Measurement Technology of Grounding Capacitance of Distribution Network Based on the Graded Adjustment of Grounding Transformer Winding

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Abstract. The traditional method of measuring grounding capacitance of distribution network is greatly affected by neutral grounding method, and the influence of harmonic elimination resistance and internal impedance of voltage transformer on measurement accuracy cannot be eliminated. Therefore, this paper proposes an accurate way to measure grounding capacitance of the distribution network which is not affected by the neutral point grounding method. It uses a special Y/△-connected grounding transformer with taps connected to the distribution network to change the zero-sequence voltage of the distribution network by adjusting the grounding tap of the high-voltage side winding of the grounding transformer, and obtains the required zero-sequence through measurement voltage and zero sequence current to find the capacitance to ground of the system. The proposed measurement method is analyzed in PSCAD/EMTDC, which shows that the method has high measurement accuracy and is safe, simple and economical for the measurement of ground capacitance current.

1. Introduction

With the economic development, the scale of cable lines has expanded, leading to the increase of grounding capacitance of the switching network, and the capacitance current to the ground increases accordingly. When a single-phase grounding fault occurs in the distribution network, if the capacitive current to ground is greater than 10A, it will cause the arc to reignite, or even destroy the phase insulation in severe cases, so the neutral point should be grounded through the arc suppression coil to compensate for the capacitive current to ground [1-4]. Therefore, the accurate measurement of grounding capacitance of the distribution network is the basis for determining the compensation capacity of the arc suppression coil.

At present, there are two kinds of methods to measure the ground capacitance of distribution network. The first type is the measurement method that needs to contact the primary equipment, such as single-phase metal grounding direct measurement method, external capacitance indirect measurement method etc. This kind of measurement method needs to directly contact the primary equipment, which has the disadvantages of test danger, complicated operation, and the measurement process has a great impact on the normal operation of the power system.
The second method for measuring the capacitance to ground of distribution network is the measurement method without contacting the primary equipment, such as sweep frequency method, two frequency method, three frequency method, etc. A method is proposed for measuring the grounding capacitance of distribution network based on the twice frequency sweep method. Although this method shortens the frequency sweep range of the frequency sweep method, it is also affected by the frequency sweep accuracy. At the same time, the arc suppression coil may be damaged due to the harmonic over-voltage caused by the grounding fault in the measurement process. A method for measuring the capacitive current of power grid by injecting three different frequencies into the neutral point is proposed. Although it overcomes the shortcomings of the three frequency method, such as injecting the frequency from the open triangle of the secondary side of the voltage transformer, which is affected by the leakage reactance of the voltage transformer, and the small measurement range, it is difficult to measure the capacitive current. The calculation process of this method is still as complicated as the conventional three frequency method, and the selection of injection signal frequency will also affect its measurement accuracy.

This paper proposes an accurate measurement method of distribution network grounding capacitance based on transformer grading regulation, which does not need additional measuring equipment. The zero sequence voltage of the system is changed by adjusting the tap of the system side winding of the grounding transformer. The distribution network grounding capacitance is calculated by measuring the required zero sequence voltage and zero sequence current, while ensuring the zero sequence voltage generated in the measurement process sequence voltage will not impact the system.

