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Comparative Study of Extension Mode Method in Reducing Border Distortion Effect for Transient Voltage Disturbance

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Abstract

Wavelet transform is an essential method for preprocessing and analyzing non-stationary signal of power quality disturbances. Recently, power quality disturbances cause various effects which reduce the accuracy of the signal such as border distortion. This paper is presenting the comparative study on extension mode scheme to reduce border distortion effect in Discrete Wavelet Transform. The three different methods namely zero padding; smooth padding of order 1 and symmetrization mode have been carried to observe their capability on reducing border distortion effectively. The implementation of these modes has been carried out in Matlab Software version R2014a. The analysis is considering the decomposition coefficient at level 4 with mother wavelet type Daubechies. With the aid of soft- threshold function, the noise and unwanted signal is effectively removed to recover the original signal. The comparative study provides the best mode to reduce border distortion effect with the presence of transient voltage is smooth padding of order 1.

Keywords*: Discrete Wavelet Transform; border distortion; power quality; transient voltage; Daubechies*

1. Introduction

The most concern of distributors for their consumers in recent years is about power quality. This crucial issue is much being studied by researchers to enhance the quality of power from time to time. Technically, disturbances are becoming the main factor that interrupt and reduce the quality of power in electrical system. Besides, this problem gives s big impact to energy price of households [1]. Classification of disturbances includes voltage sags, harmonic distortion, transient voltages and flickers. Thus, power quality analysis continuously improved by various techniques and methods correspond with the digital technology development such as signal processing or image processing. However, signal processing methods are the best tools to be used for analyzing compared to image processing. It is because, image processing more suitable to be used in medical department especially for disease diagnosing such as the identification of dental caries on the panoramic image [2].

In processing the signal, time-frequency domain is used to analyze signal with fast changing spectral content [3]. Thus, several techniques of signal processing are introduced in system application. There are involving discrete Fourier transform, Wavelet transform and discrete short-time Fourier transform. Among others, power system application for wavelet analysis is highly recommended and proposed compared with the Fourier transform because it have a lot of advantages in term of trade-off between frequency and time resolution at different frequencies [4]. Theoretically, Wavelet transform will apply to detect the duration of disturbances in the system. Statistics is used to calculate the recognition indexes in the waveform before the extracted features such as amplitude and frequency is obtained. These processes also lead to the determination of classifying types of disturbances based on the duration of harmonic content in the signal [5].

Furthermore, conventional wavelet transform technique has been used to detect electrical and electromechanical oscillation in real time. However, its efficiency of detection is highly affected by the choosing of mother wavelet and the oscillation will fail detected if the

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transient is overdamped [6]. Nonetheless, the drawback of conventional-wavelet methodologies can be overcome by scaling and wavelet coefficient energy with border distortions [7] [8].

However, the dictation of wavelet transforms in detecting the transient yield some drawbacks which is border distortion effect [9]. The existing of this problem comes from improper extension method in implementation of those techniques. Several years ago, some extension method discovered by [10] to yield high compression and quality of the signal. The r-factor pseudo circular extension is introduced by sub-sampled and up-sampled the signal before it's being filtered. The filtered component is then added to form a perfect reconstructed coefficient. The empirical experiment is able to reduce the reconstructed errors by 20%. Although this method does produce much better result compared to symmetric extension and circular extension method, it only applicable for finite extents signal such as images not strictly useful for infinite signal.

Besides, various extension methods have been developed to overcome border distortion effect [11]. Extension methods such as zero padding, smooth padding of order 1 and symmetric extension are the most popular methods which has always been used recently having its own drawbacks [3], [12], [13]. The extension method is broadly used to compress the data, thus needs much awareness when the analysis and synthesis procedures go through [14]. A smooth extension method which is Fourier Series extension has been proposed by [3] to overcome distortion effect at the boundaries. Fourier series introduced a model to undergo fitting process by finding the model's parameter to minimize the summed square of residual. The Fourier Series result then is extended for convolution calculation in order to define data beyond the border. The methods provide the best performance in reducing boundary effect in the wavelet.

Therefore, in order to evaluate the best performance method in reducing border distortion, the comparative study of extension mode method of Discrete Wavelet Transform in Matlab software for transient induced by power disturbances is proposed in this paper.

