FOOTPRINT OF NON-TYPICAL DISTURBANCES USING WAVELET TRANSFORM

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ABSTRACT

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. 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.

In CIRED 2011 session, we raised up this issue for discussion and analysis [1]. A continuation for this work is done in this paper and merged with the stream of indices and quality objectives recommended by Cigre Working Group C4.07[2]. The scope of disturbances studied by the authors includes non-typical disturbances (intermittent faults, load switching, unidirectional impulsive transients…etc). The cause/effect relation of these events were proved using Wavelet Transform technique; WT. These PQ disturbances were captured from the Distribution System in Egypt by means of Disturbance Recorders. The used technique is further expanded to be used in analyzing co-related disturbances in order to prove the capability of WT in discovering the footprint of non-stationary PQ disturbances.

1. INTRODUCTION

The existing PQ standards specify Discrete Fourier Transform (DFT) 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. In CIRED'2011 session, we raised up this issue for discussion and analysis [1].

The sources of PQ disturbances are existed and scattered within the power system at different voltage levels. Their effects propagate through the power system. In order to have a complete picture of the PQ disturbances and the propagation of their effect into the power system, all PQ monitoring devices have to be synchronized via GPS. Since the DR's are also existed and scattered within the power system, and moreover have GPS synchronization, the authors in [3] have suggested DR's as a suitable candidate for the proposed large scale PQ system.

This paper introduces additional PQ disturbances with a comparison between the analysis using FT and WT to emphasize the superiority of WT over FT. Also, a prototype Large Scale PQ Monitoring System using synchronized DR's is explained. The captured PQ incidences are analyzed using WT that proves to have sole footprint for each PQ disturbance, and can automatically held the cause/effect relation between incidents occurring at different locations within the distribution system. This can save time and effort and represents a step for identifying and localizing the source and cause of a PQ disturbance.

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 multi-resolution 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.

Analysis for measured PQ disturbances that captured by DR's, is done using both FT and WT. The DFT analysis was done by means of digital recorder's supported software, while the DWT analysis is made using the MATLAB software. To check the effectiveness and capability of the two techniques, DFT analysis is made during two different windows representing out-of and within the disturbance, and WT is made for the whole record length. Most of PQ disturbances have non stationary nature rather than 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.

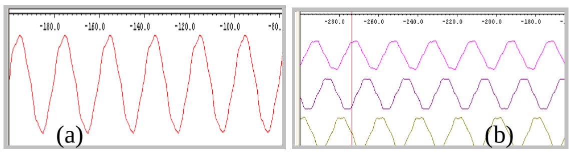

Figure 1: Records for Voltage (a) and Current (b) Harmonics

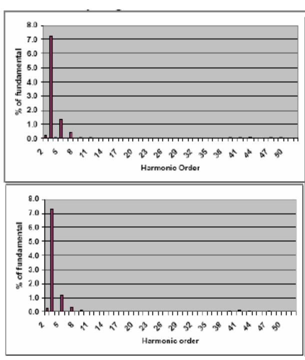

Fig. 2: FT analysis of voltage

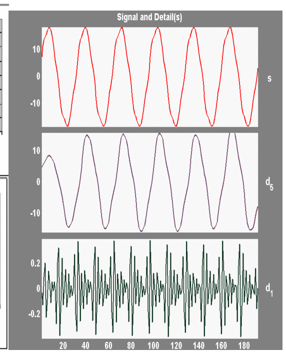

Fig. 3: WT analysis of voltage (details d1, d5)

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 (a,b) shows two recorded cases for voltage dip, with different severities and durations.

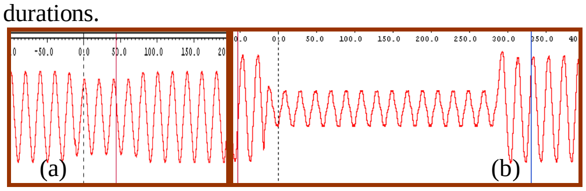

Fig. 4: Voltage Dip Records

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.

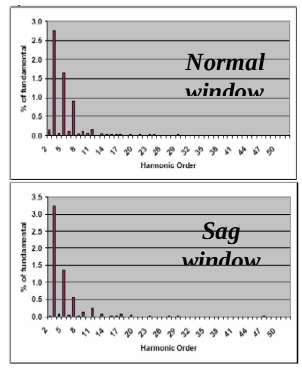

Fig. 5: FT analysis of voltage dip

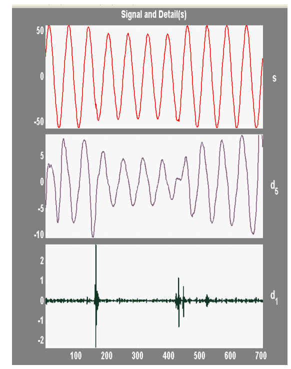

Fig.6: WT analysis (d1, d5) in 4a-Normal/Sag periods

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.

