Time-Frequency analysis of Power Signal: Application to Substation Monitoring and Management System.

I. Kamarulafizam, Sh-Hussain, M.M Mokji, S. Ronisham, *A. Ghani, *M. Yusof

Centre for Biomedical Engineering,
Faculty of Electrical Engineering,
Universiti Teknologi Malaysia, Johor, Malaysia.

*Iconergy Sdn Bhd, Subang Jaya, Malaysia

mr_fizam@yahoo.com, hussain@fke.utm.my, musa@fke.utm.my, ronicsoft@yahoo.com,
iconergy@pd.jaring.my, usofmad@yahoo.com

Abstract- This paper presents a power disturbance detection and classification method based on Time-Frequency analysis. We will discuss how the choice the kernels affect the characteristic of the distribution function. Here we consider a non-stationary testing harmonic composed of a fundamental frequency of 50Hz and its second and third harmonic frequency components. The 50Hz signal is on for the entire record extending from 0 to 1second, while the 100Hz signal is from 100ms to 350 ms and 200Hz signal is from 200ms to 550ms. As for comparison, we will use the same testing signal for different type of kernels. This technique has been applied in a substation monitoring and management system which monitors the power quality at the substation as well as the street lighting panel.

Keyword-Time-Frequency, Harmonics, Sag, Swell, Power Quality Disturbance.

I. Introduction

Recently, the quality of power signals at both the transmission level and distribution level has been investigated by employing signal processing techniques. The quality of power is based on the fact that the voltage signals in power systems are to be maintained at a constant voltage and a fundamental frequency, i.e., 60 Hz or 50 Hz. However, various sources of disturbance introduce transient waveform changes that degrade power quality. As the duration of many disturbances is less than a cycle of the fundamental frequency, Fourier analysis is very limited because Fourier analysis cannot provide localized time information for the transient disturbance signal[l]. Various signal processing techniques, especially wavelet analysis that provides localized scale information, has been an important tool for the analysis of non-stationary disturbance signals. In Malaysia, substation intrusion has become a major issue when many power failure cases occur due to substation intrusion by unauthorized person. This problem cause many losses especially to the service provider for fault correction and equipment replacement. Through this system, we tend to detect the signature of substation intrusion in term of the disturbance of the power signal. This happen especially when the intruders try to disturb or alter the existing power connection. In this paper, we introduce time-frequency analysis, which is an alternative method to deal with nonstationary power disturbance signals. In addition, the application of the time-frequency analysis will be discussed for the potential assessment of power quality.

II. Power Quality Disturbances

Time-frequency analysis is motivated by the analysis of nonstationary signals whose spectral characteristics change in time. One of the first approaches to time frequency analysis was the short-time Fourier transform (STFT): take the Fourier transform of the nonstationary signal for short time duration by a time localization window. The squared STFT is called the spectrogram. When the signal is *z(t),* and its localization window is *h(t),* then the definition of spectrogram, *SP,(t,w),* is as follows:

$$SP_z(t,\omega) = |S_z(t,\omega)|^2 = |\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} z(\tau)h(\tau - t)e^{-j\omega\tau}d\tau|^2 \quad (1)$$

However, the uncertainty principle **[4]** limits the use of the **STFT,** and indeed all types of time-frequency distributions. The Heisenberg uncertainty principle is defined by product of time resolution, ***At,*** and frequency resolution, ***Aw,*** as follows:

$$\Delta t \Delta \omega \geq \frac{1}{2} \quad (2)$$

The Heisenberg uncertainty principle states that we cannot make the time resolution and frequency resolution arbitrary small when we deal with time and frequency together.

Then in 1948, Wigner and Ville derived the distribution and it is called Wigner-Ville distribution, $WV_x(t,w)$

$$WV_x(t,\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} x^*(t-\frac{\tau}{2})x(t+\frac{\tau}{2})e^{-j\tau\omega}d\tau \quad (3)$$

However, the Wigner-Vile distribution suffers severe interference effects for multi-component signals, even though it was the first time-frequency distribution to provide localized information of signals such as instantaneous frequency, group delay, etc. [5]. The interference terms degrade the time-frequency resolution of the Wigner-Ville. Both Spectrogram and WD are members of Cohen's class of distribution [6]. In the 199O's, Choi and Williams suggested the Choi-Williams distribution, and Jeoung and Williams provided the reduced interference distribution (RID) to overcome the problems of interference effects.

Table 1.0: Kernel filters for quadratic Time-Frequency Distribution.

