# ERRORS PRODUCED BY METHODS OF DETECTION OF VOLTAGE SAG

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***Abstract.*** *The detection of disturbances in power quality is a major task for the efficiency of the electric system. It should be done by monitoring the electrical signal using signal processing methods to identify these events. The proposed monitoring start with the decomposition of the signal generated in a bench simulation of voltage sag and uses the Fourier Transform Window and Wavelet Transform. The detection is to identify the event before classification without* additional *help of complementary techniques. It appears that both have a good efficiency in the detection of voltage sag, and the Wavelet Transform* gives *better performance.*

***Keywords****: Fourier Transform Window, Wavelet Transform, Disturbances in Power Quality, Detection, Voltage Sag.*

## 1. INTRODUCTION

The non-sinusoidal loads and fluctuations in energy consumption cause disturbances in electrical power that can affect performance, equipment life and affect or disrupt industrial processes. These same non-sinusoidal loads are composed of highly sensitive electronic devices that require reliable power supply and require high level of power quality (PQ). The diagnosis of disorders begins with the acquisition of samples of the signal, aiming through his study of mathematical tools used to decompose these signals into elementary signals or extract relevant characteristics of the signal.

During the study of disorders to check the quality of electric power tools go through the steps of detection and classification. The detection step it is the perception of the existence of the event power quality finishing in a pre-assessment. Following the disorder is classified by comparing the benchmarks of the disturbances. Both tools are backed by complementary methods such as digital filters, Neural Networks, Fuzzy technique, etc. for classification after detection of the disorder in the following cases: The Fourier Transform Window (FTW) when need to sort event of short duration, temporary and transitory character and Wavelet Transform (WT) to a concentration of energy disorder analyzed as Parseval's theorem signal study is similar to the reference signal. The highlight of this work is to evaluate the performance of WT in the FTW and detection step without tools and auxiliary methods (Cesario, 2011).

## 2. BASIC CONCEPTS

The PQ of a system is the compatibility between source power and electrical equipment connected to this source. In the Brazilian electric system is directly linked to the supply of an electrical signal in the sinusoid wave pattern of constant amplitude and constant frequency of 60 Hz.

Due to the electrical characteristics of the operating system such as the presence of demand variation, asymmetry in the connection charge, system fault, starting of large loads, presence of non-linear loads, etc, changes occur in the pattern of supply and characteristics intrinsic to PQ. These changes may be permanent or short time. Voltage Variations Short Time are phenomena that have significant deviations in the Root Mean Square (RMS) voltage in a short period of time, such as an outbreak, peak and voltage sag.

Voltage Sag as defined by IEEE Standard 1159-1995, is a decrease in RMS voltage between 0,1 p.u. e 0,9 p.u., at the power frequency, with durations from 0.5 cycles to 1 minute.

The correct interpretation of the results obtained by a device that purports to detect the presence of voltage sag is directly linked to the understanding of the methodology used by the equipment. Different methods of calculation and parameterization result in different answers and therefore different interpretations. Knowing the techniques used to process the signals and the different responses in each type is essential (Gonçalves *et al.*, 2007a).

### 2.1. Window Fourier Transform in the Analysis of Electric Power Quality

Obtaining information in the time domain and frequency are used as parameters for characterization data for the study of power quality disturbances. The expansion is a Fourier series representation of periodic functions by sum of harmonic sine functions. The Fourier transform (FT) is used to represent a non periodic signal by a function and general rough and consists of a period of a periodic signal in the frequency domain as Eq. (1) (Gonçalves *et al.*, 2007b).

$$S(\omega)=\int_{-\infty}^{+\infty} s(t).e^{-j.\omega.t}dt, \tag{1}$$

where $\omega$ is multiple frequency $n$ of the fundamental frequency $\omega_0$.

The FT implicitly includes the assumption of the signal being analyzed be stationary (Bollen, Gu, 2006 and Lathi, 2007), because the occurrence of the disorder in the passage of time domain to frequency domain, part of the information is lost in such a way that can not identify a particular event, ie, when one observes the FT of a signal is not possible to say that time began or ended a particular event. The identification is only possible if disturbance analysis window is positioned exactly on the occurrence of the event. However, in a dynamic system can not predict when the disturbance occurs.

