Two-terminal Fault Location Method Based on the Lines Converted Midpoint and HHT

Yutian Wang, Huixin Wang, Shuqing Zhang, Hanlu Shangguan

Institute of Electrical Engineering, Yanshan University, Qinhuangdao, Hebei Province, 066004, China

Abstract

Aiming at the problems of travelling wave's speed velocity discontinuity problems in the hybrid transmission line composed by cables and overhead lines, a new method of two-terminal fault location based on the converted midpoint of the transmission line and HHT is presented in this paper. First, the hybrid transmission line was reduced to a single parameter line to get the midpoint of the line. Then, the HHT (Hilbert- Huang Transform) was used to detect the travelling waves' heads. The search direction of the fault was calculated according to the time difference Δt between two measurement endpoints from travelling wave of the fault point. When travelling waves moved $\Delta t/2$ from the converted midpoint along the search direction, the point was the fault point. The simulation results by ATP and Matlab show that this method is correct and accurate.

Keywords: *Error fault location, Travelling wave, two-terminal location, converted midpoint, HHT*

1. Introduction

Electricity distribution network has many branches and complex structure, and its fault location has been the difficult problem studied. With the rapid development of power systems, cable-overhead line hybrid transmission lines have applied to power cables widely, increasing the difficulty of fault location.

The theoretical study of fault location method based on the principle includes intelligent ranging methods, fault analysis methods and travelling wave methods [1]. Fault analysis methods are mainly represented by the impedance method; intelligent Ranging methods include Kalman filtering, pattern recognition, probability and statistics decision-making, fuzzy theory and optical ranging, intelligent simulated annealing algorithm ranging method. All these are in the research stage currently, having not applied to practice. Travelling wave method is divided into single-terminal and two-terminal location methods. Single terminal location has larger error ranging as it is difficult to overcome the system impedance and resistance of the transition in principle; The fault location based on two-terminal electrical quantities has good prospects as the ability of eliminating transition resistances and impedances of the system in principle[2]-[3].

The velocity of travelling waves in the cable and overhead lines is inconsistent, difficult to range directly. Considering the impact of a hybrid circuit to traveling wave fault location, a new two-terminal fault location method combined line converted middle points and the HHT was proposed, and the problem of wave velocity discontinuous was solved.

2. An effective fault location method by converted midpoint

The principle of two-terminal fault location is based on the time difference between the first travelling waves arrive at both ends of the distance generated by fault voltage and current. When the fault of one-phase ground occurs, the voltage and current travelling waves will transfer along the way to both ends. Distance measurement devices installed at both ends of the bus record the initial time when travelling waves reach the terminals and calculate the distances. The Nomenclatures used in this paper are given bellow:

v is the travelling wave speed of overhead lines.

u is the travelling wave speed of cable lines.

D is the length of the fault line.

D_{MF} is the theoretical distance from the fault point F to the bus M.

D_{NF} is the theoretical distance from the fault point F to the bus N.

L_{MF} is the actual distance from the fault point F to the bus M.

L_{NF} is the actual distance from the fault point F to the bus N.

Δt is the time difference of travelling waves arrive at two measurement endpoints.

t_m is the time when the first wave of travelling waves reach M-side of the bus.

t_n is the time when the first wave of travelling waves reach N-side of the bus.

P_0 is the midpoint of the line

P_1 is the converted midpoint of line *MN*

The formulae following express the two-terminal fault location Method

$$\begin{cases} \dfrac{D_{MF}}{v} - \dfrac{D_{NF}}{v} = t_m - t_n \\ D_{MF} + D_{NF} = D \end{cases} \quad (1)$$

$$\begin{cases} D_{MF} = \dfrac{1}{2}[v(t_m - t_n) + D] \\ D_{NF} = \dfrac{1}{2}[v(t_n - t_m) + D] \end{cases} \quad (2)$$

Wave velocity has a relationship with the line medium and is basically constant in a line with the single electrical parameters [4]. The formulae of (1) and (2) have good application effects to the line with single electrical parameters such as high voltage power lines. However, the formulae above cannot be applied to measure distances directly in the small current grounding system, because the speed of wave propagation is discontinuous due to the existence of the alternating lines of overhead and cable.

