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A novel redundant haar lifting wavelet analysis based fault detection and location technique for telephone transmission lines

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ABSTRACT

The redundant lifting scheme is a perfect tool for wavelet decomposition and reconstruction conducted in the time domain without decimation procedure. In this paper based on the redundant haar lifting wavelet analysis and time domain reflectometry (RHLW-TDR) a novel fault detection scheme is introduced to detect the fault of the telephone transmission lines. The fault time tags are extracted directly from the wavelet detail coefficients. Furthermore, the proposed algorithm is improved to adaptive morphological redundant haar lifting wavelet analysis based time domain reflectometry (AMRHLW-TDR). Comparing to the conventional wavelet based TDR technique, the simulation test and practical experiment results verified the accuracy and convenience enhancement of the proposed methodology and its improved version.

1. Introduction

To quickly and accurately inspect the fixed phone transmission system is of great significance to save the time and cost of telecommunication maintenance. Up to date, time domain reflectometry (TDR) [1–4] has been demonstrated great potential for detection of fixed phone transmission system.

Whereas owing to that the accuracy of this single pulse echo based technique is subjected to the attenuation with the distance and the phase change distortion with frequency as well as the influence of the noisy signals, several alternatives has been proposed. Song et al. [5] proposed time–frequency domain methodology utilizing the time–frequency cross-correlation function, which reveals high accuracy and overcomes the disadvantages of conventional techniques. Liu et al. also [6] combined the time–frequency cross-correlation function with correlation matching method to facilitate the improvement of the traditional method. Moreover, Smail et al. [7] proposed an improved scheme combining the neural networks (NNs) with TDR relying on the numerical modeling of wiring network and NNs which can approximate a wide range of functions provided that they are previously trained. However, this scheme suffers great computation cost and complex data training procedure.

The potential benefits of applying wavelet transform for analysis of transient signals in power systems have been recognized in recent years. Magnago and Abur [8] presented wavelet based technique for transmission system. Nevertheless, there are inherent drawbacks containing boundary problems in both time and frequency domain induced by traditional wavelet decomposition. Ji et al. [9] and Jiang et al. [10] introduced a novel and effective signal processing tool lifting scheme to extract the features (polarities and maxima) of the fault-generated reflected waveforms. But one of the drawbacks of this algorithm is the down-sampling procedure that the length of the

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Nomenclature

$\vee$	the comparator to obtain the greatest element
$\wedge$	the comparator to obtain the least element
λ_j	the threshold in layer j
a^l	the scaling coefficient in layer l
a_l^n	the reconstructed denoised scaling coefficient in layer l
d^l	the detail coefficient in layer l
d_l^n	the reconstructed denoised detail coefficient in layer l
d_n	the decision at location n
d_j	the denoised detail signal in layer j
$D(x,y)$	the decision map
Dis	the discontinuities of the fault cable
f_s	the sampling frequency
$g(x)$	the gradient function
N_I	the incidence point
N_R	the reflection point
P^0	the initial predictor
P^l	the constructed predictor in layer l
T	the gradient threshold
T_i	the transit start time of the incident waveform
T_r	the transit start time of the reflected waveform
U^0	the initial updater
U^l	the constructed updater in layer l
v_p	the velocity of propagation
$x(n)$	the signal obtained by synthesis step
$x'(n)$	the signal obtained by analysis step

approximation signal would halve as the decomposition level increasing, which would reduce the detection precision of the fault location. Furthermore, Arpaia et al. [11] designed the optimal adaptive lifting scheme based wavelet filter by utilizing a cultural algorithm. Compared with genetic algorithms, the improved procedure showed better performances in corrosion rate measurement via electrochemical impendence spectroscopy for buried pipelines.

Motivated by Li et al. [12] and Yang et al. [13]that to avoid the decimation process and to rely on advanced wavelet analysis algorithm, this paper develops a fault location scheme integrating the redundant haar lifting wavelet analysis scheme and the adaptive morphological arithmetic with TDR for telephone transmission lines. The remainder is organized as follows. In Section 2 fundamental concepts of redundant lifting scheme, morphological wavelet as well as TDR technique is reviewed. Section 3 provides an introduction to the proposed scheme and its modified version. Subsequently the simulation experiment and practical test verification are carried out to assess the effectiveness and accuracy of the methodology in Section 4. Concluding remarks are presented in the last section.

2. Brief review on redundant lifting scheme, adaptive morphological wavelet, and TDR

2.1. Wavelet analysis

2.1.1. Redundant lifting scheme

In order to construct wavelets in settings where translation and dilation, and thus the Fourier transform cannot be used, Sweldens [14,15] proposed the lifting scheme, a new tool in the construction of bi-orthogonal wavelets. Subsequently Lee et al. [16] introduced a new structure for the undecimated wavelet transform, which combines the stationary wavelet transform with a lifting scheme and could be described as the unsampled predict and update steps without the split stage. In addition, Rao and Giriprasad [17] comprehensively reviewed the recent developments on lifting scheme of second generation wavelet analysis. It is concluded that optimized lifting schemes are almost based on the prediction or statistical models according to the taxonomy of lifting schemes. The specific process of the space-adaptive based redundant lifting wavelet transform which could obtain well reconstructed denoising signal described as follows [18].

1. Decomposition. The initial updater and predictor can be constructed according to [19].

$$U^0 = [0.25, 0.25]; \quad P^0 = [0.5, 0.5] \tag{1}$$

The updater and predictor in layer l can be calculated as, respectively.

$$U^l = \left[u_1, \underbrace{0, \ldots, 0}_{2^l-1}, u_l, \underbrace{0, \ldots, 0}_{2^l-1}, \ldots, u_N\right] \tag{2}$$

$$P^l = \left[p_1, \underbrace{0, \ldots, 0}_{2^l-1}, p_l, \underbrace{0, \ldots, 0}_{2^l-1}, \ldots, p_N\right] \tag{3}$$

Then

$$a_{l+1} = a_l + U^{l+1} a_l \tag{4}$$

$$d_{l+1} = d_l + P^{l+1} d_l \tag{5}$$

where the a_i represents the scaling coefficient in layer i, d_i represents the detail coefficient in layer j.

2. Reconstruction. The scaling coefficient a_l in the last layer and all the denoised wavelet coefficients $d_j (j = 1, 2, \ldots, l)$ are used to reconstruct the denoised signal a_l^n, illustrated as follows

$$a_{ld} = d_{l+1} + P^{l+1} a_{l+1} \tag{6}$$

$$a_{la} = a_{l+1} - U^{l+1} a_{ld} \tag{7}$$

$$a_l^n = (a_{la} + a_{ld})/2 \tag{8}$$

2.1.2. Adaptive morphological wavelet

Heijmans and Goutsias [20] proposed a general and flexible approach for wavelet-type multi-resolution signal decomposition and reconstruction that contains both linear and nonlinear schemes. Then Piella et al. [21] and