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Extension Mode in Sliding Window Technique to Minimize Border Distortion Effect

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Abstract

This paper deals with border distortion effect at starting and ending of finite signal by proposing sliding window technique and basic extension mode implementation. Single phase of transient and voltage sag is chosen to be analyzed in wavelet. The signal which being used for the analysis is simulated in Matlab 2017a. Disturbance signal decomposes into four level and Daubechies 4 (db4) has been chosen for computation. The proposed technique has been compared with conventional method which is finite length power disturbance analysis. Simulation result revealed that the proposed smooth-padding mode can be successfully minimized the border distortion effect compared to the zero-padding and symmetrization

Keywords*: Border distortion; sliding window; extension mode; wavelet transform*

1. Introduction

Power quality monitoring is very crucial to protect the electrical and electronic equipment from breakdown. The fast evolve of digital tools such non-linear load, data processing equipment, and switching load causes power disturbances and reduce power quality in the system [1].Previously, PQ has been evaluated manually which is by visual inspection instead of pre-processing technique. Thus it come out with many complications such super massive measured data, lack of information and time-consuming inspection for diagnose [2]. The improvement of monitoring systems are always follow up to cater PQ recognition in terms of its versatility, reliability, and precision to deal with the disturbances.

Demanding of processing tools especially to detect and localize non-stationary signals accurately heading to the enhancement of time-frequency analysis. The evolution of signal processing tools namely wavelet transform overcoming conventional Fourier analysis's drawback which can perfectly localize signal in frequency domain but failing in time domain [3]. The capability of wavelet in recognizing indexed in waveform make it well perform to extract features for gaining amplitude and frequency information [4]. It has the ability to classify types of power disturbances based on duration of harmonic content in the signal.

Wavelet transform analysis is broadly used for the purpose of denoising, data compression and features extraction [5-7]. It is much effective to detect nonlinearities in the system [8]. However, wavelet transform suffer from drawback known as border distortion effect. Computing the convolution requires non-existence values beyond the boundary while wavelet shifting toward the edges. As a result, border effect yielded at the boundary part due to lack of information [7], [9]. Is also shows that the signal processing facing technical problem that causes the data failures [10]. The effect might questioned the accuracy of data analyze and possess longer period sequence.

To deal with border distortion, the border should be treated differently from the other parts. There are two ways to deal with the border. First, by curtail the data after the convolution process but the risk is there's might be data losses at the edges which sometimes contain the important information. The other one by applying artificial extension at borders before data processing. These extension scheme has been introduced several decade ago [11-12]. Three basic extension mode named zero-padding, smooth-padding and symmetrization well known that each method has drawback. Thus the most appropriate extension mode should be chosen based on the requirement.

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Habsah *et al*. [4] revealed that smooth-padding mode is the best extension mode to reduce border effect for transient and voltage sag signal. Those researcher cover only for finite length signal to reduce the border. Hence, this paper is organized to identify the effect of border distortion after extension mode implementation at sliding window wavelet signal. The proposed technique is being compared with conventional technique [4]. The signal is simulated in Matlab 2017a prompt and Matlab Toolbox.

2. Research Method

2.1 Wavelet Formulation

Wavelet transform is a powerful signal processing tool in recognizing power disturbance pattern based on its features extraction [13]. It has the capability to analyze the signal in multi resolution either localize in time or space [3], [14]. Previously, Fourier Transform is used to analyzed the stationary signal but not capable for non-stationary analysis as the time information is lost [15]. Fourier transform equation can be defined as

$$F(\omega) = \int_{-\infty}^{+\infty} f(t)e^{-j\omega t}\, dt \qquad (1)$$

From the equation, -∞ to +∞ indicate that time information will be lost. While Wavelet transform is an effective tool to analyze non stationary signal because of Mother Wavelet function used as the basis function. Mother wavelet function ψ(t) equation is defined as:

$$\psi(t)_{(a,b)} = \frac{1}{\sqrt{a}}\psi\left[\frac{t-b}{a}\right] \qquad (2)$$

