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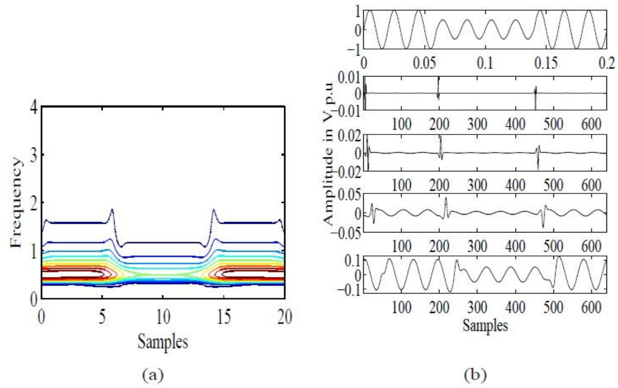

Fig. 3: Localization of pure sine wave in (a) S-transform (b) SGWT decomposition

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.

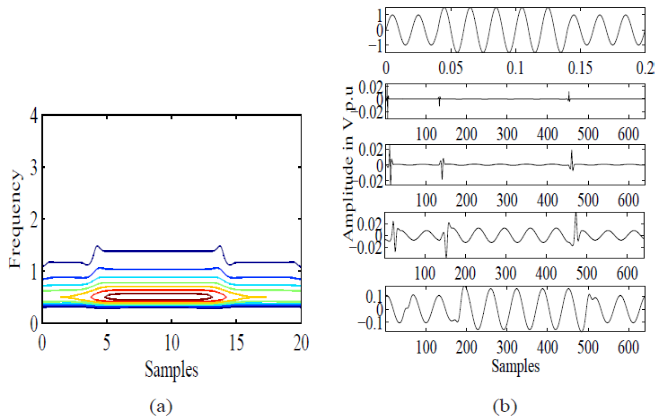

Fig. 4: Localization of sine wave with swell in (a) S-transform (b) MODWT decomposition

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 predictions property 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.

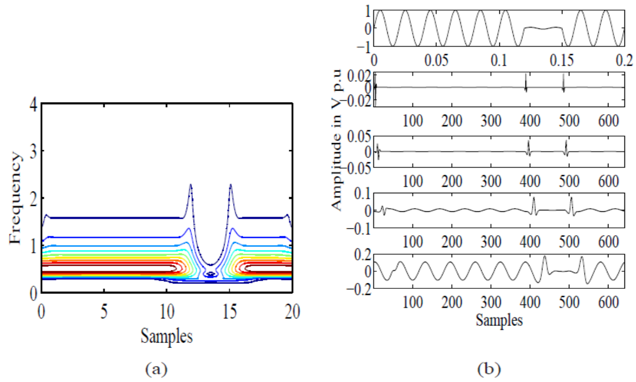

Fig. 5: Localization of sine wave with interruption in (a) S-transform (b) MODWT decomposition

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.

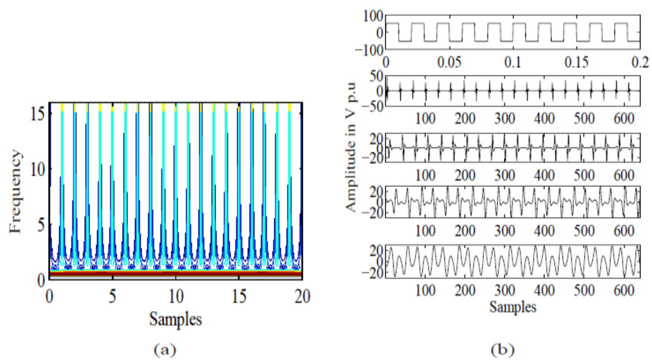

Fig. 6: Localization of sine wave with notch in (a) S-transform (b) SGWT decomposition

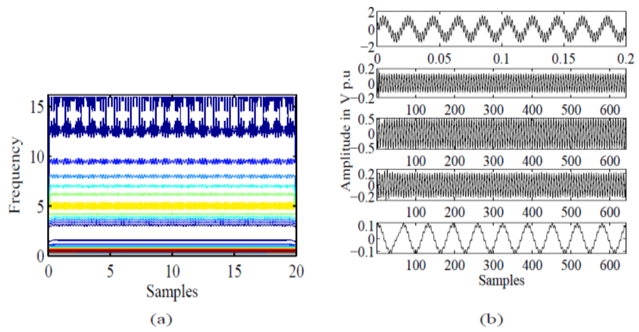

Fig. 7: Localization of sine wave with oscillatory transient in (a) S-transform (b) MODWT decomposition

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 1st two levels are almost zero and for harmonic signal, 1st 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.

