Method of Locating Ground Fault in Low Resistance Grounding Distribution Network by Grounding Wire Current

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Abstract. Three-core cables are increasingly used in urban distribution networks. The shielding layer, armor layer of the three-core cable and the earthing electrode constitute the earth-electrode network. When a ground fault occurs, a regular ground wire current distribution is formed in the network. This paper analyzes the distribution law of ground current, and according to the distribution law, puts forward a kind of grounding fault location method of neutral point small resistance grounding grid, and finally designs and implements the grounding fault location system.

Keywords: Distribution Network, Ground Fault, Ground Wire Current, Low Resistance Grounding System, Ground Fault Location

1. Introduction

The "ground wire" in this paper refers to the copper foil shielding layer and armor layer of three core cables in the distribution network. They form the grounding network of the distribution network with the grounding electrode of the distribution network. "Ground wire current distribution" refers to the current distribution in the grounding network when the grounding fault occurs in the distribution network [1, 2].

Because the fault current is small and the fault characteristics are not obvious, the line selection of neutral point small current grounding grid has not been satisfactorily solved. At the same time, the capacitive current to the ground of the power grid is increasing. In order to suppress the transient overvoltage of the healthy phase caused by the single-phase grounding fault in the distribution network with non effectively grounded neutral point, the neutral point grounding method [3, 4] is gradually accepted in the distribution network, and is gradually promoted.

Due to the complex environment of distribution network, single-phase high resistance grounding fault occurs from time to time. When high resistance grounding fault occurs, the grounding fault current is small and the protection sensitivity is low, which often cannot be reflected. Therefore, improving the grounding fault protection sensitivity of small resistance grounding system [5, 6] has become a research hotspot.

The structure of distribution network is complex, there are many horizontal branch lines, and there are many vertical (from load to substation bus) stages. At present, it is far from being able to meet the
requirements of improving power supply reliability and reducing fault tracking range. Therefore, people hope to more effectively isolate the grounding fault, reduce the scope of power disconnection due to grounding fault, and start to explore the research of grounding fault section [7, 8]. The research of grounding fault location and precise location [9] has attracted many scholars. However, due to the large number of distribution network nodes, forked lines and large differences in the length of lines, it is very difficult to study transient location such as traveling wave. Therefore, these researches are still in the stage of theoretical discussion and are difficult to be applied in practice.

More and more 10kV urban distribution network is transformed into three core cable power supply mode. The copper foil shielding layer and armor layer of the three core cable and the grounding electrode of the distribution network constitute the grounding grid of the distribution network. When the grounding fault occurs in the grid, the distribution of ground current is formed in the grounding grid. According to the distribution law of ground current in the grounding grid, this paper puts forward a grounding fault location method for the neutral point small resistance grounding grid, which belongs to the grounding fault location section, and designs and implements the grounding fault location system [10].

2. Distribution of Ground Current in Distribution Network with Neutral Point and Small Resistance Grounding

![Figure 1. Three phase simulation model of grounding fault in three core cable distribution network](image)

Due to the symmetry of three core cable cores and the mutual contact of three-phase copper foil shielding layers, there is no induced voltage in the copper foil layer during normal operation of power grid, so the cables are grounded at two ends. Figure 1 is a simple cable distribution network.

The cable adopts the π type model. When single-phase grounding fault occurs in cable distribution network, there is only zero sequence current in ground current, and all zero sequence current flows into grounding network. According to the symmetrical component theory, when a single-phase ground fault occurs at \( f \), the voltage, \( \hat{U}_{afg} \), \( \hat{U}_{bf} \), and \( \hat{U}_{cf} \), at the fault point can be decomposed into three symmetrical components: positive sequence, negative sequence and zero sequence voltage:

\[
\begin{align*}
U_{afg} &= U_{1fg} + U_{2fg} + U_{0fg} \\
\hat{U}_{bf} &= a^2 U_{1fg} + a U_{2fg} + U_{0fg} \\
\hat{U}_{cf} &= a U_{1fg} + a^2 U_{2fg} + U_{0fg}
\end{align*}
\] (1)
Among them: \( a = e^{i20^\circ} = \frac{1}{2} + \frac{j}{2} \sqrt{3} ; a^2 = \frac{1}{2} - \frac{j}{2} \sqrt{3} . \)

