Method of High-speed Railway Traction Nets Fault Single-ended Traveling-wave Location Based on Wavelet Transformation Adaptive Matching

Zhi-cheng WANG∗ and Jie ZHAO
Mechanical and Electronic Engineering of East China University of Technology, Jiangxi Engineering Research Center for New Energy Technology and Equipment, Nanchang 330013, China

*Corresponding author

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Abstract. In order to reduce the influence of the transmission dispersion characteristics on the wave head detection and the wave transmission velocity measurement, put forward a new algorithm. This method combined with wavelet transform singularity and similarity algorithm, extracted the reconstruction high-frequency signal of wavelet function multi-scale decomposing structure, to calculate fault traveling-wave positioning. Got characteristic value point, calculated arrival time of traveling-wave head, obtained the reference speed of traveling-wave by simulation experiment results. Analysis result of the field test data showed that the high-speed railway traction nets fault positioning method can extract the faults characteristic effectively, and eliminate the influence of traveling-wave dispersion characteristic, and the fault positioning error is no more than 100 m.

Introduction

Transmission line transport distance of the high-speed railway traction network is long, exposure in the wilderness, and the failure more often occurs in the circle-traffic inconvenience mountain foothills. That the problems of rapid and accurate positioning have not solved to the railway electric traction department, arouse great threats for the safe operation of the traction system, also bring heavy burden to operation maintenance personnel of traction network transmission line. Therefore, putting forward the traveling-wave fault positioning method of electrification railway traction network at home and abroad, detection and location use transient traveling-wave generated by fault [1-4].

Accuracy of traction network transmission line fault single end traveling-wave positioning depends mainly on time and speed parameters[5]. Traction network transmission line fault produce wide area band transient signal, traveling-wave is rich in high frequency component; traveling-wave propagation with dispersion characteristics, and different frequency wave signal with different attenuation characteristics, lead to traction network fault traveling-wave head signal occurrence distortion, affect accurate judgment of traveling-wave arrival time and the determination of traveling-wave velocity, reduce the accuracy of traveling-wave fault location.

Conventional method of travelling-wave positioning is the application of wavelet transform for time parameter, speed parameter is equal to the speed of light, ignore the influence of the travelling-wave dispersion along the transmission line to the spread. The method in this paper is expected to solve the question that accuracy of conventional positioning method is not high.

This method combined with wavelet transform singularity and similarity algorithm, extract the starting point of the waveform change trend and characteristics of initial the traveling-wave pre-and post as decision condition to get traveling-wave head. Travelling wave arrival time determine by adaptive matching method from the extractive traveling-wave feature point position; obtained the reference speed of traveling-wave by simulation experiment results, the accuracy of positioning is higher.
Wavelet Transformation Adaptive Matching Basic Principle

Wavelet Transformation Theory

In order to realize accurate distinguish fault traveling-wave point of discontinuity, which is travelling-wave arrival time and can also improve the accuracy of fault location as one of the important conditions [6]. This paper choose wavelet analysis algorithm for high speed railway traction network fault traveling-wave signal processing, wavelet transform mathematical expression for:

\[ C(\alpha, \tau) = \alpha^{-\frac{1}{2}} \int_{-\infty}^{\infty} f(t) \phi\left(\frac{t-\tau}{\alpha}\right) dt \]  

In the formula of the wavelet transform, \( C(a, \tau) \): wavelet coefficient of primitive function \( f(t) \); \( a \): Scale (compression or stretch) quantity; \( \tau \): displacement; \( (\phi) \): wavelet function family.

Corresponding to the analysis of high-speed railway traction network fault traveling-wave signal, the specific wavelet transformation process as follows. Converting into discrete form after convert analog travelling-wave to digital by acquisition system module:

\[ f_n(x) = \sum_{k \in Z} c_n^k \phi(2^n x - k) \]  

Using Mallat algorithm step by step for this type of signal decomposition, the decomposition process as shown in figure 1.

![Figure 1. Mallat algorithm for Wavelet decomposition](image)

Singularity Theory

Sampling signal of high speed railway traction network fault traveling-wave is one dimensional discrete data, supposed \( f_w(x) \) is wavelet function transformed by traveling-wave signal, If the scale \( s \), in a neighborhood \( S \) of \( x_0 \), for all \( x \):

\[ |f_w(x)| \leq |f_w(x_0)| \]  

Then, It says \( x_0 \) for modulus maxima point of wavelet transformation; \( f_w(x_0) \) for the modulus maxima of wavelet transformation. Using modulus maxima point to create new wave function \( f_{\text{max}}(x), \) the modulus maxima of wavelet transformation should meet the type conditions:

\[ |f_{\text{max}}(x)| \leq K s^\alpha \]  

In the formula, \( f_{\text{max}}(x) \) for the modulus maxima of wavelet transformation of signal \( f(x); \) \( K \) is constant; \( S \) for decomposition scale; \( \alpha \) for Lipschitz index.

