International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 13 (2017) pp. 3714-3718
© Research India Publications. http://www.ripublication.com

Time-Frequency Analysis of Non-Stationary Waveforms in Power-Quality via Synchrosqueezing Transform

G. Sahu[1, 2, #] and A. Choubey[1]

[1]*Department of Electronics and Communication Engineering, National Institute of Technology, PIN -831014, Jamshedpur, Jharkhand, India.*

[2]*Department of Electronics and Communication Engineering, Raghu Engineering College, PIN - 531162, Visakhapatnam, India.*

[#]***ORCID: 0000-0002-0263-1346***

Abstract

An accurate time-frequency representation (TFR) can provide useful information in non stationary data analysis and processing. The traditional methods like short-time Fourier transform (STFT) and wavelet transform (WT) based TFR approaches are leads to a tradeoff between time and frequency resolution. A recently proposed synchrosqueezing transform (SST), which is an extension of the WT, has been successfully used as a potential tool for time-frequency analysis of signals with time varying characteristics. This paper introduces a novel approach for the visual localization and detection of various non-stationary power quality disturbances present in a power network using SST. In this study we considered different types of power-quality (PQ) disturbances as input data. The extensive simulation results show that the SST based approach is very much effective in characterization of PQ events compared to traditional continues wavelet transform (CWT).

Keywords: Continues wavelet transform; power-quality disturbances; synchrosqueezing transform; time-frequency representation.

INTRODUCTION

In the commercial world, along the increased use of sensitive power electronic devices and modern equipments, the power quality (PQ) related problems are becoming a serious and challenging issue. The presence of PQ disturbances in an electric power system can leads to instability, short life time and malfunctions in the affected loads connected to the system [1]. The accurate detection and appropriate mitigation action is very much essential to improve the PQ [2]. The manual procedures adopted for the PQ detection are proven to be costlier and inefficient. Hence, several signal processing techniques are developed and successfully implemented for the effective detection and classification of PQ events. One of the most widely used time frequency analysis approach is Fourier Transform (FT). The FT is very much capable of extracting the harmonic component of the PQ signal under analysis. However due to transient nature of most of the PQ disturbance signals, use of FT alone is not enough to provide both time and frequency resolution. Short time Fourier transform (STFT) was put forward as an alternative to FT. the STFT have been implemented for the detection and characterization of the PQ events [3]. The use of fixed window length in STFT reduces its analytic ability to characterize non-stationary signals [4]. To overcome the disadvantages associated with FT based techniques, the wavelet transform (WT) was introduced and extensively used for the time-frequency analysis of wide range of PQ disturbance signals by academicians and researchers. Further the use WT based approaches are extended to noise reduction, data compression and feature extraction of different non stationary PQ signals [5-9]. Researchers proposed wavelet based Multiresolution analysis (MRA) approach to reduce the computational time for online applications. A wide range of PQ disturbance signals were characterized based on the energies of the decomposed signal using MRA in wavelets [10]. Unfortunately, the capability of wavelet transform is often significantly degraded in real time scenario in noisy environments. Due to this reason, to large extent efforts have been initiated by different research groups to improve the time-frequency resolution of different non-stationary signals [11-13]. According to Heisenberg uncertainty principle, the TF resolution is limited by $\Delta t.\Delta f \geq \frac{1}{4\pi}$, where $'\Delta t'$ and $'\Delta f'$ denotes the time resolution and frequency resolution respectively. It is clear from the above statement that the time resolution and frequency resolution are inversely proportional to each other. There are numerous number of approaches based on S-transform, modified S-transform, Hilbert transform, Hilbert-Huang transform, Gabor Transform, Gabor-Wigner transform, Kalman filter and their hybrid transform techniques [14-17] have been reported by different researcher from time to time for the impending assessment of PQ disturbances via time frequency representation (TFR). In general time frequency analysis method is used as an important alternative tool for the detection and identification of non stationary PQ disturbance signals.

