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Comparison between Wavelet Packet Transform and M-band Wavelet Packet Transform for Identification of Power Quality Disturbances

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Abstract

Due to large incorporation of nonlinear loads in the present day distribution system, the voltage and currents are significantly distorted. This distortion of an electrical signal results in large economic loss and loss of data. Therefore all over the world more and more attention is paid to Power Quality (PQ) problems identification and its solutions. It is very much essential to correctly identify PQ disturbance to derive the appropriate compensation strategies.This paper focuses on the identification of the PQ disturbances such as voltage sag, voltage swell, and voltage sag with harmonics, voltage swell with harmonics, momentary interruption, flicker, transients and harmonics using M-band Wavelet Packet Transform (M-band WPT). These PQ problems are simulated in MATLAB environment as per their IEEE 1159-2009 standard definition. Detection of PQ disturbances is carried out using a statistical parameter RMS_{wpt} computed for each decomposition coefficient of conventional WPT and M-band WPT. Finally the results obtained using both the mathematical tools are compared and concluded.

Keywords: IEEE Standards, M-Band Wavelet Packet Transform, Power Quality

1. Introduction

Power quality has been an issue that is becoming increasingly essential in industrial electricity and consumers point of view in recent times. The disturbances such as voltage sag, swell with and without harmonics, momentary interruption, harmonic distortion, flicker, transients etc are causing problems such as malfunction, instability, short life times, failure of electrical equipments and so on[1]. Many methods or techniques are found in order to implement all the process of detection and analysis of PQ disturbances. Namely, wavelet transform, Fourier transform, S-transform, Multi Resolution Analysis (MRA), Fuzzy Logic, Neural Network, Hidden Markov model and many more methods which are built from different mathematic equations or tools[2–6]. The Fourier Transform is suitable to analyze stationary signals but not suitable for non-stationary signals such as the transient signals[7]. The Short Time Fourier Transform (STFT) was the most significant tool developed under Fourier Transform[8]. STFT can localize the time factor depending on the

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preferred set window. If the concept of fixed window width is removed, many cycles of a high frequency signal can be captured, while for a low frequency signal very few cycles are within the windows. Due to this, resolution of Fourier Transform is poor at low frequency but it improves as the frequency increases[9–11]. Wavelet Transform simultaneously gives time and frequency information and hence it has been used for the detailed analysis of power quality. Popular extensions to the wavelet transforms are the wavelet packet transforms[12] and the M-band wavelet transforms. The *wavelet packet* system was proposed by Ronald Coifman [Rus92, CW92] to allow a finer and adjustable resolution of frequencies at high frequencies[13]. One of the motivations for M-band WPT is a need to get a more flexible tiling of the time-scale plane than that resulting from the 2 band WPT or the STFT.

In the present work an attempt is made to compare the performance of M-band wavelet packet transform with M=3 (3-band WPT) and WPT (i.e., 2-band Wavelet packet transform) in the detection of various PQ disturbances. The studied PQ disturbances are simulated under MATLAB environment. The simulated signals are processed with conventional WPT up to level 3 and also with 3-band WPT up to level 2 decomposition. A statistical parameter RMS is calculated for each WPT coefficient at each decomposition level for both the techniques.

This paper is organized as follows: Section 2 discusses theory of M-band wavelet transform to serve the required objective. Section 3 presents simulation of PQ disturbances. Section 4 gives the computation of statistical parameter and simulation results. Section 5 presents the comparison of simulation results. Finally Section 6 concludes the paper.

2. Wavelet Packet Transform and M-Band Wavelet Packet Transform

The wavelet transform maps function $f(x) \in L^2(R)$ onto a scale-space plane. The wavelets are obtained from a single prototype function $\psi(x)$ by scaling parameters a and shift parameters b[14]. The continuous wavelet transform of a function *f(x)* is given as,

$$W(a,b) = \int f(x)\psi_{a,b}(x)dx \tag{1}$$

Where $\psi_{a,b}(x) = a^{-\frac{1}{2}}\psi\left(\frac{t-b}{a}\right)$ is a window function called the mother wavelet, a is a scaling parameter and b is a translation parameter. M-band wavelet decomposition is a direct generalization of the above two-band case[15,16].

