Fault Location Of Multi-point Hybrid Transmission Line Based On HHT

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Due to the discontinuous wave impedance, uneven line parameters, and complex and changeable fault transient traveling waves of overhead-cable hybrid transmission lines, the traditional double-ended traveling wave ranging method will produce large errors. Aiming at this problem, this paper proposes a fault location method for multi-point hybrid transmission lines based on Hilbert-Huang transform (HHT). First, the effective identification of the traveling wave head is completed at both ends of the line and at the connection point between the overhead line and the cable line, and then the HHT is used to extract the time when the fault traveling wave head reaches the measurement point, and finally it is substituted into the multi-point ranging equation to calculate the fault. The result of the ranging. The simulation results of MATLAB/PSCAD show that the method proposed in this paper avoids the influence of traveling wave velocity on the ranging accuracy, and is not affected by the line structure. Compared with the traditional double-ended ranging method, its ranging accuracy is higher. At the same time, it can also meet the requirements of engineering practice positioning accuracy within 200m.

Keywords: able-overhead line hybrid transmission line; Hilbert-Huang transform (HHT); fault location; traveling wave

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1. Introduction

Power lines are an integral part of the power transmission system, and their main task is to conduct and transmit electrical energy. There are two types of transmission lines: overhead transmission lines and cable transmission lines. Among them, the former has the characteristics of low cost, easy construction, short period and easy maintenance in the construction process, so it has become one of the transmission forms often used in the transmission system. Compared with overhead lines, cables have the advantages of occupying less land area, higher reliability, and less maintenance workload, and have become the main form of power transmission in cities. With the development of modern power systems and the requirements of city managers and citizens for the beauty of urban appearance, a new type of transmission line that combines overhead transmission lines and cable transmission lines has emerged in recent years. Overhead transmission lines, and new hybrid transmission lines using cable transmission lines in urban areas [1]. In addition, hybrid transmission lines are also widely used in trans-sea and trans-waterway transmission fields. In the future, In the future, this hybrid form of transmission lines will be more and more widely used.

In my country's medium-voltage distribution network transmission, the power transmission system usually uses the form of grounding the neutral point through the arc suppression coil. During the operation of the system, various faults will occur. Among them, the probability of a single-phase-to-ground short-circuit fault can reach 80% [2]. After such a fault occurs in the power transmission system, it can still operate for one to one Two hours [3], within this period of time, if the location of the fault can be accurately located in a timely and rapid manner, the burden of manual line inspection and the stability and stability of the entire medium-voltage distribution network transmission system will be greatly reduced. Economical [4, 5]. The current fault location methods include intelligent method, traveling wave method, fault analysis method and frequency analysis method [6]. The fault analysis method is simple in principle and low in cost.

Documents [7, 8] use this method to first determine the fault area, and then realize the fault location of the overhead line-cable hybrid transmission line. However, the methods proposed in the literature [7, 8] do not consider the accuracy of the transition resistance and the sampling value of the electrical quantity, and there are pseudo-roots, and these factors will affect the ranging accuracy of the entire fault location. Compared with the fault analysis method, using the traveling wave method for fault location has the advantage that the fault location is not affected by factors such as the operation mode of the power system and the transition resistance. Reference [9] proposes a fault search algorithm based on pre-value look-up table, reference [10] uses continuous wavelet transform algorithm, and reference [11, 12] uses time discrimination method to process fault traveling wave signals separately to realize hybrid transmission lines fault location. However, using the traveling wave method for fault location has the problem that the traveling wave head is difficult to capture. The spectrum analysis method has the advantage of not needing to identify the wave head of the traveling wave. Literature [13] proposed a fault location algorithm based on the time-frequency characteristics of the traveling wave, but the spectrum analysis method has the problem that the spectrum is difficult to analyze. With the rapid development of computer technology and communication technology, a new fault location method, namely intelligent method, has emerged, which has very high reliability. The literatures [14, 15] all use artificial intelligence technology to learn and train the sample set, and find out the deep relationship between the electrical parameters during fault and the electrical parameters during non-fault through the comparison and analysis of big data, and then realize a more accurate fault. ranging. However, this method has a large workload, is difficult to write, and is complicated to implement.

