A Fault Location Method Based on Multiple Signal Classification Algorithms

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Abstract

Aiming at the difficulty of identifying transient traveling wave head in traveling wave ranging, a fault location method based on multi-signal classification algorithm is proposed, which does not need to identify the nature of traveling wave head. For transmission lines, fault location can be achieved by the relationship between the natural frequency of fault traveling wave and fault distance, because the discontinuity of wave impedance after fault will form the natural frequency spectrum. The natural frequency method is used to locate the fault location, and the MUSIC algorithm is introduced to obtain the principal components of the natural frequency, so as to obtain the fault distance. The simulation calculation of MATLAB shows that the method is not affected by fault distance, transition resistance, fault type and wiring mode, and the ranging is accurate and robust.

Keywords

Transmission line, fault location, natural frequency, MUSIC.

1. Introduction

High-voltage transmission line is the economic lifeblood of power system, which bears the important task of transmitting electric energy. Power system disintegration accidents caused by line faults have occurred both at home and abroad, so line faults must be cleared in time. When a fault occurs, the transmission line protection system should analyze and respond, isolate the fault line and maintain the stability of the system. Fault location means finding the fault location after the fault occurs, removing the fault and restoring the operation. Accurate fault location is very important to the maintenance of the line and the reliability of the system. Fault location technology has been greatly developed in the past decades. According to its working principle, it can be divided into natural frequency method[1]and traveling wave method[2].

The natural frequency method is based on the traveling wave natural frequency localization method. It does not need to identify the characteristics of traveling wave head, and locates the fault according to the calculation relationship between the natural frequency and the fault distance[3].

Literature [4] has done a lot of research on the feasibility of natural frequency method for fault location, and systematically studied the relationship among the natural frequency of fault traveling wave, fault distance and system condition of line terminal under the condition of any system equivalent impedance value. Reference [5] Considering that series capacitors and their non-linear protective devices make fault location difficult for series compensation lines, a fault location algorithm for series compensation transmission lines based on traveling wave natural frequency is proposed. In reference[6], the natural frequency method is applied to fault location of HVDC lines. The mechanism of the influence of natural frequency on traveling wave fault location is analyzed, and a fault location algorithm for HVDC lines based on the natural frequency of traveling wave is proposed.

Fault location technology based on single-ended natural frequency has the advantages of simplicity, reliability, easy realization and wide applicability. At present, this method is applied in the theoretical and experimental stage. However, with the development of communication technology, GPS and spectrum analysis technology, fault location technology based on single-ended traveling wave natural frequency has strong vitality, and has great development prospects in future relay protection.

2. Natural Frequency Spectrum Analysis

(A) The fundamental principle of natural frequency

The transient traveling wave propagating along the transmission line after the fault occurs in the frequency domain as a series of harmonic forms of a specific frequency, called the natural frequency. Among them, the frequency value with the highest energy and the largest amplitude is called the natural frequency principal component. The relationship between fault distance and principal component of natural frequency is given in reference[7]:

$$d = \frac{v}{2f} \tag{2.1}$$

Where:

d Fault distance; v Traveling wave velocity, It can be seen from reference [8] that the velocity of wave is 0.987 times that of light, $v = 2.961 \times 10^8 m/s$; f Principal Component Value of Natural Frequency.

(B) Extraction of Natural Frequency of Fault Traveling Wave

The frequency of the fault traveling wave does not change with time. The fault traveling wave can be used in the form of harmonics. The parameter spectrum estimation method based on sinusoidal harmonic/damped sinusoidal harmonic model is adopted. Multi-signal classification MUSIC[9] algorithm-extraction The natural frequency of the fault traveling wave.

The steps of MUSIC algorithm:

(1) Estimation of Sample Autocorrelation Matrix Based on N Accepted Signal Data, $R = \frac{1}{N}\sum_{n=1}^{N} x(n)x^H(n)$;

(2) Characteristic decomposition of the calculated covariance matrix, $R = U\sum U^H$;

(3) Determining its principal eigenvalue $\lambda_1, \lambda_2, \cdots, \lambda_p$ and Sum subeigenvalue σ^2, store the principal eigenvalue vector $s_1, s_2, \cdots, s_p$;

(4) MUSIC calculation and peak search;

(5)find $P_{MUSIC}(\omega)$ Peak value, Frequency Principal Component of the First Peak.