Daubechies et al., proposed an effective WT based time-frequency representation approach known as synchrosqueezing transform (SST) for the analysis of speech signals [18]. SST used as an efficient algorithm for investigating signals with non-stationary characteristics and it provides an improved spectral resolution. SST is a very much capable to track the close frequencies and fast changing instantaneous frequencies [19]. Further, the application of SST was extended to the studies related to electrocardiography signals, gearbox fault diagnosis and seismic signals. [20-22].

In this paper, A SST based time-frequency representation is applied to analyze and identify different types of PQ disturbance events. Finally the analysis results of PQ events by SST and CWT are compared with each other.

SYNCHROSQUEEZZING TRANSFORM

The CWT of a time series is given as :

$$C_p(x,y) = \{p(t), \psi_{x,y}(t)\} = \frac{1}{\sqrt{x}} \int p(t).\ \psi * \left(\frac{t-y}{x}\right).dt \quad (1)$$

Here" $*$ " stands for the complex conjugate operation, ψ is a suitably chosen mother wavelet, x is the scaling factor, y represents the time shift factor and a is the scaling factor. The cross correlation of $p(t)$ with different wavelets will represent the CWT, which are derived from the translated and scaled version of the mother wavelet. The $\psi(t)$ can be expressed as:

$$\psi(t) = w(t).e^{i2\pi f_0 t} \quad (2)$$

Where $w(t)$ and f_0 represents the window function and frequency of the wavelet respectively. At each time point along the scale direction, there exists a maximum value of $C_p(x,y)$. All these maximum values can be represented as a curve. A set consists of all these maximum values can be represented as:

$$X = \{(x_r, y) \in R^2; M_p(x_r, y) = max\left(\left|C_p(x_i, y)\right|\right)\} \quad (3)$$

Where (x_r, y) and $\left|C_p(x_i, y)\right|$ represents the ridge point at any time point y and modulus of the wavelet coefficient respectively.

By performing WT, The Instantaneous Amplitude (IA) and the Instantaneous Frequency (IF) of the signal $p(t)$ can be calculated from (x_r, y) as

$$f_{inst}(t) = \frac{2\pi f_0}{2\pi x_r(t)} \quad (4)$$

$$a_I(t) \cong \frac{2\left|C_p(x_r(t),t)\right|}{\sqrt{x_r(t)}|\widehat{w}(0)|} \quad (5)$$

Where, $\widehat{w}(0) = \widehat{w}(\omega)|_{\omega=0}$, $\widehat{w}(\omega\ )$ is the Fourier transform of $w(t)$.

The time frequency information of the signal can be extorted by using the WT as depicted by Eq. (4) and Eq. (5). However, the WT more often yields a blurred time-frequency contour and may cause misunderstanding of the signal. To improve the time-frequency representation, an alternative transform technique, the synchrosqueezing algorithm was proposed by Daubechies et al. [19].

Let us assume that the signal under analysis has a constant IF and a constant IA, i.e.

$$f_i(t) = f, a_i(t) = a \quad (6)$$

Substituting Eqs. (6) Into Eqs. (1), yields

$$C_p(x,y) = \frac{1}{\sqrt{x}} \int \hat{p}(\xi)\hat{\varphi}(x\xi)e^{iy\xi}\, d\xi = \frac{a}{2\sqrt{x}}\hat{\varphi}(xf)e^{iyf} \quad (7)$$