Let $\phi(x)$ be the scaling function satisfying,

$$\phi(x) = \sum_k h(k)\sqrt{M}\ \phi(Mx-k) \tag{2}$$

In addition there are M-1 wavelets which also satisfy,

$$\psi^{(j)}(x) = \sum_k \sqrt{M}h^{(j)}\psi(Mx-k) \tag{3}$$

$$\phi_{ik}(x) = \sum_K M^{-\frac{i}{2}}\phi(M^{-i}x-k) \tag{4}$$

$$\psi^{j}_{ik}(x) = \sum_K M^{-\frac{i}{2}}\psi(M^{-i}x-k) \tag{5}$$

$$j = 1, 2...., M-1$$

Equation (4) and (5) represent scaling function and M-1 wavelets in discrete form respectively.

Figure 1 and Figure 2 show the structure of implementation of conventional WPT and 3-band resp. Conventional Wavelet Transform (WT) splits and down samples only detail component further whereas WPT splits and down samples detail as well as approximate component to the next level as shown in Figure 1.

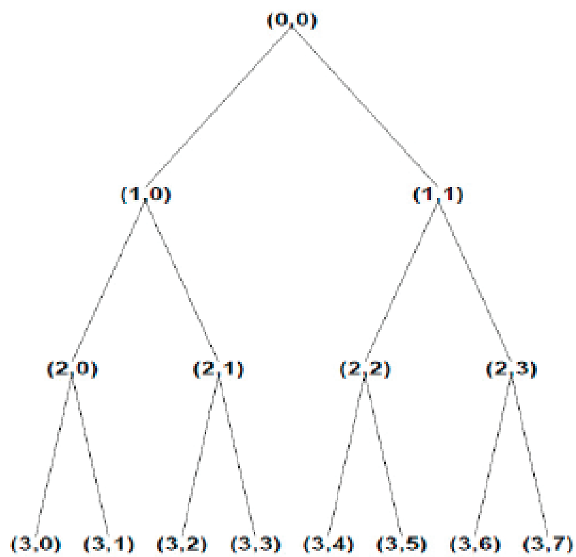


Figure 1. Three Level decomposition of 1-D signal using WPT.

M-band WPT is the direct generalization of 2-band WPT. The M-band WPT generates large number of sub bands which gives better accuracy and it is required for superior segmentation. Figure 2 shows the execution of 3-band WPT up to decomposition level 2. At level (0,0) the sampled signal is passed through first level of three-band biorthogonal linear phase wavelet filters resulting in one approximate and two detail coefficients. This process is repeated at each decomposition level.

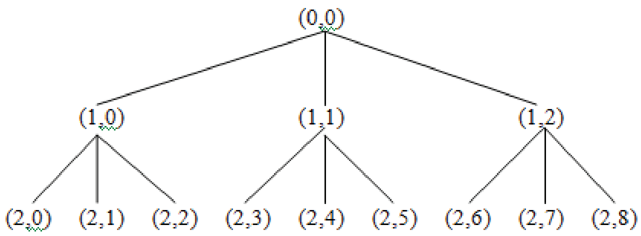


Figure 2. Two Level decomposition of 1-D signal using 3-band WPT.

The time–frequency localized basis functions perform well in applications like signal analysis[17]. Ideal M-band filter bank with $M > 2$ subbands is the extension of the two band filter bank which improve the frequency resolution to $\Delta\omega = \frac{\pi}{M}$ [18]. In M channel filter bank the bandwidth of the filter bank is divided into M bands as shown in Figure 3[19].

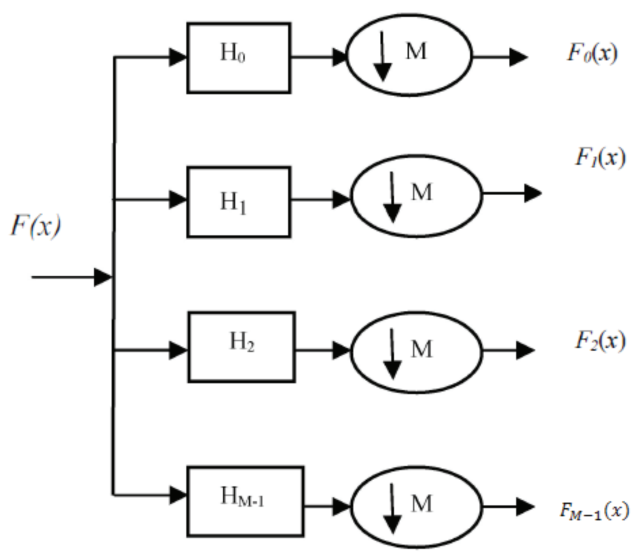


Figure 3. M channel analysis filter bank.