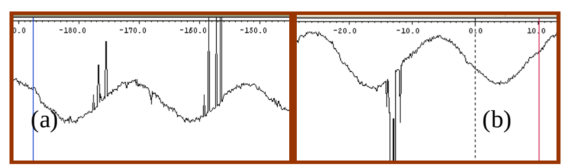

Fig.7: Impulsive Transient Records

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.

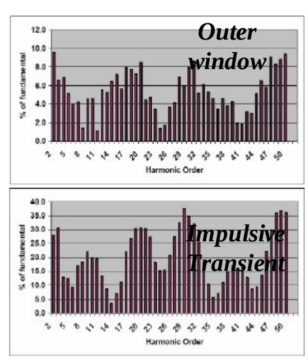

Fig. 8: FT analysis of impulsive transients in 7a

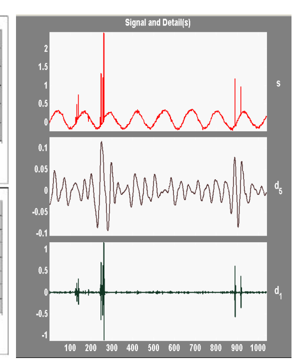

Fig. 9: WT (d1, d5) of the impulsive case

In WT analysis (Fig. 9), d1 and d5, which reflect the dominant harmonic contents in the transients, show also the instants of current spikes and their severity. Besides 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. From the above cases, and others in [1], the superiority of WT over FT can be concluded.

3. SOLE SIGATURE 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 and intermittent fault.

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.

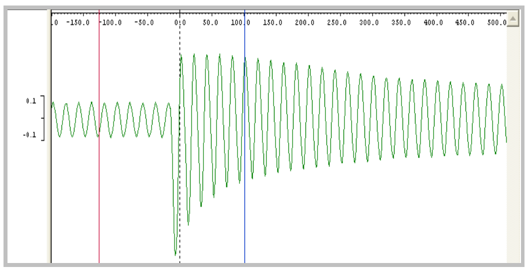

Fig. 10: Inrush currents due to load switching

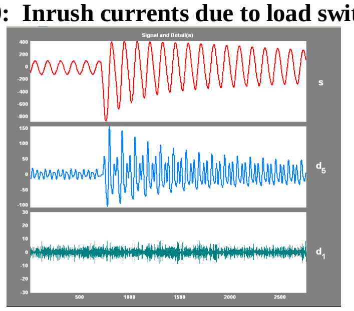

Fig. 11: Corresponding WT analysis

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.

3.2 Intermittent Faults

Intermittent faults occur as a result of arcing at certain points in the electrical system where insulation is weakened due to pollution. The heat generated by the arc causes the dryness of the insulation where it can withstand the operating voltage again, but its deterioration due to fog or moisture causes arcing again and so on. These types of faults is accompanied by momentary change in voltage as shown in Figure 12, and has bad effect on rotating machines where repeated sudden torque can affect the rotor shaft.

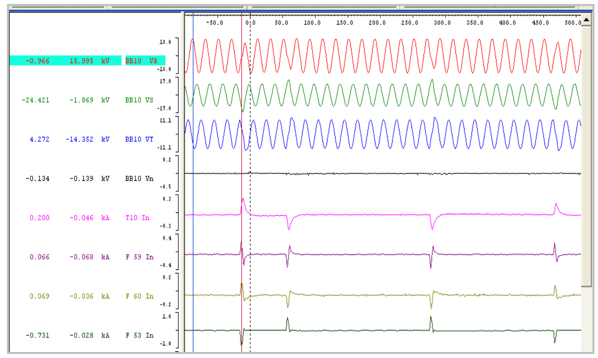

Fig.12: Intermittent fault on phase R

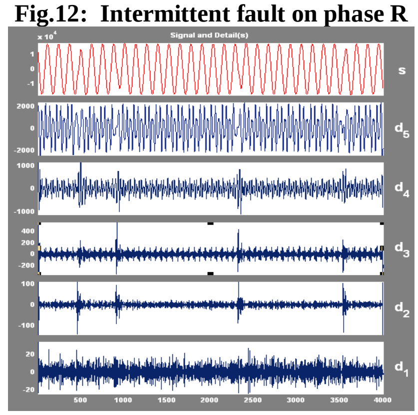

Fig.13: Corresponding WT Analysis

Figure 13 shows the WT analysis of the faulty phase voltage (phase R). The WT gives exceptional success for the detection of intermittent faults with unique signature as details d2, d3, d4 and d5 indicate. The instant of the intermittent fault occurrence can be detected by the shown spikes (4 times in the selected period of the record). Thus, the sole signature of a faulty insulator can be captured and identified.

