A Review of Fault Location Methods for Small Current Grounding Systems

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Abstract. Small current grounding system is mainly used in China's distribution network. When single-phase grounding fault occurs in the distribution network, it is important to quickly and accurately select the fault line and locate the fault section to ensure the safe and stable operation of the system. In this paper, the fault location methods for the small current grounding system are described in detail, the advantages and disadvantages of various methods are compared, the main problems existing in the low-current grounding system are pointed out, and the future development direction is prospected.

1. Introduction

Small current grounding system can be divided into active positioning and passive positioning according to the difference of its use signal. The active localization method mainly uses the external diagnosis signal for fault localization, including signal injection method, the current residual increment method; The passive localization method mainly relies on the fault signals such as voltage and current of the fault line itself for fault location when single-phase grounding fault occurs, which can be divided into steady-state localization method and transient localization method.

2. Active positioning methods

2.1. Signal injection method

The principle of the signal injection method ("S" injection method) is that when the single-phase ground fault occurs in the system, the primary side of the fault phase is short-circuited and temporarily inactive, and the specific frequency signal is injected into the ground phase’s PT through the external device. The injection signal forms a loop through the fault line’s grounding point and the voltage transformer neutral point, and using the detecting device to detect the special signal path to determine the fault line and the fault area [1]. Since the method determines the fault section by the applied signal and does not make use of the fault information of the fault line itself, it is suitable for the neutral point ungrounded system and the arc suppression coil grounding system. However, due to the limited capacity of the voltage transformer, the injected signal content is small and difficult to detect, especially when there is a large transition resistance at the grounding point and intermittent arc ground fault, the reliability is greatly reduced.
In view of the unstable situation of arc burning at the fault point, the reference [2] proposed the positioning method of "using DC to open circuit, using AC to locate". After the fault line is powered off, firstly, a constant high-voltage DC signal is injected into the fault line to ensure that the grounding point is in a breakdown state to avoid recovery insulation; then an AC signal is injected, and the fault path is detected by detecting the flow path of the injected AC signal.

Reference [3] analysis the influence of transition resistance at the grounding point, parameters of arc suppression coil and distributed capacitance of the line on the injected signal, and proposes to reduce the frequency of the injected signal and select the line using the difference of phase information of the injected signal between the fault line and non-fault line.

2.2. The change of zero-sequence current

For the neutral point arc-suppression coil grounding system, the problem of fault location cannot be achieved by zero-sequence current phase. The literature [4] points out that the arc-suppression coil parameter changed will cause the zero-sequence current to change, but only the zero-sequence current in the fault section has a change amount, by comparing the parameters before and after the change of current variation can determine the fault section.

For metallic grounding, the change of arc suppression coil parameters will not cause the change of zero sequence voltage, so only the zero sequence current in the fault section will change after the change of parameters. But for the fault point is grounded through the transition resistance, the change of the arc suppression coil parameter will cause the zero sequence voltage to change, so that the zero sequence current of the non-fault section will also change.

For the distribution network structure shown in Figure 1, it is assumed that a single-phase ground fault occurs at d, A, B and C are three FTU detection points. The zero-sequence equivalent circuit is
shown in Figure 2. After setting the fault, the parameters of current flowing through each detection before the arc-suppression coil changed is $I_A, I_B, I_C$. And the current of the arc suppression coil is $I_L$, and the zero sequence current of the test of lines is $I_\Sigma$, the current reference direction is as shown in the figure.

If the system is in overcompensated state, ignore the line resistance. The following equation is established:

$$\begin{align*}
I_a &= I_L - I_\Sigma - U_0 \omega C_a \\
I_b &= U_0 \omega C_b \\
I_c &= I_L - I_\Sigma - U_0 \omega (C_a + C_b + C_c)
\end{align*}$$

