

The Application of S-Transform to Reduce Border Distortion Effect Based on Window Length

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ABSTRACT

The enhancement of powerful signal processing tools has broadened the scope research in power quality analysis. The necessity of processing tools to compute the signals accurately without border distortion effect presence has demanded nowadays. Hence, S-Transform has been selected in this paper as a time-frequency analysis tools for power disturbance detection and localization as it capable to extract features and high resolution to deal with border distortion effect. Various window length signal has been analyzed to overcome the border distortion effect in S-Transform. To ascertain validity of the proposed scheme, it is validated with IEEE 3 bus test system and simulation results show that the proposed technique can minimize the border effect while detecting transient and voltage sag during fault system. As a result, the longest window length which is four cycle, outperform the least MSE value which indicate the best performance. While, the shortest window length resulting highest MSE value which indicate the worst performance.

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1. INTRODUCTION

Power quality disturbances (PQD) can be initiated by various causes, i.e. fault and switching which can cause undesired effect to electrical system. These disturbances lead to non-stationary signal occurrence and need powerful processing tool which can be used for compression, reconstruction and feature extraction of signal analysis [1], [2].

Hence, advanced mathematical algorithm and artificial intelligent technique are proposed to effectively detect and localize power disturbance [3]. However, with the advancement of time-frequency analysis, some drawbacks have been occurred on analyzed signal. The border distortion at the end points is generated after the computation process. This technical problem can cause measured data failures and peaks at the starting and ending signal [4]. Border effect can be reduced by using the extension mode method in Wavelet Transform as proposed by [5]. But it never been discovered using ST analysis as it visualizes the disturbance in time-frequency contours form. The border cannot be detected from that contours unless each frequency extracted from ST output.

Generally, ST is a combination element of STFT and WT algorithm. Initially, Fourier Transform is introduced to decompose the signal into frequency domain. Unfortunately, it does not provide any information regarding on time. Extended of this situation, short-time FT (STFT) is introduced to solve the problem by using sliding window concept. However, STFT come out with a limitation which is fix window length thus causing the variation of window cycle and gives low time resolution at high frequency.

In 1980s, I. Daubechies proposed wavelet transform (WT) based on decomposition signal according to time-scale instead of frequency and using mother wavelet with adaptable scaling properties known as multi resolution [6]–[8]. WT features give effective time and frequency information for real power quality

events such as transient and voltage events [9]. Extended from it, S-Transform (ST) is proposed by [10] to increase the effectiveness of detection and localization PQD event. In simply words, it is Continuous Wavelet Transform with phase correction and uses the window to localize the spectrum in time similar to STFT [9], [11]. The main advantage of ST is it provides multi resolution analysis while maintaining the absolute phase for each frequency.

Many researchers used ST to extract the features to be used as an input in classifier technique. In [12], S. Shabuddin *et. al* proposed S-Transform to detect various power disturbances in transmission network system. In [13], M. H. Jopri *et. al* used ST to analyze disturbances signal of power distribution system. The features are extracted in form of time-frequency representations in order to classify the harmonic signal. Besides, ST has been used for image detection. In [13], D. Minghui *et. al* proposed ST and Hough-Transform to represent better localization of time-frequency and yielded robust watermarking algorithm against geometric attacks. But, none of them focusing on border distortion effect generated in ST analysis.

Therefore, this paper proposed an idea to identify border distortion magnitude based on frequency level extracted from the signal analysis in ST. Window length of original disturbance signal has been varied to test their efficiency in the analysis. The longest window length is recorded to be the best used for an analysis due to lowest border magnitude presented. To validate the result, the signal is simulate in three phase bus sytem in MATLAB/Simulink.

2. RESEARCH METHOD

2.1 S-Transform (ST) Theory

S-transform is extended idea from Continuous Wavelet Transform (CWT) based on moving Gaussian window [14] with a phase correction. It provide frequency contour which can localize the signal at the higher noise level. Thus, it can be defined as

$$S(t, f) = e^{-j2\pi f\tau} W(\tau, d) \quad (1)$$

Where the mother wavelet is define as

$$W(t, f) = \frac{|f|}{\sqrt{2\pi}} e^{-\frac{t^2 f^2}{2}} e^{-j2\pi f t} \quad (2)$$

