Wavelet Analysis-Based Simulation Study Of Small-Current Ground Fault System Routing

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Abstract. Small-current grounding is commonly used in medium-voltage distribution networks in China, including ungrounded neutral points, grounding via arc extinguishing coil and resistance grounding. In this paper, the power system modeling simulation of the grounding system via arc extinguishing coil and the transient characteristics when single-phase grounding occurs are studied. The principles and methods for selecting the wavelet basis function in transient component line selection are given. Wavelet analysis of the line current is carried out. It is verified by simulation that the wavelet analysis method in the small current ground fault selection can compare the difference of different lines.

1. Introduction
Various methods based on artificial neural networks (ANN) have been carried out by many scholars to route single-phase ground faults, and active research on transient processes using wavelet algorithms is still ongoing [1-3], and the search for the optimal wavelet basis functions is ongoing [4]. However, experiments for simpler methods are still being explored, including how to use the optimal wavelet basis function for the analysis of the zero-sequence voltage and current transient components. In this paper, we first model the power system, set up a single-phase ground fault for one of the lines, and then decompose the transient fault current signal using a wavelet algorithm and compare and analyze the use of commonly used wavelet basis functions.

2. Neutral Points Through The Arc Extinguishing Coil Grounding System Fault Analysis
When the use of arc extinguishing coil, single-phase grounding current distribution will change greatly, assuming that the network shown in Figure 1, the neutral point access arc extinguishing coil, when the line on the A-phase ground, the capacitive current size and distribution with the arc extinguishing coil is the same, the difference is in the grounding point and an additional inductive component of the current \( I_L \). Therefore, the total current flowing back from the grounding point is \( I_f = I_L + I_{c_L} \), where \( I_{c_L} \) is the whole system capacitance current to ground. \( I_L \) is the current of the arc extinguishing coil. Let \( L \) be used to represent its inductance, then \( I_L = \frac{-E_d}{j\omega L} \).
After the single-phase ground-fault current occurs, the voltage balance equation in Figure 2 is listed

\[ u(t) = u_L + u_R + u_C = L \frac{di}{dt} + iR + u_C = LC \frac{d^2u_c}{dt^2} + RC \frac{du_c}{dt} + u_c \]  

(1)

The characteristic equation of this differential equation is

\[ LCP^2 + RCP + 1 = 0 \]  

(2)

It has the following solutions.

\[ P_{1,2} = -\frac{R}{2L} \pm \sqrt{\frac{R^2C - 4L}{4L^2C}} = -\delta \pm \sqrt{\delta^2 - \omega_0^2} \]  

(3)

where \( \delta = \frac{R}{2L} \) is the attenuation coefficient of the free component, and \( \omega_0 = \frac{1}{\sqrt{LC}} \) is the free oscillation frequency of the loop.

When \( R < 2\sqrt{\frac{L}{C}} \), when \( \delta < \omega_0 \), let \( \omega = \sqrt{\omega_0^2 - \delta^2} \), which represents the angular frequency of the free oscillation of the loop, then at this time the \( P_{1,2} = -\delta \pm j\omega \). The solution of this differential equation equation consists of two components, the own component and the forced component. The free component is.

\[ u_c^* = Ae^{-\delta t} \sin(\omega t + \theta) \]  

(4)

\[ i^* = C \frac{du_c^*}{dt} = CAe^{-\delta t} [-\delta \sin(\omega t + \theta) + \omega \cos(\omega t + \theta)] \]  

(5)

When R and L are neglected, their forced components are

\[ u_c^* = U_n \sin(\omega t + 90^\circ) \]  

(6)

\[ i^* = -U_n \omega C \sin \omega t \]  

(7)

Therefore.

\[ u_c = u_c^* + u_c' = Ae^{-\delta t} \sin(\omega t + \theta) + U_n \sin(\omega t + 90^\circ) \]  

(8)

\[ i = i^* + i = CAe^{-\delta t} [-\delta \sin(\omega t + \theta) + \omega \cos(\omega t + \theta)] - U_n \omega C \sin \omega t \]  

(9)
According to the initial condition, when the moment of closing the gate, \( t = 0 \), \( u_c = 0 \), \( i = 0 \), the unknowns \( A \) and \( \theta \) can be found by the following equation.

\[
A \sin \theta + U_m = 0
\]

\[
CA[-\delta \sin \theta + \omega' \cos \theta] = 0
\]

We can obtain

\[
\sin \frac{\omega'}{\delta} = \frac{U_m}{\sin \theta}, \quad A = -\frac{U_m}{\sin \theta} = -U_m \frac{\omega_b}{\omega}.
\]

After substituting the above equation and simplifying it, the circuit current can be found as follows.

