equipment for primary and secondary level and installation
- Networks with high-impedance grounding
  - Selection of suitable equipment for primary and secondary level
  - Ground fault trials after installation
- Networks with low-impedance
  - Measurements for data collection
  - Detailed ground fault current calculations
  - Selection of suitable equipment for primary and secondary equipment
  - Protection coordination
  - Ground fault trials after installation

REFERENCES

[1] DIN VDE 0845-6-2, 2014, *Electromagnetic influence of electric power supply on telecommunication systems*, DIN/VDE-DKE, Berlin, Germany, Figure 1.

[2] EN 50522, 2010, *Earthing of power installations exceeding 1 kV a.c.*, CENELEC, Brussels, Belgium, Table 1.