The scale parameter of d is inverse of frequency f . however, mother wavelet equation in (1) does not satisfy with zero mean property. Thus, S-Transform can be define as

$$S(\tau, f) = \int_{-\infty}^{\infty} g(t) \frac{|f|}{\sqrt{2\pi}} e^{-\frac{(\tau-t)^2 f^2}{2}} e^{-j2\pi f t} dt \quad (3)$$

The S-Transform also can be written in Fourier Transform form

$$S(\tau, f) = \int_{-\infty}^{\infty} G(\alpha + f) e^{-\frac{2\pi^2 \alpha^2}{f^2}} e^{j2\pi \alpha \tau} d\alpha \quad f \neq 0 \quad (4)$$

From eq. (3) and (4), the discrete time-series of S-transform correspond to $g(t)$ by making $\tau \rightarrow kT$ and $f \rightarrow \frac{n}{NT}$.

$$S\left[kT, \frac{n}{NT}\right] = \sum_{m=0}^{N-1} G\left[\frac{m+n}{NT}\right] e^{-\frac{2\pi^2 m^2}{n^2}} e^{\frac{j2\pi mk}{N}}, \mathbf{n} \neq \mathbf{0} \quad (5)$$

Where $k, m=0, 1, \dots, N-1$ and $n = 0, 1, \dots, N-1$.
For $n=0$

$$S[kT, 0] = \frac{1}{N} \sum_{m=0}^{N-1} G\left[\frac{m}{NT}\right] \quad (6)$$

2.2 Extracted Frequency Level Based on Window Length

The convolution theorem and efficiency of the FFT help to accelerate the discrete S-Transform computation process. S-transform resulting the complex value matrix where each column correspond to time and row correspond to frequency [9]. The instantaneous maximum amplitude can be obtained from

$$A = abs(S[jT, n/NT]) \tag{7}$$

While the phase angle can be calculated using

$$\phi = \tan^{-1}\{ImagS[jT, n/NT]/Reals[jT, n/NT]\} \tag{8}$$

Based on this research scope, the minimized border distortion was discovered at imaginary part of the highest frequency level of S-transform which is

$$K = ImagS[jT, n/NT] \tag{9}$$

Where K represent sampling interval of the signal at the highest frequency level. The window length of sampling interval has been selected as one-cycle, two-cycle, four-cycle and full-cycle signal for the analysis.

3. RESULTS AND ANALYSIS

3.1 Simulation of Transient and Voltage Sag Signal

A single line-to-ground fault is created in three phase bus system for signal analysis. For example, in Figure 1, transient and voltage sag fault for the duration of 0.1s is created on phase A at 0.1s. The distance relay at 300km located between bus 1 and bus 2 is considered in this study. Figure 2 shows the transient and sag voltage measured by the distance relay between bus 1 and bus 2. Once the fault occurred in the system, the signal at the upstream is further simulated at 0.35s simulation time stop.