(D)MUSIC algorithm simulation verification

To verify the effectiveness and accuracy of MUSIC algorithm, ideal signals can be artificially set and processed. By comparing the output signals of Fourier transform (FFT) and MUSIC algorithm, the effectiveness and reliability of MUSIC algorithm can be verified.

When the input is the superposition of several ideal single-frequency signals, the mathematical expression of the simulation signal is as follows:

$$\begin{aligned} x(t) &= 48\cos(2\pi \times f_1 t + \pi) + 35e^{(-20t)}\cos(2\pi \times f_2 t - 0.3\pi) \\ &+20e^{(-40t)}\cos(2\pi \times f_3 t - 0.5\pi) \end{aligned} \tag{0.1}$$

where, f_1=300Hz, f_2=582Hz, f_3=882Hz, The time domain waveform of the simulation signal is shown in Fig. 1.

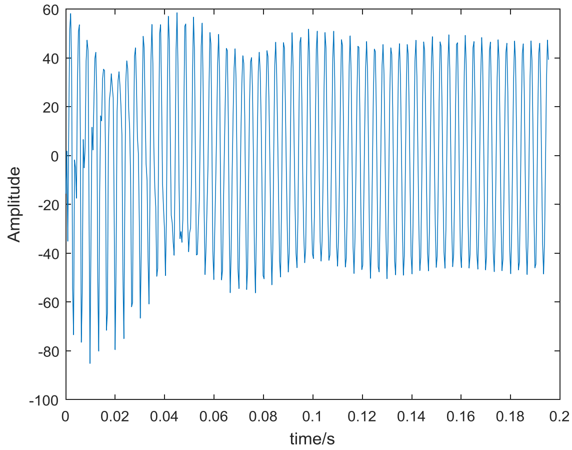

Fig. 1 Input ideal signal waveform

where, The abscissa is time and the ordinate is amplitude. Firstly, the original signal is processed by Fourier transform, and its spectrum is shown in

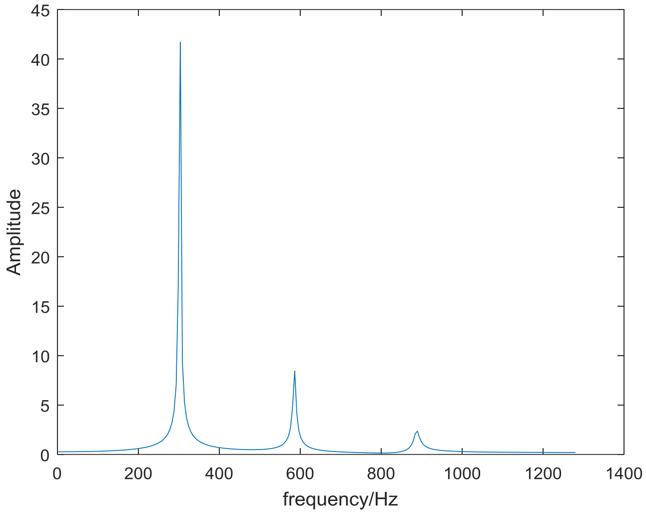

Fig. 2 FFT Transform Result Diagram

From Fig. 2,FFT transform can recognize the components of ideal signal better, but it can not distinguish the amplitude of frequency accurately. Especially, the distortion of frequency component amplitude of f_3=882Hz is serious. The MUSIC algorithm is used to estimate the parameters of the signal data, and the results are shown in Fig.3.

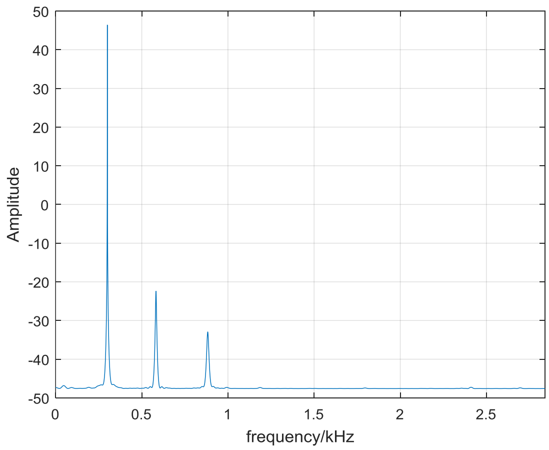

Fig. 3 MUSIC algorithm result graph

From Fig. 3, it can be seen that the MUSIC algorithm can accurately extract the frequency components of three ideal signals, and the mutation of each component is obvious and clear. Compared with the traditional Fourier transform detection results, the MUSIC algorithm has higher frequency resolution and the ability to extract signal frequency accurately. It shows that the MUSIC algorithm proposed in this paper is more conducive to the detection of transient signal frequency.

