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Analysis of Power Quality Disturbances Using Spectrogram and S-Transform

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Abstract – *The performance analysis of spectrogram and S-transform for power quality disturbances such as swell, sag, interruption, harmonic, inter-harmonic, and transient based on IEEE Std 1159-2009 are presented. These analyses are performed to identify the best performance for detection of power quality disturbances.*
This is important to provide the improvement of power quality which capable to accurately measured, detect the power quality phenomena. Therefore the accurate detection of power quality disturbances can be developed based on the best techniques. By using both techniques, the temporal and spectral information are obtained. From the time frequency representation (TFR) the signal parameters are estimated such as instantaneous root means square voltage (RMS), total waveform distortion (TWD), total harmonic distortion (THD) and total non-harmonic distortion (TnHD).The signal characteristics are calculated from signal parameters to verify the performances of both techniques, the APE results are used to identify the accuracy of these techniques. By perform the analysis; the results show the S-transform is a better tool to analyze the transient disturbances whereas for voltage variation and harmonic disturbances the spectrogram gives higher accuracy result.
As a conclusion both techniques are capable to analyzed power quality disturbances, and it clearly shows that, the S-transform has an advantages in term of time-frequency resolution which capable to detect and localized various kind of power quality disturbances and it essential for the development of advanced real-time monitoring. ***Copyright © 2014 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Power Quality, S-Transform, Time Frequency, Spectrogram, Resolution*

Nomenclature

TFR	Time Frequency Distribution
TWD	Total Waveform Distortion
THD	Total Harmonic Distortion
TnHD	Total Nonharmonic Distortion
APE	Absolute Percentage Error
STFT	Short Time Fourier Transform
$z_{vv}(t)$	Voltage variation
$z_{wd}(t)$	Waveform distortion
$z_{trans}(t)$	Transient
$S(t,f)$	Input signal in time frequency
$g(\tau)$	Gaussian window
σ	Standard deviation
Δf	Frequency resolution
Δt	Time resolution
$T_{d,swell}$	Duration of swell
$T_{d,sag}$	Duration of sag
$V_{rms,ave}$	Average rms
t_{trans}	Duration of transient
t	Time
f	Frequency
pu	Per unit

I. Introduction

The increasing of non-linear loads such as power converters, arc furnaces and motor drives are connected to the power system introduced serious power quality problems for the system especially for industrial customers. These electronic devices are introduced distortion in term of phase, frequency, and amplitude of the power system, which lead to severe problems such as malfunctions equipment, overheat, overvoltage, instability, light flicker and data losses. Therefore, the analysis of detection power quality disturbances are required to provide a clear understanding of what happen in the system and the problem will be minimize by perform a suitable corrective and preventive measure [1].

Time-frequency analysis techniques are extensively used in analyzing power quality disturbances.

These techniques have been effectively providing the useful information to address a variety of problems in power system.

Previously, most of researchers used Short Time Fourier Transform (STFT), although this technique has

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capability to extract feature in time and frequency and suitable for harmonic analysis, [2] it still have a limitation of fixed window width which causes fixed time-frequency resolution therefore it difficult to detect occurrences time for high frequency signal and it also sensitive to noise level [3]-[8]. The wavelet transform is widely used to avoid the disadvantages of STFT for analyzing power quality disturbances. It is effective in providing time–localized information for sag, transient and overvoltage and required to testing various wavelet for best detection and classification result [5], [8]-[11].

Furthermore, wavelet transform incapable to give accurate results under a noise condition. Both techniques have been successfully used for power quality disturbances detection but each technique not capable to analyze various power quality disturbances effectively.

Recently, time frequency analysis is S-transform which combination element of STFT and S-transform.

It capable to detect disturbances correctly in the presence noise [5], [12]. Dash has been used the S-transform to detect the power quality disturbances. For example [13] researcher mentioned S-transform is superior for analyzing transient signal. The capabilities between both techniques in term of identifying a suitable time-frequency resolution are not discussed very clearly in previous research. Therefore, this paper is proposed to compare the performance of spectrogram and S-transform which is useful in process of selection the effective technique for analyzing the various kinds of power quality disturbances. The results show S-transform is a better tool to analyze the transient disturbances whereas for voltage variation and harmonic disturbances the spectrogram gives higher accuracy result.

II. Power Quality Signals

Power quality disturbances divided into three categories: voltage variation, waveform distortion and transient signal. Swell, sag and interruption are under voltage variation, harmonic and interharmonic are for waveform distortion and transient signal. The modeling of this categories are formed in complex exponential signal based IEEE Standard 1159 and can be expressed as [14]:

$$z_{vv}(t) = e^{j2\pi f_1 t} \sum_{k=1}^{3} A_k \Pi_k (t - t_{k-1}) \quad (1)$$

$$z_{wd}(t) = e^{j2\pi f_1 t} + A e^{j2\pi f_2 t} \quad (2)$$

$$z_{trans}(t) = e^{j2\pi f_1 t} \sum_{k=1}^{3} \Pi_k (t - t_{k-1}) + \\ + A e^{-1.25(t-t_1)/t_d} e^{j2\pi f_2 (t-t_1)} \Pi_2 (t - t_1) \quad (3)$$

$$\begin{aligned} \Pi_k(t) &= 1 \quad \text{for } 0 \le t \le t_k - t_{k-1} \\ &= 0 \quad \text{elsewhere} \end{aligned} \quad (4)$$

where $z_{vv}(t)$, represents voltage variation, $z_{wd}(t)$ represents waveform distortion and $z_{trans}(t)$ represents transient signal. k is the signal component sequence, A_k is the signal component amplitude, f_1 and f_2 are the signal frequency, t is the time while $\Pi(t)$ is a box function of the signal. In this analysis, f_1, t_0 and t_3 are set at 50 Hz, 0 ms and 200 ms, respectively, and other parameters are defined as below.

