A Fault Section Location Method Based on Matrix Beam Algorithm

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Abstract. A fault segment localization method of resonant grounding system based on matrix beam algorithm is proposed. Analyzing the difference of the positive-sequence real-time current in the fault-added state between the upstream and downstream of the fault point when a single-phase ground fault occurs in a small-current grounding system. The criterion of the fault section is that the positive-sequence real-time current mainly flows through the upstream of the fault point. On this basis, the matrix beam algorithm is used to extract the instantaneous positive-sequence real-time power frequency amplitude of each detection point on the fault line of the resonant grounding system, and the area between two adjacent detection points with the largest amplitude difference on the fault path is the fault section. In addition, the effectiveness of the method is verified by the built matlab model.

1. Introduction
In China, the resonant grounding system in small current grounding systems is widely used because it has the function of compensating for fault current[1]. According to the fault data of the power sector, the probability of a single-phase ground fault occurring in the resonant grounding system is about 80%. Therefore, on the basis of fault line selection, determining the distance of the fault point or the location of the section is important for improving the reliability of power supply[2-4].

At present, there are two main methods for locating fault zones. The first is based on the fault segment location of the injected signal. The method determines the location of the fault point by detecting the distribution of the injected signal in the system, but such methods have the disadvantages of increasing cost and being affected by PT capacity, and the positioning effect is not ideal; the second method is based on the fault segment positioning of the fault signal. The method uses the characteristics of the voltage and current signals generated by the fault itself to determine the fault location. The fault signal includes the transient signal and the steady state signal. Transient signals are rich in content, but the time is short and difficult to measure. The characteristics of steady-state signal faults are not obvious, which makes the difference between the upstream and downstream of the fault point small, affecting the fault segment location, and the number of fault features extracted by mathematical tools is also affected by factors such as grounding resistance, fault closing angle, and fault location[5-6], which affects the correctness of fault segment location.

The matrix beam algorithm does not need filtering, and can truly reflect the composition of the fault transient signal, and has the advantages of strong anti-noise ability and fast calculation speed. In this paper, the matrix beam algorithm is used to extract the instantaneous positive sequence current frequency amplitude under the additional state of fault, and the fault segment is determined according to the criterion that the instantaneous positive sequence real current mainly flows upstream of the fault...
point. Finally, a 10kV matlab system simulation model is built to verify the effectiveness of this method under different fault conditions.

2. Fault Analysis of Instantaneous Sequence Network in Fault Attached State

When a single-phase ground fault occurs in the resonant grounding system, the system generates a positive sequence fault current. In this method, the instantaneous positive sequence current of the additional state is defined as: the difference between the positive sequence current after the fault and the fault current before the fault.

The fault-added state instantaneous positive sequence network model is shown in Figure 1. There are three outgoing lines in the system, and there are two line branches on the third line. In the figure 1, a, b, c, d, e, and g are the six detection points installed on the faulty line three. For each detection point, the instantaneous positive sequence current of each detection point of the fault line is $\Delta i_a$, $\Delta i_b$, $\Delta i_c$, $\Delta i_d$, $\Delta i_e$, and $\Delta i_g$, and when the single-phase ground fault occurs at the point f of the line, the relationship between the instantaneous positive sequence currents at each detection point on the upstream and downstream of the fault point is analyzed as follows.

![Fig 1. Fault-added state instantaneous positive sequence real part network model](image)

The dotted line in Figure 1 is the flow path of the instantaneous positive sequence current of the fault-added state in the system, which can be obtained from the analysis in Fig 1:

1) Analysis of the fault path at the branch

Instantaneous positive sequence current difference between adjacent detection points b and c:

$$\Delta i_b - \Delta i_c = 0$$

(1)

Instantaneous positive sequence current difference between adjacent detection points b and d:

$$\Delta i_b - \Delta i_d = \Delta i_f$$

(2)

2) Analysis of fault sections

The positive sequence current of each detection point upstream of the fault point is:

$$\Delta i_{up} = \Delta i_b = \Delta i_c = \Delta i_e = \Delta i_f$$

(3)

The positive sequence current of each detection point downstream of the fault point is:

$$\Delta i_{down} = \Delta i_g = 0$$

(4)

The positive sequence current difference between upstream and downstream of fault point is:

$$\Delta i_{up} - \Delta i_{down} = \Delta i_f$$

(5)