2. Research Method

2.1. Discrete Wavelet Transform

Wavelet coefficient leads to huge computational burden thus, DWT is introduced to overcome this problem [15]. DWT is implemented to obtain the real-time signal of wavelet transform. The real implementation of wavelet transform including successive pairs of low pass and high pass filter at each scaling stage of transform [16]. The high pass filter will analyze high frequency signal while and the low pass filter will analyze low frequency signal. In this paper the decomposition at level 4 is used in identifying the power quality problem.

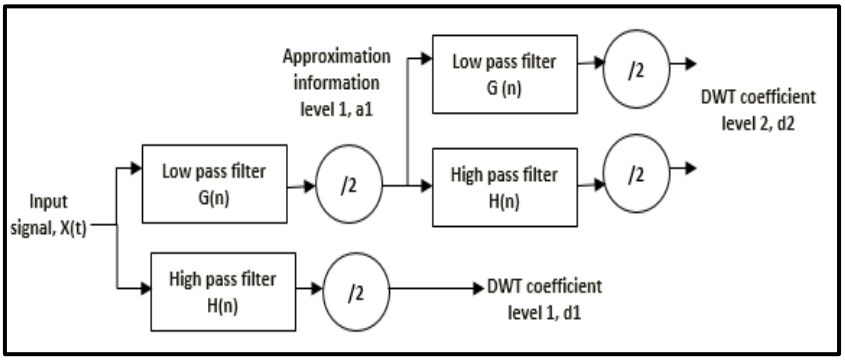

Figure 1. Algorithm of decomposition process in DWT

Figure 1 shows the algorithm of decomposition process for 2 level of discrete wavelet transform. The input signal is divided into two parts which are LPF and HPF. The down sampling is needed to remove multiple sample signal while the determination of filter bank level is depending on availability of bandwidth [17].

2.2. Extension Mode Method

Various extension mode methods have been discovered few decades ago. Three of the most popular modes involves zero padding (zpd), smooth padding of order 1 (spd) and symmetrization (sym). It is proven that each of them have their own drawbacks and should be chosen appropriately for analysis. Basically, this paper does the comparative study for three types extension mode, which effectively reduce border distortion effect of wavelet when there is transient disturbance occurrence.

2.3. Transient Voltage Event

Transient voltage event can be defined as a sudden change in voltage for a temporary time which usually depict as approximately about 1 millisecond. It is one of the classification of power disturbances which affect the power quality besides of voltage sag, harmonics, and flickers. Power disturbances can be caused by fault which occur side supplier side fault in lines. Besides, it also may causes from load changes, capacitive or switching load and inductive load. The energy exchanges that comes from the transients are subjecting the circuit components to higher stress which can cause excessive current or voltage variations [18]. Transients also can be classified into two categories which are impulsive and oscillatory. Transient is caused by switching capacitive banks which is one of the most common sources of degradation in distribution system. The capacitance and inductance from the system causes the oscillation of frequency, thus it is called as oscillatory. On the other hand, impulsive transient generally causes by sudden variation in the current and generates peaks in voltage. There are associated with the manual command of switches and interrupters [19].

2.4. Threshold Denoising Function

Threshold function is a vital parameter that needs to be considered in this experiment. It impact the de-noise performance [20] which functions to remove noise or unwanted signal to recover the original signal. Two types of threshold that are commonly used are hard threshold and soft threshold. In hard threshold function, the coefficients with absolute values lower than the threshold are set to zero. While the soft threshold function in addition shrinks the remaining nonzero coefficients toward zero [21].

Hard threshold expression:

$$W\delta = \begin{cases} W, & |W| \geq \delta \\ 0, & |W| < \delta \end{cases} \quad (1)$$

Soft threshold expression:

$$W\delta = \begin{cases} sng(W)(|W| - \delta), & |W| \geq \delta \\ 0, & |W| < \delta \end{cases} \quad (2)$$

From above expression, W are the original wavelet coefficients while $W\delta$ are the wavelet coefficients obtained by denoising and δ denotes the threshold. In this paper, soft threshold is used in the analysis because it easy to handle in mathematics and can be applied in the wavelet sub-band with few details. Hard threshold is commonly use to preserve the image edge information and closer to the actual information [22].

Figure 2 depicts the existence of unwanted signal or known as noise after the signal is analyzed. This unwanted signal is reducing the accuracy of signal information and should be removed to recover the original signal.