In order to increase the performance of two-band WPT in practical cases frequency resolution in low and high frequency region should to be increased by increasing the number of subbands in that region. This limitation of two band can be resolved by M-band WPT.

3. Simulation of Power Quality Disturbances

Various PQ disturbances like voltage sag, voltage swell, voltage sag plus harmonics, voltage swell plus harmonics, Momentary interruptions, flicker, transients and Harmonics are generated using MATLAB script file with variation in magnitude and time as per IEEE 1159-2009 standards.Figure 4 (a)-(b) shows the simulated voltage sag, voltage swell with the time period of 2 seconds.

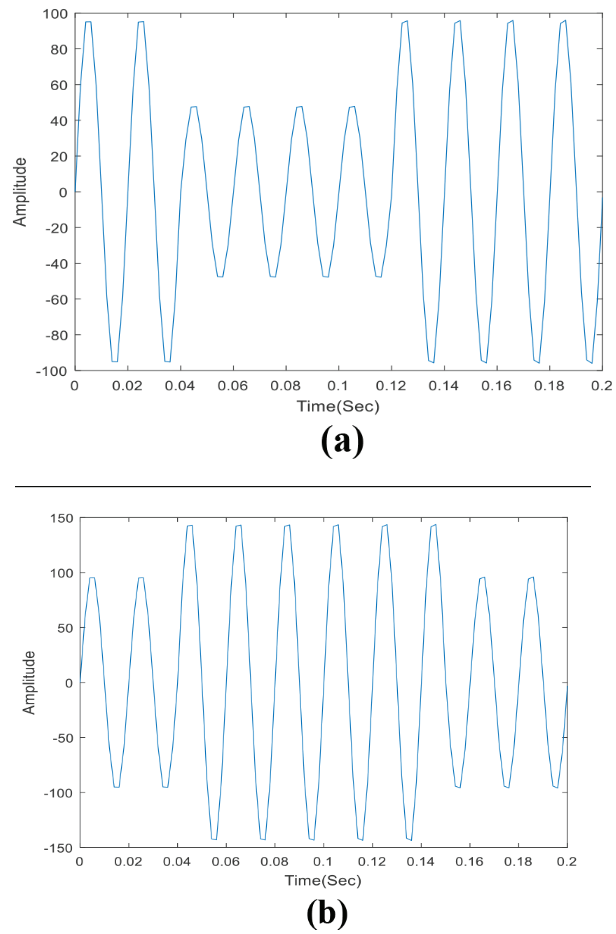


Figure 4. **(a)** Voltage sag; **(b)** Voltage sag swell.

Flicker captured for 0.2 second is shown in Figure 5 (a). Simulated Harmonics along with 50% voltage sag and Harmonics with 50% voltage swell for 5 cycle's duration are shown in Figure 5 (a) and (b) resp.