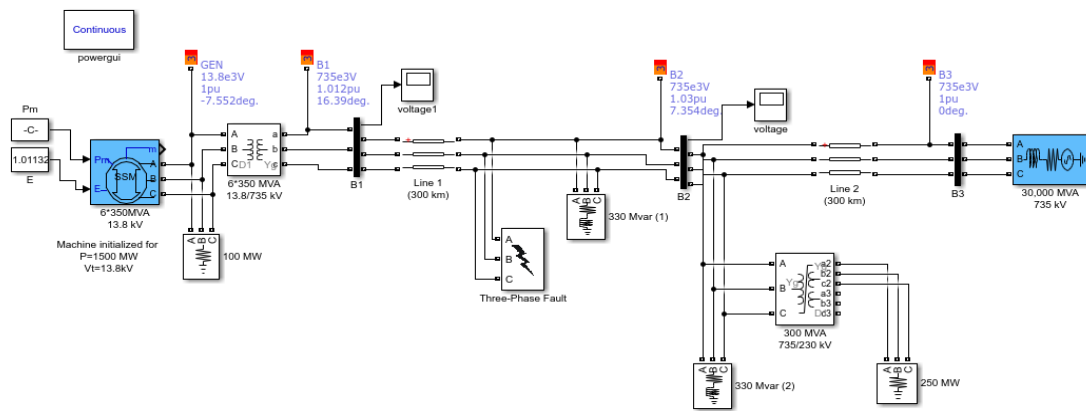


Figure 1. Three phase 3 bus system

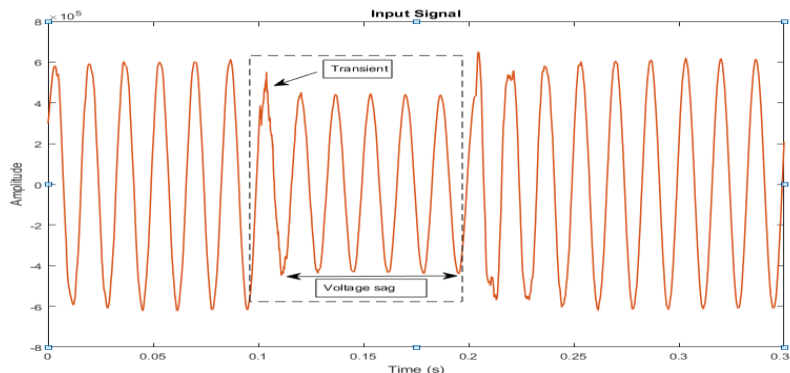


Figure 2. Transient and voltage sag input signal

3.2 S-Transform Contour Simulation

In this part, S-Transform analysis is applied to the signal to detect the transient and voltage sag fault. Figure 3 (a) shows S-transform contour of full-cycle signal to illustrate the fault occurred at 0.1s. While Figure 3 (b) shows the S-Transform output extracted from the analysis to determined border distortion effect at the starting and ending signal.

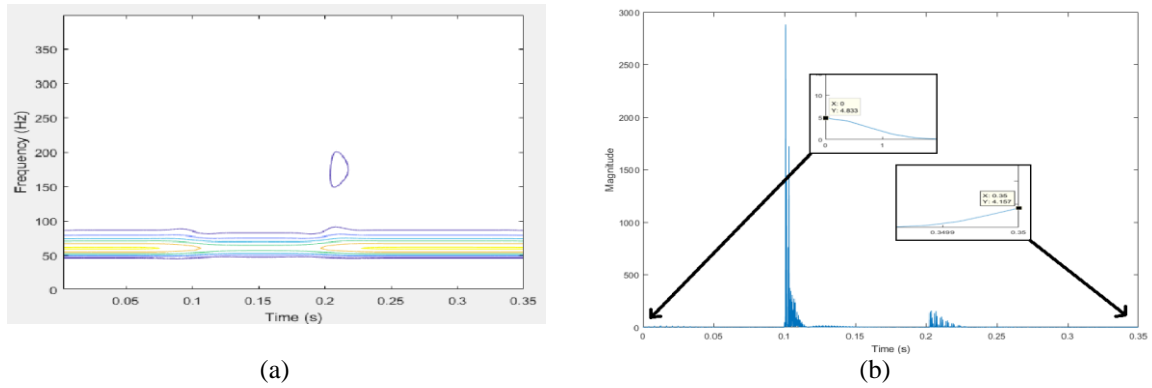


Figure 3. (a) S-Transform contours, (b) Border distortion effect

3.3 Effect of Window Length

Window length variation affecting the time and frequency resolution of the signal. Figure 5 demonstrate the varying window length has been employed for the analysis. The analysis signal detected at 0.09367s which is before the disturbance occurred for all cases. The longest window length (full-cycle signal) based in Figure 1 was analyzed first as a referenced as it resulting the lowest border magnitude based in Figure 4(b).

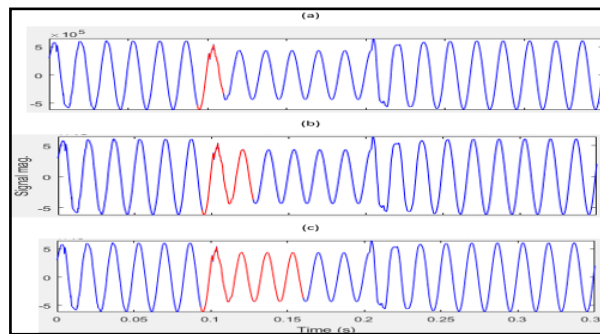


Figure 4. (a) One-cycle window length, (b) Two-cycle window length, (c) Four-cycle window length

Based on Table 1 the highest window length resulting the lowest border magnitude at the starting and ending of the s-transform output which are 137.2 and 79.44. The border effect can be clearly observed from Figure 6 where is one-cycle window length derived the highest border magnitude and four-cycle window length derived the lowest border magnitude respectively.