Assume that the zero sequence voltage is $U_0'$, the current flowing through each detection is $I'_A, I'_B, I'_C$, the current of the arc suppression coil is $I'_L$, and the zero sequence current of the test of lines is $I'_\Sigma$ after the arc suppression coil parameters are changed. It can get the following those conclusions:

$$\begin{align*}
\Delta I_A &= I_A - I'_A = \frac{U_0}{\omega L} - \frac{U_0}{\omega L} \\
\Delta I_B &= I_B - I'_B = (U_0 - U_0') \omega C_b \\
\Delta I_C &= I_C - I'_C = \frac{U_0}{\omega L} - \frac{U_0}{\omega L}
\end{align*}$$

Convert according to $\frac{U_0}{U_0'}$: $I'_A = I_A \frac{U_0}{U_0'}, I'_B = I_B \frac{U_0}{U_0'}, I'_C = I_C \frac{U_0}{U_0'}$, the change of zero sequence current is:

$$\begin{align*}
\Delta I_A &= I_A - I'_A = \frac{U_0}{\omega L} - \frac{U_0}{\omega L} \\
\Delta I_A &= I_B - I'_B = 0 \\
\Delta I_C &= I_C - I'_C = \frac{U_0}{\omega L} - \frac{U_0}{\omega L}
\end{align*}$$

Therefore, after the zero-sequence current is converted according to the zero-sequence voltage, the section with the current change amount is the fault section.

3. Passive positioning methods

The passive positioning method is to locate the fault information such as the current and voltage of the line itself after the fault occurs, and it can be divided into a steady state analysis method and a transient analysis method.

3.1. Zero sequence current comparison

The zero-sequence current comparison method is a method of segment positioning using the amplitude and phase characteristics of the power-frequency zero-sequence current after the fault.

After a single-phase ground fault occurs in a neutral point ungrounded system, the zero-sequence current of the fault zone before the fault point is the sum of the capacitance current of all non-faulty lines to ground and the capacitance current from the fault point to the end of the line, and the direction flows from the fault point to the bus bar; and the zero-sequence current of the downstream section of
the fault point is the capacitor current from the point to the end of the line, and the direction flows from the fault point to the end of the line. Generally speaking, the amplitude of the zero-sequence current upstream of the fault point is much larger than the amplitude of the fault downstream, and the fault section can be determined according to the zero-sequence current amplitude.

In addition, according to the characteristics of the polarity of the zero-sequence current on the upstream and downstream of the fault point, the fault section can be located by using the phase of the power-frequency zero-sequence current. However, this method is only applicable to neutral point ungrounded systems, which are more affected by line length, operation mode, and transition resistance.

3.2. Transient characteristic band method

When a single-phase ground fault occurs in a small-current grounding system, the transient component of the fault current is several times or even tens of times larger than the steady-state component. If the fault is located according to the transient information at the time of the fault, it should have higher sensitivity and reliability.

The literature [5-6] analyzes the transient situation of single-phase earth fault in small current grounding system, and proposes the concept of characteristic frequency band (SFB). Reference [5] pointed out that in the characteristic frequency range, the sound line can be equivalent to the concentrated parameter capacitance, and the zero sequence current or reactive power polarity of the fault line and the sound line are opposite, which is not affected by the arc suppression coil. The proposed feature frequency band provides a new idea for the detection method based on fault transient signals.

In [7-8], based on when the faulty occurred, the transient zero-sequence current has a capacitive relationship in the characteristic frequency range, by comparing the amplitude and polarity of the transient zero-sequence current for fault location. In [9], it is proposed to use the characteristics of the transient reactive power direction of the fault zone and the non-fault zone in the characteristic frequency range to perform segment location. The article points out that in the SFB, all the lines in the zero-sequence network can be equivalent to the concentrated parameter capacitance. The reactive power detected by the sound line and the fault point to the detection point of the load section is the equivalent capacitance absorption from the detection point to the load. The power detected by the fault detection point to the detection point at the bus bar is mainly the power absorbed by the equivalent capacitance of all the healthy lines.

Define transient reactive power:

\[
Q_0 = \frac{1}{T} \int_0^T i_0(t) u_0(t) dt = \frac{1}{\pi T} \int_0^T i_0(t) \int_{-\infty}^{+\infty} \frac{u_0(t)}{t-\tau} d\tau dt
\]

\(^\wedge 0\) is zero sequence voltage after Hilbert transformed. Fault section can be located by according to the fault point to the bus section, the reactive power of each detection point meets \(Q_0 > 0\), and the reactive power of other detection points meets \(Q_0 < 0\).