Where 1/a is frequency and $1/\sqrt{a}$ is the normalizing constant of each scale parameter. While b is parallel translation of time axis. The Continuous Wavelet Transform (CWT) is define as:

$$CWT_{\psi}x(a,b) = \frac{1}{\sqrt{|a|}}\int_{-\infty}^{+\infty} x(t)\,\psi^{*}\left(\frac{t-b}{a}\right) dt \qquad (3)$$

Terms *a* and *b* indicate the dilation and translation which determine the frequency length of wavelet and shifting position respectively. Extended of CWT, the Discrete Wavelet Transform (DWT) is introduced to overcome the computational derived from CWT. Also, DWT can be practically applied and easier to implement. The discrete wavelet transformation is:$DWT(m,n)$

$$= \int_{-\infty}^{+\infty} x(t)\,\psi_{m,n}^{*}(t)dt \qquad (4)$$

Where; $\psi_{m,n}(t) = a_0^{-m/2}(\frac{(t-na_0^m b_0)}{a_0^m})$

These parameters are a=a_0^m, $b = nb_0a_0^m$

Where m, n Z; m, n represent frequency localization and time localization respectively. In this paper, db4 mother wavelet is used to detect disturbance signal and obtain time detection information and detail frequency.

2.2 Proposed Scheme

The effectiveness of extension mode employed is being compared between the proposed technique and the conventional technique. Figure 1 shows the general flow of proposed technique. For conventional technique, finite length of disturbance signal will undergo DWT analysis and the extension mode will be implemented before the decomposition process. This paper proposed to periodize the disturbance signal into two-cycle window length for decomposition and extraction coefficient. It's namely sliding window because the periodized window signal will slide until to the finite length. The contrasting reconstruction event for both cases will be identified after the implementation of extension mode method.

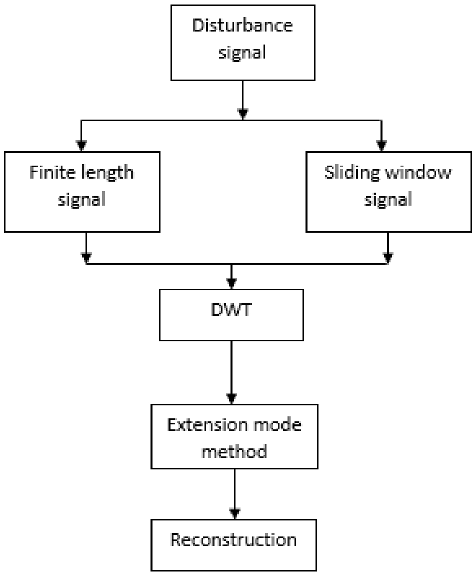

Figure 1. Flow chart of proposed technique

2.3 Extension Mode Theory

DWT algorithm is based on convolution and downsampling. Once, a convolution process performed in finite length signal, the border distortion will arise. Thus, the border should be treated differently from the other parts from the signal. The extension mode is one of the techniques to reduce border effect. It has been employed to each level of decomposition process to get perfect reconstruction. Previously, S.Habsah *et al.* [4] had employed extension mode method to reduce the border for non-stationary finite length signal and discovered that smooth padding yielded satisfying result. In this paper, three basic extension mode will be employed to identify its effectiveness on minimizing border distortion effect when sliding window signal is hired. All these algorithms is simulated in Matlab 2017a prompt window and Matlab Toolbox.

The extension mode formulation [16] that will recover in this paper are:

1. Zero-padding (zpd) – signal is extended by adding zero samples.

$$ ...\ 0\ 0 \mid x1\ x2\ ...\ xn \mid 0\ 0\ ... \quad (5) $$

2. Symmetric-padding (sym) – signal is extended by mirroring samples.

$$ ...\ x2\ x1 \mid x1\ x2\ ...\ xn \mid xn\ xn-1 \quad (6) $$

3. Smooth-padding (spd) – signal is extended according to the first derivatives calculated at the edges (straight line). Smooth padding works well in general for smooth signals.

$$ \frac{\delta f}{\delta x} = f(x-1) - f(x) \quad (7) $$

3. Results and Analysis

3.1 Finite Length Signal

Set data analyzed in this paper is transient and voltage sag disturbance signal using sampling frequency of 12850Hz. The signal contain of 257 samples per cycle and at 50Hz frequency used. Figure 2 shows input signal used to be analyzed in this paper. The RMS voltage signal of 240V and fault occurred at 0.17s at 0.1s has been employed for decomposition computation.