2. Accurate measurement method of grounding capacitance of distribution network

2.1. Principle
The measurement principle of grounding capacitance of non directly grounded distribution network based on transformer tap adjustment is shown in Figure 1[5], in which, \( \hat{E}_A, \hat{E}_B, \hat{E}_C \) are three-phase power supply potentials of non directly grounded distribution network, \( C_A, C_B, C_C \) are the grounding capacitance of the non directly grounded distribution network, and \( r_A, r_B, r_C \) are the leakage resistance of the non directly grounded distribution network to the ground. The neutral point of indirectly grounded distribution network \( O \) is led out through the grounding transformer connected by \( Y/\Delta \). When the switch \( S_0 \) is closed, it means that the neutral point is grounded through impedance \( Z_0 \). When \( Z_1 = R \), it means that the neutral point is grounded through small resistance. When \( Z_2 = R + j\omega L \), it means that the neutral point is grounded through arc suppression coil series resistance. When the switch \( S_0 \) is open, it means that the neutral point is not grounded. Grounding mode. \( A_H, B_H, C_H \) is the high voltage side winding of \( Y/\Delta \) connection grounding transformer. The head end of the high-voltage side winding of the grounding transformer is directly connected with the three-phase line of the non directly grounded distribution network. Tap taps are set at different positions of each phase winding on the high-voltage side of the grounding transformer. The tap taps of each phase winding can be connected to the grounding switch \( S \) through the outgoing line, which are three vacuum circuit breakers. In addition, the normally closed contacts of the two vacuum circuit breakers can be connected in series to realize locking protection, so as to ensure that two points of the winding of the grounding transformer system will not be grounded when any one phase tap is adjusted to be grounded. In the system side winding of the grounding transformer, a plurality of tapping taps \( X \) are evenly arranged. The total number of turns of each phase winding is \( N \), and the number of tapping taps of each phase winding is \( n \). The tap gear number of each phase increases from the system neutral point to the feeder outlet, which are \( 1,2,\cdots,m \). The number of coil turns from tap to neutral point \( N \) is \( N_1, N_2, \cdots, N_m, a_h, b_h, c_h \) are low voltage side winding of grounding transformer.
When the tap corresponding to a phase winding on the high voltage side of the grounding transformer \( X \) is grounded, increasing the gear of the tap can make the neutral voltage \( U_0 \) increase with the increase of the grounding gear. When measuring the capacitance to the ground, the neutral point displacement voltage should not exceed the maximum deviation value of the power system operation regulations, so as to ensure that the safe and stable operation of electrical equipment and power system will not be affected in the process of measuring the capacitance to the ground. Therefore, when measuring the capacitive current to the ground, the tap of the grounding transformer should be selected to be grounded at the lower gear.

As shown in Figure 1, according to Kirchhoff’s current law, the KCL equation is established for the closed surface surrounded by dotted line, we have[6]

\[
-(I_0 + I_s) = (E_A + U_0)(\frac{1}{r_A} + j\omega C_A) + (E_B + U_0)(\frac{1}{r_B} + j\omega C_B) + (E_C + U_0)(\frac{1}{r_C} + j\omega C_c)
\]

(1)

Neglecting the influence of three phase to earth parameter asymmetry in distribution network, we have \( C_A = C_B = C_C = C_0, r_A = r_B = r_C = r_0 \). By substituting them into (1), we get the following result:

\[
-(I_0 + I_s) = (E_A + E_B + E_C)(\frac{3}{r_0} + j3\omega C_0) + U_0(\frac{3}{r_0} + j3\omega C_0)
\]

(2)

Due to the symmetrical potential of three-phase power supply in distribution network:

\[
E_A + E_B + E_C = 0
\]

(3)

Substituting (3) into (2):

\[
C_z = 3C_0 = \frac{1}{2\pi f} \text{Im}\left(\frac{-(I_0 + I_s)}{U_0}\right)
\]

(4)

Where \( C_z \) is the total capacitance of three phases to ground of non directly grounded distribution network. Capacitive current to ground is:

\[
I_c = U_0 \cdot j\omega C_z = \omega C_z U_0
\]

(5)

Where \( U_0 \) is the phase voltage of indirectly grounded distribution network and \( f \) is the frequency of distribution network.

2.2. Implementation process

The implementation process of grounding capacitance measurement for non directly grounded distribution network based on grading regulation of grounding transformer is as follows. Firstly, the minimum gear of tap on the system side winding of the grounding transformer is adjusted for
grounding, the zero sequence voltage value calculated to primary side $U_0$ is measured from open delta voltage transformer, and the zero sequence current value calculated to primary side $I_0$ and the zero sequence current on tapped earth wire of high voltage side winding $I_s$ is measured from zero sequence current transformer. Then, using equation (4), the accurate measurement of distribution network to ground capacitance, leakage resistance and leakage current can be achieved. The measurement method is grounded through the minimum gear of tap on the system side of distribution network grounding transformer to generate small zero sequence voltage, avoiding the risk of system impact and protection maloperation caused by excessive zero sequence voltage, without affecting the normal operation of distribution network, and the measurement process is safe and reliable.

3. Simulation analysis

In order to verify the accuracy of the proposed method, a 10KV non-directly grounded distribution network model as shown in Figure 2 is built in PSCAD / EMTDC for simulation analysis[7].