In view of the above problems, this paper proposes a fault location method for multi-point hybrid transmission lines based on Hilbert-Huang change based on the premise of using the traveling wave method through comparative analysis. The traveling wave is collected at the node of the cable, and then the Hilbert-Huang transform is used to obtain the time when the traveling wave head reaches different measurement points. Finally, the multi-point ranging method is used to accurately locate the fault. Simulation experiments are carried out through MATLAB/PSCAD. The experimental results show that the method proposed in this paper is not affected by factors such as transition resistance, and is also easy to identify the wave head and wave impedance discontinuity caused by the complex and changeable fault transient traveling wave. The instability of traveling wave velocity caused by it is considered. The fault location distance has higher accuracy than the traditional distance measurement method, and can also meet the engineering practice location requirements of the fault location location accuracy within 200m.

2. Multi-point traveling wave ranging principle

2.1. The traveling wave refraction reflection process in the hybrid transmission line

Compared with a single transmission line, when a hybrid transmission line fails, in addition to the fault point, there will also be other points where the impedance value is discontinuous, that is, the connection point between the cable and the overhead line. Due to the existence of these points, the refraction and reflection processes of fault traveling waves in hybrid transmission lines are more complicated than those in single transmission lines. When the fault occurs in the overhead line segment, the propagation path of the fault traveling wave is shown in Fig. 1 Figure 1 The MO segment represents the overhead line segment; the ON segment represents the cable segment.

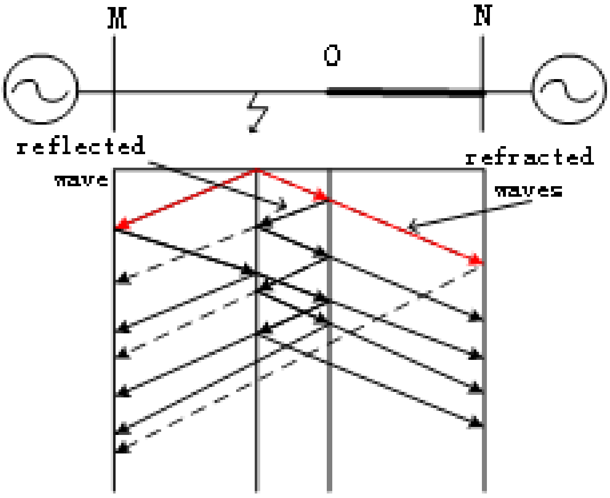


Fig. 1. Propagation path diagram of fault traveling wave

As can be seen from Fig. 1, the propagation of fault traveling waves in hybrid transmission lines is an extremely complex process. Through the comparative analysis of the fault traveling wave propagation path diagram, it can be concluded that the fault traveling wave waveform obtained on both sides of the hybrid transmission line is formed by a series of refracted waves and reflected wave forms superimposed on each other according to a certain time sequence.

2.2. Ranging principle

It can be seen from Fig. 1 that the traditional double-ended ranging algorithm will affect the accuracy of fault location because the traveling wave will appear refraction at the continuous point of impedance. Therefore, in order to solve these problems, this paper presents a fault location method for multi-measurement breakpoints [16]. The method proposed in this paper is based on the traditional double-end ranging, in addition to collecting fault traveling waves from both ends, an additional point is selected from the line to collect fault traveling waves. And the traveling wave velocity has the same velocity in the same type of transmission line to effectively reduce the traveling wave velocity imbalance problem caused by the discontinuity of traveling wave impedance points, and thus lead to the increase of fault location deviation.

