HARMONIC ANALYSIS OF ACTUAL POWER QUALITY PROBLEMS: WAVELET TRANSFORM VS. FOURIER TRANSFORM

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ABSTRACT

Wavelet Analysis (WA) has a special feature of variable time-frequency localization which is very different from Fourier Transform (FT) that can not deal with non-stationary signals. Wavelet algorithms process data at different scales so that it may provide multiple resolutions in both frequency and time. WA can detect and classify the disturbances due to its ability for assessing the non-stationary signals from both level and duration points of view.

*This paper holds a comparison between the two techniques for the analysis of actual power quality disturbances that were captured from the Distribution System by means of Fault Recorders. These disturbances include voltage sags, swells, interruptions, impulses, notches, harmonics ...etc. They were analyzed using both WT and FT techniques. Wavelet decomposition is used to identify the fundamental frequency component as well as all harmonic components in real Power Quality (PQ) recorded cases. Comparison between the harmonic analysis results obtained by both FT and WA techniques is provided in this work. The obtained results emphasize tha*t wavelet decomposition is ideal for obtaining much better characterization and more reliable discrimination of PQ disturbances.

1. INTRODUCTION

With the increase of power system complexity beside the pressures on both utility and customers for more reliable power, arises the need for a Real Time Power Quality Monitoring System. The information collected by such a system helps the Utility to verify the contractual requirements, report the network performance indices and identify solutions for the Power Quality problems. Such monitoring system should be capable to detect, localize, and classify PQ disturbances with acceptable accuracy through automatic correlation between the causes and effects of PQ events. The existing Power Quality standards specify Discrete Fourier Transform as a base for the reference instrument of PQ monitoring. It does not preclude the application of other analysis principles, such as digital filter banks or Wavelet Transform analysis. However, such instrumentation could not be used for assessing the compliance of non-stationary signals, which constitute a considerable kind of the PQ disturbances.

This paper provides a comparison between the two techniques, WT and FT, for the analysis of actual power quality disturbances that were captured from the Egyptian Interconnected Power System by means of Digital PQ-Monitoring devices and Disturbance Recorders. The scope of disturbances covered in this paper includes most of PQ problems arising in distribution networks such as voltage sags, swells, interruptions, impulsive transients, notches and harmonics. Results obtained show that the DWT technique is more suitable and can cover the majority of PQ disturbances regarding analysis, recognition and classification.

The obtained results pointed out the need for changing the power quality monitoring devices' design to be based also on WT analysis instead of FT analysis only. This will help in designing fast and accurate on-line power quality systems for monitoring, analysis, recognition and classification, based on cause/effect principle associated with different events. The results obtained also stimulate having a new look to the base of PQ standards.

2. WT VERSUS FT FOR PQ DISTURBANCE ANALYSIS

Wavelet Transform is a linear transformation much like Fourier Transform with one important difference that it allows time localization of different frequency components for a given signal. Windowed Fourier Transform also partially achieves the same goal but with a limitation of using a fixed width windowing function. As a result, both frequency and time resolution of the resulting transform will be fixed. In the case of the wavelet transform, the analyzing functions, which are called wavelets, will adjust their time-widths to their frequency in such a way that higher frequency wavelets will be very narrow and lower frequency ones will be broader. This property of multiresolution is particularly useful for analyzing power system transients, which contain localized high frequency components superimposed on power frequency signals. For a continuous input signal, the time scale parameters can be continuous leading to a continuous wavelet transform. On the other hand, the discrete wavelet transform can also be defined for discrete time signals [1].
Analysis for measured PQ disturbances that captured by

DR's, is done using both FT and WT. The FT analysis was done by means of digital recorder's supported software, while the WT analysis is made using the MATLAB software. To check the effectiveness and capability of the two techniques, FT analysis is made during two different windows representing out-of and within the disturbance, and WT is made for the whole record length. Power Quality problems may be divided into two categories: stationary and non-stationary. Most of PQ disturbances have non stationary nature.