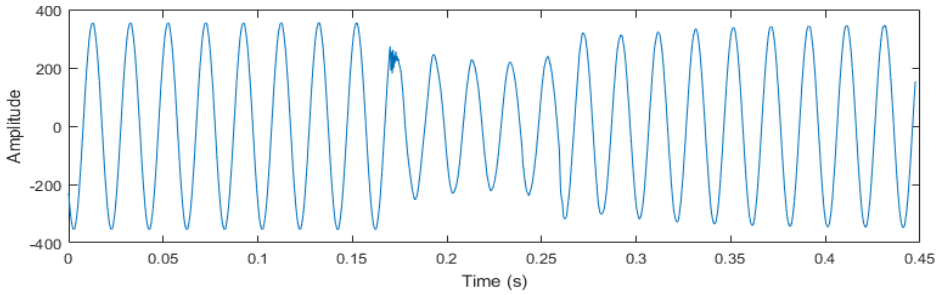

Figure 2. DWT input signal

To test the effectiveness of extension mode algorithm, different case studies are implemented to determine whether the proposed technique is perform the minimization of border effect at different scenario of wavelet signal decomposition. The case studies used in the study are:

Case 1: In this case, finite length disturbance signal is decompose into 4 level decomposition coefficient. Then, the coefficients are reconstructed with applying extension mode method. This case is known as finite length signal decomposition.

Case 2: In this case, finite disturbance signal is extracted into two-cycle window length. Then, the signal decomposed into 4 level decomposition coefficient. The signal is continued extracted for next two-cycle window length until the highest index signal. This case known as sliding window decomposition computation.

For all case studies, the extension mode algorithm has been executed 2 times to gain an accurate result. First case, the extension mode is implemented before the decomposition computation algorithm. While for 2nd case, the extension mode is implemented at each two-cycle decomposition computation stage. To realize the effectiveness of the technique, mean square error (MSE) is evaluated for both cases.

3.2 Finite Length Signal Decomposition

In this case, three types of extension mode (zero-padding, symmetrization and smooth padding) are implemented. Figure 3 shows decomposition signal at level 4.