Table I gives the details of signal modeling and their control parameters for this research. Meanwhile, the characteristics of power quality disturbances are depend on voltage magnitude, frequency and duration.

TABLE I
MODELING POWER QUALITY DISTURBANCES

Signal	Parameter	Time
Swell	$A_1 = A_3 = 1, A_2 = 1.2$	$t_1 = 40$ ms, $t_2 = 200$ms
Sag	$A_1 = A_3 = 1, A_2 = 0.8$	$t_1 = 40$ ms, $t_2 = 200$ ms
Interruption	$A_1 = A_3 = 1, A_2 = 0$	$t_1 = 40$ ms, $t_2 = 200$ms
Harmonic:	$A = 0.25$	$f_2 = 250$ Hz
Interharmonic	$A = 0.25$	$f_2 = 275$ Hz
Transient: A	$A = 0.5$	$f_2 = 1000$ Hz, $t_2 = 115$m

Based on the duration of existences of power quality disturbances, it can be divided in short, medium or long duration as depicts in Fig. 1.

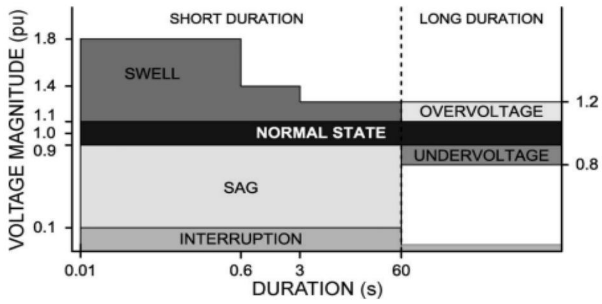

Fig. 1. Characteristics of power quality disturbances

III. Time- Frequency Analysis

Spectrogram

Spectrogram is the squared magnitude of the STFT.

The spectrogram time frequency representation is calculated as follows [15], [16]:

$$S(t,f) = \left| \int_{-\infty}^{\infty} x(\tau) w(\tau - t) e^{-j2\pi f} dt \right|^2 \quad (5)$$

where $x(t)$ is the signal under analysis and $w(t)$ is the window function. The hanning window is selected because of its lower peak side lobe which is narrow effect on other frequencies around fundamental value (50 Hz in this study) and other frequency components.

S-transform

S-transform employs a moving and scalable localizing Gaussian window. It combines a frequency dependent resolution with simultaneous localizing the real and imaginary spectra.

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The general S-transform is defined by the equation [17]:

$$S(\tau,f)=\int_{-\infty}^{\infty}h(t)g(\tau-t,f)e^{-j2\pi ft}dt \qquad (6)$$

where $h(t)$ is the signal and $g(t)$ is a window function.

Windows function is a modulated Gaussian function expressed by:

$$g(\tau)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\left(t^2/2\sigma^2\right)} \qquad (7)$$

where standard deviation, σ is function of time and frequency, f defined as:

$$\sigma=\frac{1}{|f|} \qquad (8)$$

The gaussian window are expressed in four window size as depicts in Fig. 2.

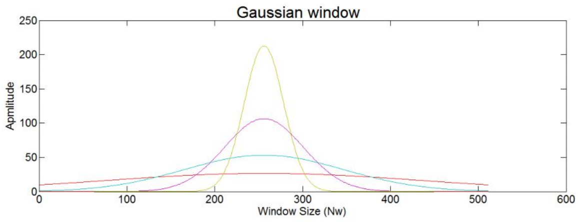


Fig. 2. Gaussian window

Comparison spectrogram and S-transform

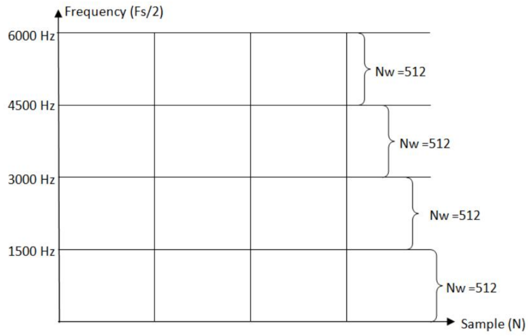
The time-frequency characteristics of spectrogram and S-transform are illustrated in Figs. 3. Fig. 3(a) shows spectrogram has a fixed window which means it has fixed time-frequency resolution for all frequency bands.

