Implementation of Maximal Overlap Discrete Wavelet Transform and S-transform for Localization of Power Quality Disturbance Signals

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Abstract

In recent times, the wavelet-based methodologies have been developed as suitable alternatives for the analysis of power quality (PQ) disturbance signals. In this paper the time-series based maximal overlap discrete wavelet transform (MODWT) technique has been implemented for the detection and the localization of different PQ disturbances. The performance of the MODWT has been compared with the traditional S-transform (ST). Ten different types of PQ disturbances of the voltage signal such as sag, swell, interruption, harmonic, sag with harmonics and swell with harmonics, spike, notch etc. are analyzed with the MODWT and ST. S-contours provide localization property of the ST. Each signal is decomposed up to fourth level by applying MODWT.

Keywords: Power quality disturbance, wavelet transform, maximal overlap discrete wavelet transform, S-transform

I. INTRODUCTION

The power quality (PQ) has become a pressing concern due to the continuous increasing of the number of loads in industries as well as in the public sectors. The disturbances contained in the loads makes the deviation of voltage and current from the ideal waveform which degrades the performance and the lifespan of the equipments [1]. The sudden decrease and increase of voltage signal are treated as sag and swell, respectively. Harmonics appears when the frequency becomes an integer multiple of the fundamental frequency. Similarly, when the electronically controlled capacitor switched on, transient type disturbances are found. For reduction of these disturbances, characterization of the signal patterns like sag, swell, interruption etc. must be done first. As a result, the automatic classification of the disturbances has become a significant issue in the modern power system [2]. However, the existing automatic recognition methods for time series pattern need enhancement with the efficiency as well as reliability.

In order to identify the type of power signal waveforms, several researchers has introduced different methodology such as the fast operated Fourier transform (FT), the short-time Fourier transform (STFT), the wavelet transform (WT), the Neural Network, the Fuzzy logic, the S-transform [3], [4], [5], [6], [7], [8] and [9]. The commonly used STFT is only suitable for steady state disturbances like sag and swell. The transient signals including notch fails to analyse due to the fixed window property [10], [11] and [12]. Heisenberg-Gabor inequality [13] limits the time-frequency resolution of the signals in STFT analysis. The WT based on multi resolution analysis (MRA) has been extensively implemented for non-stationary signal characterisation.

The automatic detection of PQ events with the discrete wavelet transform (DWT) is a common topic in past studies [14],[15]. But the application of DWT is restricted with the size of the signal. So, a modified version of DWT is known as maximal overlap discrete wavelet transform (MODWT) is adopted in this paper in order to analyse signal of any length. The coefficients of the proposed method are not affected by changing the starting point and also has no restrictions on the size of signal unlike the traditional DWT. The MODWT has been implemented [16], [17] as ‘undecimated DWT’ with the context of infinite sequence. Similarly, MODWT has implemented as ‘translation invariant DWT’ [18], and ‘time-invariant DWT’ [19].

The paper is organised as follows. Section-II describes the brief theory of MODWT for carrying out the process of detection. The PQ disturbance model is given in Section-III. In Section-IV, the effectiveness of ST and MODWT is presented to detect different PQ disturbances. Finally the Section-V, concludes the paper.

II. MAXIMUM OVERLAPPING DISCRETE WAVELET TRANSFORM (MODWT)

The motivation for implementation of MODWT is the flexibility in selection of starting point of a time series signal. The MODWT can be implemented to any segmented signal N to be an inter multiple of 2j , for j = 1, 2, 3, . . . , J is the scale and J is the level of MODWT decomposition [14], [15]. The basic block diagram of MODWT has been presented in Fig. 1. The MODWT scaling filters h and wavelet filters g are represented as are represented as (1) and (2)

\[ \hat{h}_j = \frac{h}{\sqrt{2}} \]  \hspace{1cm} (1)

\[ \hat{g}_j = \frac{g}{\sqrt{2}} \]  \hspace{1cm} (2)

The quadrature mirrors filters used in MODWT are presented as (4) and (3)

\[ \hat{h}_j = (-1)^{j-i} \hat{h}_{i-1} \]  \hspace{1cm} (3)

\[ \hat{g}_j = (-1)^{j-i} \hat{g}_{i-1} \]  \hspace{1cm} (4)