The multi-point ranging method based on traditional double-end ranging is shown in Fig. 2, where M, K, and N are the positions where the traveling wave collector is placed. The MK segment is the first line, and the line length is L. Section KN is the second line, and the line length is L_1, t_M, t_N, and t_K are the times when the traveling wave head at the fault point reaches the M, N, and K measurement points, respectively. The derivation of the multi-point ranging equation is as follows:

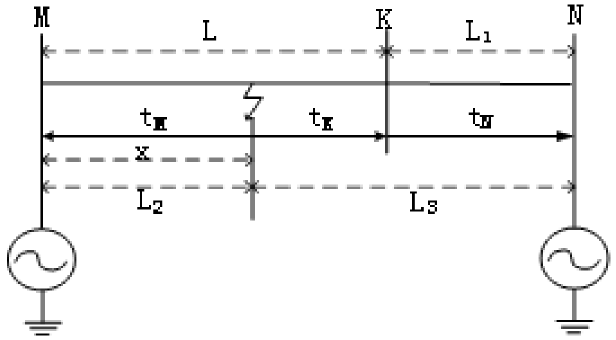


Fig. 2. Principle of multi-point fault location

According to the principle of double-ended ranging [17],where v is the velocity of the traveling wave.

$$x=\frac{L+(t_M-t_K)v}{2} \tag{1}$$

$$x=\frac{(L+L_1)+(t_M-t_N)v}{2} \tag{2}$$

From formula (1) and formula (2), it can be solved simultaneously:

$$x=\frac{1}{2}L+\frac{t_M-t_K}{2(t_N-t_K)}L_1 \tag{3}$$

It can be seen from equation (3) that the fault traveling wave velocity will not affect it based on the traditional multi-point ranging method of double-end ranging, so it is only necessary to capture the fault traveling wave to reach each measurement point when performing fault location. Therefore, the result of fault location is directly affected by the identification of the fault traveling wave head.

3. Traveling wave head calibration based on hilbert-huang transform

After the power transmission system fails, the electrical quantity in the line usually contains a lot of information components. After classifying the collected information, there will be information such as the time of the fault, the distance of the fault, and the size of the fault. At present, there are several digital signal processing methods such as derivative method, wavelet transform, Hilbert-Huang transform and so on. The main problem of the derivative method is that it is easily affected by noise, and the possible singular points cannot be judged as fault signals. Compared with the wavelet change, the derivative method does not have the above problems but does not have the advantage of self-adaptation, so it is necessary to choose A suitable wavelet basis function and decomposition scale are used to analyze the fault signal [18], and the Hilbert-Huang transform is used in this paper to process the traveling wave signal.

3.1. Hilbert-Huang transform

In 1998, a real signal processing method based on instantaneous frequency appeared: Hilbert-Huang Transform, or HHT for short, which was proposed by N.E.Huang et al. HHT consists of two parts, one of which is Empirical Mode Decomposition (EMD), and the other is Hilbert Transform (HT).

3.1.1. Empirical Mode Decomposition

EMD method is an adaptive and efficient nonlinear signal processing tool, through EMD, a relatively complex data signal can be decomposed into a limited number of intrinsic mode functions (IMF). The eigenmode function can describe the oscillatory structure and frequency structure of the signal in each local region. Because the IMFs obtained by EMD decomposition are based on local time scales, the method can be applied to nonlinear and nonstationary processes. EMD has two advantages, one is that the signal decomposition is unique, and the other is that no matter how complex the signal is in the time and frequency domains, it has good localization characteristics. At the same time, after decomposing the signal using EMD, the signal can also be reconstructed according to the requirements [19, 20]. On this basis, the flow chart of the sieving process for the EMD decomposition of the signal X(t) is shown in Fig. 3.