Dennis Gabor adapted the Fourier transform to analyze a part of the signal in time, the method of "open windows" in the signal (Oliveira, 2007a, 2007b). Gabor's adaptation is a technique called Short Time Fourier Transform (STFT) or window Fourier transform (WFT).

The technique is to "open windows" in the signal into a sequence of intervals, where each sequence is small enough so that the waveform is an approximation of a wave almost stationary.

The windowing is accomplished through the use of the multiplication of an input signal *s(t)* for a given window function *g(t-τ)* whose position varies in time (is translated by the parameter $\tau$), ie, divides the signal into small segments in time. Thus, for each window is applied to FT and the signal is placed in two dimensions, time and frequency. Thus, one can define the WFT of a continuous signal *s(t)* as follows in Eq.(2):

$$S(\tau,\omega)=\int_{-\infty}^{+\infty} s(t).g(t-\tau).e^{-j.\omega.t}dt, \tag{2}$$

where $g(t-\tau)$ is previous windowing function $s(t)$ by a function $g(t)$ transferred around the time $\tau$.

Thus, each window has a frequency spectrum that displays the contents of this small frequency interval mapped in a two-dimensional function (time and frequency), as shown in figure 1.

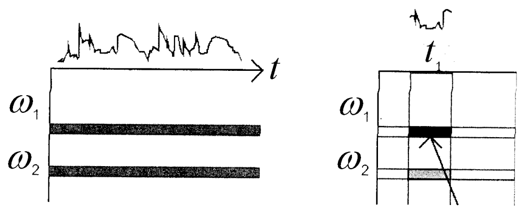


Figure 1. Fourier Transform Window. Source: Bollen; Gu, 2006 e Lathi, 2007 with adaptations.

In figure 1, the sign in the above analysis of the chart is divided into series $t_1$ (time $\tau$), ie, each segment of the series lasts $t_1$. Then, the FT is applied in these segments.

Intuitively, when the analysis is viewed as a filter bank, the resolution in time increases with the center frequency of filters, ie, performs the analysis filter bank consisting of bandpass with constant relative bandwidth (or quality factor $Q$ constant. Relation between stored energy and average power dissipated). With constant $Q$, the $t$ and $\omega$ resolutions change with the center frequency as Lathi (2007):

$$\Delta t.\Delta\omega \geq \frac{1}{2}. \tag{3}$$

The WFT can also be represented by the distribution of energy spectral density in the plan $\tau$ x $f$ or plan $\tau$ x $f$ x $E$, as shown in figure 2 and figure 3, where $f = \frac{\omega}{2\pi}$ and $E$ is the power spectral density.

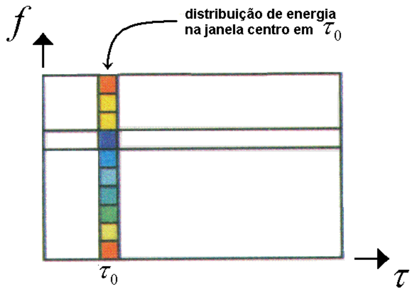


Figure 2. Principle of Spectrogram - spectral density in the plane $\tau$ x $f$. Source: Bollen and Gu (2006) with adaptations.

