Study of Fault Locations in Transmission Line Using S Transform

Shang Liqun and Zhai Wensong

Abstract

The key of fault locations based on traveling waves are accurate recognition of wave fronts. The existing methods are difficult to recognize wave fronts when high impedance faults and small angle faults occurred in a transmission line. An accurate fault locating method based on S transform is presented. It can independently analyze the characteristic of the signal's amplitude change over time on each frequency component, and accurately judge the mutations. It has clear advantages compared with a wavelet transform. The simulation results show its correctness.

Keywords: fault location; wave front recognition; S transform; wavelet transform.

1. Introduction

There are mainly two types of fault location methods in a transmission line, namely the impedance method and the traveling wave method. The traveling wave method is that once the circuit failure occurs, measuring the time of the fault signal transient traveling wave to the measuring terminal is to identify the fault location. It is unaffected by the structure of the circuit, the fault types and the transition resistance, which is its superiority in theory. The key of fault locations based on traveling waves is accurate recognition of wave front and the corresponding time. The fault location using a wavelet analysis method that analyzes the comparison of fault signals of the results of measurement distance in different scales to select the appropriate wavelet is proposed in [1]. However, the selection scale has a great relationship with the frequency components of the fault transient signal and the sampling frequency. For instance, if the selection scale is too small, the impact of the noise is too large to correctly identify the wave front; while the selection scale is too large, the mutation of the wave front is not obvious and even disappear. In addition, if the selection scale is not appropriate, the fault location will fail. The fault location based on morphological signal singularity is proposed in [2]. In spite of the simple calculation and the good real-time performance, the calculation result of the fault location is not accurate as it is very difficult to select the structural elements with high fault signal matching, which can directly affect the accuracy of the monitoring and the speed of the dynamic response. This paper provides a fault location algorithm based on S transform method in transmission line, which is kind of extra time window Fourier transform time-frequency reversible analysis method. It inherits and develops the localization idea [3] of the continuous wavelet transform and short time Fourier transform, which has good time-frequency analysis

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and feature extraction characteristics. Meanwhile, it overcomes the defects of short time Fourier transform window height and width fixed. And it is more detailed decomposition than the continuous wavelet transform in the high frequency part; and it is, especially for a long distance transmission line and more obvious than the advantages of wavelet transform method.

2. Principle of A Traveling Wave Fault Location Method And Basic Principle Of S Transform Method

2.1 Principle of A Traveling Wave Fault Location Method

The traveling wave method can be divided into one-terminal method and two-terminal method according to the information source required by the fault location. At present, the proposed traveling wave fault location methods have 6 kinds of A, B, C, D, E, F, among which the types of A, C, E, F belong to the one-terminal method, and the types of B, D belong to the two-terminal method. Development of a traveling wave fault location in a transmission line experienced two stages: early stage and modern stage. The arrival time and propagation time of a transient traveling wave are measured by the electronic counter or the cathode ray oscilloscope in the early time traveling wave method, and those are measured by various digital signal processing algorithms in the modern traveling wave method. The method to achieve a fault location based on time differences between the traveling wave of the fault point to the bus and then reflecting to the fault point and again reflecting to the bus from the fault point is one-terminal traveling wave method. And the two-terminal traveling wave method is through detecting the time and velocity of the two fault initial traveling wave fronts to reach the bus at both ends of the line to achieve fault locations.

In the theory, the two-terminal fault location method has high reliability, but it has a high investment, and it is easy to be influenced by the time synchronization system (GPS), where once the two terminal data synchronization system goes wrong, it will lead to the fault location failure. In contrast, the one-terminal traveling wave fault location method is simple, low cost and highly real time, which does not need data synchronization of two ends. In this paper, a one-terminal traveling wave method is used for a fault location of transmission line. The principle of one-terminal traveling wave fault location is shown in Figure 1 [5].

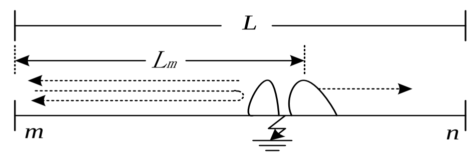


Figure 1: One-terminal fault location principle

Assuming the length of a line is L , the fault distance L_m from a fault point to the bus terminal of m can be expressed as:

$$L_m = \frac{1}{2} v(T_2 - T_1) \tag{1}$$

Where T1 is the time of the initial traveling wave of the fault point, and T2 is the time of arrival of the reflected wave from the fault point to the bus of m, and v is wave velocity.