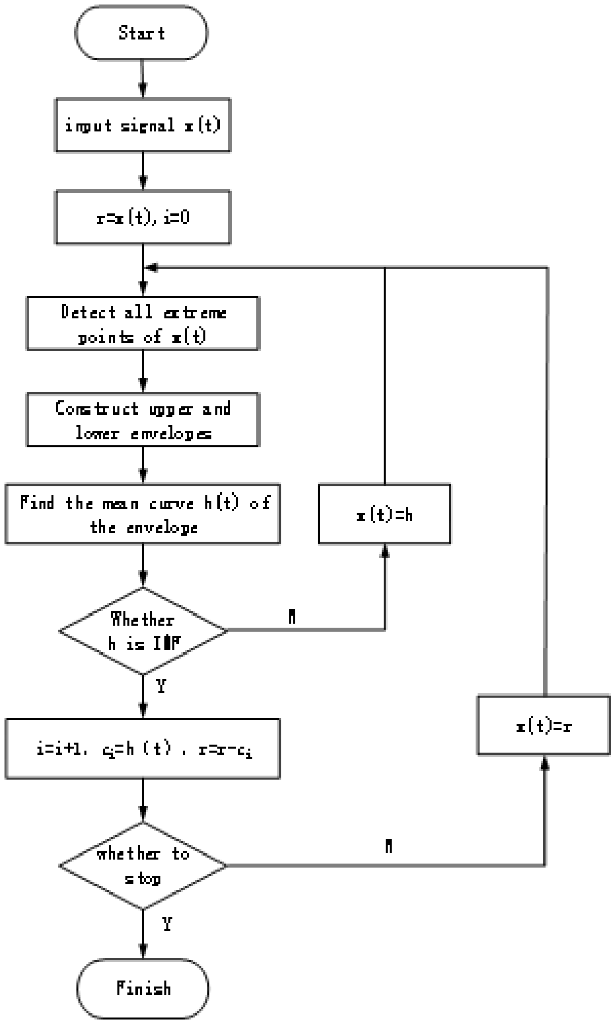


Fig. 3. EMD screening flow chart

3.1.2. *Hilbert transform*

The Hilbert spectrum can be obtained by performing Hilbert transform on each IMF. The Hilbert spectrum is a time-domain spectrum, and the moment when the traveling wave head reaches the measurement point can be identified through the Hilbert spectrum. The Hilbert changes are as follows:

HT for each IMF gets

$$s(t) = \mathrm{Re}\sum_{i=1}^{n} a_i(t)e^{j\phi_i(t)} = \mathrm{Re}\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt} \tag{4}$$

Equation (4) is called the Hilbert amplitude spectrum, abbreviated as the Hilbert spectrum, and denoted as

$$H(\omega, t) = \mathrm{Re}\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt} \tag{5}$$

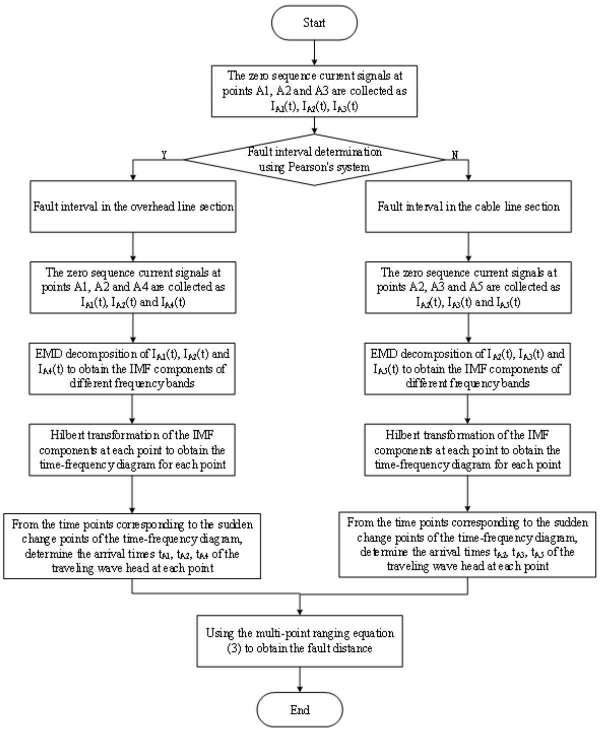


Fig. 4. Flowchart of the ranging algorithm based on HHT transform

3.2. Fault area judgment

This paper uses the Pearson coefficient to judge whether the fault occurs in the overhead line segment or the cable line segment. The Pearson correlation coefficient is widely used to measure the degree of correlation between two variables, and its value is between (-1, 1). The Pearson correlation coefficient between two variables is defined as the quotient of the covariance and the standard deviation between the two variables, as shown in Equation (6).

$$\rho_{x,y} = \frac{\mathrm{cov}(X,Y)}{\sigma_x\sigma_y} = \frac{E\left[(X-\mu_X)(Y-\mu_Y)\right]}{\sigma_x\sigma_y} \tag{6}$$

When $\rho_{x,y} \in (-1, 0)$, the fault occurs in the overhead line; when $\rho_{x,y} \in (0, 1)$, the fault occurs in the cable line.