Therefore, the three-phase circuit in Figure 1 can be divided into three symmetrical circuits for analysis. Because the phases of positive sequence and negative sequence are 1200 different from each other, the sum of the three currents at any time is equal to zero and does not flow through the fault point F. therefore, when we only need the distribution of ground current, because there is only zero sequence current and no positive sequence and negative sequence current in the ground current, the three-phase circuit in Figure 1 can be used. It can be simplified to zero sequence equivalent circuit (Figure 2), and the distribution of single-phase ground fault current in ground wire can be accurately analyzed only in zero sequence circuit.

![Figure 2. Zero sequence equivalent circuit of grounding fault in three core cable distribution network](image)

In the figure: \( i = 1 \sim n \) is the number of grounding electrode from the grounding pole of the main substation to the grounding pole on the user side; \( j = 1 \sim m \) is the number of the ground wire connected to the resistance of the "I" grounding electrode, \( m \) is the total number of ground wires connected to the "I" grounding resistance; \( I_{di,j} \) is the current of the j ground wire connected to the i grounding electrode; \( R_{ci,j} \), \( R_{Fci,j} \) and \( C_{ci,j} \) is the resistance of copper foil shield layer (three-phase) and armor layer of cable j between j and i+1 respectively. And each phase distribution capacitance; \( R_{di,j} \) is the i-grounding electrode resistance; \( R_N \) is neutral point grounding resistance; \( E_a \), \( E_b \) and \( E_c \) is three-phase power potential respectively. \( R_{ci,j} = R_{ci,j} \parallel R_{Fci,j} \) is the resistance of the ground wire in Clause j between i and i+1.

In Figure 2, \( \hat{U}_{0,fi} \) is the zero sequence voltage of the three-phase power grid in case of single-phase ground fault at f; \( \hat{i}_k = -3I_0 \) is the fault current flowing through the fault point f. According to the "Substitution Theorem" of the circuit, we replace the neutral grounding resistance \( R_N \) with \( \hat{I}_N \) current source, where \( \hat{i}_N \) is the current flowing through the neutral grounding resistance. And \( \hat{U}_{0,fi} \) is divided into \( \hat{U}_{0,fi} = \hat{U}_0 \) and \( \hat{U}_{0,fi} \) . And make \( \hat{U}_{0,fi} = \hat{U}_{0,fi} + \hat{U}_{0,fi} \). Because the current of voltage source \( \hat{U}_{0,fi} \) is the same as that of voltage source \( \hat{U}_{0,fi} \). It's equal to \( \hat{i}_k = -3I_0 \). The current source \( \hat{i}_k = -3I_0 \) is used to replace the voltage source \( \hat{U}_{0,fi} \). The zero sequence model for analyzing ground current distribution in single-phase ground fault of cable distribution network in Fig. 3 is obtained.
resistance
to resistance

Figure 3. Zero sequence simulation model of three core cable distribution network with ground fault

According to the superposition principle of linear circuit, figure 3 can be divided into three circuits, and the ground current \( I_{ldi,j} \), \( I_{nedi,j} \) and \( I_{kedi,j} \) can be analyzed and calculated independently in the three circuits. When a single-phase ground fault occurs in the neutral point small resistance grounding grid, \( I_{nedi,j} \) and \( I_{kedi,j} \) is much greater than \( I_{ldi,j} \), and ignoring \( I_{ldi,j} \) has little effect on the amplitude of \( I_{edi,j} \), therefore, the ground current can be equal to the sum of two parts, that is, \( I_{edi,j} = I_{nedi,j} + I_{kedi,j} \).