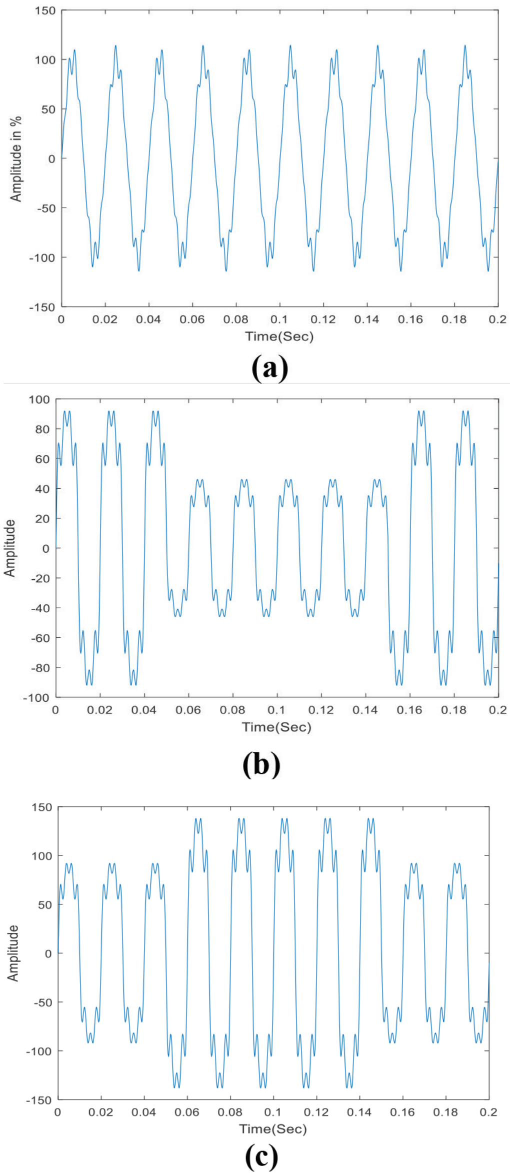


Figure 5. **(a)** Flicker; **(b)** Voltage sag with Harmonics; **(c)** Voltage swell with Harmonics.

Transient (with period in milliseconds) and Harmonics pattern simulated for 0.2 seconds are shown in Figure 6 (a) and Figure 6 (b). Generated Momentary interruption with time period of 0.2 second is shown in Figure 6 (c).

4. Computation of Statistical Parameter and Simulation Results

All these simulated disturbances are processed with WPT and 3-band WPT. Statistical parameter is calculated for each decomposition coefficient for each PQ disturbance as

$$RMS_{wpt} = \sqrt{\frac{\sum_{k=1}^{n}(x_k)^2}{n}} \quad (6)$$

Where n=length of decomposition coefficient.

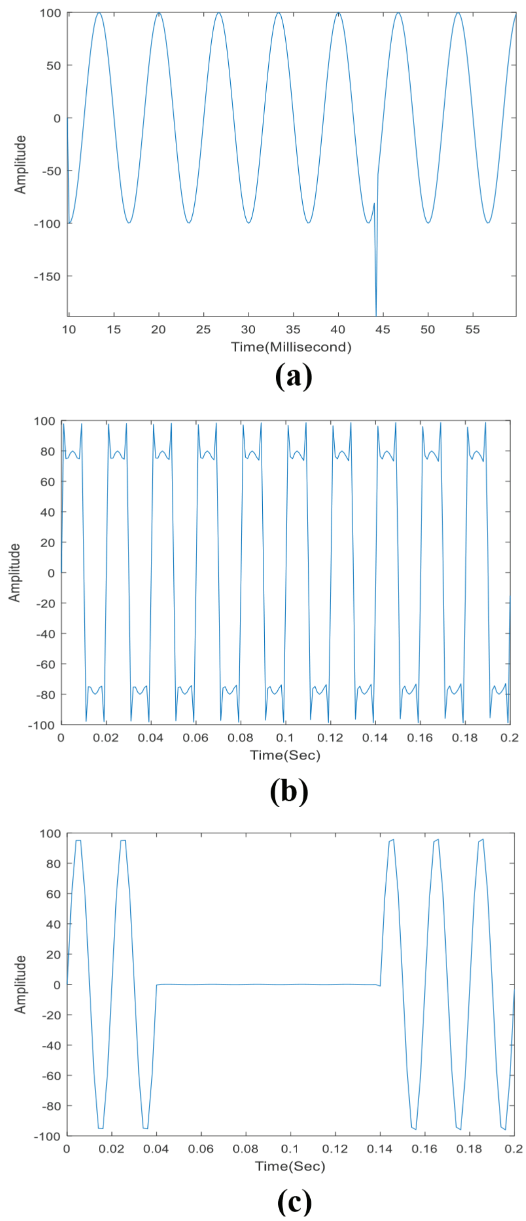
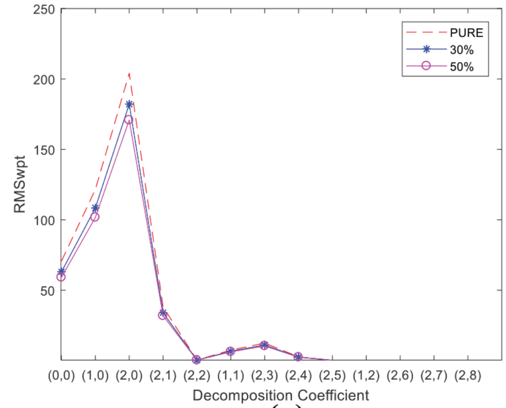


Figure 6. **(a)** Transient; **(b)** Harmonics; **(c)** Momentary interruption.