3.3. Fault location process

A1, A2, A3, A4 and A5 in the diagram refer to the placement points of the traveling wave collector.The multi-point location fault equation and HHT transformation are applied to the overhead cable hybrid transmission line, and the specific fault locating steps are shown in Fig. 4.

4. Simulation verification

4.1. Simulation model and its parameters

In this paper, a small current grounding system with a simulation experimental model of 110/10KV is built in PSCAD software, as shown in Fig. 5. Among them, the Bergeron model is used in the overhead line (MO segment) part; the coaxial cable model is used in the cable line (ON) part. The overhead line and cable line are each 10km, the sampling frequency is 1MHz, the system simulation time is 0.3s, and the fault occurs in 0.2s.

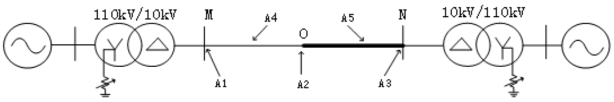


Fig. 5. System simulation model

Overhead line parameters: Use the LGJ-300/40 parameters of the steel-cored aluminum twisted pair to establish an overhead line model, which is arranged in an inverted triangle between the three-phase power supplies of the overhead line, and the vertical distance between phase C and phase A and phase B is 0.7 m. The horizontal spacing is 1.11 m, the DC resistance on the overhead line is 0.09614Ω/km, and the geometric topology is shown in Fig. 6.

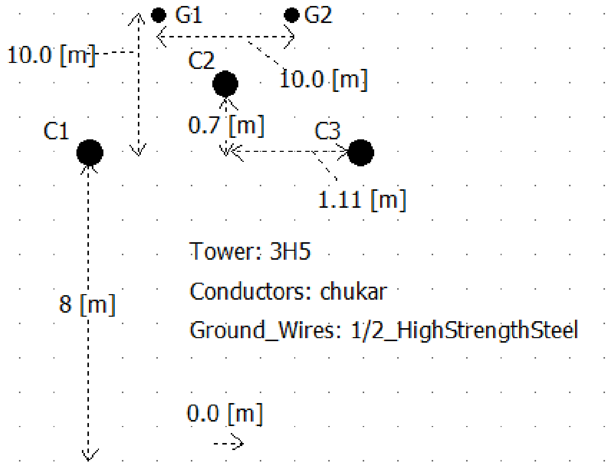


Fig. 6. Topological diagram of overhead line

Cable data: The optical cable line model established by the YJLW0264/110kV1*400mm2 parameters in the XLPE insulated power cable, the geometric structure of the cable is shown in Fig. 7.

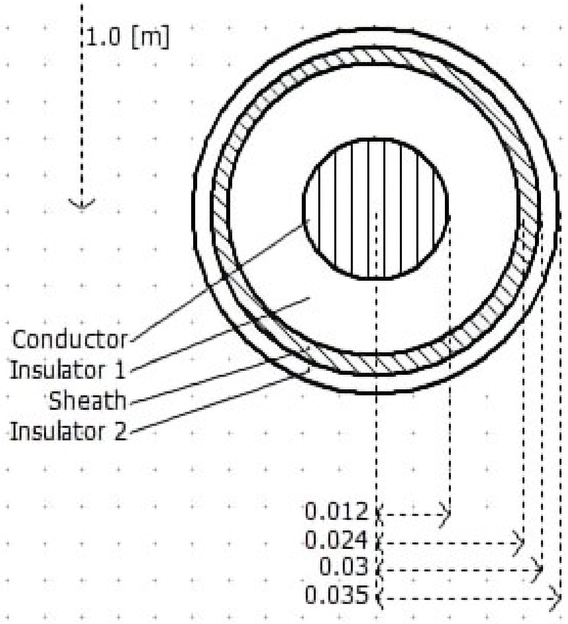


Fig. 7. Distribution of cable geometric parameters

4.2. Simulation verification

This paper takes the single-phase ground fault in the transmission system as an example for simulation verification. In this paper, five traveling wave collectors A1, A2, A3, A4, and A5 are set up in the entire 110kV/10kV system, and the collection positions are shown in Fig. 5. Assuming that the fault occurs at a distance of 5km from the A1 terminal, the measured transient zero-sequence currents before and after the system fault are shown in Fig. 8.