The modulus maxima point of wavelet transformation and signal mutation point is one-to-one[7,8]. The polarity of modulus maxima of wavelet transformation say mutation point change direction, the size of modulus maximum say mutation point change strength. According to the fault wave noise strength, calculate the wavelet modulus maxima point and reduce the noise signal further by adjusting the value of \( k \) and \( \alpha \), reflect the location, polarity and feature information of signal singularity accurately, and the characterization of fault information.
Adaptive Matching Method

When traction network transmission line fault occurs, the fault signal voltage amplitude produced by high pressure high frequency wave sensors to collect conversion, traveling-wave sensor cause oscillation harmonic easily. so, derivation and absolute value operate further for the waveform function \( f_{\text{max}}(x) \) extracted by wavelet transform modulus maxima data. Filtering slowly changing oscillation signal. To set the wave function by the data processing:

\[
f_j(x) = \sum_{n \in \mathbb{Z}} f(n)
\]

(5)

Data acquisition system set a certain acquisition time delay for acquisition, delay data acquisition system includes their hardware circuit noise, take a maximum noise for \( u_n \). Starting by \( x = 0 \), to compare the value of the noise signal and \( \text{fabs}(x) \). If \( f_j(n_0) > u_n \), determine the corresponding sampling time of the point \( n_0 \) as initial wave starting point \( t_0 \).

Extract the starting point of the waveform change trend and characteristics of initial the traveling-wave pre-and post and its characteristics as a decision condition, can select multiple characteristic value according to the actual situation, as:

\[
\begin{align*}
    m_1 &= \frac{f_j(n + 2) - f_j(n + 1)}{f_j(n + 1) - f_j(n)} \\
    m_2 &= \frac{f_j(n) - f_j(n - 1)}{f_j(n + 1) - f_j(n)}
\end{align*}
\]

(6)

To extract position point of traveling-wave head, which will calculate the \( m_1 \) and \( m_2 \) as decision condition. Then, using the same method to calculate \( m \) value corresponding to the data behind the starting point \( n_0 \) corresponding \( m \) value. As for point \( p \), calculate:

\[
\begin{align*}
    m'_1 &= \frac{f_j(p + 2) - f_j(p + 1)}{f_j(p + 1) - f_j(p)} \\
    m'_2 &= \frac{f_j(p) - f_j(p - 1)}{f_j(p + 1) - f_j(p)}
\end{align*}
\]

(7)

definition at the same time:

\[
\Delta m = \frac{m_1 + m_2}{m_1 - m_2}
\]

(8)

If \( \Delta m < \beta \), (where \( \beta \) stands for attenuation coefficient of fault traveling-wave, to some a certain line, predefined the value based on the standard waveform data, is correction coefficient), determine corresponding time of the function \( f_j(x) \) as fault reflection traveling-wave head wave arrival time \( t_1 \). The distance between fault point \( k \) and starting point can be calculated by:

\[
s_i = v \times (t_i - t_0)
\]

(9)

Principle of Fault Location

Identify Traveling-wave Arrival Time

Discrimination algorithm of the traveling-wave head arrival time is shown in figure 2.
Figure 2. Initial point position algorithm of the traveling-wave head.

As shown in figure 2, using wavelet function db6 for 5 scale wavelet decomposition to process traveling-wave signal, reconstruction high frequency of wavelet decomposition structure, get reconstruction high frequency traveling-wave signal of 5 scale decomposition; after calculating the modulus maximum points, Constructing the traveling-wave form after the data processing, can judge the general location of traveling-wave head. Due to the traveling-wave head rise quite gentle, have a delay between Maximum appeared and the actual traveling-wave head emergence, impact accuracy of fault location, so, in order to accurate time arrived of traveling-wave head further. This article base on the wavelet transformation modulus maxima, and combine with the adaptive matching method.

