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Wavelet based noise cancellation technique for fault location on underground power cables

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Abstract

This paper describes a new algorithm to identify the reflective waves for fault location in noisy environment. The new algorithm is based on the correlation of detail components at adjacent levels of stationary wavelet transform of current signal from one end of the cable. The algorithm is simple and straightforward. Simulation results based on a real power transmission system proved it can detect and locate the fault in very difficult situations.

Keywords: Fault location; Fault classification; Underground power cable system; Stationary wavelet transform

1. Introduction

The potential benefits of applying wavelet transform in power cable fault location have been recognized by many researchers [1–9]. The wavelet transform has the ability to localize the signals in both time and frequency domains. This makes it particularly useful in capturing the transients at one end or both ends of the cable and locate the fault position. This refers to single-ended or double-ended fault location. Between these two approaches, single-ended approach is less expensive and more reliable as it does not need communication link between the ends of the cable and requires only one equipment to operate rather than two at both ends. This reduces the errors caused by the different equipment and synchronization of time at both ends. Therefore, single-ended approach is more practical and accurate in fault location.

The single-ended approach uses reflected transients from either the fault or other end to locate the fault. This raises some problems of detecting the reflected transients on underground power cable system. If the reflections are from fault point, they will be very weak because part of the signals will transmit to the other end from fault point. If the reflections are from the other end, same problem still exists as part of the signals will reflect back. At the same time, the signal will travel a long way to reach the measurement end. Since the high frequency transients have a very high attenuation in the cables, the reflection will become weak after the long way traveling. It is clear that the magnitudes of the reflections are much smaller than the first transient. In addition, the measurement will be noisy. Sometimes the noise level may be higher than the reflections. Then how to discriminate the weak reflection from the noise is a big issue.

The transients have many irregular signals, and all of them are useable signal. However, only transients at specific frequency are useful to locate the fault. The rest are useless. Therefore, this paper considers unnecessary signals as noise. In this paper, a new algorithm was proposed to discriminate the reflected signals from noise and thus locate the fault. The algorithm is based on the correlation of the wavelet coefficients at multi-scales. For wavelet transform, the stationary wavelet transform (SWT) is introduced instead of conventional discrete wavelet transform (DWT). Stationary wavelet transform uses upsampling at each level of decomposition that causes redundancy. In wavelet transform, the number of elements per scale and location is fixed-independent of scale. The redundancy increases the elements per scale and location at coarse scales. In term of denoising, there

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is an advantage in having more orientations than necessary at coarse scales. It is better in noisy signal processing [10,11].

After brief review of the stationary wavelet transform in second section, fault classification algorithm and noise cancellation technique for fault location will be discussed in Sections 4 and 5, based on a real cable system described in Section 3. The algorithms will be tested by simulations in Section 6. The last section concludes the paper.

2. Stationary wavelet transform

In this section, the basic principles of the SWT method will be presented. In summery, the SWT method can be described as at each level, when the high and low pass filters are applied to the data, the two new sequences have the same length as the original sequences. To do this, the original data is not decimated. However, the filters at each level are modified by padding them out with zeros.

Supposing a function $f(x)$ is projected at each step j on the subset V_j $(\ldots \subset V_3 \subset V_2 \subset V_1 \subset V_0)$. This projection is defined by the scalar product $c_{j,k}$ of $f(x)$ with the scaling function $\phi(x)$ which is dilated and translated:

$$c_{j,k} = \langle f(x), \phi_{j,k}(x) \rangle \qquad (1)$$

$$\phi_{j,k}(x) = 2^{-j}\phi(2^{-j}x - k) \qquad (2)$$

where $\phi(x)$ is the scaling function, which is a low-pass filter. $c_{j,k}$, is also called a discrete approximation at the resolution 2^j.

If $\varphi(x)$ is the wavelet function, the wavelet coefficients are obtained by:

$$\omega_{j,k} = \langle f(x), 2^{-j}\varphi(2^{-j}x - k) \rangle \qquad (3)$$

where $\omega_{j,k}$ is called the discrete detail signal at the resolution 2^j.

As the scaling function $\phi(x)$ has the property:

$$\frac{1}{2}\phi\left(\frac{x}{2}\right) = \sum_n h(n)\phi(x - n),$$

where $h(n)$ is the low-pass filter. $c_{j+1,k}$ can be obtained by direct computation from $c_{j,k}$

$$c_{j+1,k} = \sum_n h(n - 2k)c_{j,n} \quad \text{and} \quad \frac{1}{2}\varphi\left(\frac{x}{2}\right) = \sum_n g(n)\phi(x-n) \qquad (4)$$

where $g(n)$ is the high-pass filter.

The scalar products $\langle f(x), 2^{-(j+1)}\varphi(2^{-(j+1)}x - k) \rangle$ are computed with:

$$\omega_{j+1,k} = \sum_n g(n - 2k)c_{j,n} \qquad (5)$$

Eqs. (4) and (5) are the multi-resolution algorithm of the traditional discrete wavelet transform. In this transform, a downsampling algorithm is used to perform the transformation. That is one point out of two is kept during transformation. Therefore, the whole length of the function $f(x)$ will reduce by half after the transformation. This process continues until the length of the function becomes one.

However, for stationary or redundant transform, instead of downsampling, an upsampling procedure is carried out before performing filter convolution at each scale. The distance between samples increases by a factor of 2 from scale j to the next. $c_{j+1,k}$ is obtained by:

$$c_{j+1,k} = \sum_l h(l)c_{j,k+2^j l} \qquad (6)$$

and the discrete wavelet coefficients:

$$\omega_{j+1,k} = \sum_l g(l)c_{j,k+2^j l} \qquad (7)$$

where l indicates the finite length.

3. Model system

The diagram of a real power cable system to be discussed in this paper is shown in Fig. 1. It is a single core cable transmission system with the voltage of 154 kV. The total length of the cable is 6.284 km. It consists of five crossbonded major sections with three minor sections for each major section. As usual, the sheaths are jointed and crossbonded between two sections.

In this paper, the single line to ground fault is considered in real power cable system to test the proposed algorithm and Alternative Transient Programs (ATP) program is used for system modeling and simulation. The sampling frequency is 1 MHz, the propagation velocities of traveling wave on power cable system is 1.67487×10^5 km/s. The applied fault inception angle is 0°, 45°, 60° and 90°, respectively. In order to calculate the distance to fault point, single line to ground fault is supposed to occur at 1–3 km from A S/S. Fault resistance is assumed to be 0, 0.5 and 1Ω, respectively.

4. Algorithm for fault classification

Wavelet transform decomposes the signal into approximation and detail coefficients, forming approximations and details. The approximations are the high-scale, low-frequency components of the signal, while the details are the low-scale, high-frequency components. The decomposition process can be iterated.

Normally the first level detail in wavelet transform contains the information to detect the fault. In order to detect the fault, threshold is set. If the signal exceeds the threshold, then it is supposed that a fault has occurred. However, the spike can be detected on all phases. It is difficult to discriminate on which phase the fault is. For many signals, the low frequency contents are the most important parts. They give the signal their identities to some extents. For SWT decomposition, the approximation contains the low frequency components. The more levels the signals are decomposed, the lower frequency the components will be.

For fault detection and classification, the 4th level approximations of current on phases A–C will be used. If the fault occurs on phase A, the magnitude of approximation on phases B and C are very low comparing to that on phase A after some delayed