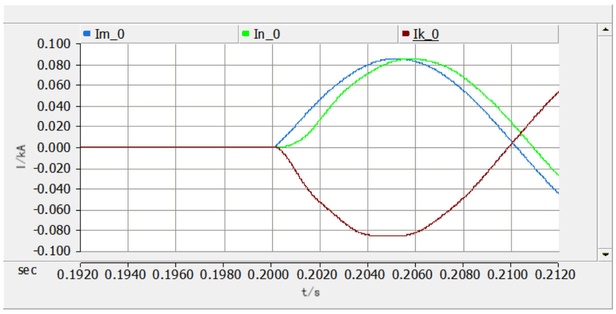
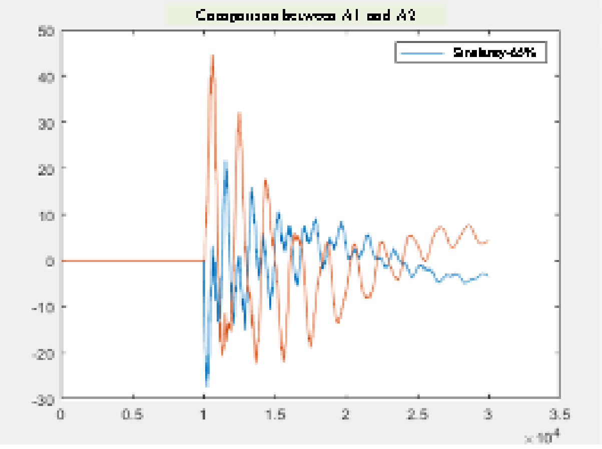
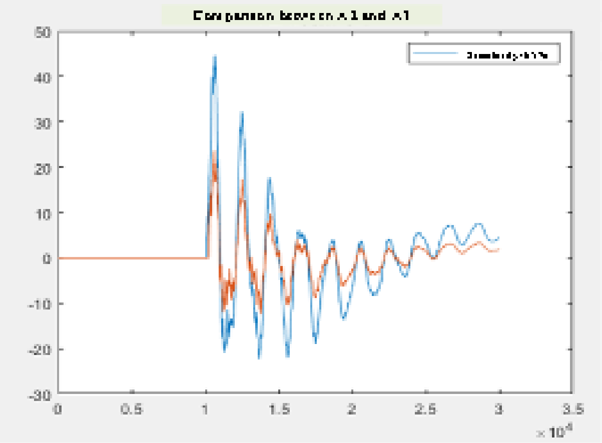


Fig. 8. Zero sequence current before and after the fault

First, use the zero-sequence currents collected at A1, A2 and A3 terminals to analyze the fault area by Pearson coefficient analysis, and obtain the similarity of the Pearson coefficient as shown in Figure.9. From formula (6), it can be known that the negative similarity is the fault area.



(a) Pearson coefficient between A1A2



(b) Pearson coefficient between A2A3

Fig. 9. Pearson coefficient similarity

Then, the zero-sequence current traveling waves of A1, A2, and A4 are extracted, and the EMD algorithm is used to decompose the line mode component of the zero-sequence current of the faulty phase. Taking the traveling wave at the A1 end as an example, the IMF component cn and residual term res obtained by EMD decomposition are shown in Fig. 10.

From the waveform of the first IMF component c1 in Figure 10, it can be seen that there is an obvious wave head mutation feature, while the remaining components do not have this feature. Therefore, take the first IMF component c1 and perform Hilbert transform to obtain the instantaneous frequency of the IMF component c1, as shown in Fig. 11.