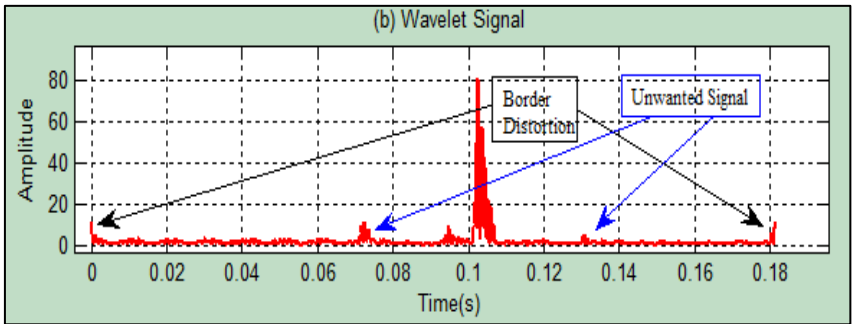

Figure 2. Unwanted signal existence in DWT

2.5. Experiment Overview

The sampling data acquisition has been analyzed in Matlab R2014a software. In conducting the experiment, 5 data sample have been used with the present of transient voltage event. The programming script and functions are built at the command window with sampling rate of 0.181s for the 1st until 3rd sample, 0.237s for the 4th sample and 0.473s for the 5th sample while the frequency is set at 50Hz. The sampling rate for each sample is different due to the irregularity or uneven sample per minute is taken. A proper mother wavelet selection is being considered to obtain an effective wavelet analysis. Thus, perform a no time delay in the real-time analysis [23]. In this experiment, mother wavelet type Daubechies with four coefficients (db4) level 4 has been chosen for signal decomposition and extract the coefficient and reconstruction process respectively. Daubechies wavelet of order 4 (db4) is suitable for fast and short transient disturbances [24]. Decomposition at level 4 resulting the best performance for analysis in terms of low production of noise in signal [25]. Figure 3 below depicts the flow for analyzing signal to be evaluated in MATLAB Simulink.

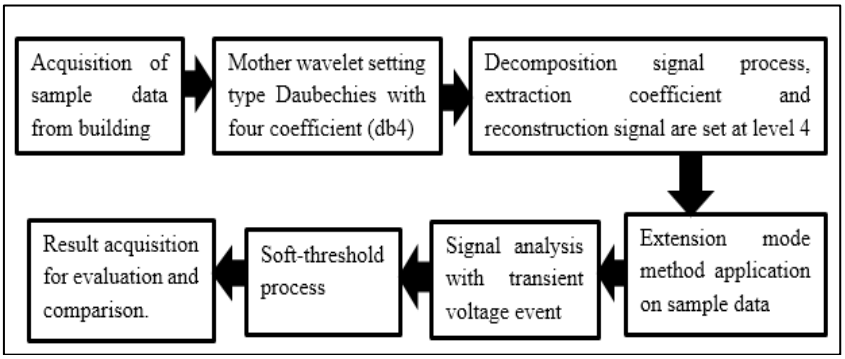

Figure 3. Flow of signal analysis in MATLAB

3. Results and Analysis

3.1. Real-Time Detection of Transient Voltage Event Using Discrete Wavelet Transform

The Matlab R2014a software has been used to analyze the sample signal of transient voltage event for DWT analysis. In this paper, the nominal voltage pure-sinusoidal voltage signal is 230V at 50Hz frequency 5 data sample used in this analysis with the range of time at 0.181s, 0.237s and 0.473s respectively. Figure 4 to Figure 8 below shows signal for 5 samples where the transient voltage event generated at 0.10s, 0.11s and 0.17s respectively with the presence of border distortion at starting and ending edge. The amplitude of border distortion is set at starting point of signal graph which is at 0s and at the end point of signal graph as shown in Figure 9 and Figure 10 respectively.

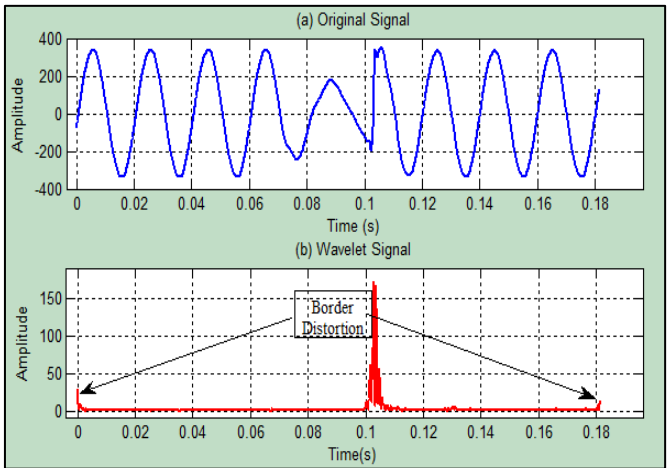

Figure 4. (a) 1st sample of transient voltage event generate at 0.1s for DWT analysis, (b) Transient voltage detection using DWT with existence of border distortion effect for 1st sample