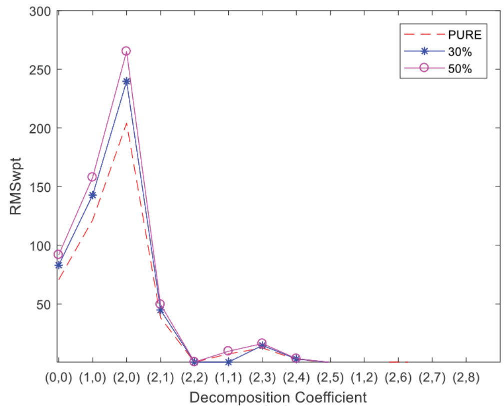
The plots of RMS_{wpt} to the corresponding decomposition coefficient are drawn for each PQ disturbance processed with WPT.

Similar plots are drawn for all the PQ disturbances processed with 3-band WPT. Each plot gives comparison between PQ results and the results for pure signal of 50Hz.

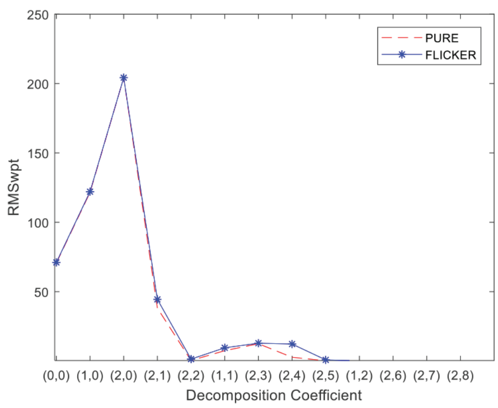
Figure 7 (a)-(c) are the plots of RMS_{wpt} to the corresponding decomposition coefficient for Voltage sag, Voltage swell and Flicker processed with 3-band WPT up to decomposition level 2. Plots for the same PQ disturbances processed with WPT decomposition up to level 3 are shown in Figure 8 (a)-(c). It can be observed from Figure 7 (a) and Figure 8 (a) that for voltage sag as the percentage of disturbance increases the value of the statistical parameter decreases



(a)

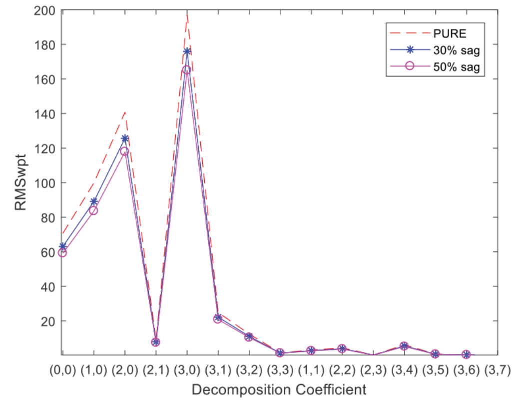


(b)

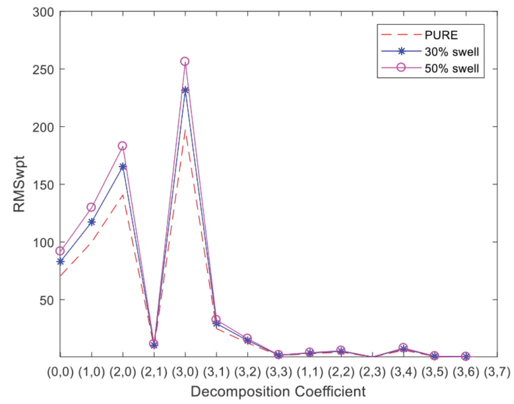


(c)

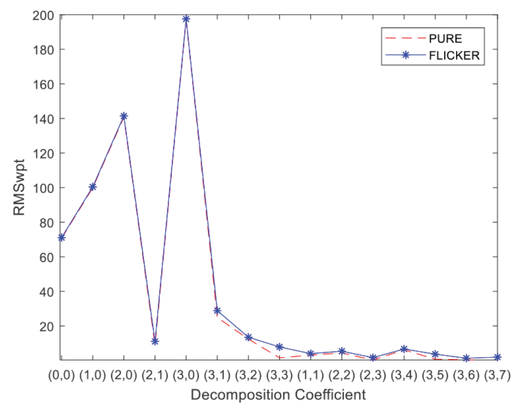
Figure 7. RMS_{wpt} study for **(a)** Voltage sag; **(b)** Voltage swell; **(c)** Flicker using 3-band WPT.