The cable length is converted as the base v, that is, the length D of the cables will be vD/u after conversion. The crossing connected lines of overhead lines and cable would then be regarded as the unity of the overhead line. The two-terminal fault location formulae (1) and (2) could be applied to the equivalent line and the fault point's position in the converted line could be obtained. The accurate location could be realized after the conversion to the original real line, eliminating the influence of the discrete wave velocity.

The converted line's midpoint of the overhead lines and cable lines is the point from which the time the wave reaches the both line ends is the same. The line structure is symmetry for a transmission line with single electrical parameters, and the midpoint of the line is the converted line's midpoint as travelling wave signals take the same time from the point to both ends. As for the mixed distribution lines, the distribution of overhead lines and cable is complex and asymmetry, the time of the travelling wave move to the both ends from the line's midpoint is different, that is, the converted midpoint is not coincident to the midpoint of the line. Fig.1 is a hybrid structure diagram of overhead line and cable line.

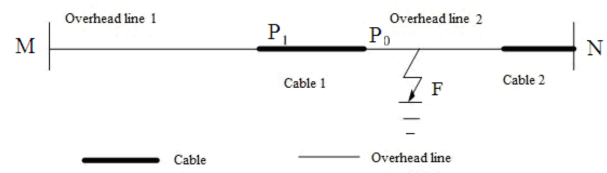

Fig .1 Hybrid structure diagram of overhead line and cable line

The steps of the new two-terminal fault location method are as follows:

(1)Determine the lengths of overhead and cable lines.

(2)Determine the wave velocity of the travelling wave propagating in various segments.

Because the unit length distribution parameters of cables are much different to the overhead lines, especially the distributed capacitance are about two orders of magnitude higher than overhead lines, resulting the apparent discontinuity of the travelling wave speed in the cable lines and the overhead lines.

According to wave propagation velocity formula (3), the wave velocity of the travelling wave propagating in various segments could be calculated.

$$v = \frac{1}{\sqrt{LC}} \quad (3)$$

Where, C and L are the unit length distributed capacitance and inductance in the various segment.

(3) Find the line converted midpoint P_1 of the line section MN. It could be determined according to the specific structure of lines and the lengths of overhead lines and cable in the various sections. If the time when the waves arrive at the line ends M and N are Tm and t_n respectively, and the corresponding time deference Δt =0, the starting point of the travelling wave is the line converted midpoint P_1.

(4) Determine the fault searching direction. When fault occurs, if the calculated parameters Δt <0, the fault is in the line section between P_1M, and the fault point could be searched from P_1 to M side. If Δt >0, the fault point could be searched from P_1 to N side. If Δt =0, P_1 is the fault point.

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(5)Determine the fault point. When travelling waves moved Δt /2 from the converted midpoint along the search direction, the point was the fault point.

3. Travelling waves' heads detection by HHT

The parameters of electric transmission Lines would vary with the change of the frequency. The cable's frequency-dependence is serious as the result of its own characters, and the wave head would have serious attenuation and distortion. HHT method has good purpose on the detection of the mutation, nonlinearity and non-stationary signals. The frequency cluster of HHT is adaptive produced, needless of the selection to primary functions. So it is suitable for the detection of electric transmission Lines signal [5]-[6].

The signal was first decomposed into a limited number of Intrinsic Mode Function (IMF) by the Empirical Mode Decomposition (EMD) method. Then, every IMF components was transformed by HHT and the instantaneous amplitude and frequency were obtained.

3.1 Signals classifying by EMD

The IMF is defined as the component satisfies the following definition.

In the whole dataset, the number of the extreme points and zero-crossing points are equal or differ by one.

The maxima and the minima envelopes are obtained by cubic spline-interpolate, and the local mean value at any point of the maxima and the minima envelopes is zero.

Obviously, most of the signal does not meet the conditions above and is not the IMF component, and it is necessary to decompose signals to the IMF by algorithm EMD, Which steps are:

(1) Calculate all the local maxima and the minima points of a time series $X(t)$, and the maxima and the minima envelopes are fitted by cubic spline-interpolate. The local mean value m1(t) of the maxima and the minima envelopes are got, and it is eliminated from the original signal $X(t)$. The residual component h1(t) is obtained:

$$h_1(t) = x(t) - m_1(t) \tag{4}$$

(2) On ideal occasion, $h_1(t)$ is the first IMF component. But, as not all the local maxima and the minima points are included by the spline-interpolate accurately, it will induct error as the result that the missing point would become a new maxima or minima point at the next spline-interpolate step. So, the second classifying will take $h_1(t)$ as a new time series, and $m_{11}(t)$ is the maxima and the minima envelopes value of $h_1(t)$. The residual component $h_{10}(t)$ is obtained。

$$h_{10}(t) = h_1(t) - m_{11}(t) \tag{5}$$

Repeated the steps for k until $h_{1k}(t)$ meet the two conditions of IMF above, and let

$$x(t)=h_1(t) \tag{6}$$

3.2 The HHT Transform to the classified signals

The Hilbert-Huang Transform Function $Y(t)$ of a time series $X(t)$ is [5]:

$$Y(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{X(t)}{t-\tau}d\tau \tag{7}$$

Whereas $X(t)$ could expressed by $Y(t)$, which is:

$$X(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{Y(t)}{\tau-t}d\tau \tag{8}$$

It can be seen from the formulae (7) and (8), $X(t)$ and $Y(t)$ constitute a pair of complex conjugate. Meanwhile, $X(t)$ and $Y(t)$ consist of the information related to time series, and the relations followed could be available:

$$Z(t) = X(t) + jY(t) = A(t)e^{j\theta(t)}$$

$$A(t) = \sqrt{X^2(t) + Y^2(t)} \tag{10}$$

$$\theta(t) = \arctan(\frac{Y(t)}{X(t)}) \tag{11}$$

From the equations above, the two important instantaneous parameters are obtained, where $A(t)$ is the instantaneous amplitude and $\theta(t)$ is the phase and another important parameter, the instantaneous frequency could be obtained by the relation of the amplitude and frequency:

$$f(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} \tag{12}$$

4. Example simulation

The small current grounding system simulation model was established using the electromagnetic transient simulation software ATP [6], shown in Fig.2. The system was coil grounding via arc suppression system, and is set over compensation. The inductance of the arc suppression is L=8.02H, and the resistance is $R_L = 80\Omega$.

Assuming the line 1 A-phase ground fault occurred, the cable length is *D*1=20km, and the over head lines length is *D*2=40km. The distance from the fault point to the M side is 11km. The cable lines' electrical parameters are:

$$R_1 = 2.415\times10^{-5}\Omega/\text{m} \quad L_1 = 5.163\times10^{-4}\text{mH/m}$$
$$R_0 = 1.965\times10^{-4}\Omega/\text{m} \quad L_0 = 3.976\times10^{-4}\text{mH/m}$$
$$C = 3.175\times10^{-4}\mu\text{F/m}$$

The overhead lines' electrical parameters are:

$$R_1 = 2.084\times10^{-5}\Omega/\text{m} \quad L_1 = 8.981\times10^{-4}\text{mH/m}$$
$$R_0 = 1.168\times10^{-4}\Omega/\text{m} \quad L_0 = 2.285\times10^{-3}\text{mH/m}$$
$$C = 1.29\times10^{-8}\mu\text{F/m}$$

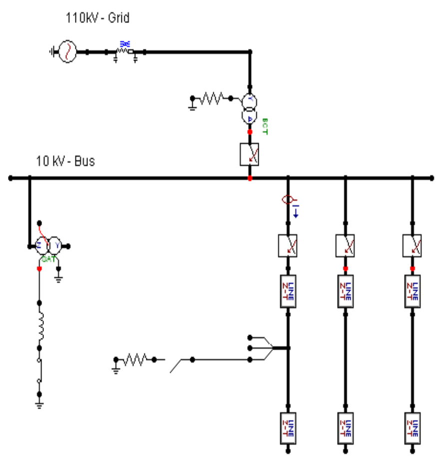

Fig. 2. Simulation model of the small current grounding system

The detected signals were converted into the mat format and then input into MATLAB and were decomposed into six IMF adaptively by EMD. The first IMF component was proceeded Hilbert Transform and time-frequency diagrams were got. The first IMF component is a frequency cluster of the travelling wave signals. The fault travelling waves head is high-frequency mutations in performance in time-frequency diagram, and the time corresponding was the time when the initial failure of the travelling wave arrived at the bus of M-side and N-side.

Fig.3 is the fault transient current travelling wave diagram of M-side and Fig.4 is the decomposed IMF components of M-side by EMD. The frequency plot of the travelling wave detected by HHT is shown in Fig.5, and the instantaneous frequency plot of the travelling wave detected at N-side is shown in Fig. 6.