When the fault occurs, current traveling wave transmitted to the two terminals of the line would be produced. According to the reflection coefficient of the current traveling wave at each point, we can know that the reflected wave of the fault point has same polarity with the initial traveling wave, and the reflected wave of the terminal bus has opposite polarity with the initial traveling wave. Detecting the same polarity of the second traveling wave front from the fault line and initial traveling wave front at the bus measuring point, it is recognized that the second traveling wave front is the reflection wave of the fault point, and the fault point position is located at the midpoint of the line, which can be calculated through the formula (1). While detecting the opposite polarity of the second traveling wave front from the fault line and initial traveling wave front at the bus measuring point, it is recognized that the second traveling wave front is the reflected wave of the terminal bus, and the fault point position is outside the midpoint in the line, which can be calculated through the following formula (2) [6]:

$$L_m = L - \frac{1}{2}v(T_2 - T_1) \quad (2)$$

To carry out traveling wave fault location, the key is to measure the time difference between the initial fault traveling wave and the second traveling wave head to reach the measuring point.

2.2 Basic principle of S transform method

S transform proposed in 1996 by geophysicists R.G. Stockwell is an extra time window Fourier transform frequency reversible analysis method, which is the extension of continuous wavelet transform using Morlet wavelet as basic wavelet. The idea is the development of continuous wavelet transform and short time Fourier transform [7]. The S transform $S(\tau, f)$ of the signal $x(t)$ is defined as follows:

$$S(\tau, f) = \int_{-\infty}^{+\infty} x(t)\omega(\tau - t, f)e^{-j2\pi ft}dt \quad (3)$$

$$\omega(\tau - t, f) = \frac{|f|}{\sqrt{2\pi}} e^{\left|\frac{-f^2(\tau-t)^2}{2}\right|} \quad (4)$$

Where $\omega(\tau - t, f)$ is Gauss window; τ is the position parameter to control the Gauss window In time axis; f is frequency; j is imaginary unit. By the formula(3), it can be seen that the S transform of the Gauss window height and width changing with frequency is different from the short time Fourier transform, which overcomes the defect of the height and width of the short time Fourier transform window fixed. The discrete representation of S transform can be expressed as follows:

$$S[m,n] = \sum_{k=0}^{N-1} X[n+k]e^{-2\pi^2k^2/n^2}e^{j2\pi km/N}, n \neq 0 \quad (7)$$

$$S[m,n] = \frac{1}{N}\sum_{k=0}^{N-1} x[k], n = 0 \quad (8)$$

$$X[n] = \frac{1}{N}\sum_{k=0}^{N-1} x[k]e^{-j2\pi kn/N} \quad (9)$$

Then carry out the S transform for the N discrete signal points $x[i](i = 0,1,\cdots,N-1)$ of acquisition using the formulas (10) and (11). The result of transformation is a plural time-frequency matrix with $n+1$ lines and m columns denoted as S matrix, of which columns correspond to the sampling time points, and lines correspond to frequency and the first line $n = 0$ corresponds to the DC component of the signal. The frequency difference between adjacent rows and the frequency corresponding to the line n can be can be respectively expressed as follows:

$$\Delta f = \frac{f_s}{N} \quad (10)$$

$$f_n = \frac{f_s}{N} n \quad (11)$$

where f_s is the sampling frequency, N is the number of sampling point[8].

The matrix of modulus of each element of the S matrix is denoted as S modulus matrix, which the column vector represents the amplitude frequency characteristic of the signal at a certain time, and the line vector represents the time domain distribution of the signal at a certain frequency.

3. A New Method of Fault Location in Transmission Line Based on S Transform

The traveling wave of fault line is a mutant and bizarre signal and its wave head is mutant in amplitude and frequency, which will be reflected by modular matrix though S transform. S transform can be used to analyze variation characteristics of each frequency component of the signal independently, and the mutant time of the signal can be determined by the change of the frequency corresponding to the traveling wave with time.

To analyze traveling wave fault location better in three-phase system, phase components of three phase coupling usually are converted to mutually independent components with phase mode transformation theory. Because the zero mode component uses the earth as the loop, the speed of the wave is unstable. To avoid the influence of the zero mode component, this paper will use linear mode component to analyze.