However S-transform involves in varied time-frequency at different frequency band as depicts in Fig. 3(b), which allow selecting a suitable window depend on the frequency band. The window length affects the time resolution, and frequency resolution. In this case, the narrow length results in coarse frequency resolution, a fine time resolution. In other words, the windows provides good localization in the frequency-domain for low frequency, while its provides good localization in the time-domain for higher frequencies [18]. In fact, the frequency resolution, is the inverse of the time window size and it can be expressed as:

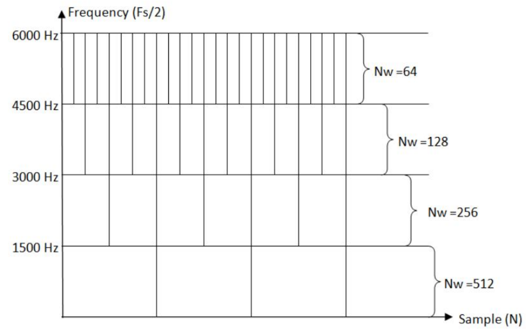
$$\Delta f=\frac{2\pi}{N}=\frac{f_s}{N} \qquad (9)$$

where N is the window length and f_s is the sampling frequency. The window length N affects also on time resolution. The time resolution is:

$$\Delta t=\frac{N}{f_s} \qquad (10)$$



(a)



(b)

Figs. 3. Time frequency characteristic spectrogram (a) and S-transform (b)

These equations prove that, a narrow window leads to good time resolution and poor frequency resolution and vice versa.

However, the spectrogram has fixed window length and it will result a fixed frequency resolution, but to have the different resolution the spectrogram should be repeated with the different window length.

Table II shows frequency bands for spectrogram technique where fixed window, Nw=512 are selected for all frequency bands. Once the fixed window size is selected, there is a fixed or same frequency resolution over all frequency bands as illustrated in Figs. 3.

TABLE II
FREQUENCY BANDS SPECTROGRAM

Level	Frequency bands	Hanning
Level 1	0Hz-1500Hz	512
Level 2	1500Hz-3000Hz	512
Level 3	3000Hz-4500Hz	512
Level 4	4500Hz-6000Hz	512

In this research, the S-transform technique are divided in four frequency bands, which is for level 1 the frequency is (0Hz-1500Hz), and then followed by level 2 the frequency is (1600Hz -3000Hz), level 3 the frequency is (3000Hz-4500Hz) and for level 4 the frequency is (4500Hz-6000Hz). The window size of S-transform technique is depending on the estimated frequency level.

At level 1 the chosen window is Nw=512 which same as spectrogram technique. Meanwhile, the window size is Nw=256 for level 2, and for level 3 the selection window is 128.

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The window chosen, Nw=64 is for frequency band level 4.

The relationship between frequency level and window chosen are illustrated in Table III.

TABLE III
FREQUENCY BANDS S-TRANSFORM

Level	Frequency bands	Gaussian
Level 1	0Hz-1500Hz	512
Level 2	1500Hz-3000Hz	256
Level 3	3000Hz-4500Hz	128
Level 4	4500Hz-6000Hz	64

IV. Signal Parameter and Characteristics

Parameters of the signal such as instantaneous RMS voltage, fundamental voltage, total waveform distortion, total harmonic distortion, and total non-harmonic are estimated from the time frequency representation (TFR) to give the signal information. This information is important to detect the presences of power quality disturbances.

From the signal parameters the characteristics of power quality disturbances are calculated. The parameters of RMS voltage are used to calculate the duration of swell, sag, interruption and RMS voltage:

$$T_{d,swell} = \int_0^T \begin{cases} 1 & \text{for } V_{rms}(t) \geq 1.1 \\ 0 & \text{elsewhere} \end{cases} dt \tag{11}$$

$$T_{d,sag} = \int_0^T \begin{cases} 1 & \text{for } 0.1 \leq V_{rms}(t) \leq 0.9 \\ 0 & \text{elsewhere} \end{cases} dt \tag{12}$$

$$T_{d,int} = \int_0^T \begin{cases} 1 & \text{for } V_{rms}(t) < 0.1 \\ 0 & \text{elsewhere} \end{cases} dt \tag{13}$$

$$V_{rms,ave} = \frac{1}{T}\int_0^T V_{rms}(t)\,dt \tag{14}$$

meanwhile, duration of transient can be identified from the parameter instantaneous total waveform distortion and can be expressed as:

$$t_{trans} = \int_0^T \begin{cases} 1 & \text{for } TWD(t) \geq TWD_{trans,thres} \\ 0 & \text{elsewhere} \end{cases} dt \tag{15}$$

where $TWD_{trans,thres}$ is the total waveform distortion threshold for transient. In this study, the threshold is set at 0.001.

Total harmonic distortion average and total interharmonic distortion average are also important characteristics. They can be calculated, respectively from the parameter of instantaneous total harmonic distortion and instantaneous total interharmonic distortion as follows:

$$THD_{ave} = \frac{1}{T}\int_0^T THD(t)\,dt \tag{16}$$

$$TnHD_{ave} = \frac{1}{T}\int_0^T TnHD(t)\,dt \tag{17}$$

V. Signal Classification

Rule-based classifier is a deterministic classification method which it is simple and easy to implement.

It develop based on IEEE Standard 1159-2009 [14] by considering the voltage magnitude and the duration of disturbances happen in order to determine the type of disturbances.