Adaptive matching method: First of all, calculated the rate of traveling-wave waveform change and the absolute value operation for the waveform change; According to the new data obtained, extract characteristic value information of the initial traveling-wave; reuse the initial traveling-wave characteristics to make self similarity analysis decision condition, to scan and match the whole fault wave data, determine the reflection fault traveling-wave head position finally. The initial wave and the reflected fault wave head point correspond to the difference of data sampling points and sampling frequency, that can calculate the time of initial point to fault point.

Determine the Traveling-wave Velocity

Due to relative stability of the traveling-wave propagation velocity, this article using simulation method to calculate the traveling-wave velocity, to provide the reference for analysis of field experiment subsequent data.

Due to know the length of the simulation experiment line, calculate traveling-wave velocity according to simulation results. The original waveform of simulation test data show in figure 3 (a), figure 3 (b) for processing waveform through algorithm. Mark fault point respectively in the original waveform and processing waveform, used the circle as shown. In order to improve the accuracy of traveling-wave velocity further, calculate the average time of simulation group treatment data.

Known the length of line for $S=153m$, the average results of the time difference $\Delta t=67.5/(2\times60\times10^6)=562\text{ns}$, obtained wave velocity $v=S/\Delta t=153m/(562\times10^{-9})s=2.72\times10^8\text{m/s}$.

![Figure 3. The result of traveling-wave positioning algorithm for guan plant data.](image)

Analysis Sample of Field Data

Experiment line select 216# feeder in Shijiazhuang (a place in Hebei Province) substation, the whole length is 22.19 Km. The purposes of field data analysis are in order to verify accuracy of positioning and this method in application.
For the Shijiazhuang substation 216# feeder, there is no reflection condition of the connection point (the junction of cable and overhead line) behind the experimental detection point, so the travelling wave data analysis only need to pay attention to the field experiment circuit switching and reflection wave signal at the end of the line for 216# feeder. Data analysis processing show in figure 4, using its waveform as an example to demonstrate.

(a) 20070122144937_728_216H.MWD processing results

(b) 20070123151945_410_216H.MWD processing results

(c) 2007032122252_414_216H.MWD processing results

Figure 4. Example of the Shijiazhuang measured data analysis results.

Shown above, to the three groups of processing data, first of all, processed Shijiazhuang original wave data by wavelet transform adaptive matching algorithm, according to the data waveform processed, conducted location of traveling-wave starting point and fault point, then the fault point coordinate map to original data waveform, mark a circle on the analysis graph of the results; identified arrival time according to the starting point t and the position of the fault traveling-wave head which were marked, determined the time difference of the traveling-wave spread between the testing point and fault point.

Use the same processing method on Shijiazhuang substation 216# feeder. when stop sending, detected other traveling-wave form to carry on the analysis, positioning the initial wave and reflection wave starting points from end of lines, and calculate experiment setting fault distance according to the simulation experiment measured wave velocity, results recorded in table 1.

Table 1. The statistics table of Shijiazhang data analysis results.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>File name of the data</th>
<th>Starting point</th>
<th>Reflection point</th>
<th>Wave velocity</th>
<th>Fault distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200701091506_216H.MWD</td>
<td>498</td>
<td>10307</td>
<td>272 m/us</td>
<td>22278m</td>
</tr>
<tr>
<td>2</td>
<td>2007010914037_216T.MWD</td>
<td>498</td>
<td>10307</td>
<td>272 m/us</td>
<td>22278m</td>
</tr>
<tr>
<td>3</td>
<td>200701091404_216T.MWD</td>
<td>498</td>
<td>10307</td>
<td>272 m/us</td>
<td>22278m</td>
</tr>
</tbody>
</table>
Known Shijiazhuang 216# feeder length 22.19 Km, table 1 shows that the most of traveling wave location system positioning error is (22278-22190)m=88m, positioning error is less than 100 m; and test results changes greatly in different time, analyzing the causes know that as the changes in the external environment (such as line load, the weather and climate conditions change, etc), produce certain negative influence to traveling-wave signal in transmission line.

Conclusion
This paper use the method of wavelet transform adaptive matching single end traveling-wave location, can extract characteristics of traction network transmission line fault traveling-wave signal effectively, and eliminate the influence of the wave dispersion and other factors on fault point location accuracy, solve problem that how to distinguish traveling-wave head time arrived, and the reference velocity of wave propagation at the same time. A large number of ranging results confirm that Using the method of wavelet transform adaptive matching single end wave positioning obtain reliability results of positioning, high positioning accuracy. In the single ended traveling-wave localization method using conditions, Positioning accuracy can meet the accurate fault location requirements for field operation.

References