2.1 Stationary Transients

Sustained harmonics in voltage and currents, shown in Figs. 1 are considered as stationary transient. Figure 2 shows the FT analysis for the case of voltage harmonics shown in Fig. 1 (a) as a stationary signal. FT success in analyzing the harmonic contents along any window within the stationary wave is well proven. WT also shows the same success in identifying the harmonic contents of the stationary signal as shown in figure 3.

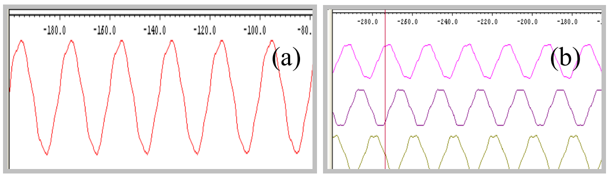

Figure 1: Records for Voltage (a) and Current (b) Harmonics

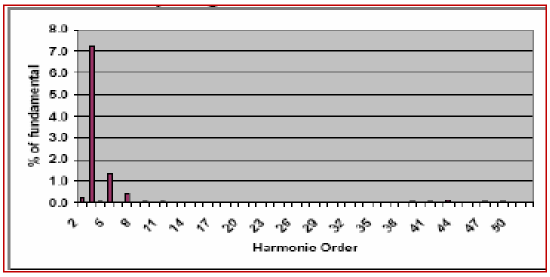

Fig. 2: FT analysis of voltage

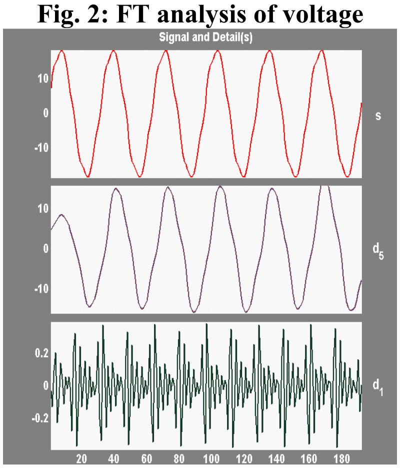

Fig. 3: WT analysis (details d1, d5)

2.2 Non-Stationary Transients

For the non-stationary signals, which constitute the majority of PQ disturbances, we will mention two cases describing the main difference between FT and WT.

Case 1.

The first case is the voltage dip. The severity of the dip may range from 0.1 to 0.9 per unit. Figure 4 shows two recorded cases for voltage dip, with different severities and durations.

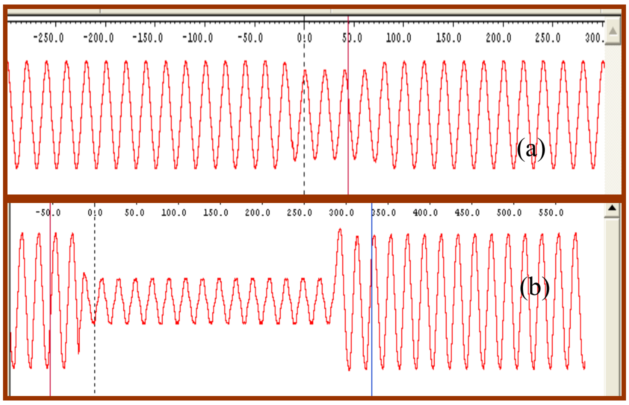

Fig. 4: Voltage Dip Records

Figure 5 shows the FT analysis during normal operation and within the voltage sag period of Fig 4(a). It is clear that there is no considerable difference in the harmonic content between the two windows, i.e the FT fails to recognize the occurrence of voltage sag. Also, the information of the time in FT analysis is totally disappeared. Figure 6 shows the WT analysis for the same case of voltage sag, where details d1 and d5, which represent the dominant harmonic contents, can recognize the occurrence of voltage sag, its percentage reduction and also identify its start, end and duration.