From the previous analysis, it can be known that the time position of the first mutation point of the instantaneous frequency can be determined as the arrival time of the traveling wave head, that is, tM $= 167\mu$s. Similarly, $t_K = 189\mu$s and $t_N = 892\mu$s can be measured. Substituting the above time into the multi-point ranging formula (3), it can be solved that $x = 4.8435$ km, that is, the distance from the fault point to the M terminal is 4.8435 km. The absolute error with the assumed fault distance is 165 m, which meets the requirement that the engineering positioning accuracy is less than 200 m.

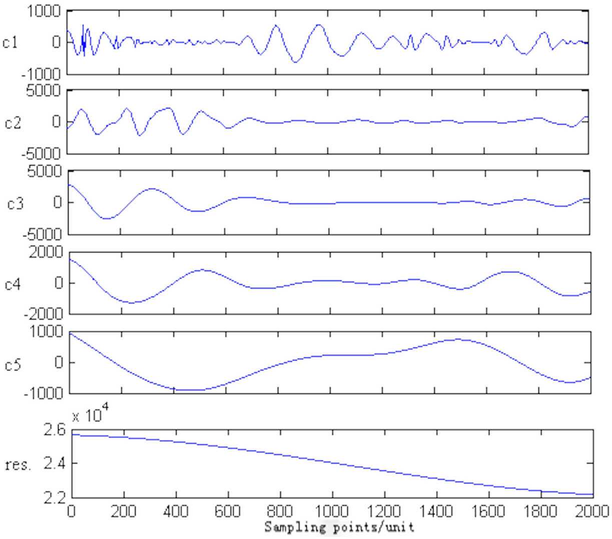


Fig. 10. EMD decomposition of M-terminal traveling wave

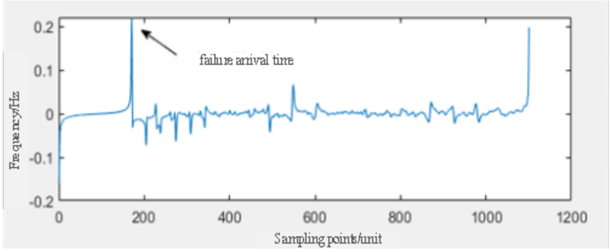


Fig. 11. Instantaneous frequency of IMF component c1

In the entire overhead wire-cable hybrid transmission line, single-phase ground faults occur at 3 km, 5 km, 8 km, 11 km, 15 km, and 17 km away from the *M* terminal, and then the distance measurement results obtained by applying the method proposed in this paper are shown in Table 1.

5. Conclusion

After analyzing the existing problems of hybrid transmission lines, this paper proposes a single-phase-to-ground fault location method for hybrid transmission lines with multiple measurement points based on HHT. In order to solve the problem of uneven traveling wave velocity caused by discontinuous impedance points of hybrid transmission lines, an improved multi-point ranging method based on traditional double-ended ranging algorithm is

Table 1. Comparison of time performance and performance with different superpixel methods

Fault location (km)	Ranging method	fault section	Ranging results (km)	Relative ranging error (m)
3	Double-ended ranging	MO	3.236	236
	Multi-point ranging		3.159	159
5	Double-ended ranging	MO	5.206	206
	Multi-point ranging		4.893	107
8	Double-ended ranging	MO	8.223	237
	Multi-point ranging		8.176	176
11	Double-ended ranging	ON	11.246	246
	Multi-point ranging		11.149	149
15	Double-ended ranging	ON	15.193	193
	Multi-point ranging		15.136	136
17	Double-ended ranging	ON	17.203	203
	Multi-point ranging		17.169	169

proposed, which can effectively solve this problem. Aiming at the problem that the traveling wave head is difficult to identify in the hybrid transmission line, EMD is used to decompose the transient zero-sequence current fault traveling wave, and then the Hilbert-Huang transform is used to realize the time of the fault traveling wave head arriving at the measurement end, so as to realize the single-phase fault traveling wave. Reliable location of ground faults.

By comparing the traditional double-end ranging method with the method proposed in this paper, the method proposed in this paper has higher fault location accuracy and more accurate feature extraction, which has certain engineering practical value.

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