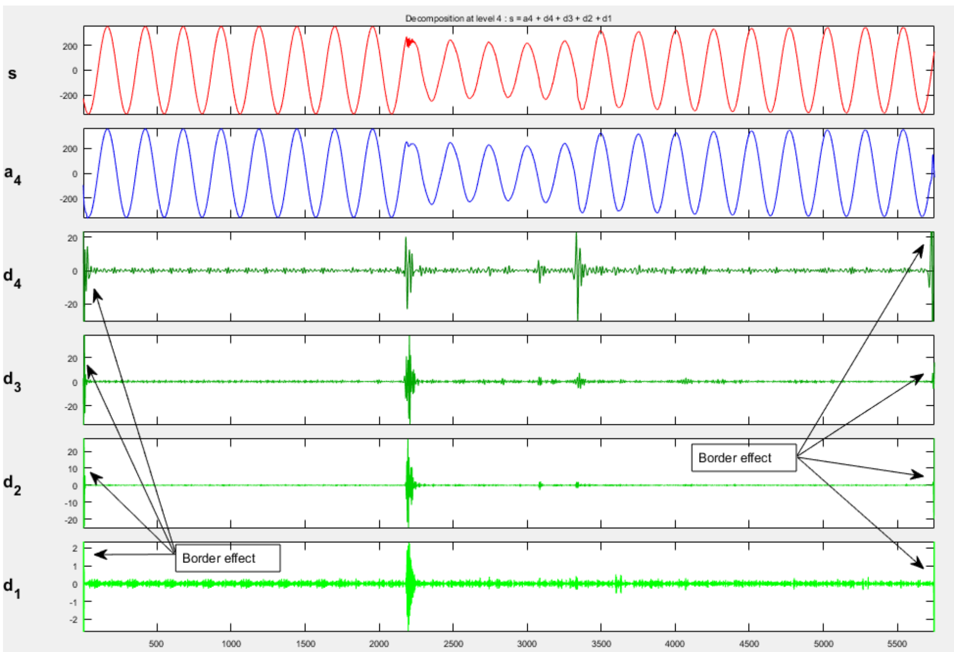

Figure 3. Approximation and details extraction

The approximation and details coefficient are extracted from the decomposition and the border effect is presented at each level. While, Figure 4 shows absolute reconstruction decomposition coefficient of wavelet analysis for input signal in Figure 2. High border magnitude at starting and ending point of wavelet illustrated a technical problem occur on an analysis. Then, triple extension modes are enforced to the signal to perform its border minimization effectiveness.

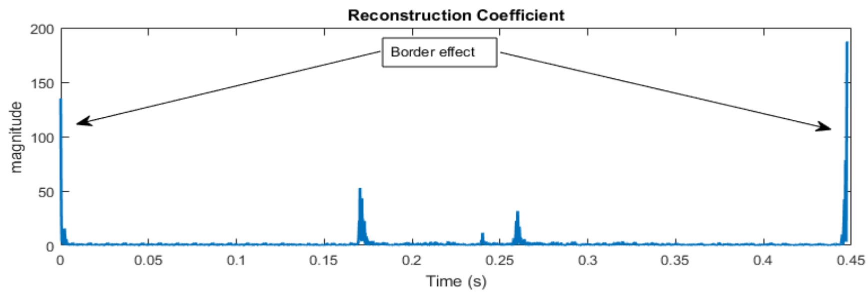

Figure 4. Reconstruction decomposition coefficient of finite length original signal

Table 1 shows border effect magnitude at last 1 value index signal analysis. Smooth-padding mode (spd) performed minimum border index magnitude while zero-padding (zpd) performed maximum border index magnitude at stating and ending point respectively. The conclusion that can be made, spd mode is able to minimize border distortion effect efficiently for transient and voltage sag signal.

Table 1. Border effect magnitude

Extension mode	Fs (kHz)	Magnitude	
		Starting	Ending
Spd		0.17	0.64
Sym	12.85	21.45	12.81
Zpd		106.20	101.00

3.3 Sliding Window Decomposition Computation

For this case, finite signal is periodized into two-cycle window length. Then, the decomposition signal using db4 at level 4 has been computed and the coefficients for each levels are extracted. The steps continued until final index of signal length. Figure 5 simply illustrated the reconstruction decomposition details coefficient of wavelet signal. Three types extension mode is implemented to each signal to analyze the effect of reconstruction wavelet analysis. Figure 6 shows the identical result for three extension mode implementation. Zero padding and symmetrization mode yielded border effect at each sliding window signal analysis. Smooth-padding resulting the optimal signal analysis with almost non border effect presented.

Figure 7 shows bar chart to compare MSE of border effect between the proposed scheme and conventional technique. From the chart, zpd shows the highest MSE evaluated based on analysis while spd shows the least MSE value. Symmetrization (sym) performed intermediate MSE border magnitude between the others. The lowest MSE value indicate that the analysis has low noise and border effect while zero padding indicate destitute border distortion effect.