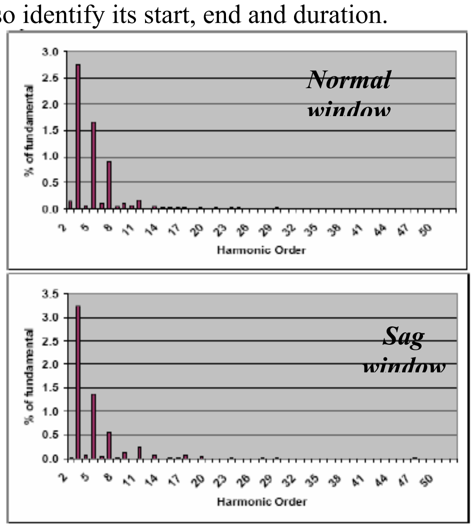

Fig. 5: FT analysis of voltage dip in Fig. 4a: during normal and sag periods

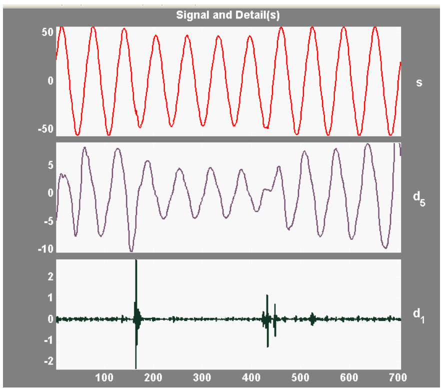

Fig. 6: WT analysis (details d1, d5) during the voltage sag record

Case 2

The second case is the impulsive transients due to arc furnace operation with failure in the SVC's filter. Impulsive transients are unidirectional spikes that occur for a very short duration (less than a cycle) in voltage, current or both. The following records (Fig. 7) show two cases of such disturbance.

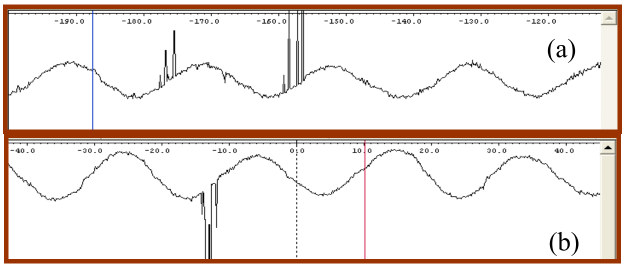

Fig.7: Impulsive Transient Records

Fig. 8 shows the FT analysis for the impulsive current transients shown in Fig. 7a for two different windows; at the impulse and far from it. The FT analysis shows almost the same harmonic contents with different amplitudes. In WT (Fig. 9), d1 and d5, which reflect the dominant harmonic contents in the transients, show also the instants of current spikes and their severity.

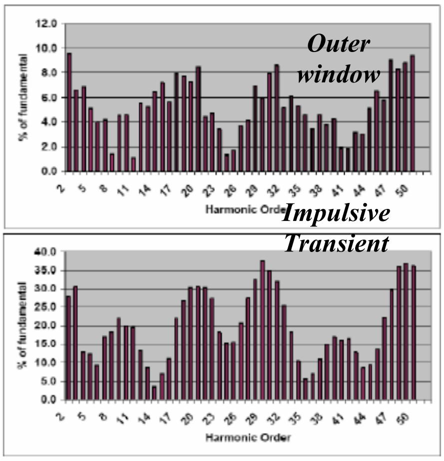

Fig. 8: FT analysis of impulsive transients in Fig. 7a

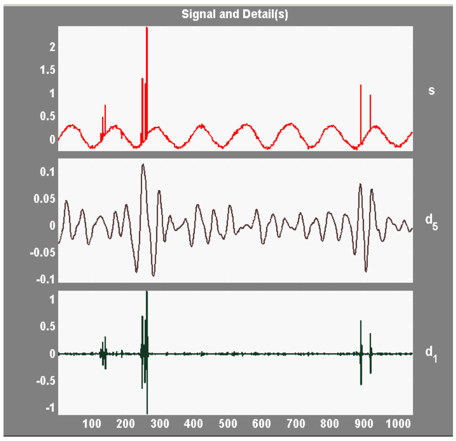

Fig. 9: WT analysis (details d1, d5) in the impulsive transient case

Beside that, while FT can't give consistent harmonic contents during the initial arc and fine arc periods, WT output, on contrary, is consistent for the same two cases of initial and fine arc periods [2]. From the above cases, and others in [2, 3], the superiority of WT over FT can be concluded.