![Figure 2. Simulation diagram of indirect grounding distribution network measurement based on grounding transformer graded adjustment](image)

The ground capacitance values of different lines from small to large are overhead lines, hybrid lines and cable lines. Changing the ground parameters of transmission lines in the simulation model is equivalent to measuring the ground capacitance and current values of different line types.

Turn on the switch $S_0$, indicating that the neutral point is not grounded. Regulating grounding transformer A phase high voltage side winding A1 tap grounding, at this time $I_0 = 0A$. By changing the three phase to ground parameters of the distribution network, from the measured neutral point voltage $U_0$ and the zero sequence current $I_0$ on the tap ground wire at the high voltage side, using equations (4) and (5), the measurement results of different grounding parameters of neutral point ungrounded system at A1 gear as shown in Table 1 below are obtained.

| Group | Actual value of grounding capacitance/μF | Measured value of grounding capacitance/μF | Relative error/% |
|-------|----------------------------------------|------------------------------------------|-----------------|
| 1     | 2.800                                  | 2.798                                    | 0.071           |
It can be seen from Table 1 that for different types of transmission lines in ungrounded neutral system, the error of measured capacitance to ground meets the requirements of measurement accuracy. When $C = 2.8 \mu F$, the changes of neutral point voltage $U_0$, zero sequence current $I_0$ and ground capacitance are shown in Figure 3, Figure 4 and Figure 5.

![Figure 3. Zero-sequence voltage waveform of neutral point ungrounded system](image1)

![Figure 4. Zero-sequence current waveform of the grounding wire of the grounding transformer tap of the neutral point ungrounded system](image2)

![Figure 5. Measurement of capacitance change waveform for neutral point ungrounded system](image3)

![Figure 6. Measurement of capacitance change waveform for neutral point through arc suppression coil system](image4)

Close the switch $S_0$, indicating that the neutral point is grounded through the arc suppression coil. Adjust the grounding transformer $A$ phase high voltage side winding tap $A_1$ grounding, change the distribution network three phase to ground parameters, change the three phase to ground parameters of distribution network, from the measured neutral point voltage $U_0$, zero sequence current $I_0$ and $I_S$, use formula (5) and (6) to get the measurement results of neutral point through arc suppression coil grounding system $A_1$ gear under different grounding parameters as shown in Table 2 below.

### Table 2. The measurement results of different ground parameters in the A1 gear of the neutral point through arc suppression coil system

| Group | Actual value of grounding capacitance/μF | Measured value of grounding capacitance/μF | Relative error/% |
|-------|------------------------------------------|------------------------------------------|-----------------|
| 1     | 2.800                                    | 2.798                                    | 0.011           |
| 2     | 5.700                                    | 5.696                                    | 0.070           |
| 3     | 10.000                                   | 10.006                                   | 0.060           |
It can be seen from table 2 that for different types of transmission lines in the neutral grounding system through arc suppression coil, the error of measured capacitance to ground also meets the requirements of measurement accuracy.

When \( C = 25\mu F \), the change of capacitance to ground is shown in Figure 6 above.

When the capacitance value fluctuates in the measurement process, the measurement value with small fluctuation or the mean value of the oscillation cycle can be selected as the measurement result, and the accurate measurement result of the capacitance to ground can be obtained.

4. Conclusion

In view of the fact that the influence of damping resistance and short-circuit impedance of voltage transformer can not be eliminated by the traditional measurement method of distribution network to ground capacitance, and that the traditional measurement method of distribution network to ground capacitance is greatly affected by the system grounding mode, a measurement method of non effective grounding distribution network to ground capacitance based on the hierarchical regulation of grounding transformer is proposed. PSCAD / EMTDC simulation analysis verifies the effectiveness of the technology. Using the special grounding transformer with tap \( Y / \Delta \) connection connected outside the distribution network, the zero sequence voltage of the distribution network is changed by grounding the tap of one phase high voltage side winding of the grounding transformer, and the required zero sequence voltage and zero sequence current are measured, so as to calculate the grounding capacitance of the distribution network. The zero sequence voltage generated by tap grounding of transformer does not exceed the allowable range of power system operation regulations, which will not cause great damage to power equipment and bring potential threat to the safe and stable operation of the system. Moreover, the technology is not affected by the neutral grounding mode of distribution network, so it is more applicable.

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