3.3. Transient zero sequence current correlation

In [10], the characteristics of transient zero-mode current are used: the transient zero-mode current waveform between adjacent detection points in the fault section is very different, and the polarity is opposite; the transient zero-mode current waveform between adjacent detection points in the non-faulty section is similar, and has same polarity. It is proposed to use the correlation coefficient for fault location.

Figure 4 shows the transient zero-mode current distribution of a single-phase earth fault in a neutral point non-effective grounding system.
Figure 3. The structure of distribution network

Figure 4. The transient zero-mode current distribution

\( i_{of} \) is the current flowing through the fault point. \( C_{as}, C_{01}, C_{02} \) are the capacitance to ground of generator, line I and line II respectively. \( C_1, C_2, C_3, C_4 \) are the capacitance to ground for the regions MN, NF, FP and PE.

The transient zero mode current flowing through the detection points M and N satisfies the following relationship:

\[
i_{OM} = i_{ON} + i_{C1}
\]

\[
i_{OM} = i_{01} + i_{02} + i_{as} + i_{L}
\]

Due to the short distance of the MN section, its current to ground capacitance is smaller than the sum of zero mode currents of all non-faulty lines. So \( i_{ON} \approx i_{OM} \) the waveforms of these two detection points are basically similar.

The zero mode current flowing through the detection point P is \( i_{OP} = i_{C4} + i_{OE} \). Therefore, \( i_{OP} \) and \( i_{OE} \) are basically similar.

When a single-phase ground fault occurs in a small current grounding system, it is equivalent to attaching a virtual voltage source to the fault point \( U_{of} \).

The actual flow of the zero-mode current flowing from the fault point is shown by the dotted line in the figure. The direction of the zero-mode current upstream of the fault point points from F to M, and the direction of the zero-mode current downstream of the fault point points from F to E. Therefore, the zero mode currents detected on both sides of the fault point have opposite polarities, and the waveforms are very different, and there is no similarity.
Define the correlation coefficient $\rho$ as:

$$\rho = \frac{\sum_{n=1}^{N} i_{01}^{n}(n) i_{02}^{n}(n)}{\sqrt{\sum_{n=1}^{N} i_{01}^{2}(n) \sum_{n=1}^{N} i_{02}^{2}(n)}}$$

$i_{01}$ and $i_{02}$ are transient zero mode currents of adjacent detection points. Comparing the correlation coefficients of each detection point, the correlation coefficient of the adjacent detection points of the fault section is close to 0; the correlation coefficient of the adjacent detection points of the non-fault section is close to 1. By setting the threshold $\alpha$, calculate the transient zero-mode current correlation coefficient on each side of the faulty line in turn and compared with the threshold. If $\rho > \alpha$, it is judged as a non-faulty section; if $\rho < \alpha$, it is judged as a faulty section.

4. Problems and development trends of fault location

When a single-phase ground fault occurs in a small current system, it is difficult to extract and discriminate the fault signal because the fault current is weak and affected by the transition resistance, the line operation mode, and the measurement accuracy of the transformer. Although it has achieved certain results in the small current system positioning method after several years of research, due to various types of ground faults, there is no fault location method suitable for all situations. Therefore, in the research of small current system fault location, the research should focus on the following problems: (1) In-depth analysis of the characteristics of small current ground faults, to improve the analysis and extraction of fault signals; (2) Combine multiple fault detection methods to solve the problem of low applicability and accuracy of a single positioning method; (3) Improve the development of transient fault indicators for fault location, make full use of fault signal transient information, and improve the automation level of distribution network.

5. Conclusion

The fault location of distribution network is of great significance to ensure the reliability of power supply. This is a summary of the fault location methods currently applied to small current systems. According to the different signals, it is divided into active positioning and passive positioning. The principle of some of the positioning methods is introduced in detail, the advantages and disadvantages of various positioning methods are analyzed and compared, and the development trend of the next step is prospected.

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