The Wavelet coefficient $C_p(x,y)$, frequently spreads out in the time-scale plane. This may leads to a blurred projection in time scale plane. To eliminate the effect at any (x,y) location for which $C_p(x,y) \neq 0$, its instantaneous frequency $f_{inst}(x,y)$ can be compute by taking derivatives

$$f_{inst}(x,y) = \frac{-i}{C_p(x,y)} \frac{d(C_p(x,y))}{dy} \quad (8)$$

Since $x, y\ and\ f$ are discrete values, the scaling step is determined as $(\Delta x)_k = x_k - x_{k-1}$ for any x_k. The synchrosqueezed transform $p(f,y)$ is computed at the centers f_j of the frequency range $\left[f_j - \frac{\Delta f}{2}, f_j + \frac{\Delta f}{2}\right]$ (with$(\Delta f = f_j - f_{j-1})$):

$$p(f_j, y) = \frac{1}{\Delta f} \sum_{x_k:\left|f_p(x_k,y)-f_j\right| \le \frac{\Delta f}{2}} C_p(x_k, y) x_k^{-3/2} (\Delta x)_k \quad (9)$$

Eqn. (9) represents the synchrosqueezed transform of the signal $p(t)$. This is synchrosqueezed along the time-frequency axis.

RESULTS AND DISCUSSIONS

In this paper, to show the efficiency of the proposed SST based TFR technique, a wide variety of synthetic PQ disturbance signals are generated by using MATLAB software. In the case study, for simplicity only four different types of PQ disturbance signals are considered. The detail description regarding each of the PQ disturbances are as given below.

Case (1): Voltage signal with swell: voltage swell is denoted by a sudden increase in amplitude from the nominal value of a standard voltage waveform.

Case (2): Voltage signal with swell and harmonics: In this case we considered a multiple PQ disturbance. The voltage waveform is interfered with harmonics for particular time duration and a sudden drop in voltage for other duration.

Case (3): Voltage signal with sag and flicker: voltage sag is denoted by sudden decrease in amplitude from the nominal value of a standard voltage waveform. The flicker is denoted by the variation of voltage for short duration but long enough to be noticeable. In this case we consider the combination of swell with flicker.

Case (4): Voltage signal with multiple spikes and momentary interruption: The impulsive transient is referred as spike. The momentary interruption is the total interruption of power for a particular duration. In this case we selected a PQ disturbance consists of multiple spikes and momentary interruption.

For analysis, the sampling frequency of all PQ disturbance signals is chosen as 3.2 kHz and a morlet wavelet is used for CWT and SST. Fig. 1(a) shows the voltage signal with swell. The CWT and SST contour of the signal are displayed in Fig. 1(b) and Fig. 1(c) respectively. From Fig. 1 it is found that both CWT and SST able to detect the disturbances, but it is evident from the results that, CWT is able to identify the PQ disturbances with lower resolution. However the SST is able to provide better time-frequency resolution. Figs 2(a)-4(a) show some of the power quality disturbances such as swell with harmonics, sag with flicker and spikes with momentary interruption signal as a function of time. 2(b)-4(b) is called as the CWT time frequency contour and 2(c)-4(c) is called SST time frequency contour. In all of the cases the SST results more distinct time-frequency resolution capability compared to CWT. The SST is capable of showing a jagged representation of the instantaneous frequency components of the non stationary PQ disturbance signals, which are hidden in CWT based TF representation.