The following pseudo code describes a rule based classifier of the power quality signal based on the signal characteristics. The threshold settings are set based on IEEE std. 1159-2009 [14].

```
Function[z]=rule_based_classifier(T_d,swell, T_d,sag, T_d,int, T_d,tran, V_rms,ave, THD_ave and TnHD_ave)
    If (T_d,swell>=10ms) & (T_d,swell<=3s)
    z=Swell signal;
    elseif (T_d,sag>=10ms) & (T_d,sag<=3s)
    z=Sag signal;
    elseif (T_d,int>=10ms) & (T_d,int<3s)
    z=Interruption signal;
    elseif(T_d,tran>=0.3ms) & (T_d,tran<50ms)
    z=Transient signal;
    elseif (THD_ave>=THD_thres) & (TnHD_ave<TnHD_thres)
    z=Harmonic signal;
    elseif (TnHD_ave>=TnHD_thres) & (THD_ave<THD_thres)
    z=Interharmonic signal;
    elseif (V_rms,ave>0.9pu) & (V_rms,ave<1.1pu)
    z=Normal signal;
    else
    z=unknown
```

VI. System Design

The general system design and process for this research is depicts in Fig. 4. Three categorized power quality disturbances are generated using Matlab based on mathematical model as presented in Eqs. (1)-(4).

The time-frequency distribution (TFD) functions are used as a tool to extract the most salient features. It used to provides two-dimensional representations that reflects the time varying spectral characteristics of the nonstationary signal and the energy of the signal distributed over the two dimensional T-F. From TFR a set of parameters are calculated such as, voltage root means square (RMS), harmonic distortion, interharmonic distortion, and waveform distortion.

This information is used to identify the characteristics of power quality disturbances. The parameter RMS voltage is used to estimate the duration of voltage swell, sag ,interruption and RMS average, meanwhile the

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parameters of average value of harmonic and interharmonic are used for harmonic and interharmonic disturbances. For transient disturbances the duration are defined from the parameter of total waveform distortion.

In classification stage, the power quality disturbances are classified using rule based classifier regarding on the voltage magnitude and the duration of disturbances occur. All of these rule based are developed based on IEEE Std. 1159-2009 as per Fig. 4.

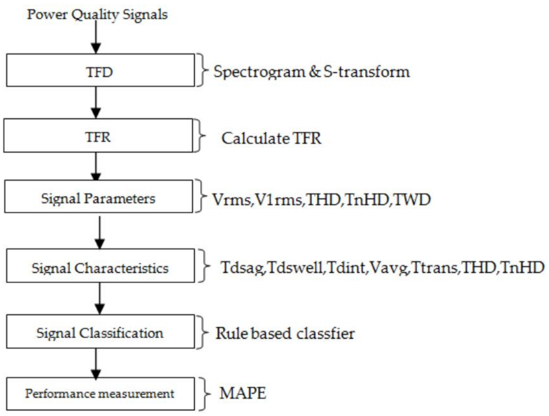

Fig. 4. Process of detection and classification

VII. Results and Analysis

VII.1. Detection of Power Quality Disturbances

a) Detection of Voltage Variation

Fig. 5 shows momentary interruption signal in duration 0.083s.The time-frequency representation (TFR) for spectrogram and S-transform in Fig. 6 and Fig. 7 are almost same around 0.078s, as both techniques used a same window at low frequency and it gives the same duration measurement for both techniques. Table IV, show the comparison results for interruption signals. The duration for swell disturbances are measured based on signal characteristics.

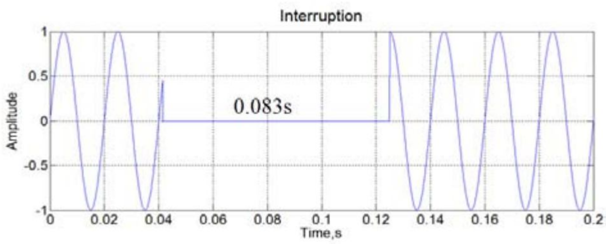

Fig. 5. Interruption signal

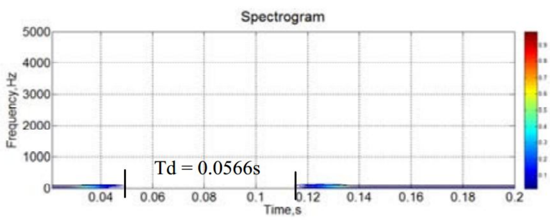

Fig. 6. TFR using spectrogram

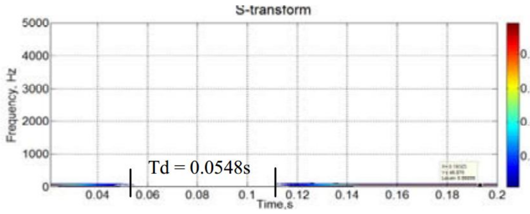

Fig. 7. TFR using S-transform

TABLE IV
ANALYSIS VOLTAGE DURATION

Actual	Spectrogram		S-transform	
	Measured	APE	Measured	APE
0.083s	0.0566s	3.2%	0.0548%	3.4%
0.075s	0.0484s	3.5%	0.047%	3.7%
0.05s	0.0252s	4.9%	0.0232s	5.3%
0.03s	0.0066s	8.25%	0.0044s	8.67%

Other than that, the APE results are calculated to measure the performances comparison of both techniques for this disturbances are presented in next chapter.

b) Detection of Harmonic and Interharmonic

Fig. 8 shows harmonic disturbance with distortion at 3555Hz and 3855Hz. Fig. 9 and Fig. 10 shows the contour plot for harmonic signal. Fig. 9 demonstrate, the spectrogram give a good result compared to S-transform as depicts in Fig. 10 because it has capability to distinguish the harmonic and inter-harmonic component due to frequency resolution. The window width for spectrogram is wider compare S-transform, so the frequency resolution for spectrogram is better compare to S-transform.