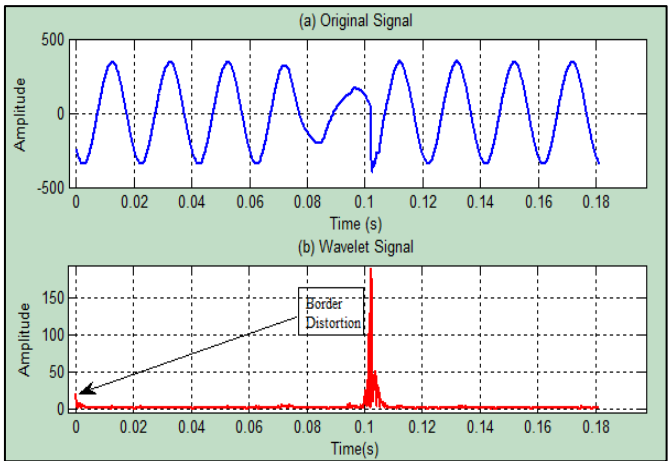

Figure 5. (a) 2nd sample of transient voltage event generate at 0.1s for DWT analysis, (b) Transient voltage detection using DWT with existence of border distortion effect for 2nd sample

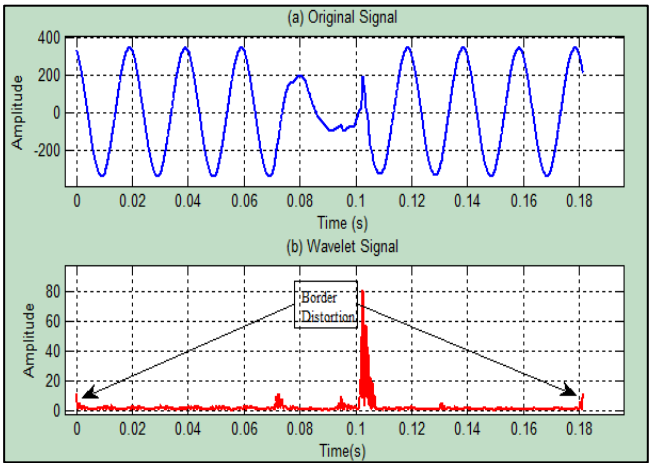

Figure 6. (a) 3rd sample of transient voltage event generate at 0.1s for DWT analysis, (b) Transient voltage detection using DWT with existence of border distortion effect for 3rd sample

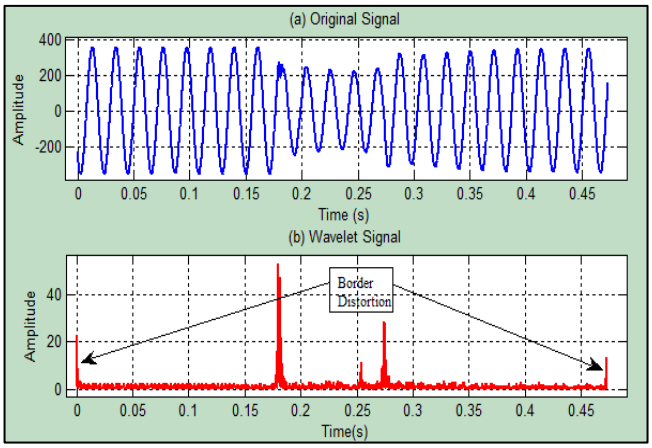

Figure 7. (a) 4th sample of transient voltage event generate at 0.17s for DWT analysis, (b) Transient voltage detection using DWT with existence of border distortion effect for 4th sample

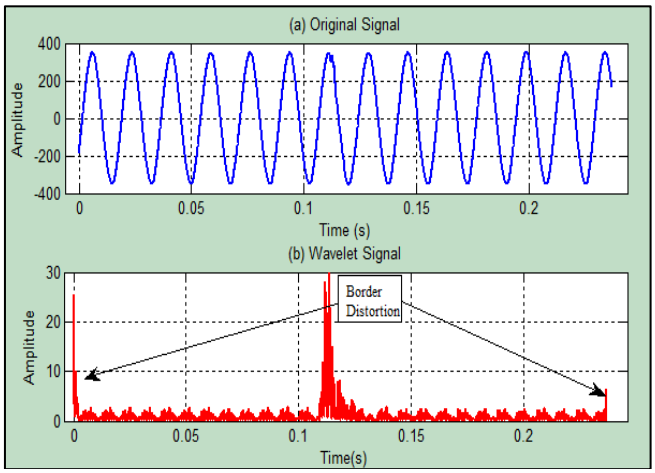

Figure 8. (a) 5th sample of transient voltage event generate at 0.11s for DWT analysis, (b) Transient voltage detection using DWT with existence of border distortion effect for 5th sample