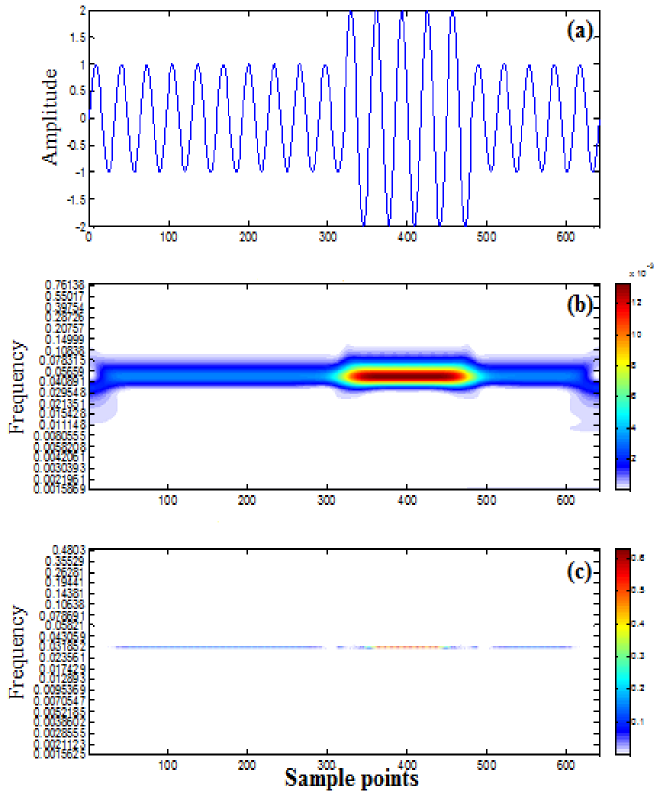

Figure 1: (a) Voltage waveform with swell.
(b) Time-frequency representation based on CWT.
(c) Time-frequency representation based on SST.

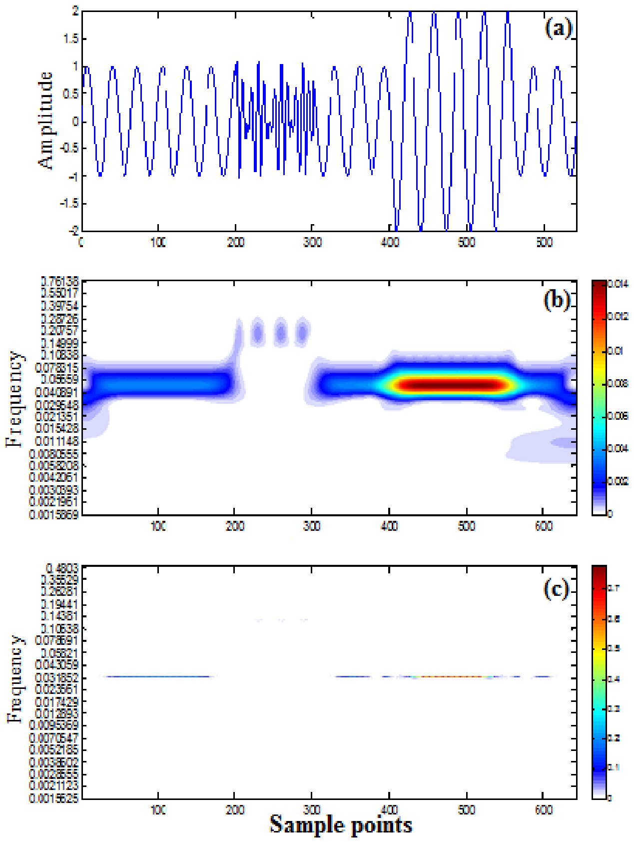

Figure 2: (a) Voltage waveform with swell and harmonics
(b) Time-frequency representation based on CWT.
(c) Time-frequency representation based on SST.

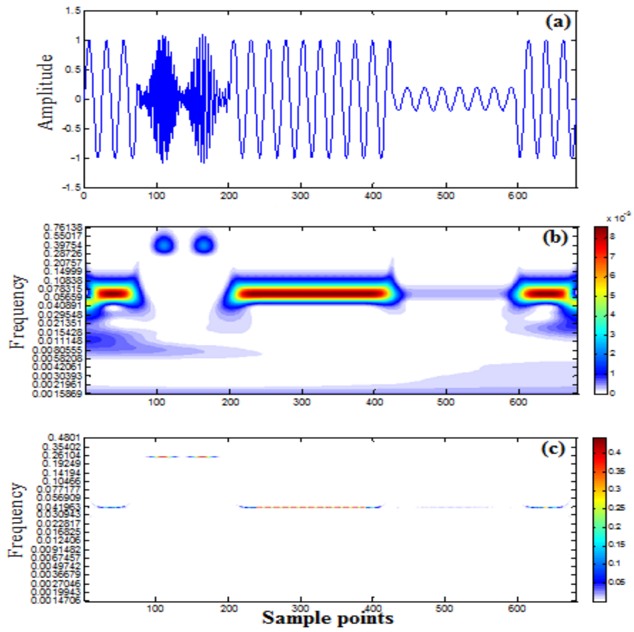

Figure 3: (a) Voltage waveform with sag and flicker.
(b) Time-frequency representation based on CWT.
(c) Time-frequency representation based on SST.