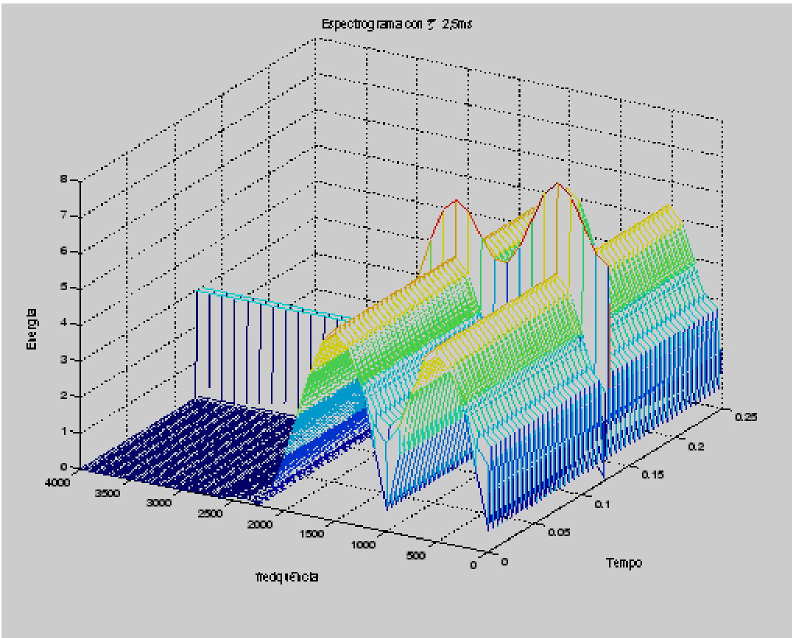


Figure 3. Example Spectrogram - spectral density in the plane $\tau$ x $f$ x $E$. Soure: Cesário (2011).

## 2.2. Wavelet Transform in the Analysis of Electric Power Quality

Wavelet Transform is a variable windowing technique, allowing an evaluation at the time of long duration (low frequency) or short (high frequency). She works with data and continuous data respectively with the discretized versions of continuous WT (CWT) and TW discrete (TWD). Associated with the Analysis Multiresolution (AMR), shifting decomposes the signal into different scales with different levels of resolution, from a main function (Brito *et al*, 1998).

The decomposition-based AMR WT and results in local representations in the time domain and frequency, unlike the FT that provides a global representation of the signal, also solving the problem of resolution of the FT. WT is a local linear transform generated by a filter bank of constant quality factor / relative frequency (Brito *et al*, 1998 and Misiti *et al*, and Others, 2008).

The scaling with displacement of wavelet function $\psi\ (t)$ is shown in Eq.(4):

$$\psi_{a,\tau}(t) = \frac{1}{\sqrt{|a|}}.\psi\left(\frac{t-\tau}{a}\right), \tag{4}$$

where *a* is the scaling parameter and is different from zero. And *τ* is the translation parameter, and that belong to the set of real numbers.

The DWT-dimensional maps a discrete signal (time) in a two-dimensional representation (time scale) at different scales with different levels of resolution. It is represented in Eq.(5).

$$F(a,\tau)=\frac{1}{\sqrt{a_0^m}}\sum_{k=-\infty}^{+\infty} f(t)\psi\left(\frac{t-n\tau_0 a_0^m}{a_0^m}\right) \tag{5}$$

where $a_0$ is a fixed dilation parameter greater than 0, $\tau_0$ is the translation factor fixed and nonzero. *m* e *q* coefficients correspond to lattice points in a two-dimensional (range-domain translation), the first being associated with discrete steps in the scale and the second discrete steps of translation.

The technique AMR allows the decomposition of a signal at different resolution levels, providing important information both in time domain and frequency. By this technique, the signal s analyzed is first decomposed into two other signals: Coefficient Approach 1 ( $cA_1$) and Coefficient Detail 1 ( $cD_1$) on each of them to a weaker version and another version detailed by low pass filters and high pass. As an example of the described, following figure 4 represents the filtered signal *s* to the 3rd level.

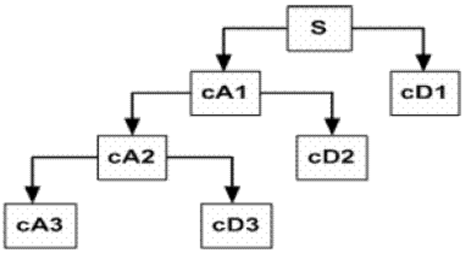


Figure 4. Successive filtrations and decompositions of a signal to the 3rd level. Source: Rodrigues (2008).

The decomposition of the input signal s is made from this filtering and decomposition in $cA_1$ and $cD_1$ to the level r, generating $cA_R$ and $cD_R$. The number of levels of decomposition is made so that the fundamental frequency of the signal is at the center of sub-band of lower frequencies in order to limit the effects of spectral content of the fundamental in the other sub-bands (Misiti *et al*, 2008).