Three phase dependent phase components are converted to mutually independent components with phase mode transformation theory (Clarke transform) before extracting traveling wave front of the fault line with S transform method and selecting the traveling wave signal with proper length before and after the fault. Then the S mode matrix is gotten by doing S transform to the line mode components. According to frequency points selected, the arrival time of wave head is determined through observing the amplitude-time curve of S mode matrix at different frequency points. Finally, observing the maximum value point of the amplitude-time curve at the maximum frequency point, the arrival time of the wave head is determined accurately. Because the S transform modulus matrix cannot determine the polarity of the wave head, the original traveling wave data of the signal is needed to make one order difference at each wave head to confirm the second traveling wave head comes from the reflection wave from the fault point or the reflection wave of the end bus, which can determine the polarity of the wave.

4. Simlation Analysis

The model of a simple two terminal power supply system is built by ATP/EMTP shown in Figure 2. The line of full length 250km is the three-phase 50Hz transmission line of 750kV voltage level, which uses the distributed parameter model. And the line parameters are respectively expressed as follows:

$$R_1 = 0.027\Omega / km; R_0 = 0.1948\Omega / km$$

$$C_1 = 0.0127\mu F / km; C_1 = 0.0127\mu F / km$$

$$X_1 = 0.8863\Omega / km; X_0 = 2.068\Omega / km$$

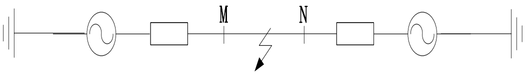
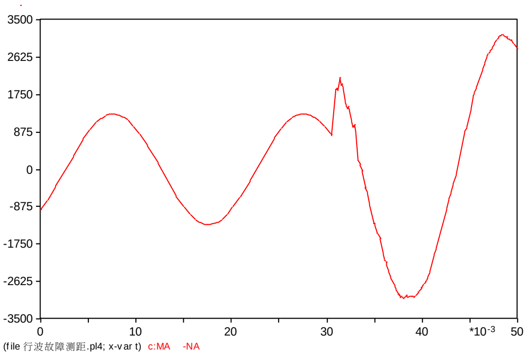
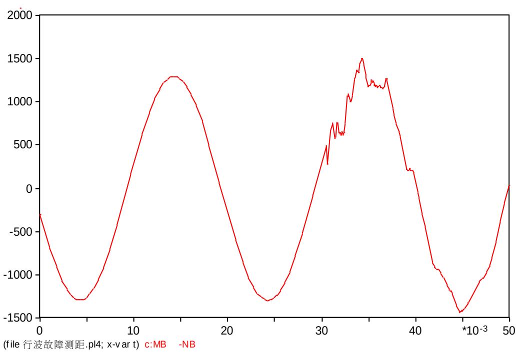


Figure 2: The model of a power system for simulation

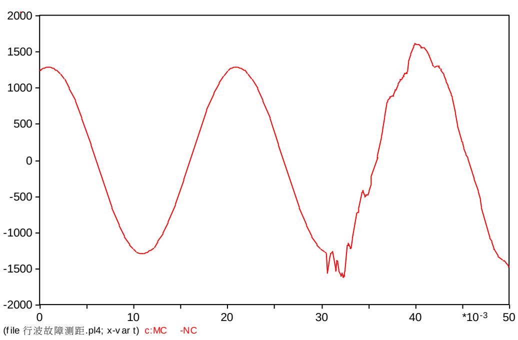
Assuming that line A phase is to ground short circuit with the grounding resistance 200Ω, and the sampling frequency is 1MHZ; and simulation time is 0.05s; and the fault occurrence time is 0.03s; the transient current traveling wave measured at the N end at the time of failure located at 100 km away from M end is shown in Figure 3.



(a) A phase current traveling wave



(b) B phase current traveling wave



(c) C phase current traveling wave

Figure 3: The wave forms of three-phase current traveling waves

In MATLAB, the data obtained from the simulation is processed, and the original data is transformed by the phase mode, and the 2000 sampling points are analyzed before and after the failure. The waveform of line mode component after the Clarke transform is shown in Figure 4.