Five samples of signal have been taken to be analyzed with the existence of transient voltage. Figure 7 depicts the signal with transient and voltage sag disturbance both happened in one event. However, this study is only focusing on transient voltage, which happened at starting discontinuities of signal by ignoring voltage sag effect.

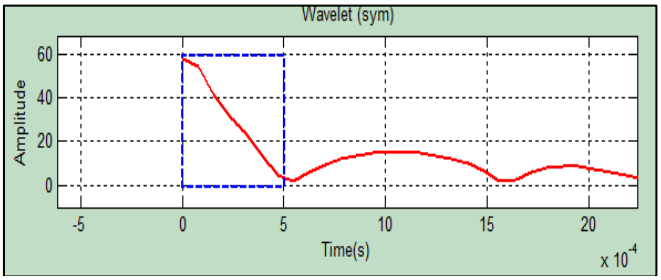

Figure 9. Region of amplitude of border distortion detection at starting point

Figure 9 and figure 10 depict the amplitude of wavelet transform signal increasement at the starting and ending edge. The amplitudes have been evaluated and recorded after applied with various extention mode. The results are then been compared with the original amplitude.

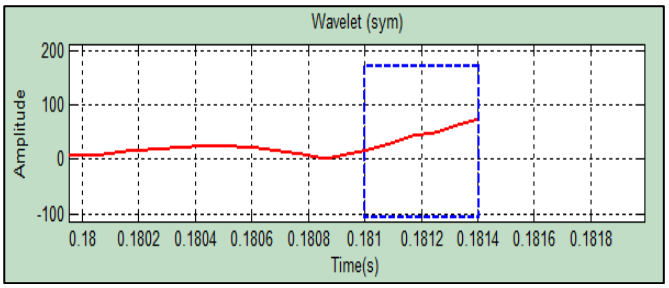

Figure 10. Region of amplitude of border distortion detection at ending point

3.2. Comparison of Border Distortion Amplitude between Zero Padding, Smooth Padding of Order 1 and Symmetrization Mode

Three types of extension mode have been analyzed to compare the best methods in reducing border distortion in DWT. There are zero padding (zpd), smooth padding of order 1 (spd) and symmetrization (sym). Figure 11-13 which represent 1st sample shows that the minimum amplitude of border distortion exists at the starting and ending point when smooth padding of order 1 is being used. Its amplitude is very small which is 0.86 and considered to be zero. Zero padding mode yielded highest border distortion at starting and ending DWT boundary. Furthermore, it yielded a lot of unwanted signal.