## 3. METHODOLOGY USED

The method is based on the monitoring system with the FTW and the WT for decomposition of the sampled electrical signal system. Tools independently detect disturbances in the signals compared the signal decomposed with a reference signal.

The sampling frequency is 30,720 Hz. She was chosen to be generated 512 points for each cycle of the network signal whose fundamental frequency is 60 Hz Thus, the discretization can be done right signal to the frequency of 15,360 Hz , which corresponds to 256 º as harmonic Nyquist theorem.

This procedure makes it feasible to compare the samples tested in each window under analysis with the fundamental signal (reference signal) or by TFJ or by TW, it is possible to detect the initial stage of the disorder and thus its location in time (ANEEL, 2001 e Belisário, 2003).

The disturbances are analyzed and recorded in the simulated test bench of the QEE 2910 Datapool (Cesario, 2011). The bench allows the generation of disturbances such as ditching instant, momentary lifting the temporary noise, harmonics, voltage fluctuation and variation in frequency that are detected and modeled by the system of acquisition and signal analysis in the areas of time and frequency (oscillograph). It also provides measurement and visualization of the waveform of voltage and current signals in real time modeling the analyzed signal. Are removed from the bench recorder information on the fundamental frequency and the detection of the event. These are, respectively, for analysis of signal disturbance and presence of the check mark from the moment of error detection.

The two methods (WTF and WT) are to identify the occurrence of the disorder using the information itself transformed and the instant of discontinuity of the energy contained in the signal analyzed, as energy ratio of each transformed as Eq.(6).

$$E(x) = |F(x)|^2. \tag{6}$$

According to Parseval's theorem, $E(x)$ is the energy contained in the function and $F(x)$ is the Fourier Transform of the function.

For WTF:

$$E(x) = |J(x,\tau)|^2, \tag{7}$$

where $J$ Window Fourier Transform of the function and $\tau$ is the displacement (range of translation) of the window.

And For WT:

$$E(f) = |W(a,\tau)|^2, \tag{8}$$

where $W$ is the Wavelet Transform of the function and $\alpha$ is the scaling.

## 4. APPLICATION OF METHODS

Voltage sag is a disorder that has as a cause of the faults in the power system, energization of high power loads, interaction between the load and power line (especially during start-up equipment) or between the load and source impedance energy. The figure 5 illustrates the sag of 0.2 pu and duration of 10 cycles.

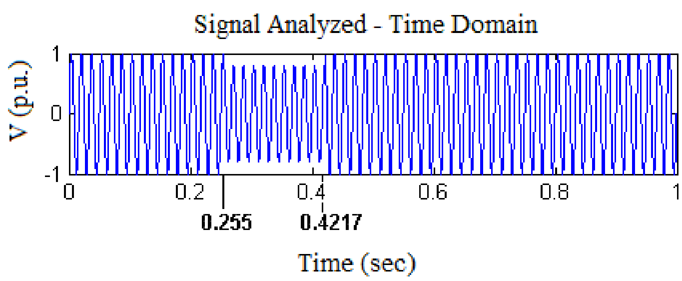


Figure 5: Sign in analysis - Detection of voltage sag by oscilograph.

The figure 5 also brings the information of the result of detection of the sag oscillograph. The event started at time 0.255 seconds and finished in time 0.4217 seconds.

### 4.1. Detection using the Window Fourier Transform

The figure 6 shows the spectrogram of the signal in two dimensions (time x frequency) and figure 7 shows the spectrogram of the signal in three dimensions (Energy x Time x Frequency) resulting from the TFJ. The graph shows that voltage sag occurred since the discontinuity of the energy of the first frequency range (60 Hz).