3. Phase mode transformation

The voltage and current at any point of a three-phase transmission line satisfy the following relationship:

$$\begin{cases} -\dfrac{\partial u}{\partial x} = L\dfrac{\partial i}{\partial t} \\ -\dfrac{\partial i}{\partial x} = C\dfrac{\partial u}{\partial t} \end{cases} \tag{3.1}$$

Where:

$u = [u_a \quad u_b \quad u_c]^T$ represents the voltage of three-phase lines;

$i = [i_a \quad i_b \quad i_c]^T$ represents the current of three-phase lines ;

L Inductance matrix;

C Capacitance matrix;

x Fault distance;

t time;

In order to simplify the analysis and calculation, a decoupling method based on modular transformation is proposed, which converts the phase space quantity into modular space quantity. Its expression is as follows:

$$\begin{cases} u = Su_m \\ i = Qi_m \end{cases} \tag{3.2}$$

In this paper, Clarke phase-mode transformation matrix is used to decouple the transient signal, as shown in (3.3).

$$\begin{cases} S = S^{-1} = \dfrac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix} \\ S = Q \end{cases} \tag{3.3}$$

Transform Formula (3.2) (3.3) into Formula Available:

$$\begin{cases} \dfrac{\partial^2 u_m}{\partial x^2} = S^{-1}LCS\dfrac{\partial^2 u_m}{\partial t^2} \\ \dfrac{\partial^2 i_m}{\partial x^2} = Q^{-1}LCQ\dfrac{\partial^2 i_m}{\partial t^2} \end{cases} \tag{3.4}$$

Where,

$u_m = [u_0, u_1, u_2]^T$ Modular component of voltage;

$i_m = [i_0, i_1, i_2]^T$ Modular component of current;

They are zero-mode component, module 1 component and module 2 component respectively. After phase-mode transformation, the three components are independent components, and there is no coupling relationship.

4. Simulation Analysis

(A) simulation example

A simulation model of 500 kV high voltage AC transmission system is established on MATLAB simulation platform. The model sketch is shown in Fig. 4.。

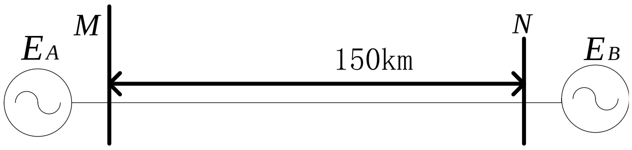

Fig. 4 500kVSketch of two-terminal transmission system

Distributed parameter model is used for the transmission line. Reference is made to the reference [10]. Specific parameters are as follows.:

$L = 150km$ Transmission Line Length,;

$R_1 = 0.0208\Omega / km$, $R_0 = 0.1148\Omega / km$ Line resistance; $L_1 = 0.8984mH / km$, $L_0 = 2.2886mH / km$ Line inductance; $C_1 = 0.01294\mu F / km$, $C_0 = 5.23\mu F / km$ Line capacitance.; $\dot{E}_M = 500\angle 0^\circ kV$, $\dot{E}_N = 500\angle 30^\circ kV$ Two side power supply ;

$f = 50Hz$ System frequency;

$1MHz$ Sampling frequency.

To evaluate the MUSIC algorithm simulations were performed considering the following influences:

.fault distance: 63.5km

.fault resistance: 80Ω

.fault type: A-phase single-phase fault

.fault time: 0.035s-0.05s.

The component of mode 1 after failure is shown in the Fig.5.