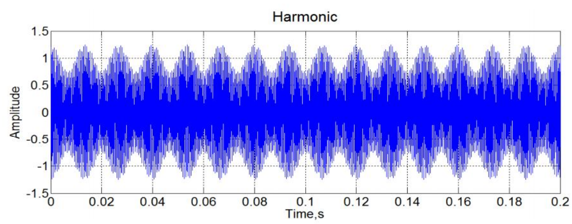

Fig. 8. Harmonic and Interharmonic signal

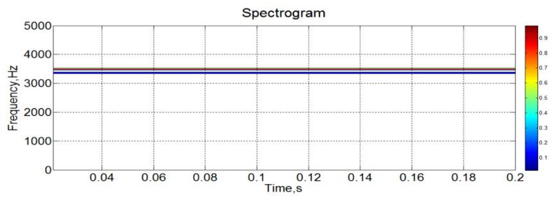

Fig. 9. TFR using spectrogram

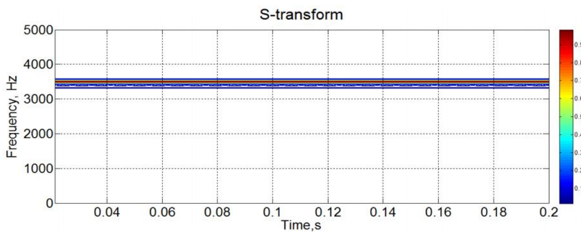

Fig. 10. TFR using S-transfom

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c) Detection of Transient Signal

Fig. 11 shows transient disturbance which consist of high and low frequency 500 Hz and 5000Hz with 12kHz of sampling frequency. The duration of transient signal is 0.07s. Figs. 12-13 show the TFR for spectrogram and S-transform. The temporal, spectral, and magnitude information are be obtain from TFR. Compare Fig. 12 and Fig. 13, the spectrogram gives the better frequency resolution while S-transform gives good time resolution as per Fig. 13.

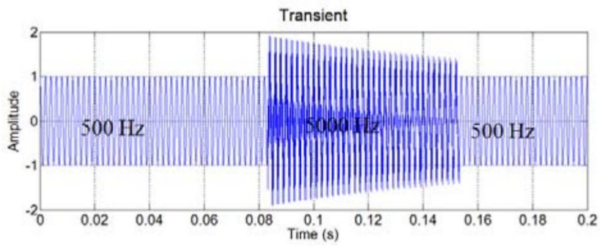

Fig. 11. Transient

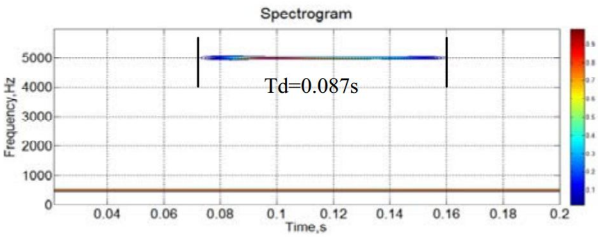

Fig. 12. TFR using spectrogram

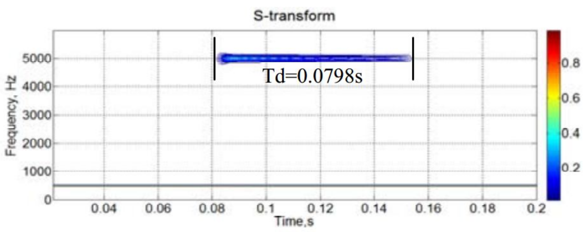

Fig. 13. TFR using S-transform

d) Signals parameter estimation

The similar transient disturbance as per Fig. 11 is analyzed using both techniques. All of the parameters are shown in Figs. 14-18. For Fig. 14 the instantaneous RMS voltage increasing momentary from 0.08s to 0.15s and its duration is 6s. Because of this disturbance only consists of harmonic component, so there is no value for the total nonharmonic distortion as per Fig. 17. But for total harmonic distortion (THD) and total waveform distortion (TWD) they have increasing percentage at 0.08s to 0.15s because of the variation of transient disturbance.