In the context of infinite sequence. Similarly, MODWT has implemented as ‘translation invariant DWT’ [18], and ‘time-invariant DWT’ [19].
where \( l = 0, 1, 2, \ldots, L - 1 \) and \( L \) is the width of the filter. The \( n \)th element of the first-stage wavelet and the scaling coefficients of MODWT with the input time series signal \( X(n) \) is presented as (5) and (6)

\[
\hat{W}_{j,n} = \sum_{l=0}^{L-1} \hat{h}_{j,n} X_{n-l \mod N}
\]

(5)

\[
\hat{V}_{j,n} = \sum_{l=0}^{L-1} \hat{g}_{j,n} X_{n-l \mod N}
\]

(6)

where \( n = 1, 2, 3, \ldots, N \) and \( N \) is the length of signal in sample.

The first-stage approximations and details can be calculated by the equations (7) and (8). The MODWT scaling coefficients \( \hat{V}_j \) and \( \hat{W}_j \), wavelet coefficients at the \( n^{th} \) element of the \( j^{th} \) stage are given by the equations (9) and (10)

\[
\hat{V}_{j,n} = \sum_{l=0}^{L-1} \hat{g}_{j,n} \hat{X}_{l,n} \mod N
\]

(7)

\[
\hat{W}_{j,n} = \sum_{l=0}^{L-1} \hat{h}_{j,n} \hat{X}_{l,n} \mod N
\]

(8)

Similarly, the approximations \( A_j \) and the details \( D_j \) of the \( n^{th} \) element of the \( j^{th} \) stage MODWT are given by the equations (11) and (12).

\[
\hat{A}_{j,n} = \sum_{l=0}^{L-1} \hat{g}_{j,n} \hat{W}_{l,n} \mod N
\]

(9)

\[
\hat{D}_{j,n} = \sum_{l=0}^{L-1} \hat{h}_{j,n} \hat{W}_{l,n} \mod N
\]

(10)

where \( \hat{g}_{j,n} \) is periodized \( g \) to length \( N \) and also \( \hat{h}_{j,n} \) is periodized \( h \) to length \( N \). So, the original time series signal can be stated in terms of the approximations and the details as follow as

\[
X(n) = \sum_{j=0}^{j=N} \hat{A}_j + \hat{D}_j
\]

(13)

In MODWT, the original signal can be regained easily from the decomposed signals like the traditional DWT and FT techniques.

III. POWER QUALITY DISTURBANCE MODEL

The PQ analysis comprises of both the stationary and non-stationary signals such as the voltage swell, sag, interruption, spike, harmonic with sag and so on. In this paper, ten types of different disturbances along with the pure sine wave are considered for analysis. These PQ disturbances are analysed with ten cycles of a waveform of 50 Hz fundamental frequency. The sampling frequency is 3.2 KHz. The signals are simulated according to the model [20] and [21].

IV. RESULTS AND DISCUSSION

The PQ disturbances presented in Table I are fed as inputs to S-transform and Fig. 1. Similarly, these ten types of power quality disturbances along with the normal sinusoidal voltage are decomposed up to fourth levels using MODWT.

A. Pure Sinusoidal Wave

A pure sinusoidal wave of voltage signal has been considered in Fig. 2. By implementing MODWT, the signal has been decomposed up to four decomposition levels are shown in Fig. 2 along with the original sine wave. The vertical axis represents the amplitude of voltage signal in volt V p.u. (per unit) and similarly the horizontal axis presents the time (in second) in terms of samples. Similarly in S-transform, vertical axis presents the frequency in kHz and the horizontal axis presents the time (in second) in terms of samples. As it is distortion free signal so there is deviation in S-contour as well as in the decomposition levels of MODWT.