It can be seen from the above analysis that the instantaneous positive-sequence real-time power-frequency current mainly flows through the upstream detection points a, b, c, and e of the fault point in Fig 1. The instantaneous positive sequence real current of the detection point d on the non-faulty branch and the detection point g downstream of the fault point are zero.
3. Fault Segment Location Based on Matrix Beam Algorithm

3.1 Principle of Fault Segment Location Based on Matrix Beam Algorithm

It is assumed that the signal can be expressed as a linear combination of M exponential functions with arbitrary amplitudes, phases, frequencies, and attenuation factors[7-8], namely:

\[ y(kT_s) = x(kT_s) + n(kT_s) = \sum_{i=1}^{M} R_i e^{(-\alpha_i + j\omega_i)kT_s} = \sum_{i=1}^{M} R_i z_i^k + n(kT_s) \quad (6) \]

Where: \( y(kT_s) \) is the sampling signal, that is, the sum of the actual signal \( x(kT_s) \) and the noise signal \( n(kT_s) \); \( R_i \) is the complex amplitude; \( \alpha_i \) is the attenuation factor; \( \omega_i \) is the signal angular frequency; \( M \) is the signal order; \( z_i = e^{-\alpha_i + j\omega_i}T_s \).

1) Signal pole \( z_i \) solution process

Construct the original matrix from the given sampled signal:

\[ Y = \begin{bmatrix} y(0) & y(1) & \cdots & y(L-1) \\ y(1) & y(2) & \cdots & y(L) \\ \vdots & \vdots & \ddots & \vdots \\ y(N-L) & y(N-L+1) & \cdots & y(N-1) \end{bmatrix}_{N-L+1 \times M} \quad (7) \]

Where: \( N \) is the sampling point, \( L \) is the beam parameter, \( L = \frac{N}{3} - \frac{N}{2} \).

The signal pole \( z_i \) is the eigenvalue of the matrix, where \( Y_1 \) is subtracted from matrix \( Y \) eliminating the last row, and \( Y_2 \) is subtracted from matrix \( Y \) eliminating the first row.

2) Solution process of signal complex amplitude \( R_i \)

According to the known matrix \( y_{N \times L} \) and \( z_{N \times M} \), the following formula can be listed

\[ \begin{bmatrix} y(0) \\ y(1) \\ \vdots \\ y(N-L) \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ z_1 & z_2 & \cdots & z_M \\ z_1^{N-1} & z_2^{N-1} & \cdots & z_M^{N-1} \end{bmatrix} \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_M \end{bmatrix} \quad (8) \]

Where: \( M \) is the number of non-zero eigenvalues of matrix \( B \).

3) Solving the parameters

According to the complex amplitude value \( R_i \), the amplitude \( A_i \), phase \( \theta_i \), attenuation factor \( \alpha_i \) and angular frequency \( \omega_i \) of the signal can be obtained:

\[ \begin{align*}
A_i &= |R_i| \\
\theta_i &= \arctan \frac{\text{Im}(R_i)}{\text{Re}(R_i)} \\
\alpha_i &= \frac{-\text{Re}(\ln z_i)}{T_s} \\
\omega_i &= \frac{\text{Im}(\ln z_i)}{T_s}
\end{align*} \quad (9) \]

3.2 Process of Fault Segment Location Based on Matrix Beam Algorithm

The method uses the matrix beam algorithm to extract the positive-sequence real-time power frequency amplitude in the additional state for segment positioning, and the steps are as follows.
4. Simulation Experiment

4.1 System Model
The system simulation model is built by using Matlab. The simulation model adopts 10kV system, and there are three outlets. The neutral point of the transmission side transformer is grounded via the arc suppression coil, as shown in Fig 3.

Fig 3. Simulation model of arc suppression coil grounding system at neutral point
The line of the distribution network is set to π type transmission line. The main parameters of the system are set as follows, the voltage level is 110kV/10kV; the positive sequence parameter is \( R_t = 0.132 \Omega/km \), \( L_t = 1.009 \times 10^{-3} \ H/km \), \( C_t = 6.1 \times 10^{-8} \ F/km \); The zero sequence parameter is \( R_z = 0.84 \Omega/km \), \( L_z = 1.009 \times 10^{-3} \ H/km \), \( C_z = 6.1 \times 10^{-8} \ F/km \).
\[ R_0 = 0.232 \Omega/km, \quad L_0 = 5.004 \times 10^{-3} H/km, \quad C_0 = 3.8 \times 10^{-8} F/km; \quad l_1 = 18 km, \quad l_2 = 20 km, \quad l_{31} = 17 km, \quad l_{32} = 14.5 km, \quad l_{33} = 16 km. \]

### 4.2 Simulation Example

The fault occurs between the detection points 8-9, the grounding resistance is 50Ω, the compensation of the arc suppression coil is 10%, and the fault closing angle is 60°. The result is as follows.