(a)



(b)

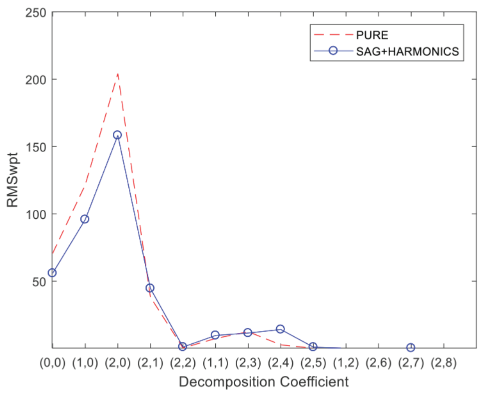


(c)

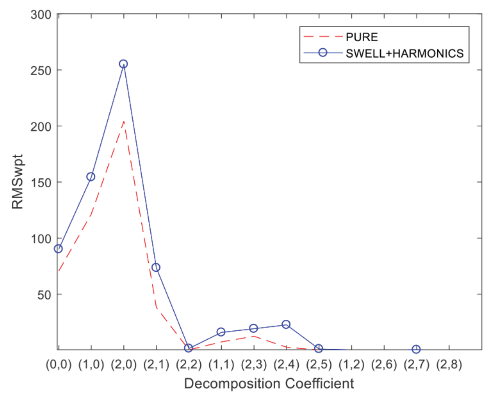
Figure 8. RMS_{wpt} study for **(a)** Voltage sag; **(b)** Voltage swell; **(c)** Flicker using WPT.

from that of pure signal especially for lower frequency region. Figure 7(b) and Figure 8(b) reveal that in case of voltage swell as the percentage of disturbance increases the value of the statistical parameter increases from that of pure signal. Figure 7(c) and Figure 8(c) are showing that in case of flicker the value of RMS_{wpt} is slightly higher than that of pure signal in case of WPT as well as in case of 3-band WPT.

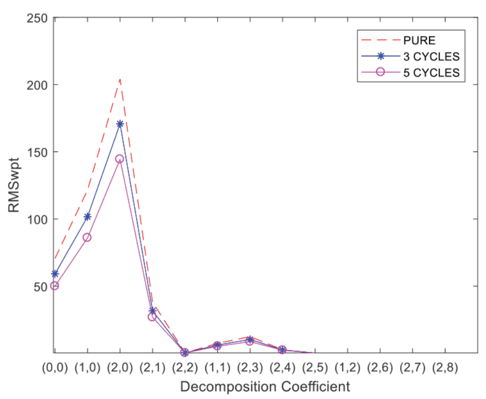
Plot for Voltage sag with harmonics, voltage swell with harmonics and Momentary interruption processed with 3-band WPT is given in Figure 9 (a)-(c) respectively. Similar plots for same PQ disturbances processed with WPT are shown in Figure 10 (a)-(c). It can be observed from Figure 9 (a) and 10 (a) that RMS_{wpt} is showing lower values than that of pure for voltage sag along with harmonics where as in case of voltage swell with harmonics the parameter is showing higher value than that of Pure signal (Figure 9(b) and Figure 10(b)). Figure 9(c) and Figure 10(c) reveal that for Momentary interruption the value of statistical parameter decreases from that of pure signal in case of WPT as well as in case of 3-band WPT.



(a)

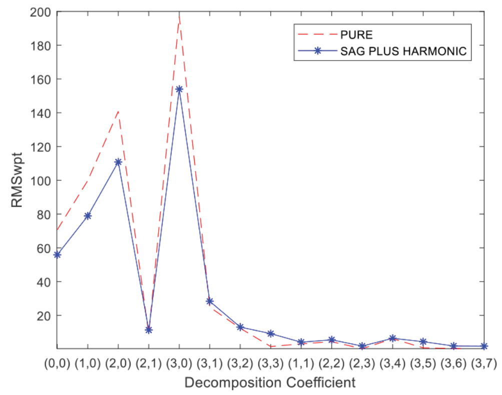


(b)

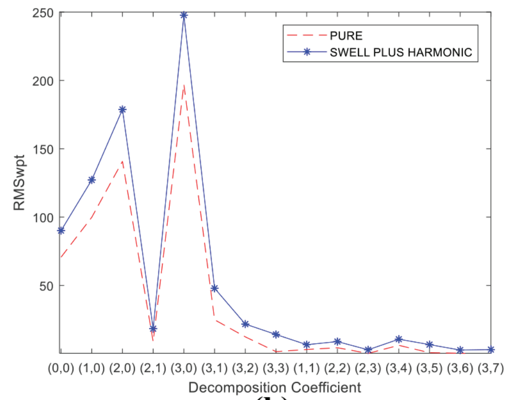


(c)

Figure 9. RMS_{wpt} study for **(a)** Voltage sag with harmonics; **(b)** Voltage swell with wiharmonics; **(c)** Momentary interruption using 3-band WPT.