B. Pure Sinusoidal Wave with Sag

A pure sine wave signal with sag is analysed in Fig. 3. The four finer decomposition levels of the MODWT decomposition along with the original signal waveform and S-contour are shown in Fig. 3.
The first decomposition level of each of MODWT shows the exact time of occurrence of the sag. The inception point of sag is shifted along with the initial point of signal towards right due to circular shifting property. The shifting property of MODWT assists the prediction of further inception. The distortions due to sag has been properly identified by the S-contours.

### C. Pure Sinusoidal Wave with Swell

Similarly, the swell in pure sine wave is detected and localized in the decomposed levels using both S-transform and MODWT in Fig. 4. The point of occurrence of the swell and also the duration can be easily identified in both the cases. The time series analysis of MODWT has given the idea for the further prediction of swell in the subsequent decomposition levels. Moreover, the MODWT provides estimation of disturbance location, which helps in the power system relaying.

### D. Pure Sinusoidal Wave with Interruption

The interruption in pure sine wave is localized and detected at the first decomposition of both MODWT and S-transform. The point of interruption is prominently identified in both MODWT decomposition levels and S-contours given in the Fig.5. One-step-ahead prediction of MODWT leads us to the arrival of the onset timing of further interruption in the signal. This one step ahead prediction is suitable for relaying.

### E. Pure Sinusoidal Wave with Notch

The pure sine wave with the notch at each cycle is considered for analysis. The notches are precisely localized at the decomposition levels of S-transform and MODWT in Fig. 6. The waveforms of MODWT and S-contours have been provided localization of notch.

### F. Pure Sinusoidal Wave with Oscillatory Transients

The transient oscillatory signal is analyzed in Fig. 7 with both S-transform contours and MODWT decomposition levels as shown in Fig. 7. The distortion due to transient properly detected in both ST and MODWT.

### G. Pure Sinusoidal Wave with Flicker

The flicker signal is considered for analysis in Fig. 8. The detection and the localization of flicker are accomplished using S-transform and shifting based MODWT are given in Fig. 8. The MODWT has provided proper localization of flicker at all levels of decomposition like ST.
H. Pure Sinusoidal Wave with Spike

Similar to the notch signal, the spike at each cycle of pure sine wave has been considered for analysis. The localization of spike has done satisfactorily with both S-contours and MODWT decomposition levels as shown in Fig. 9.

I. Pure Sinusoidal Wave with Harmonics

The harmonics with fundamental is analysed in Fig. 10 with S-transform and MODWT. From the Figs. 10 and 2, it can be observe that for sinusoidal signal the magnitude of 1<sup>st</sup> two levels are almost zero and for harmonic signal, 1<sup>st</sup> two levels have some magnitude both in MODWT. The presence of harmonic is properly localized by S-transform contours.

J. Pure Sinusoidal Wave with Sag and Harmonics

The distortions of a pure sine wave due the sag and harmonic are localized in the decomposition levels of S-contours and MODWT as shown in Fig. 11.

K. Pure Sinusoidal Wave with Swell and Harmonics

Similarly, the swell with harmonic signal is considered for analysis. The swell with harmonic is detected and localized at the decomposition levels of MODWT decomposition and S-transform as shown in Fig.12.

The aforementioned PQ signals are simulated with a core-i5, 2.40 GHz under MATLAB environment. The MODWT use a low-pass filter and a high-pass filter (quadrature mirror filter) to split the frequency band of these aforementioned input signals in order to get scaling and wavelet coefficients, respectively, but there is no down sampling in MODWT. Though S-transform is a common technique for analysis of signals, it is very complex. It suffers from computational burden and the system becomes sluggish. The shifting property of MODWT can be used for future prediction of occurrence of disturbances.
V. CONCLUSION

The Wavelet Transform is a significant tool for the analysis in PQ environment disturbances. The S-transform and the time series based MODWT have been used to localize the PQDs. Ten types of PQ disturbances along with the sinusoidal voltage signal wave form are properly analyzed with the MODWT. Though S-transform is good technique for analysis of signals but it suffers from computational burden. The computational complexity of S-transform makes the system sluggish. The down sampling free MODWT provides the proper localization of PQDs along with the shifting. Elimination of down sampling overcomes the restriction in the choice of signal length. MODWT is simple and requires less running time as compared to S-transform.

REFERENCES