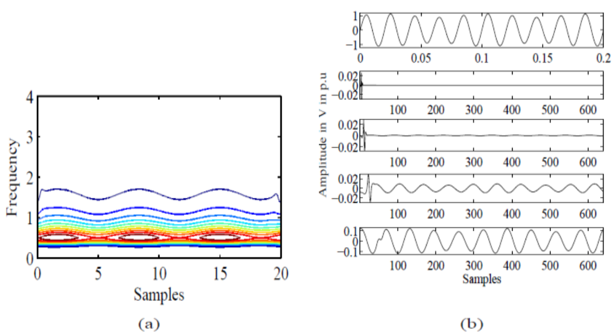

Fig. 8: Localization of sine wave with flicker in (a) S-transform (b) MODWT decomposition

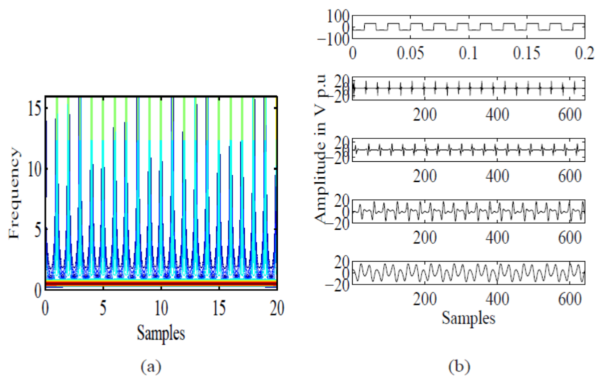

Fig. 9: Localization of sine wave with spike in (a) S-transform (b) MODWT decomposition

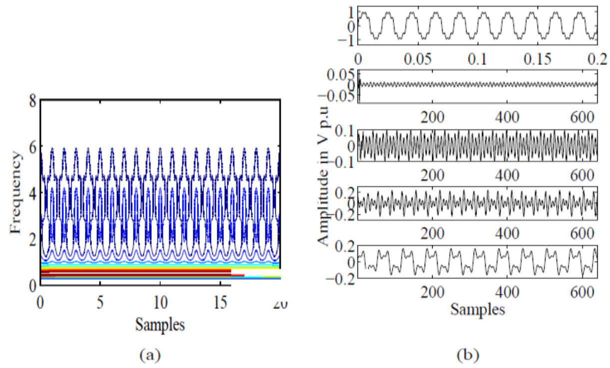

Fig. 10: Localization of sine wave with harmonics in (a) S-transform (b) MODWT decomposition

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.

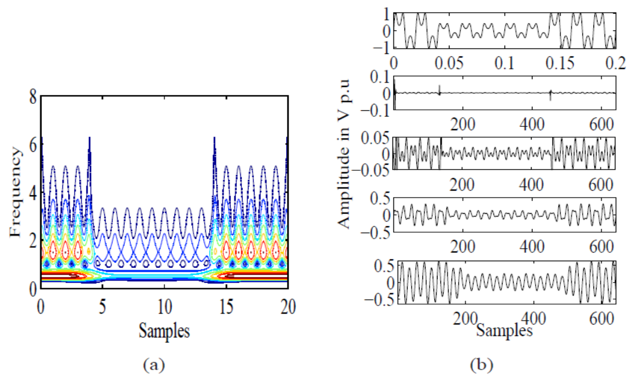

Fig. 11: Localization of sine wave with sag and harmonics in (a) S-transform (b) MODWT decomposition

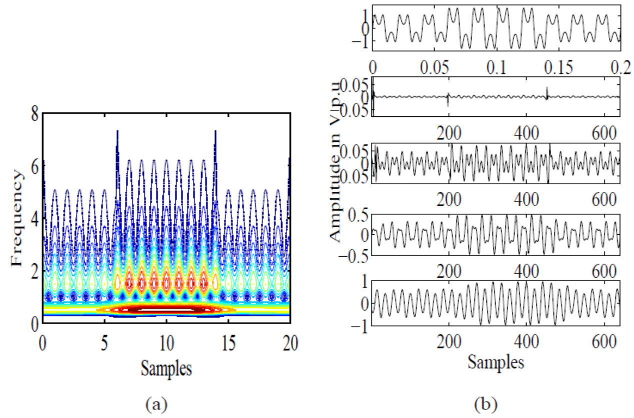

Fig. 12: Localization of sine wave with swell and harmonic in (a) S-transform (b) MODWT decomposition

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.

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