\[
i = \frac{U_m}{\omega L} e^{-\delta t} \sin \omega t - U_m \omega C \sin \omega t
\]

In fact, since \( \delta \ll \omega_b \), so it can be approximated as \( \omega' \approx \omega_b \), then we get.

\[
i = U_m \omega_b C e^{-\delta t} \sin \omega_b t - U_m \omega C \sin \omega t = U_m \omega C \left( \frac{\omega_b}{\omega} e^{-\delta t} \sin \omega_b t - \sin \omega t \right)
\]

Since \( U_m \omega C \) is the capacitive current \( I_C \) in the steady-state case, and also when \( t = \frac{T_a}{4} \) when \( \sin \omega_a t = 1 \), the value of the free component is the largest, so the maximum current value \( i_{max} \) of the first half wave in the transition process can be found, and \( i C \frac{\omega_b}{\omega} e^{-\delta t} \sin \omega_b t \).

If the fault occurs near the instantaneous value of the phase voltage is zero, the value of the transient component of the capacitance current is very small, and the maximum value of the capacitance current is related to the instantaneous value of the phase voltage at the moment of grounding during the transition.

3. Modeling

Based on the above theoretical analysis, the three-phase power system is simulated and analyzed. In Figure 3 of the simulation model, the power supply uses the "Three-phase source" model [5], the output voltage is 11kV, the internal wiring is Y-shaped connection, the positive sequence parameters: 0.01273\( \Omega/km \), 0.9337e-3 H/km, 12.74e-9 F/km, and the zero sequence parameters: 0.3864\( \Omega/km \), 4.1264e-3 H/km, 7.751e-9 F/km. Parameters: 0.3864\( \Omega/km \), 4.1264e-3 H/km, 7.751e-9 F/km. V-1 is the voltage and current measurement module. Figure 4 shows the amplitude-phase analysis of the line current, from which it is not possible to determine the faulty line, so further wavelet analysis of the line current is required.
4. Simulation Of Currents Using Wavelet Analysis

Daubechies wavelets are the most widely used and more mature family of orthogonal real wavelet functions in engineering [4], referred to as the DbN wavelet family (N is the wavelet sequence number). There are 49 wavelets in this series, which are (Db1~Db49), and they all have finite tight branching. The characteristics of this wavelet family are: the branch length is L=2N, the order of vanishing moments Mv=N; the time localization becomes gradually worse as the sequence number N increases, but the regularity increases and the frequency domain localization becomes better.

The concentration of wavelet energy is measured using the following.

$$E_{\text{total}} = \sum_{i=1}^{N-1} |\psi_i|^2$$  \hspace{1cm} (14)

The above equation is the total energy of wavelet $\psi_i$, where N is the length of half wavelet function make $E_{\text{local}} = \sum_{i=n}^{N} |\psi_i|^2$

Eq. is the local energy of wavelet in $2n$ length, then the degree of wavelet energy concentration is expressed as the $D_{\text{cent}}$ value when $E_{\text{local}}/E_{\text{total}}=70.7\%$.

$D_{\text{cent}}$ is defined as.

$$D_{\text{cent}} = 1 - n / N$$  \hspace{1cm} (15)

| Serial no. | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $D_{\text{cent}}$ | 0.7227 | 0.7365 | 0.7405 | 0.8184 | 0.8250 | 0.7808 | 0.8019 | 0.7833 | 0.7765 |

From the above table, we can see that, Db5 and Db6 are more concentrated in energy, and the energy tends to be stable from Db10. In this paper, Db2, Db5 and Db10, as well as the number of decomposition layers, will be compared and analyzed.

Firstly, Db2, Db5 and Db10 are decomposed three times (the analysis results for Db5 are omitted), and it can be seen from Figure 5-8 below that Db10 has lost data when processing some of the signals, so the choice of Db2 is appropriate.
From the following figures 9-10, the wavelet decomposition layer increases, the decomposition signal becomes clearer. This paper omitted the decomposition of line 2, line 2 characteristics with line 1. After comparison, it was found that the faulty line was in the negative direction for the first time.
away from the origin at the 8th level of decomposition. It is the basis for line selection and has a wide processing capability on the time scale.

Figure 9. Line1 Db2

Figure 10. Line3 Db2

5. Conclusion
In this paper, the power system modeling simulation of the grounding system via arc extinguishing coil and the transient characteristics when single-phase grounding occurs are studied. The principles and methods of wavelet basis function selection in transient component selection are compared, and the effect of Db2 is better than other wavelet basis functions by comparative analysis. It is verified by simulation that the wavelet analysis method in the small current ground fault selection can compare the difference of different lines. The wavelet method proposed in this paper needs further verification in practical applications.

References
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