![Instant positive sequence real current waveform of each detection point](image)

**Fig 4.** Instant positive sequence real current waveform of each detection point

**Table 1.** Instantaneous positive sequence real power frequency amplitude of each detection point

| Rg(Ω) | Fault path judgment | Fault path | Instantaneous positive real current power frequency amplitude | Fault section |
|-------|---------------------|------------|------------------------------------------------------------|---------------|
| 50    | 0.65 0.79           | 2-8        | 0.65 0.65 0.79 0 0.04                                      | 8-9           |

### 4.3 Method Adaptability Analysis

In the following, taking the fault between the detection points 5 and 6 as an example, the fault segment positioning results under different grounding resistances Rg, different fault closing angles \( \theta \) and different compensation degrees \( p \) are analyzed, as follows:

**Table 2. Determination of fault branch under different grounding resistance (\( \theta = 45°, \ p=10% \))**

| Rg(Ω) | Fault path judgment | Fault path | Instantaneous positive real current power frequency amplitude | Fault section |
|-------|---------------------|------------|------------------------------------------------------------|---------------|
| 10    | 0.66 0.67 0.68 0.69| 2-3-5      | 0.64 0.66 0.63 0.67 0.68 0.65                              | 5-6           |
| 100   | 0.58 0.67 0.66 0.65| 2-3-5      | 0.59 0.58 0.67 0.62 0.65 0.65                              | 5-6           |
| 1000  | 0.55 0.54 0.54 0.54| 2-3-5      | 0.55 0.55 0.54 0.54 0.47 0.54                              | 5-6           |

**Table 3.** Judgment of fault branch under different compensation modes (\( \theta = 90°, \ R_g=100Ω \))

| p     | Fault path judgment | Fault path | Instantaneous positive real current power frequency amplitude | Fault section |
|-------|---------------------|------------|------------------------------------------------------------|---------------|
| 10%   | 0.58 0.67 0.66 0.65| 2-3-5      | 0.59 0.58 0.67 0.62 0.65 0.65                              | 5-6           |
| 0%    | 0.26 0.36 0.36 0.36| 2-3-5      | 0.28 0.26 0.36 0.36 0.36 0.38                              | 5-6           |
| -10%  | 0.79 0.69 0.69 0.69| 2-3-5      | 0.72 0.79 0.69 0.66 0.69 0.67                              | 5-6           |

**Table 4.** Determination of Fault Branches under Different Fault Closing Angles (\( p=10%, \ R_g=100Ω \))

| \( \theta \) | Fault path judgment | Fault path | Instantaneous positive real current power frequency amplitude | Fault section |
|--------------|---------------------|------------|------------------------------------------------------------|---------------|
| 0°           | 0.58 0.69 0.60 0.59| 2-3-5      | 0.68 0.58 0.69 0.60 0.59 0.59                              | 5-6           |
| 45°          | 0.68 0.63 0.65 0.65| 2-3-5      | 0.64 0.68 0.63 0.65 0.65 0.65                              | 5-6           |
| 90°          | 0.58 0.67 0.62 0.65| 2-3-5      | 0.59 0.58 0.67 0.62 0.65 0.65                              | 5-6           |
After the above simulation data analysis, we can get the following conclusions:

1) Under different fault conditions, the difference between adjacent detection points on the fault path is close to zero, and the gap between the faulty branch and the adjacent detection point on the non-faulty branch is large, so that the fault path can be judged;

2) Under different fault conditions, the instantaneous positive-sequence real-time power frequency amplitude downstream of the fault point extracted by the matrix beam is 0, and the instantaneous positive-sequence real-time power frequency amplitude upstream of the fault point is large, thus correctly determining the faulty section.

5. Conclusion
In this paper, a fault segment localization method for resonant grounding system based on matrix beam algorithm is proposed. The instantaneous positive-sequence real-time current frequency amplitude of fault-added state caused by single-phase ground fault is analyzed, and its fault point is analyzed. Based on the characteristics of the downstream, the matrix beam algorithm which can extract the instantaneous power frequency amplitude of the real-time current is proposed with high precision. After further simulation, the method is effective under different fault conditions.

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