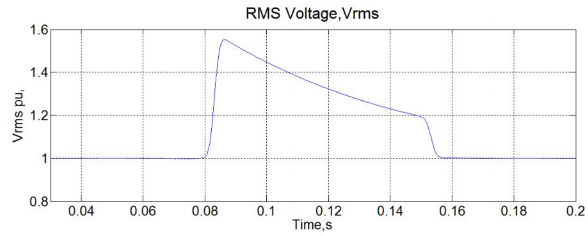

Fig. 14. RMS voltage

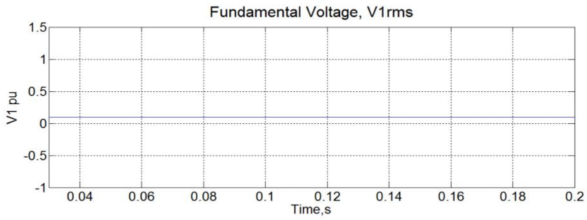

Fig. 15. Fundamental voltage

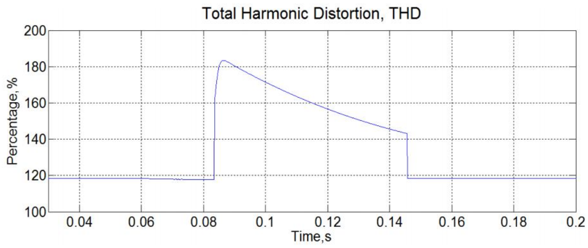

Fig. 16. Total harmonic distortion

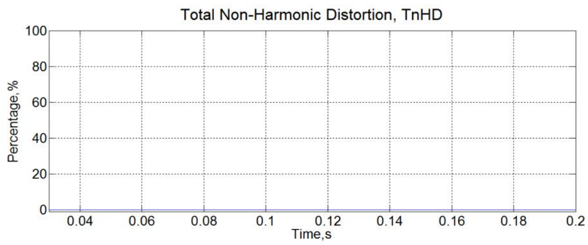

Fig. 17. Total nonharmonic distortion

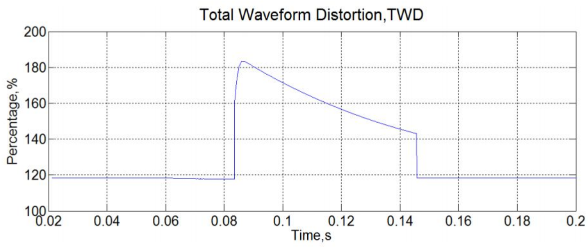

Fig. 18. Total waveform distortion

VII.2. Performance Measurement

a) Mean absolute percentage error

The accuracy of both techniques is evaluated to determine the optimal techniques for detection and classification power quality disturbance.

In order to obtain the accuracy of the simulation, means absolute percentage error (MAPE) can be calculated by generated several set data of power quality event.

The low MAPE results give the highest accuracy of the system:

$$MAPE = \frac{1}{N}\sum_{n-1}^{N}\left|\frac{x_i(n)-x_m(n)}{x_i(n)}\right| \times 100\%$$

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b) Performance measurement of voltage variation

Several set of voltage sag, swell and interruption disturbances are generated in Matlab based on signal modeling in previous section with frequency sampling, f_s=12kHz. The duration of each voltage variation disturbances are varied from t=40ms-200ms. The results in Fig. 19 indicates that the swell and sag disturbances give similar results with actual duration for both techniques. It means that sag and swell disturbances can well be detected and localized.

The similarity results for both techniques because same window which is N_w = 512 are chosen, that resulting a same time-frequency resolution. But for interruption disturbances the spectrogram give best results compare to the S-transform.

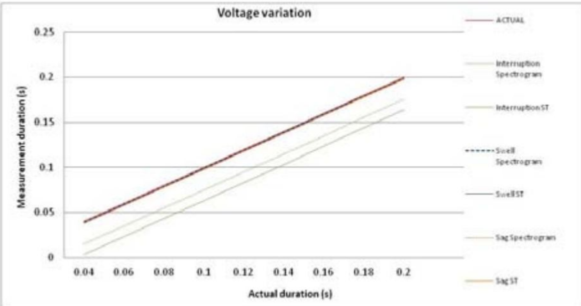

Fig. 19. Voltage variation

c) Performance measurement of transient signal

The transient signal are analyzed with different frequencies at the same duration which is 0.01s.

The frequency of this transient signal are varied from 100 Hz - 6000 Hz with step size of frequency is 100Hz.

Fig. 20 shows the analysis results for transient, these results are obtain from the parameter estimation from spectrogram and S-transform.

The comparisons of both techniques are represented in duration and the accuracy of time resolution for each technique. The spectrogram remains constant duration which is 0.05s along the frequency 100Hz - 6000Hz because the fixed window, Nw=512 are used. Meanwhile for S-transform technique, the duration changes.

The lower frequency bands used a wide window, Nw=512 which resulting longest duration 0.04s and at higher frequency level, the duration is 0.013s, which close to the actual duration for this analysis. The results prove that, S-transform technique has a good time resolution at higher frequency, because the narrow window length is selected.

The dotted line in the graph also shows the accuracy (MAPE) of both techniques where the higher frequency bands give highest accuracy of S-transform, which is 0.45%,with window size Nw=64,while the lowest accuracy for S-transform is 3% with window size of Nw=512 at lower frequency bands. But for the spectrogram the accuracy are constant for all frequency bands which is 2% . Thus, this analysis has proved that, the window width selection were affected the time resolution of the disturbances.

d) Performance measurement of harmonic and interharmonic signals

Fig. 21 shows the result for this analysis, it can be seen that the effect of window length introduces the low frequency resolution at higher frquency level.The frequency resolution for S-transform are changes at four frequency bands,where at level 1(0Hz-1500Hz) it used the wider window length, Nw =512 and it give a fine frequency resolution compare to the narrow window length, Nw=64. At frequency level 4 (4500Hz – 6000Hz), it provide the coarse frequency resolution compare to other level.