Name	Kernel $\phi(\theta,\tau)$
Wigner-Ville	1
Spectrogram	$\int h^*(u-\frac{\tau}{2})h(u+\frac{\tau}{2})e^{-j\theta u}du$
Choi-Williams	$e^{-\frac{\theta^2\tau^2}{\sigma}}$
RID	2D Low pass filter

It suggests some modification on the kernel filter which using a 2D low pass filter in the Doppler-Lag ambiguity domain. Choi-Williams Distribution (CWD) and Modified B Distribution (MBD) are the most effective method deploying RID technique. CWD uses a Gaussian Kernel Filter while MBD
uses a time-only kernel which provide a almost cross-term free with high-resolution time-frequency plane.

$$C_x(t,\omega;\phi) = \frac{1}{4\pi^2}\int\int\int x^*(u-\frac{\tau}{2})x(u+\frac{\tau}{2})\phi(\theta,\tau)e^{-j\theta t-j\tau\omega+j\theta u}d\theta d\tau du \quad (4)$$

Note that the time-frequency distributions within the Cohen's class are bilinear transformations. The nonstationary time series will be expressed as a distribution function of time, frequency, and kernel. In comparison with Fourier analysis, time-frequency analysis provides "instantaneous" information for frequency content. The kernel of the time-frequency distribution plays an important role in determining the characteristics of the distribution. Some of the properties of the various time-frequency distributions are discussed in the next section with aid of
a computer simulation.

III. Common Power Quality Disturbances

Transient- Transient or spikes are very short duration over-voltage or over-current power surges. **Sags-** Sags or 'brownouts', among the most commonly recorded power disturbances, occur when there is a momentary voltage drop of 10 percent or more. **Surges & Swells-** Normal utility power is transformed to 240 volts for most electronic equipment. Power surges are momentary condition where the voltage can jump to over 100 percent of the peak voltage or more than 480 volts. Swells are over voltage condition that occurs over longer duration, with excess voltage of 5 percent above normal for a period of time. **Harmonics-** Harmonics are lower frequency electrical currents that are generated by electronic equipment (non-linear loads).

VI. Substation Monitoring and Management System

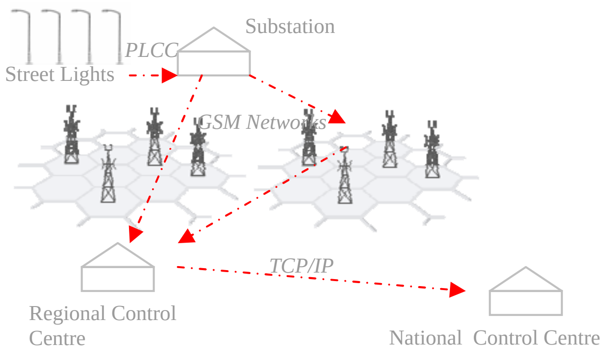

Figure 1.0: System Design

Figure 1.0 describes the whole design of substation monitoring and management system. It consists of feeder controller, feeder interface, dsp unit, regional control centre and national control centre. Feeder controller detects problem with the streetlight and reports to feeder interface. The feeder interface receives the inputs from feeder controller and dsp unit and sends the alert notification to regional control centre via sms. The regional control centre then submits the report to the server located at national control centre. Both feeder controller and feeder interface are designed using standard microcontroller while dsp unit is running on a analog devices dsp processor.

V. Simulation of the Fault Operation

Harmonic analysis with various kernels

The spectrogram, Wigner-Ville, Smoothed Wigner-Ville, Choi William, B- Distribution and Modified B-Distribution are shown in figure 1, 2, 3, 4, 5 and 6. For each time-frequency distribution, the corresponding time series data and spectrum are provided. The plot in the left box is the time series data that generates the time frequency distribution in the centre. While the plot in the bottom box is the squared Fourier transform of the time series data.

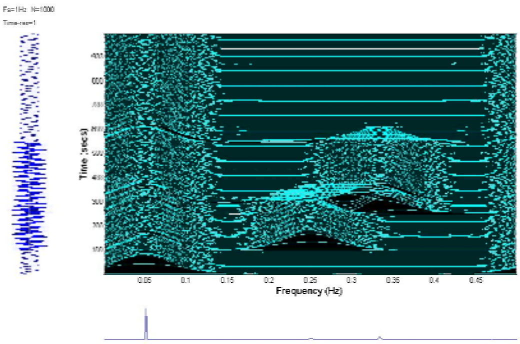

Fig 2.0. Spectrogram

The spectrogram of the testing signal is provided in Fig. 2.0. The spectrogram detects nonstationary characteristics well enough to identify the nonstationary harmonic content. The fundamental frequency (50 Hz) component consists of a strip-like distribution for the entire time series. The second harmonic frequency component (100 Hz) exists from around 100 ms. to 350 ms. The third harmonic frequency component (200 Hz) exists from around 200 ms. to 550 ms. The amplitude of the distribution is expressed as the level of darkness of the distribution. The spectrogram is equivalent to the observation of the time series that has been intentionally manipulated. However, its distribution has relatively poor resolution such that its distribution is smeared in the frequency domain. This result comes from the localization window. This phenomenon is based on the uncertainty principle: the tradeoff between time resolution and frequency resolution. Even though the spectrogram shows the localized distribution of the signal, important parameters such instantaneous frequency, group delay, and time-frequency marginal distribution etc. are not available. Due to these and other limitations, the spectrogram is not a popular distribution in time-frequency analysis.