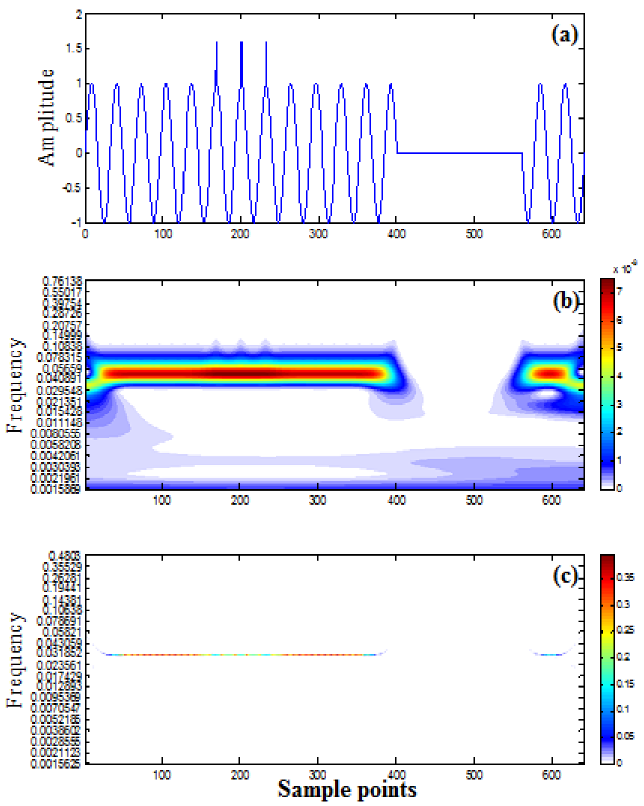

Figure 4: (a) Voltage waveform with multiple spikes and momentary interruption. **(b)** Time-frequency representation based on CWT. **(c)** Time-frequency representation based on SST.

CONCLUSION

In this paper, we have presented the synchrosqueezing transform (SST) for the time-frequency analysis of non stationary PQ disturbance signals. The SST based TFR approach shows promising results for the detection and localization of power quality events. It is evident from the results that SST has a superior time-frequency resolution compared to CWT. The SST characteristics are very much useful for the detection of accurate location of different disturbances occurs in standard quality power signals. Further we can conclude that SST is an important tool to solve PQ disturbance classification related problems.

REFERENCES

[1] R. C. Dugan, M. F. McGranaghan and H. W. Beaty, Electric Power System Quality McGraw-Hill, New York, 1996.

[2] I. Y. Chung, D-I. Won, J-M Ahn and S-I Moon, “Development of a network based power quality diagnosis system,” Elect. Power Res, vol. 77, pp. 1086-1094, 2007.

[3] Y. Gu and M. H. J. Bollen, “Time-frequency and time-scale domain analysis of voltage disturbances,” *IEEE Transactions on Power Delivery*, vol. 15, pp. 1279–1284, Oct. 2000.

[4] A. M. Gargoom, N. Ertugrul and W. L. Soong “A comparative study on effective signal processing tools for power quality monitoring,” *Proceedings of 11th Eur. Conf. Power Electron*. Appl. (EPE), 2005, pp. 1-10.

[5] O. Poisson, P. Rioual and M. Meunier “Detection and measurement of power quality disturbances using wavelet transform,” *IEEE Transactions on Power Delivery*, vol 15, pp. 1039–1044, Jul. 2000.