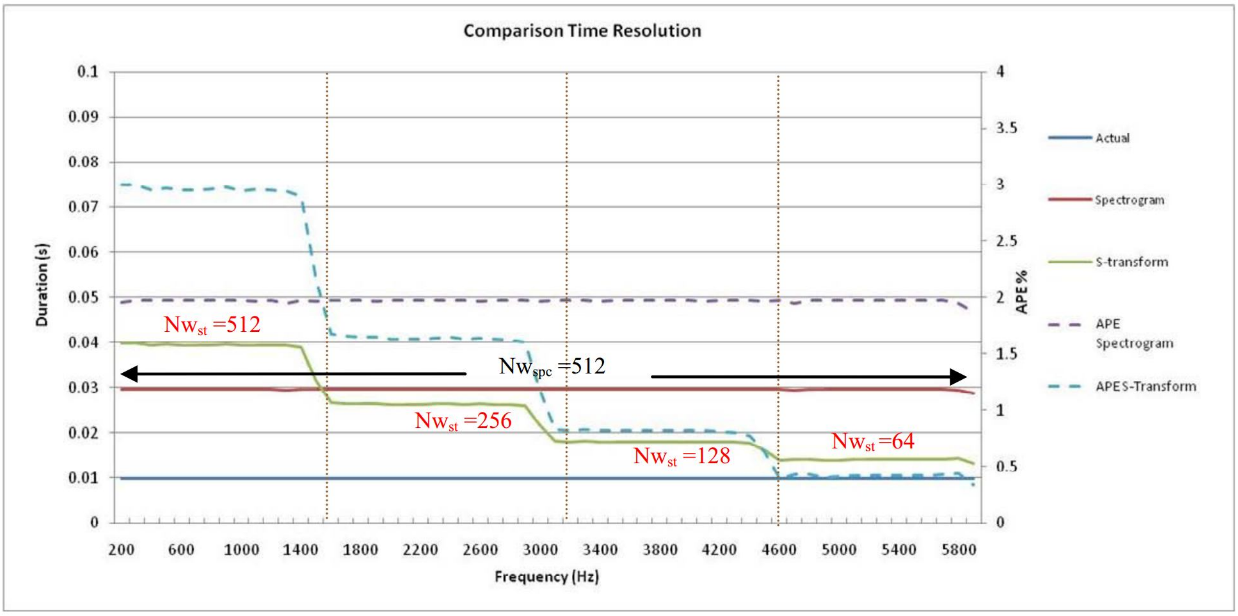

Fig. 20. Analysis of time resolution for transient signals

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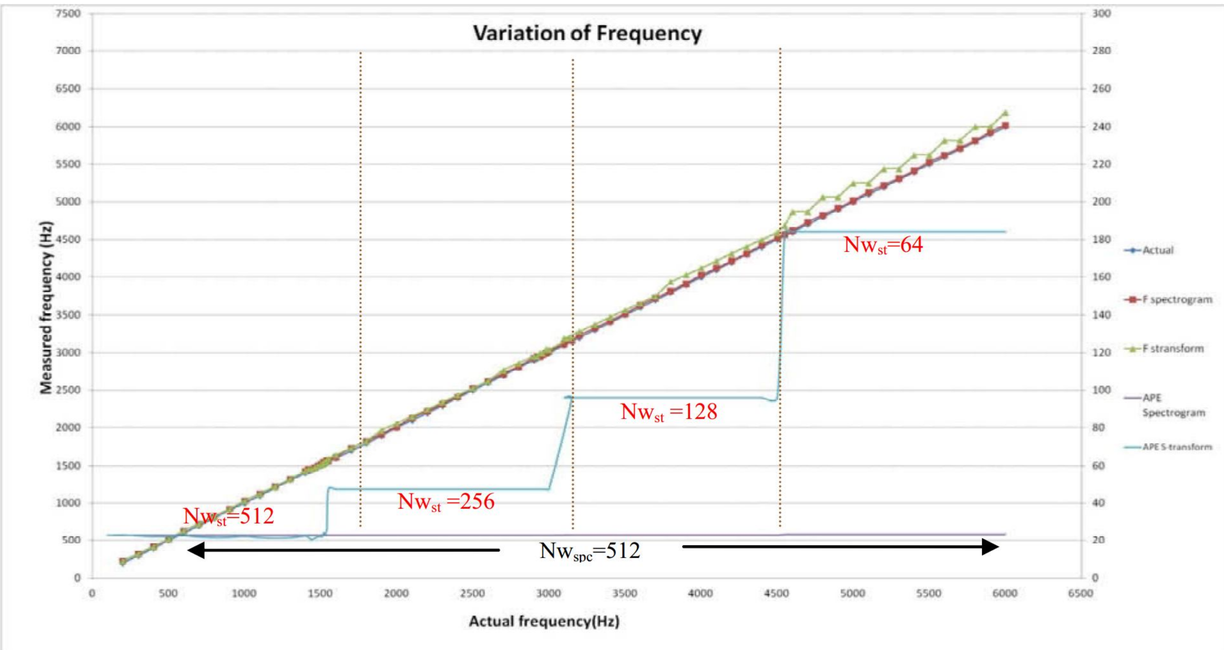

Fig. 21. Analysis of frequency resolution for harmonic signals

It also presents that, at lower frequency bands the calculated frequency for both techniques is close to the actual frequency while at high frequency the calculated frequency for S-transform gives different value from actual.

It means the spectrogram give the accurate detection for harmonic and interharmonic signals compared to the S-transform.

The performances comparison in term of MAPE also presented in Fig. 21,where the spectrogram give a lowest APE=20% for all frequency band.Meanwhile the APE for S-transform always changed depend on the frequency band. For example, at frequency band level 1 (0Hz – 1500Hz), the MAPE is almost same with spectrogram,but it will increased to 43% at level 2 (1500Hz -3000Hz),almost 100% at level 3 (3000Hz-4500Hz) and for level 4, the highest APE are indicated which is 182%.

The lowest MAPE, indicates that the techniques are offer more accuracy for analyze the harmonic and interharmonic signal.Thus, it can be conclude that, the spectrogram is better for harmonic and interharmonic disturbances detection as it has a fixed window so it can result the good and constant frequency resolution for all frequency bands.