Table 1. Magnitude of Border Distortion

Fs (kHz)	Window length (cycle)	Sampling index	Frequency (kHz)	Magnitude	
				Starting	Ending
25.6	21	8961	4.481	4.83	4.16
	4	1708	0.855	46.06	39.96
	2	854	0.428	91.20	79.44
	1	427	0.215	137.20	117.20

3.4 Border Index Analysis

Further analysis extended from previous border magnitude has been analyzed by measuring mean square error (MSE) for the border. Thus, 5 point at starting and ending signal length respectively extracted from analysis signal have been calculated to define MSE as in Table 2. Those point index is chosen based on the graph at the border started increase and decrease respectively. The MSE for each selected cycle has been compared with full-cycle border index (Figure 6) to identify the optimum value based on their window length.

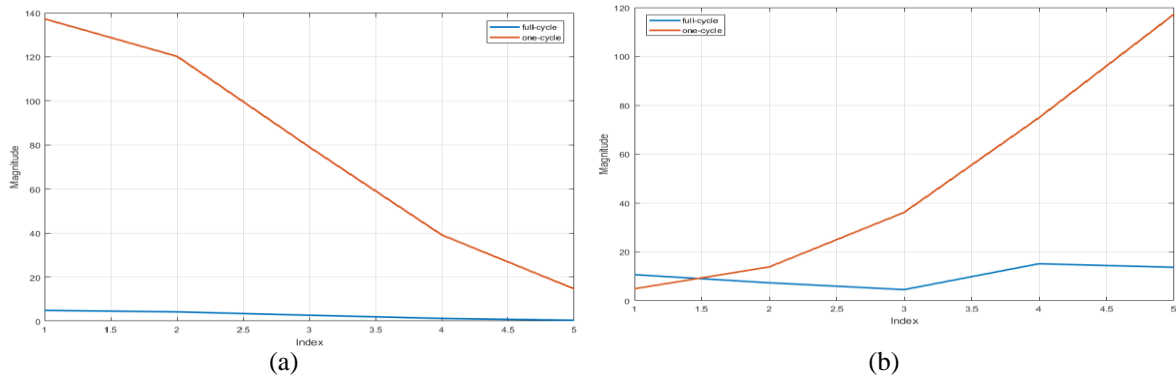


Figure 5. (a) Border index selected at starting point, (b) Border index selected at ending point

Bar chart in Figure 7 indicates MSE at the starting border is the highest for one-cycle window length. While four-cycle window length indicates the lowest MSE value which are 731. Equivalent to the MSE at the ending border, indicate the optimum value for longest window length which is 490. While MSE at starting and ending border for one-cycle widow length outperform the highest MSE value which are 7690 and 3073 respectively. Further analysis result can refer in Table 2.

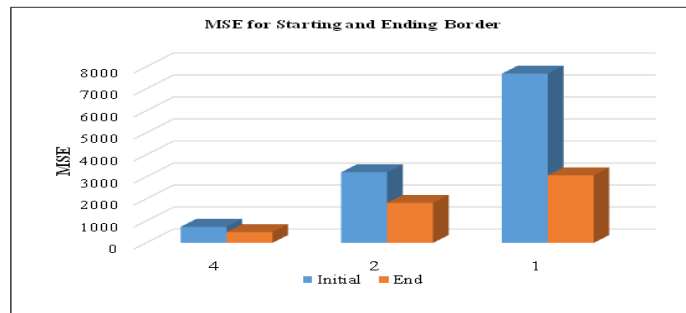


Figure 6. MSE of border distortion

Table 2. MSE Value for Various Window Length

Window length (cycle)	Border index	MSE	
		Starting	Ending
1	5	7690	3073
2		3212	1821
4		731	490

4. CONCLUSION

The attainment of least border magnitude has been discovered by extracting the highest level frequency of imaginary phase ST. Window length of signal analysis gives the main factor affecting the border distortion magnitude. The longest window length yielded lowest border magnitude. The performance of border distortion reduction can be observed from the MSE of various window length signal. From the result, four-cycle window length signal presented the least MSE while one-cycle window length

outperformed the worst MSE result. The least MSE indicate the best performance for border distortion reduction rather than higher MSE value. This technique is proven to detect different border distortion magnitude with different window length of signal.

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