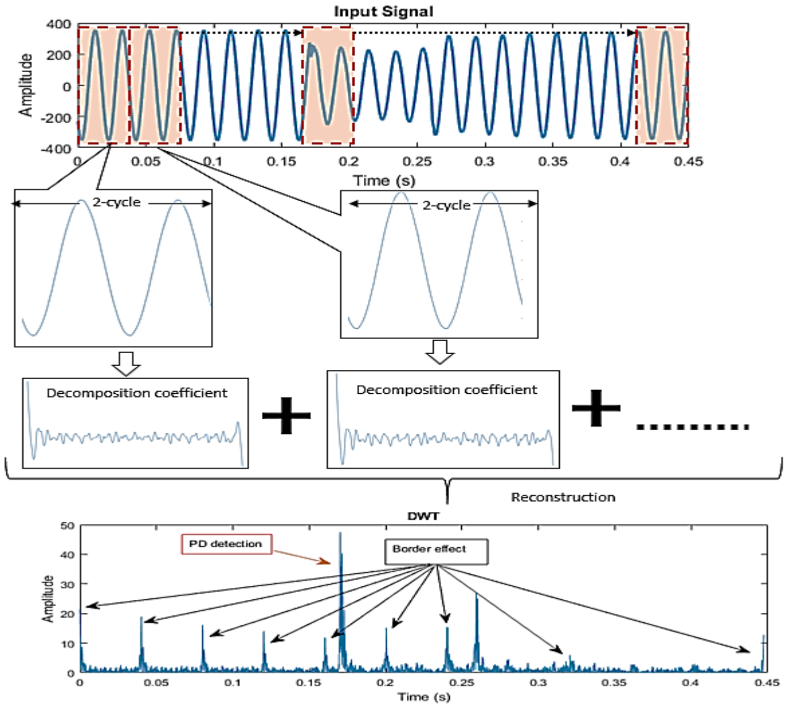

Figure 5. Decomposition coefficient reconstruction for sliding window signal with implementation of symmetrization extension mode

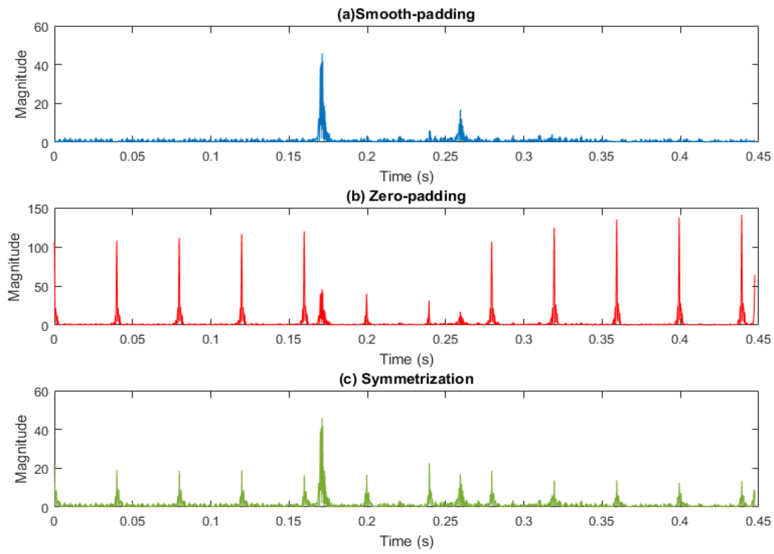

Figure 6. (a) Smooth-padding sliding window reconstruction. (b) Zero-padding sliding window reconstruction. (c) Symmetrization sliding window reconstruction

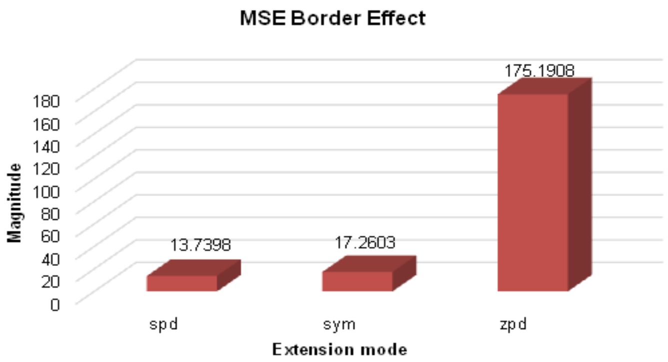

Figure 7. MSE border effect for three different extension mode

4. Conclusion

This paper has presented the implementation of extension mode method for sliding window wavelet decomposition to minimize border distortion effect. Proposed technique has been compared with the conventional technique by evaluating MSE value for each cases. The consequence of sliding window technique is it produced border effect at each periodized window for both symmetrization and zero-padding mode. Thus, it can be concluded that the proposed technique effective only for smooth-padding mode employed but not capable for symmetrization and zero-padding implementation.

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