2.1. Distribution of Ground Current under Single Action of Neutral Current

In Figure 3, since the capacitive reactance of the distributed capacitance is far greater than the resistance of the grounding electrode and the resistance of the ground wire, the distributed capacitance is regarded as an open circuit, and \( I_N = -3I_0 = 0 \) (open circuit) and \( U_0 = 0 \) (short circuit) form a circuit under the action of the neutral current \( I_N \) alone, as shown in Figure 4. It can be clearly seen from Figure 4 that the neutral point current \( I_N \) starts from the neutral point grounding element \( R_N \), passes through the ground wire and grounding electrode resistance to the earth \( e \), returns to the grounding fault point \( f \), and returns to the neutral point impedance \( R_N \) through the three-phase conductor of the fault line to form a loop. This current only flows through the line from the fault point to the neutral impedance \( R_N \), and other lines (such as non-fault lines) do not flow through this current.

Figure 4. Distribution of ground current under single action of neutral current \( I_N \)

2.2. Distribution of Ground Current under the Action of Fault Current \( I_k \) at Fault Point \( f \)

In Figure 3, because the capacitive reactance of the distributed capacitance is much greater than the resistance of the grounding electrode and the resistance of the ground wire, the distributed capacitance is regarded as an open circuit, and the fault current \( I_k \) of fault point \( F \) is formed by \( I_N = 0 \) and
$U_0 = 0$, as shown in Figure 5. It is also clear from Figure 5 that the fault current $I_k$ does not flow through the conductor, but only through the ground wire and grounding electrode.

![Figure 5. Distribution of ground current under the action of fault current $I_k$ alone](image)

### 3. Simulation Verification

In order to verify the effectiveness of the proposed method, the three-phase simulation model of three core cable distribution network in Figure 1 is selected.

In the simulation, cables $L_{1,1}$, $L_{1,2}$ and $L_{1,3}$ are 400mm², 2km, 2km and 3km in length respectively, while cables $L_{2,1}$ and $L_{2,2}$ are 240mm², 2km in length, corresponding to $C_{1,1} = C_{1,2} = 0.652 \mu F$, $C_{1,3} = 0.978 \mu F$, $C_{2,1} = C_{2,1} = 0.532 \mu F$; $R_{Cu1,1} = R_{Cu1,2} = 1.075 \Omega$, $R_{Cu1,3} = 1.612 \Omega$, $R_{Cu2,1} = R_{Cu2,2} = 0.917 \Omega$, $R_{Fe1,1} = R_{Fe1,2} = 0.414 \Omega$, $R_{Fe1,3} = 0.621 \Omega$, $R_{Fe2,1} = R_{Fe2,2} = 0.778 \Omega$; $R_{el,1} = 0.5 \Omega$, $R_{el,2} = 2 \Omega$, $R_{e,2} = R_{e,3} = R_{e,3} = 4 \Omega$; \( R_N = 10 \Omega \).

The simulation results are shown in Table 1. In the table, $f_i$ indicates that the grounding fault occurs on the cable, and this simulation is on $L_{2,2}$, while $f_M$ indicates that the grounding fault occurs on the bus or switchgear, and this simulation is on the terminal bus of $L_{1,2}$ cable.