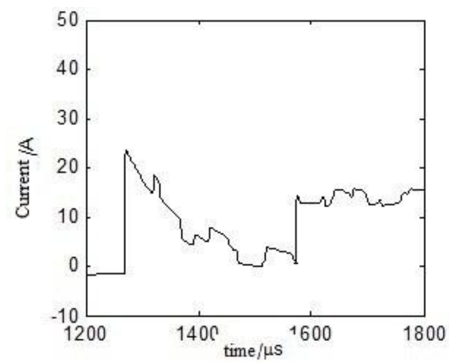

Fig .3. The fault transient current travelling wave of M-side

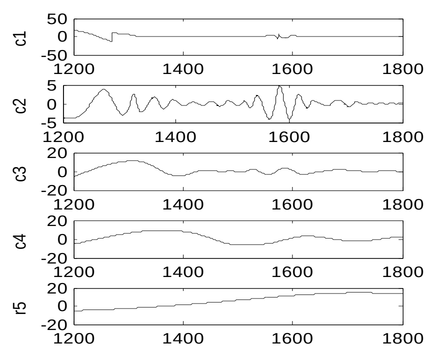

Fig.4 The decomposed IMF components of M-side by EMD

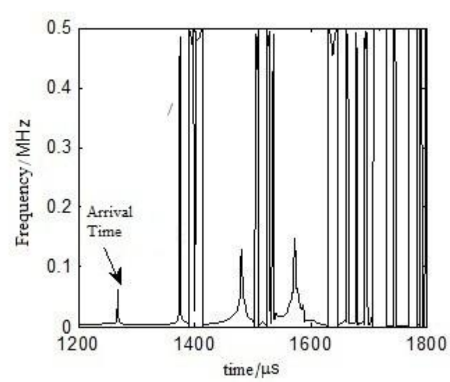

Fig. 5 The frequency of the travelling wave detected at M-side

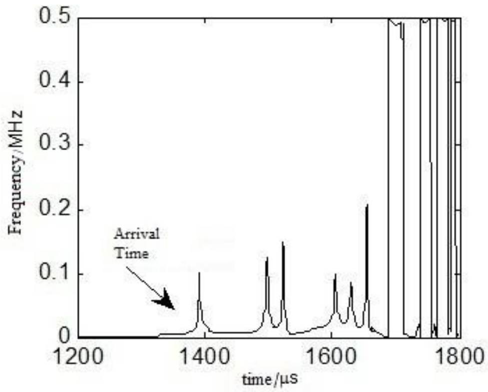

Fig. 6 The frequency of the travelling wave detected at N-side

From the Fig.5 and Fig.6, it can be seen that:

$$t_m = 1.270 \times 10^{-3} s \text{ , } t_n = 1.391 \times 10^{-3} s$$

By the formulae (2), D_{MF} and D_{NF} could be calculated as:

$$\begin{cases} D_{MF} = 21.85\text{km} \\ D_{NF} = 58.15\text{km} \end{cases} \quad (10)$$

After converted to the actual lines, the actual distances from the fault point F to the M-side and N-side were:

$$\begin{cases} L_{MF} = 10.925km \\ L_{NF} = 49.075km \end{cases} \quad (11)$$

Experiments show that the measurement error is 0.075km, with a high accuracy.

5. Conclusion

This paper proposed a new method of two-terminal fault location based on the lines converted midpoint and HHT. The two-terminal fault location algorithm based on the lines converted midpoint is not affected by the dielectric media, solving the discontinuous problem in mixed lines with a high ranging accuracy. Considering the factors of the signal itself, the travelling wave was decomposed by EDM and the wave's head was detected by HHT, improving the measuring accuracy. It provides a correct and accurate method for the fault location in the small current grounding system.

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Yutian Wang received the Master degree at Harbin Industrial University in 1981, the Doctor degree at Harbin Industrial University in 1995; He has been employed at Yanshan University since, and currently, he is a professor at Yanshan University; He has been supported by the National Natural Science Foundation of China, Natural Science Foundation of Hebei Province, and has received the awards of science and technology progress of Hebei Province and the Mechanical Industry Community. His articles published are over 50. His interests are in Intelligent Information Processing and photoelectric measurement.