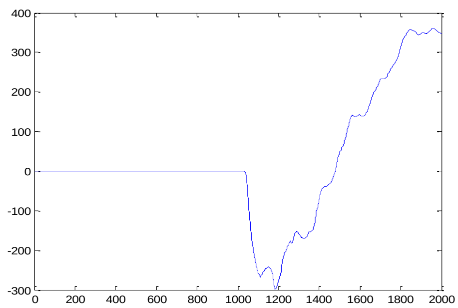
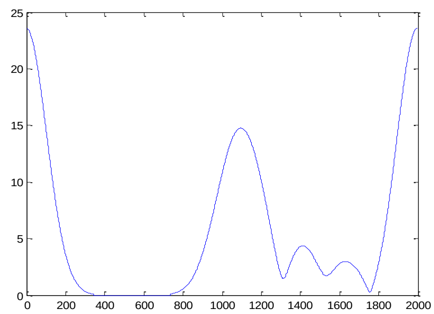
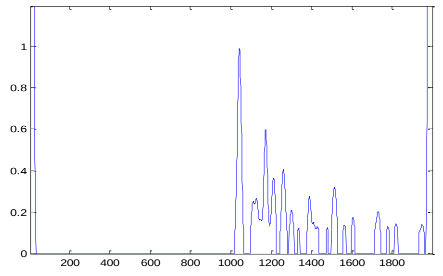


Figure 4: The wave forms of current modes

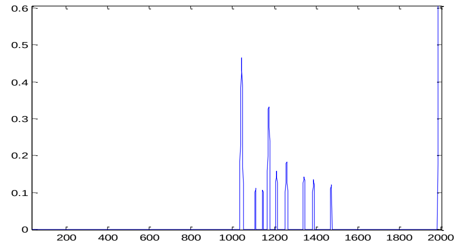
After the fault component of the linear mode current does the S transform, the amplitude time curve of the traveling wave signal at the frequency of 10kHz, 100kHz, 200kHz and 500kHz is shown in Figure 5.



(a) Amplitude time curve of 10kHz



(b) Amplitude time curve of 100kHz



(c) Amplitude time curve of 200kHz

Figure 5: The results of S transform

It can be clearly seen that the higher the frequency, the more obvious the performance of the traveling wave head from Fig.5. In the amplitude time curve of 400kHz, the initial traveling wave front is the most obvious, and the amplitude reaches the maximum at the 1043rd sampling point. By first order difference, the polarity of initial wave head of traveling wave can be judged as negative, and the polarity of the second traveling wave head is negative, and the polarity of the third traveling wave head is positive. Therefore, it can be known that the second traveling wave head is the reflection wave from fault point , the third traveling wave head is the reflection wave of the end bus, and the fault point is within the midpoint. Selecting the M end as the rang end, $L_m = 99.83km$ can be calculated from the one-terminal range formula according to the results of S transform $t_1 = 10.43ms$, $t_2 = 11.10ms$ and assuming the $v = 298000km/h$ .Obviously this method is more accurate to determine the fault location.

Similar to the above, a number of simulation experiments of this method at different fault points are carried out, and the results are shown in Table 1.

Table1: Results of fault location(S transform method)

d/km	t_1/ms	t_2/ms	L_m/km	ε/km
50	10.22	10.55	49.17	0.83
100	10.43	11.10	99.83	0.17
125	10.54	11.38	125.16	0.16
150	10.65	11.32	150.17	0.17
200	10.86	11.20	199.34	0.66

Note: d is the distance between the fault and the bus M, ε is the deviation, Tab.2 is the same.

Table 2: Results of fault location (wavelet method)

d/km	t_1/ms	t_2/ms	L_m/km	ε/km
50	10.30	10.64	51.36	1.36
100	10.51	11.18	99.18	0.82
125	10.62	11.46	125.53	0.53
150	10.73	11.74	151.01	1.01
200	10.95	12.30	201.78	1.78

It can be seen that the results of fault locations of the S transform method are more accurate from the Table 1. The results calculated with the method of a traditional wavelet transform are shown in Table 2. When the high resistance fault occurs in the long-distance transmission line, the traveling wave front amplitude is small, and the singularity of the wave head becomes slow under the chromatic dispersion, the impulsive corona and other factors. From the above results, it can be known that in above case the wavelet transform method based on the principle of modulus maximum singularity detection is difficult to determine the traveling wave front, and the results of that method have great deviation. At this time, the S transform method can be used to accurately determine the arrival time of the traveling wave head.

5. Conclusions

(1) The simulation results show that the new fault location method based on S transform can accurately calibrate the traveling wave front of the fault signal when the remote transmission line is in fault, especially in the place near the middle of the line, the measurement results are very accurate.

As can be seen from Fig.5, the results of S transform are more intuitive and easy to understand. Compared with wavelet analysis, the advantage of S transform is more obvious and the deviation of the result of S transform is smaller.

(3) The research of this paper is based on the simulation experiment. In practical application, there are many factors that affect the traveling wave detection. The method can improve the reliability of the method by using the appropriate filtering method to eliminate the influence of the noise. In addition, it is very necessary to further study the new methods of detection and identification of a traveling wave.

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