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The lowest APE, indicate that the techniques are offer more accuracy for analyze the harmonic and interharmonic signal.

Thus, it can be conclude that, the spectrogram are better for harmonic and interharmonic signal detection as it have a fixed window so it can result the good and constant frequency resolution for all frequency bands.

VIII. Conclusion

The performance analysis presented in this paper provides the understanding comparison between spectrogram and S-transform for power quality disturbances detection. The analysis of this research is conduct with sampling frequency 12kHz, mean it will measure the spectral from 0-6000Hz. The results indicate the voltage variations give almost same results in duration measurement for both techniques.

Referring IEEE 1159-2009 Std, it states the harmonic content are 0-5000Hz..Spectrogram give superior result in detecting harmonic and interharmonic for all frequency, whereas for S-transform it also can measure at all frequency.

However S-transform gives accurate frequency measurement at low frequency which is from 0-1500Hz, and for higher frequency S-transform is not capable to differentiate harmonic and interharmonic distortion cause by narrow window which resulting a higher frequency resolution.

In the real situation most of harmonic distorted at 0Hz-1000Hz only. Therefore the S-transform also can be used for harmonic detection.

While for transient, S-transform shows good results in detecting time disturbances at all frequency. As a conclusion, the simulation results demonstrate S-transform gives good duration measurement at higher frequency and frequency measurement for low frequency.

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References

[1] Suresh Kumar, V., Ramela, K.R., Zobaa, A.F., A cuk converter to improve the ride-through capability of low power adjustable speed drives for voltage sag and swell, (2013) *International Review of Electrical Engineering (IREE),* 8 (4), pp. 1302-1310.

[2] K. Oyedoja, Obiyemi,Obiseye, "Wavelet Transform in The Detection of Electrical Power Quality Disturbances," *International Journal of Engineering and Applied Sciences,* 2012.

[3] C. M. GHEORGHE Daniel, CZIKER Andrei, VASILIU Răzvan, "Virtual Instrument for Power Quality Assesment " *Journal of Sustainable Energy* 2012.

[4] D. Mishra, "Sag, Swell and Interruption Detection Using Wavelet in LabVIEW," *International Journal of Computer & Electrical Engineering,* vol. 5, 2013.

[5] A. F. A. K. Daud, N. Hamzah, H. S. Nagindar Singh, "New Windowing Technique Detection of Sags and Swells Based on Continuous S-transform (CST) " *International Journal of New Computer Architectures and their Applications* 2012.

[6] R. S. Latha, C. S. Babu, and K. D. S. Prasad, "Detection & analysis of power quality disturbances using wavelet transforms and SVM," 2011.

[7] Z. Leonowicz, T. Lobos, and K. Wozniak, "Analysis of non-stationary electric signals using the S-transform," *COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering,* vol. 28, pp. 204-210, 2009.

[8] S. E. A.Arabi Parizi , S.Hasheminejad, "Power Quality Disturbance Classification Using S-transform and Fuzzy System Oriented By PSO Algorithm," *International Journal on Technical and Physical Problems of Engineering,* 2012.

[9] Hapeez, M.S., Hamzah, N.R., Hashim, H., Abidin, A.F., A new approach of wavelet De-Noising on various types of acoustic emission partial discharges signals, (2013) *International Review of Electrical Engineering (IREE),* 8 (3), pp. 1133-1141.

[10] Yong, P., Linna, H., Lifang, W., Application of wavelet entropy and RBF technique based on initial current travelling wave for transmission line protection, (2013) *International Review of Electrical Engineering (IREE),* 8 (5), pp. 1616-1623.

[11] Adewole, A.C., Tzoneva, R., Distribution network fault detection and diagnosis using wavelet energy spectrum entropy and neural networks, (2014) *International Review of Electrical Engineering (IREE),* 9 (1), pp. 165-173.

[12] A. H. Alex Wenda , M.A Hannan , Azah Mohamed , Salina Abdul Samad, "Web Based Automatic Classification of Power Quality Disturbances Using S-transform and Rule Based Expert System," *Journal of Information & Computational Science,* 2011.

[13] H. S. Li Jiasheng, Xiao Weichu and Qiu Biao, "The Application Study of S-transform Modulus Time Frequency Matrix in Detecting Power Quality Transient Disturbances," *Information Technology Journal,* vol. 11, pp. 354-358, 2012.

[14] "IEEE Recommended Practice for Monitoring Electric Power Quality," *IEEE Std 1159-2009 (Revision of IEEE Std 1159-1995),* pp. c1-81, 2009.

[15] A. R. Abdullah, A. Z. Sha"ameri, and N. M. Saad, "Power quality analysis using spectrogram and gabor transformation," in *Applied Electromagnetics, 2007. APACE 2007. Asia-Pacific Conference on*, 2007, pp. 1-5.

[16] A. R. Abdullah and A. Z. Sha"ameri, "Power quality analysis using linear time-frequency distribution," in *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, 2008, pp. 313-317.

[17] N. H. T. Huda, A. R. Abdullah, and M. H. Jopri, "Power quality signals detection using S-transform," in *Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International*, 2013, pp. 552-557.

[18] R. G. Stockwell, "A basis for efficient representation of the S-transform," *Digital Signal Processing,* vol. 17, pp. 371-393, 2007.

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