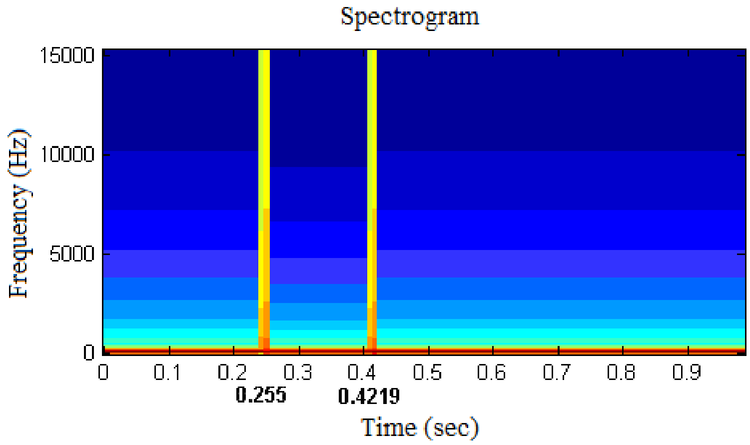


Figure 6. Detection of voltage sag by WFT - Spectrogram in two dimensions.

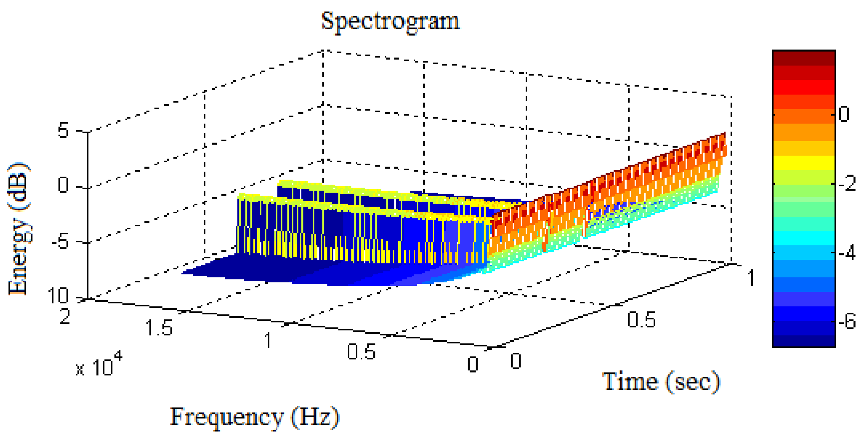


Figure 7. Detection of voltage sag by WFT - Spectrogram in three dimensions.

The figure 6 and figure 7 also illustrate the result of the detection information from the oscilograph of the voltage sag. The event started at time 0.255 seconds and finished in time 0.4219 seconds.

### 4.2. Detection using the Wavelet Transform

It has been the result in figure 8 WT using the AMR. In this analysis on the first level of decomposition is possible that the algorithm presents the variations in the sampled window. Such variations are responsible for initiating (0.255 seconds) and end (0.4217 seconds) the sag. Through these data it can be stated that the proposed algorithm using the TW was able to detect anomalies in signal voltage and the initial time the system returned to steady state.

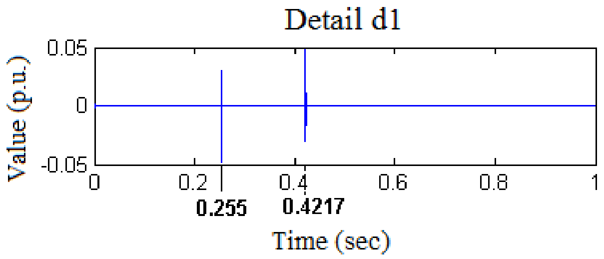


Figure 8. Detection of Voltage Sag by WT - The first decomposition level.

### 4.3. Results

With the results obtained it appears that both methods have satisfactory efficiency for the detection of voltage sag disturbances. These results are shown in Tab. 1. To calculate the percentage of error was considered the total of events recorded by these methods.

Table 1. Efficiency in detection of disorders

| Event | Percentage error | |
|---|---|---|
| | TFJ | TW |
| Sag | 0.12% | 0% |

## 5. CONCLUSION

This study aimed to analyze the comparative performance of the WTF and WT in identifying the disorder sag during operation of an electrical system. The differential of this study was the comparison of two methods without the aid of complementary tools to identify the presence of the event.

It was shown that screening using the WTF and WT were assertive in identifying sag according to the method used to fit the window (WTF) and the level of decomposition (WT AMR). The WT provides information about the frequency content of signals similar WTF. However, unlike the WTF, WT is able to concentrate in small time intervals of high frequency content and time intervals for low frequency content, highlighting the detection is for this reason.

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