### Table 1. Simulation result data

|                | Cable section | $L_{1,1}$ | $L_{1,2}$ | $L_{1,3}$ | $L_{2,1}$ | $L_{2,2}$ |
|----------------|---------------|-----------|-----------|-----------|-----------|-----------|
|                | Head/End      | Head/End  | Head/End  | Head/End  | Head/End  | Head/End  |
| $f_i (0 \Omega)$ Grounding | $I_o$ (A) | 10.8/10.3 | 476.1/476.2 | 11.1/10.0 | 22.3/22.0 | 547.8/373 |
| $\Delta I$ (A) | 0.5 | -0.1 | 0.1 | 0.3 | 510.8 |
| $f_o (0 \Omega)$ Grounding | $I_o$ (A) | 10.1/9.5 | 490.6/490.7 | 10.5/9.2 | 24.0/23.8 | 23.6/23.4 |
| $\Delta I$ (A) | 0.6 | -0.1 | 1.3 | 0.2 | 0.2 |
| $f_i (10 \Omega)$ Grounding | $I_o$ (A) | 5.5/5.2 | 242.4/242.5 | 5.7/5.1 | 11.4/11.2 | 278.9/190 |
| $\Delta I$ (A) | 0.3 | -0.1 | 0.6 | 0.2 | 259.9 |
| $f_o (10 \Omega)$ Grounding | $I_o$ (A) | 5.1/4.8 | 248.5/248.6 | 5.3/4.7 | 12.2/12.0 | 12.0/11.9 |
| $\Delta I$ (A) | 0.3 | -0.1 | 0.6 | 0.2 | 0.1 |
| $f_i (100 \Omega)$ Grounding | $I_o$ (A) | 1.0/1.0 | 44.7/44.7 | 1.0/0.9 | 2.1/2.1 | 51.4/3.5 |
| $\Delta I$ (A) | 0 | 0 | 0.1 | 0 | 47.9 |
| $f_o (100 \Omega)$ Grounding | $I_o$ (A) | 0.9/0.9 | 45.6/45.7 | 1.0/0.9 | 2.2/2.2 | 2.2/2.2 |
| $\Delta I$ (A) | 0 | -0.1 | 0.1 | 0 | 0 |
| $f_i (1000 \Omega)$ Grounding | $I_o$ (A) | 0.1/0.1 | 4.9/4.9 | 0.1/0.1 | 0.2/0.2 | 5.6/0.4 |
| $\Delta I$ (A) | 0 | 0 | 0 | 0 | 5.2 |
| $f_o (1000 \Omega)$ Grounding | $I_o$ (A) | 0.1/0.1 | 5.0/5.0 | 0.1/0.1 | 0.2/0.2 | 0.2/0.2 |
| $\Delta I$ (A) | 0 | 0 | 0 | 0 | 0 |
4. Grounding Fault Location System
The grounding fault location system has been implemented in a 10kV distribution network of Szh power supply company. The system consists of several ground current monitoring modules (DX), substation, Rola communication system and a set of master station system, as shown in Figure 6.

![Figure 6. System composition](image)

Each ground current monitoring module is composed of on-off current transformer, ground current measurement and 484 communication. The transformer is directly sheathed on the ground wire at the beginning and end of the cable, as shown in Figure 7. After A / D analog-to-digital conversion, the ground current data is calculated and processed, and transmitted to the substation by 485 communication system. Rola is installed in the main substation and substation. Rola communication system consists of Rola RF module of each substation and a data radio station. The master station system interacts with the data transmission station of Rola communication system through RS232 interface. After the master station system obtains the real-time data collected by each grounding current monitoring module, the location of grounding fault is determined according to the proposed grounding fault location method.

![Figure 7. Installation drawing of ground current transformer](image)

5. Conclusion
The structure of distribution network is complex, with many vertical series, many horizontal branches, and large difference of line length. The grounding fault line selection and grounding fault protection are far from meeting the requirements of quickly isolating the grounding fault of distribution network nearby, improving the power supply reliability and reducing the fault tracking range. Therefore, the fault section location and fault location begin to attract attention. This paper opens up a new way for the location of grounding fault section from the aspect of signal extraction.
Based on the analysis of the distribution law of ground current in the neutral grounding network with small resistance, this paper draws the following conclusions: ① the ground current of all cable sections without ground fault is traversing, that is, the ground current at the head and end of the cable is equal in magnitude and direction; ② The sum of the ground current at the head and end of the grounding fault cable section is equal to the fault current at the grounding fault point; ③ If the ground current of all cable sections is through, that is, the ground current at the head end and the end of the cable is equal in size and direction, then there is a ground fault on the end bus of the cable with the largest ground current (including in the switch cabinet), and the ground fault is not on the cable. According to this distribution law, this paper proposes a grounding fault location method for neutral point small resistance grounding grid, and finally designs and implements the grounding fault location system. This method can also locate high resistance grounding fault.

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