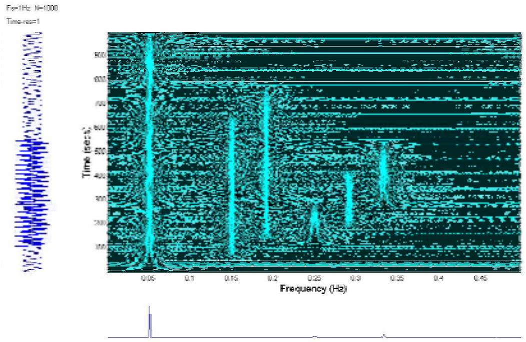

Fig 3.0. Wigner-Ville

The Wigner-Vile distribution of the testing signal is provided in Fig. 3.0. As one can observe from Fig. 3.0, it is very difficult to interpret the distribution. The fundamental, second, and third harmonics are roughly detected, however, some unexpected frequency components at 90 Hz and 150 Hz are displayed. However, the Fourier spectrum on the bottom shows no frequency content at the corresponding frequencies. This result is caused by the cross terms: the interference of different frequency components introduces cross negative terms at the average frequency of different components. This is a significant drawback of the Wigner-Ville distribution.

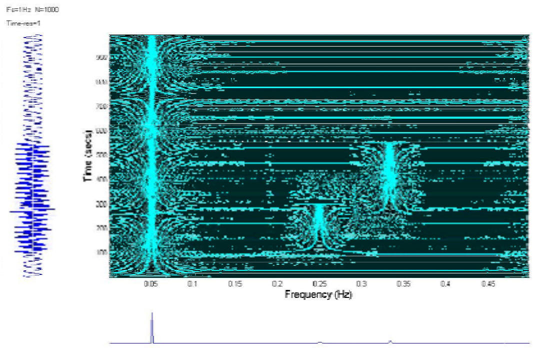

Fig 4.0. Smother-Wigner Ville

Smoothed Wigner-Ville distribution applies a smoothed filter after WVD transformation. It shows minor reduction on the cross term but it fails to provide a good resolution of the expected frequency content. CWD eliminates most of the cross term but from the figure 5.0, the cross term can still be observed.

The Modified B distribution in Fig. 6.0 shows the best result in terms of minimizing the cross interference effects. Furthermore, the Modified B distribution enables us to extract parameters of the time series such as instantaneous frequency, group delay, etc. These parameter calculations facilitate the physical interpretation of non-stationary signals. Just as the choice of a mother wavelet basis affects the wavelet transform results in timescale resolution, the choice of a kernel in time frequency analysis determines time frequency resolution. In the rest of the paper, we employ the Modified B distribution kernel for the analysis of disturbance signals in power systems.

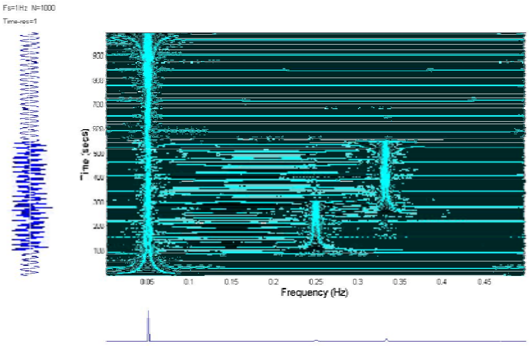

Fig 5.0: Choi William

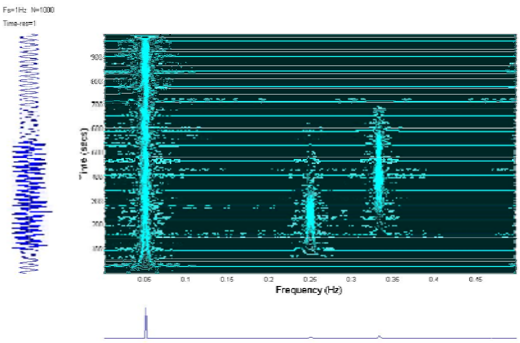

Fig 6.0: Modified-B Distribution

Sag and Swell

Changes in the amplitude of the sine wave can be classified as sag, swell, sustained over/ under voltage. While changes in frequency aren't very common except under extreme fault conditions, phase shifts during sags or swells do occur [7].

VI. Conclusions

The paper presents the application of a digital signal processing technique for the analyses of power quality disturbances. Among the different types of kernels in Cohen's class, the reduced interference distribution function is shown to be best suited to analyze transient power time and frequency that can be potentially used for power quality assessment. This paper also describes an automatic maintenance for Tenaga Nasional Berhad (TNB) to reduce the cost of power failure correction and maintenance as this system provides automatic alert upon disturbances. disturbance signal with high resolution in time and frequency domain. In addition, the MBD via the reduced interference distribution is shown to be a good estimator of a disturbance in terms of

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