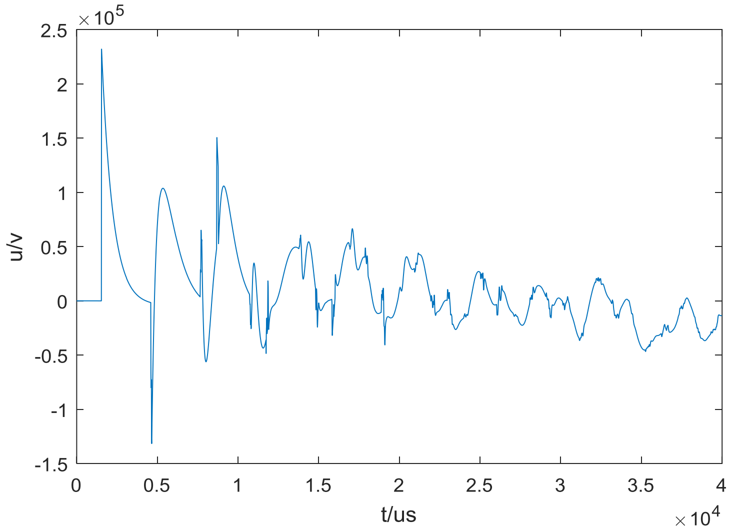

Fig. 4 Phase A Voltage Component

MUSIC spectrum analysis is performed on the component, and the spectrum is shown in

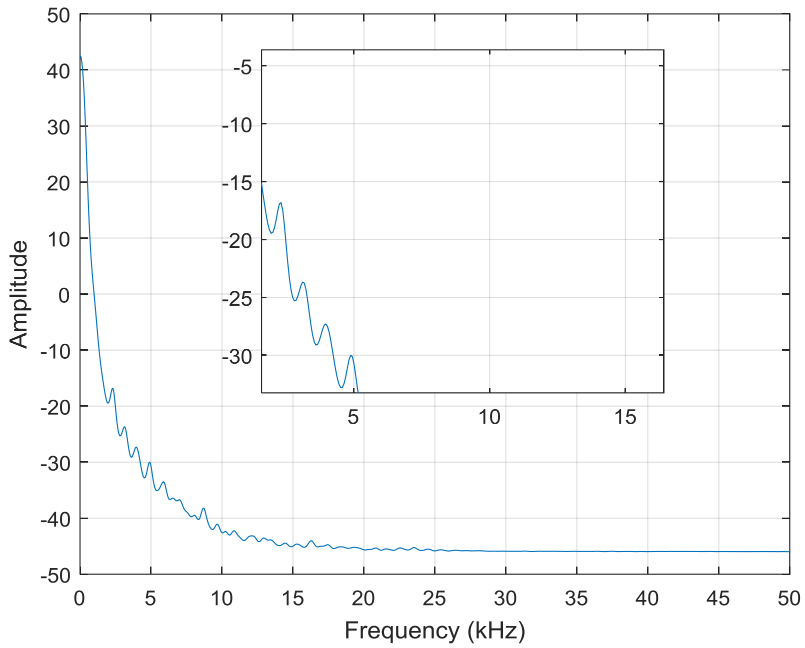

Fig. 5 Component spectrum of u_1

It can be seen that the first point with the largest amplitude is the main frequency point., $f_1 = 2.32kHz$,the fault distance can be obtained by bringing f_1 and v into equation (2.1).

$$d = 2.961\times10^8 / \left(2\times2.32\times10^3\right) = 63.81km$$

Fault distance equal to $63.81km$,measurement error equal to 0.48%,The measurement results are accurate and reliable, and can meet the needs of practical engineering.

(B) Adaptability Analysis

(i) Different fault distances

Single-phase short-circuit grounding fault occurs in different locations of transmission lines. The results and errors of distance measurement are shown in Table 1. The results show that with the increase of fault distance, the results of the proposed method are still valid, and the results are quite accurate, which meets the engineering requirements.

Table 1 Ranging results for different fault distances

Fault type	Fault distance /km	Transition resistance /Ω	Ranging results /km	error /(%)
Single-phase	10	0	10.23	0.23
	30		30.12	0.40
	50		49.76	0.48
	80		79.68	0.40

(ii) Different fault types

Different fault types are simulated on the line with fault distance of 100 km. Transition resistance, fault location results and errors are shown in Table 2. The experimental results show that the change of fault types does not affect the effect of fault location in this paper, and it is still quite accurate.

Table 2 Location results for different fault types

Fault type	Fault distance /km	Transition resistance / Ω	Ranging results /km	error /(%)
A-G	100	80	100.36	0.36
AB-G		80	101.08	0.08
AB		80	99.57	0.43
ABC-G		80	100.21	0.21

5. Conclusion

A lot of simulation results show that the proposed method is not affected by fault distance, transition resistance and fault type, and has strong robustness, and the ranging error is within acceptable range.

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