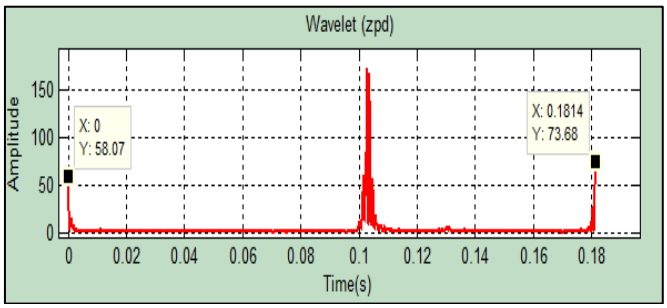

Figure 11. Identification of border distortion when using ‘zpd’ mode

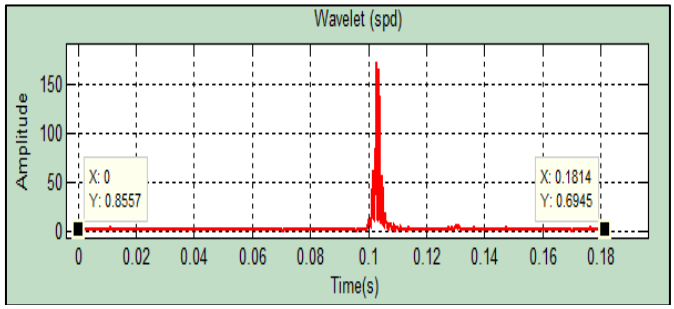

Figure 12. Identification of border distortion when using ‘spd’ mode

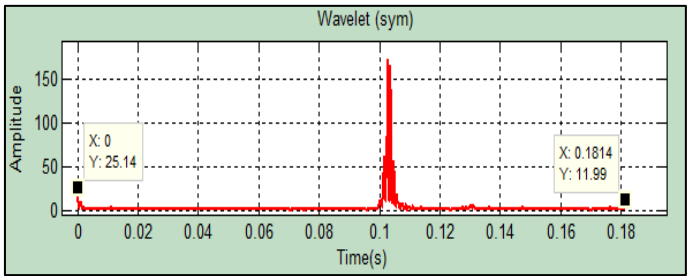

Figure 13. Identification of border distortion when using 'sym' mode

3.3. Signal-to-Noise Ratio (SNR) Evaluation of Border Distortion

The comparison of actual amplitude and border distortion amplitude yielded at the starting point and ending point has been analyzed. The signal-to-noise ratio is then being evaluated to observe the best performance of extension mode for each sample. Table 1 shows the amplitude of border distortion at starting point, while Table 2 shows the amplitude of border distortion yielded at ending point. The SNR of border is evaluated at Table 3. The least value of SNR represents the effectiveness of extension mode in reducing the border distortion. Equation for SNR is represent as:

$$SNR=\left(\frac{Asignal}{Anoise}\right)^2 \quad (3)$$

Where A signal is root mean square of amplitude voltage for analyze signal while Anoise is root mean square for ariginal signal which contain noises.

Table 1. The amplitude of border distortion at starting point of wavelet

Sample	Amplitude Before Extension Mode	Amplitude After Extension Mode		
		zpd	spd	sym
1	27.95	58.07	0.86	25.14
2	19.97	118.70	0.34	18.85
3	10.45	186.20	2.17	10.08
4	22.62	106.20	0.17	21.45
5	25.52	118.40	0.78	22.83

Table 1 depicts the amplitude of the border distortion at starting point is sudden increased after been applied with zero padding (zpd) mode method for each sample signal. While the amplitude of the border is slightly reduced after the use symmetrization (sym) extension mode. Lastly, smooth padding (spd) extension mode successfully minimized the border distortion amplitude compared to symmetrization mode.

Table 2. The amplitude of border distortion at ending point of wavelet

Sample	Amplitude Before Extension Mode	Amplitude After Extension Mode		
		zpd	spd	sym
1	12.99	73.68	0.70	11.99
2	1.62	161.60	0.40	1.30
3	10.91	81.61	1.34	9.84
4	13.55	101.00	0.64	12.81
5	6.41	73.14	0.76	4.74

The amplitude of the border distortion at ending point also has been analyzed in this paper. Based on Table 2, smooth padding is resulting in an optimum value which is the least value of the amplitude of border compared to symmetrization and zero padding mode.

Table 3. SNR of border distortion at starting and ending point

Extension mode	Sample	SNR	
		Starting	Ending
zpd	1	4.32	32.17
	2	35.33	9950.68
	3	317.49	55.95
	4	22.04	55.56
	5	21.52	130.19
spd	1	0.00	0.00
	2	0.00	0.06
	3	0.04	0.02
	4	0.00	0.00
	5	0.00	0.01
sym	1	0.81	0.85
	2	0.89	0.64
	3	0.93	0.81
	4	0.90	0.89
	5	0.80	0.55

Table 3 above depicts the SNR result for every signal analysis. The minimum value of SNR represents the best performance of the analysis. Therefore, from the above table, smooth padding (spd) mode shows a very small value of the amplitude of border which mostly given zero reading and few results shown approximately near to zero. Zero padding mode depicts the highest SNR while symmetrization gave average result.

4. Conclusion

The attainment of best extension mode selection in reducing border distortion of Discrete Wavelet Transform has been presented in this paper. By using db4 of decomposition signal and level 4 of the Daubechies mother wavelet for reconstruction, the algorithms are able to detect transient voltage event. However, border distortion effect yielded at the starting and at the ending point. The border distortion effect has been reduced by implementing smooth padding of order 1 mode in DWT analysis. The result shows the amplitude of border for most sample are very small after used 'spd' mode. Furthermore, with the aid of soft-threshold implementation, the noise or unwanted signals are being removed in the analysis. Smooth padding mode will be the best candidate to be used in reducing border distortion effect due to power quality disturbance especially transient voltage.

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