(a)



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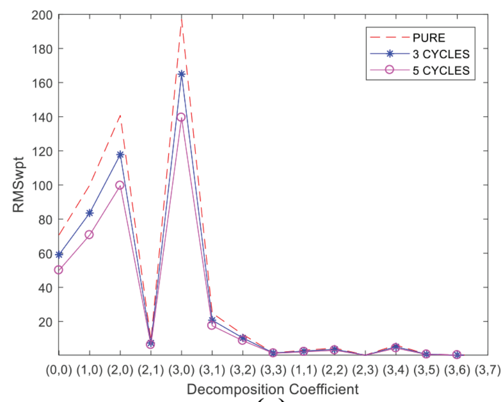
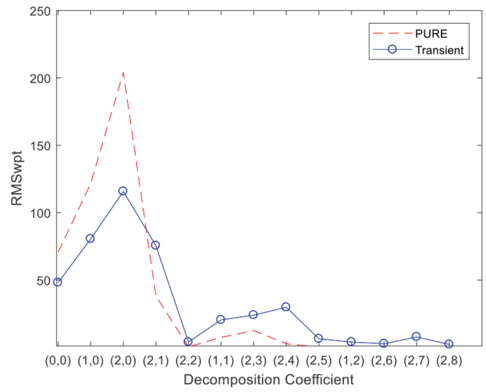


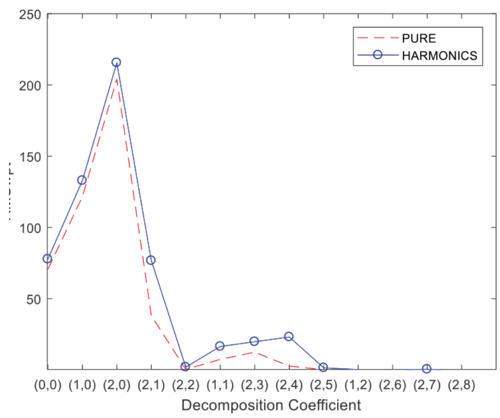
(c)

Figure 10. RMSwpt study for **(a)** Voltage sag with harmonics; **(b)** Voltage swell with harmonics; **(c)** Momentary interruption using WPT.

Depiction of similar plots for Transient and harmonically polluted signals using 3-band WPT and WPT are given in Figure 11(a)-(b) and Figure 12 (a)-(b) resp. In case of Transient the RMS_{wpt} values are lower than that of pure signal for lower frequency bands whereas in case of Harmonics the RMS_{wpt} value increases from that of pure signal.

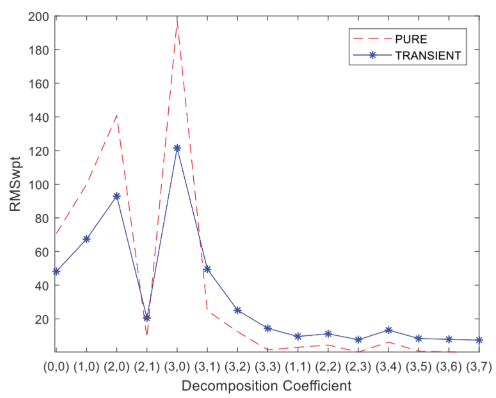


(a)

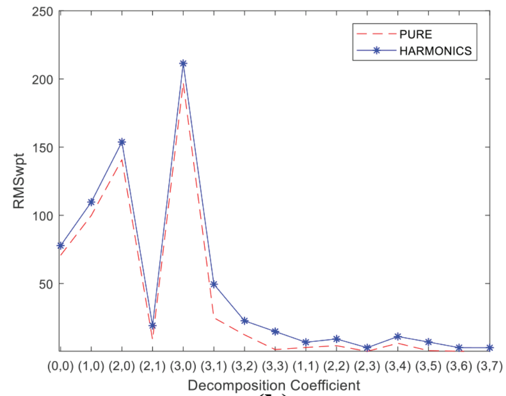


(b)

Figure 11. RMSwpt study for **(a)** Transient; **(b)** Harmonics using 3-band WPT.