[6] A. M. Gaouda, M. M. A. Salama, M. R. Sultan, A. Y. Chikhani, “Application of multiresolution signal decomposition for monitoring short-duration variations in distribution systems,” *IEEE Transactions on Power Delivery*, vol. 15, pp. 478–485, Apr. 2000.

[7] S. Santoso, E. J. Power and P. Hofman, “Power Qualty assessment via wavelet transform analysis,” *IEEE Transactions on Power Delivery*, vol. 11, pp. 924-930, 1996.

[8] H.T Yang, and C. C. Liao, “A de-noising scheme for enhancing wavelet-based power quality monitoring system,” *IEEE Transactions on Power Delivery*, vol. 16, pp. 353-360, 2001.

[9] S. Santoso, E. J. Power and W. M. Grady, “Power quality disturbance data compression using wavelet transform method,” *IEEE Transactions on Power Delivery*, vol. 12, pp. 1250-1257, 1997.

[10] S. Nath, P. Sinha and S. K. Goswami, “A wavelet based novel method for the detection of harmonic sources in power system,” *Inter. Jour. Electr. Power Energy Sys*. Vol. 40, pp. 54-61, 2012.

[11] J. Zhong and Y. Huang, ‘Time–frequency representation based on an adaptive short-time Fourier transform,” *IEEE Transactions on Signal Processing*, vol. 58, pp. 5118–5128, 2010.

[12] O. Talakoub, J Cui J and W. Wong, “Approximating the time-frequency representation of bio-signals with chirplets,” *EURASIP Journal on Advances in Signal Processing*, 2010.

[13] L. Zhang L, G. L. Xiong, H. S. Liu H. Zou and W. Guo, “Time–frequency representation based on time-varying autoregressive model with applications to non-stationary rotor vibration analysis,” *Sadhana*, vol. 35, pp. 215–232, Apr. 2010.

[14] P. K Dash, B. K. Panigrahi and G. Panda, “Power Quality analysis using S-Transform,” *IEEE Trans. Power Del.*, vol. 18, pp. 406-411, 2003.

[15] S. H. Cho, G. Jang and H. H. Chang, "Time frequency analysis of power quality disturbances via the Gabo-Winger Transform," *IEEE Trans. Power Del.*, vol. 25, pp. 494-499, 2000.

[16] N. C. F. Tse, J. Y. C. Chan,W. H Lau and L. L. Lai, " Hybrid Wavelet and Hilbert transform with frequency shifting decomposition for power quality analysis," *IEEE Trans. Instrum. Meas.*, vol. 61, pp. 3225-3233, 2012.

[17] A. A. Abdelsalam, A. A. Eldesouky and A. A. Sallam, Characterization of power quality disturbances using hybrid techniques of linear kalman filter and fuzzy-expert system, *Elect. Power Syst. Res.*, vol. 83, pp. 41-50, 2012.

[18] I. Daubechies and S. Maes, "A nonlinear squeezing of the continuous wavelet transform based on auditory nerve models," in Wavelets in Medicine and Biology, Boca Raton, FL, USA: CRC Press, 1996, pp. 527–546.

[19] I. Daubechies, J Lu and H. T. Wu "Synchrosqueezed wavelet trans-forms: an empirical mode decomposition-like tool," *Applied and Computational Harmonic Analysis*, vol. 30, pp. 243-261, 2011.

[20] G. Thakur and H. T. Wu "Synchrosqueezing-based recovery of instantaneous frequency from non-uniform samples," *SIAM Journal on Mathematical Analysi*, vol. 43, pp. 2078-2095, 2011.

[21] P. wang, J. Gao and Z. wang, "Time-frequency analysis of seismic data using synchrosqueezing transform," *IEE Geoscience and Remote Sensing letters*, vol. 11, pp. 2042-2044, 2014.

[22] C. Li and M. Liang, "Time-frequency signal analysis for gearbox faulty diagnosis using a generalized synchrosqueezing transform," *Mechanical Systems and Signal Processing*, vol. 26, pp. 205-217, 2012.