3. SOLE SIGNATURE FOR PQ PROBLEMS USING WT

In this section, more non-stationary PQ transients are introduced and analyzed using WT to get their sole signature. These cases include: current inrush in load switching, intermittent fault and also a case of circuit breaker restriking.

3.1 Load Switching Inrush

Switching of an unloaded feeder to a load causes a sudden flow of current as shown in Figure 10, which is a real record captured by DR for such load switching. The current inrush is caused by the sudden application of voltage to cold loads and stand-still motors. The motors will draw the starting current of decaying nature. The load inrush is characterized by the appearance of both decaying DC and AC components.

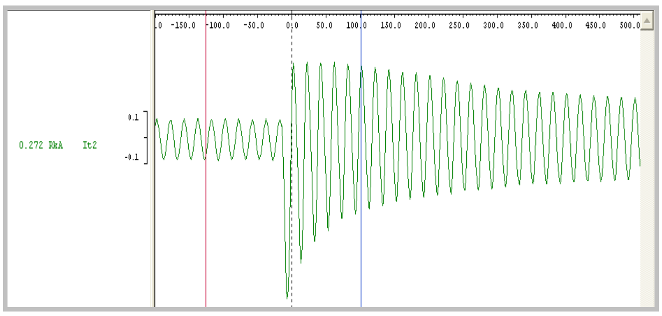

Figure 10: Inrush currents due to load switching-on

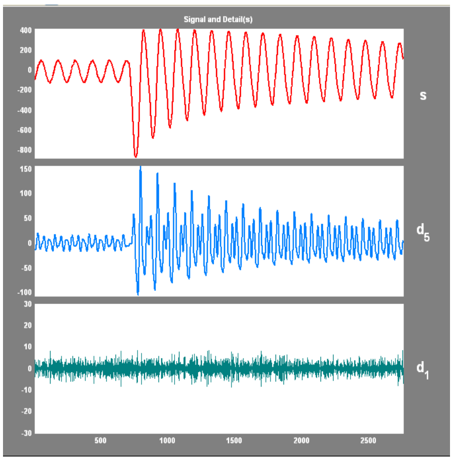

Fig. 11: Corresponding WT analysis

Detail d5 in the WT analysis (Figure 11) identifies accurately both the instant of the load switching and the inrush, with its decaying nature**.** This indicates the success of WT analysis in detecting and identifying the load switching inrush case of PQ disturbances.

4. CAPABILITY OF WT ANALYSIS

From the above mentioned analysis, and the analysis of the cases studies in references [2, 3, 4], it can be noticed that detail d1 detects the moment of sudden changes in the waveform, i.e, the instant of transient start (e.g Figures 6,9). On the other hand, d1 has repetitive oscillations with the same small amplitude variable pattern in case of power system harmonics (e.g Figure 3). Detai1 d1 has noisy nature in other situations (e.g Figure 11). In all PQ cases, the combination between details d1 and d5 can give the special signature of each PQ problem, while the value and shape of detail d5 are different for different cases. Moreover, WT can discriminate between the transformer inrush [2] and load inrush (Figure 11).

Results obtained above show that the WT technique is more suitable and can cover the majority of PQ disturbances regarding analysis, recognition and classification. In addition, each PQ problem has its own sole signature which leads to a step to have a monitoring system based on the cause/effect relation.

5. CONCLUSIONS AND RECOMMENDATIONS

This paper presents power quality disturbances captured from the Egyptian Network by means of digital PQ analyzers. The captured records including sags, swells, interruptions, transients, notches and harmonics are analyzed by both FT and WT. Due to the limited no. of pages, some of them only presented. The effectiveness of WT, especially for the analysis of non-stationary PQ disturbances, appears in giving a consistent identification for the disturbances and their causes. In this work, it has been proven that WT can detect and classify the disturbances due to its ability for assessing the compliance of non-stationary signals from both level and duration points of view.

The obtained results point out the need to change the power quality monitoring devices' design to be also based on Wavelet analysis instead of Fourier analysis only. This will help in designing fast and accurate on-line power quality systems for monitoring, analysis, recognition and classification, based on cause/effect phenomena associated with different events. The results obtained also stimulate having a new look to the base of PQ standards.

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