(a)



(b)

Figure 12. RMS_{wpt} study for **(a)** Transient; **(b)** Harmonics using WPT.

5. Comparison and Discussion of Results

We have decomposed simulated PQ disturbances like voltage sag, voltage swell, flicker, voltage sag along with harmonics, voltage swell along with harmonics, momentary interruption, transient and harmonics up to decomposition level 3 using WPT and same disturbances are processed with 3-band WPT decomposition up to level 2.

The number of subbands generated is the first parameter considered for comparison between the performance of conventional WPT and M-band WPT. Table 1 shows comparison of the number of WPT and 3-band WPT coefficients at decomposition level 2 and level 3.

More number of decomposition coefficients implies more number of subbands which gives scope for better quality analysis of the disturbances. Thus 3-band WPT allows finer level analysis as compared to WPT.

Table 1. Comparison of the number of WPT and 3-band WPT coefficients at decomposition level 2 and level 3

Decomposition level	No. of WPT coefficients generated	No. of 3-band WPT coefficients generated
Level 2	4	9
Level 3	8	27

Second parameter considered for comparison is execution time. Table 2 shows that for each PQ disturbance the execution time for 3-band WPT is less than that of WPT.

Table 2. Comparison of average execution time take for analysis by WPT and 3-band WPT

PQ disturbance	Avg. Execution time in seconds for analysis	
	3-band WPT (decomposition level 2)	WPT (decomposition level 3)
Voltage sag	3.64	4.86
Voltage swell	3.75	5.15
Flicker	1.67	2.61
Voltage sag+harmonics	3.79	4.73
Voltage swell+harmonics	3.85	4.68
Momentary interruption	4.04	5.29
Transient	1.88	2.47
Harmonics	1.82	2.66

Third parameter is accuracy and computational complexity. Table 3 shows behaviour of RMS_{wpt} value as compared to pure signal for each PQ disturbance processed with WPT and also with 3-band WPT. From Table 3 and the analysis plotted in Figure 7- Figure 12, we can state that the results of 3-band WPT decomposed up to 2 level are almost same as those of WPT decomposed up to level 3.Thus 3-band WPT is giving equally accuracy of results with less computational complexity than conventional WPT for each PQ disturbance studied.

6. Conclusion

Comparison of the performance of WPT and 3-band WPT in identification of PQ disturbances is done using the statistical parameter RMS_{wpt}. Based on the analysis of the trend of a statistical parameter RMS_{wpt} computed and plotted for various PQ disturbances studied, it is observed that in case of 3-band WPT and also in case of WPT the statistical parameter RMS_{wpt} is showing same trend as compare pure signal for each PQ disturbance. This can be considered as a strong reason for the reliability of the proposed method for the detection and measurement of PQ disturbances.

While comparing 3-band WPT and conventional WPT mainly three parameters are noticed i.e. execution time, more number of subbands and third one is computational complexity. It is observed that 3-band WPT is superior to WPT in terms of execution time and computational complexity. It takes less execution time and is computationally less complex than WPT. 3-band WPT gives more number of sub bands than WPT at same decomposition level. This indicates that 3-band WPT allows finer analysis of any PQ disturbance than WPT with less execution time and less computation complexity.

Table 3. Comparison of behaviour of RMS wpt value as compared to pure signal for each PQ disturbance processed with WPT and also with 3-band WPT

PQ disturbance	Behaviour of RMS_{wpt} value as compared to pure signal	
	3-band WPT (decomposition level 2)	WPT (decomposition level 3)
Voltage sag	Decreases with the increase in the percentage of disturbance	Decreases with the increase in the percentage of disturbance
Voltage swell	Increases with the increase in the percentage of disturbance	Increases with the increase in the percentage of disturbance
Flicker	Slightly higher	Slightly higher
Voltage sag+harmonics	Lower	Lower
Voltage sag+harmonics	Higher	Higher
Momentary interruption	Decreases with the increase in time duration	Decreases with the increase in time duration
Transient	Lower especially for lower frequency bands	Lower especially for lower frequency bands
Harmonics	Higher	Higher

Hence it can be concluded that M-band WPT is a superior tool than conventional WPT in the study of PQ disturbances. In future these results can be used further for the accurate identification of PQ disturbances giving better Power Quality.

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