5. LARGE SCALE PROTOTYPE FOR PQ MONITORING SYSTEMS

In order to determine the causes and sources of PQ disturbances, one must have the capability to detect and localize those disturbances and further, identify their types. Manual procedures have been developed for this purpose; however, due to the large amount of effort required, such procedures are costly and inefficient. PQ monitoring system should be capable to detect, localize, and classify such disturbances accurately and fast.

The creation of a prototype system for PQ monitoring was initiated by complains from one distribution company about a repeated interruption of supply in some areas due to occasional tripping of some feeders by their earth fault protection. There was no clear reason for such random tripping since, as shown in Figure 16, the appearance of the residual current and the higher value of the phase current was not due to an earth fault (no voltage drop is shown on any of the three phases).

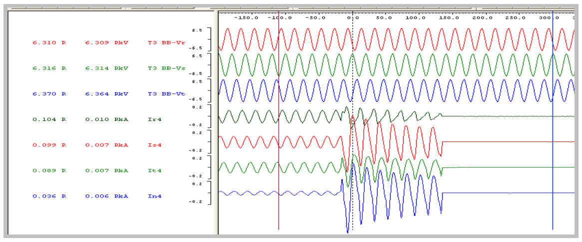

Fig.16: V&I channels of the interrupted feeder

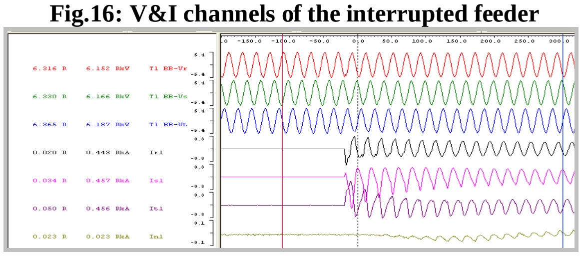

Fig. 17: V&I channels of the switched-on feeder

For monitoring this feature in those areas, four (4) DR's have been installed at four distribution 66/11 kV transformer substations to which the feeders under complain were connected. The recorders were synchronized via GPS time source, and their set parameters and triggering functions were adjusted to monitor and capture unusual values of voltages and currents in those feeders. When one feeder at certain substation was tripped, the records of all DR's were reviewed. It was clear that the tripping of the feeder had happened at the same moment when another feeder at another substation was switched-on, with load current inrush as shown in Figure 17. The analysis of the reason behind such behaviour is the subject of other work.

The analysis of the currents of both feeders has been conducted using WT, where the start point of the selected intervals is at t = -110 milliseconds and their end is at +300 milliseconds. A common feature of load current inrush is clear in Figures 16 and 17. Comparison of signatures seen in detail d5 shown in Figure 18 with detail signature d5 in the previous Figure 11, prove this fact. Also the start point of the inrush is identified at the same sample number (same instant) determined by detail d1. This incident and its analysis using WT proves the capability of the proposed technique and shows that Large Scale On-Line PQ Monitoring System based on WT added functions in DR's, can automatically held the cause/effect relation between incidents occurring at different locations within the power system. In fact DR's nowadays have sophisticated triggering functions which can be selected, edited and adjusted to capture the PQ disturbances in the power systems.

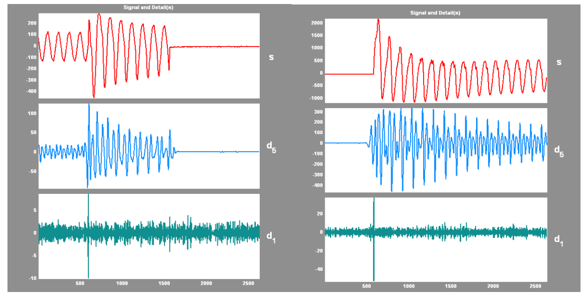

Figure 18: WT analysis of one feeder tripping during load inrush in another feeder

6. CONCLUSIONS AND RECOMMENDATIONS

- The effectiveness of WT, especially for the analysis of non-stationary PQ disturbances, appears in giving a consistent identification (footprint/sole signature) 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 to assess the compliance of non-stationary signals from both level and duration points of view.
- An illustration of how the DR's, if equipped with GPS time synchronization and S/W analysis based on WT, can be used for holding a cause/effect relation between incidents occurring simultaneously at different locations in the power system. The proper selection of the triggering functions and their values assures simultaneous triggering of the DR's to capture the PQ problems occurring at the same moment at different locations within the power systems.
- There is a need for changing the power quality monitoring devices' design to be based on Wavelet analysis besides Fourier analysis. 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.
- For this purpose, the authors recommend conducting more research in this direction to figure out the advantages of WT technique and the improvement it will introduce to the field of PQ disturbance recognition, analysis, classification and measurements.

REFERENCES

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[2] Working Group C4.07. "Power Quality Indices and Objectives" (Electra, no. 216, Oct. 2004)

[3] Mohamed A. El-Hadidy, Dalal H. Mostafa, "Large Scale Power Quality Monitoring Systems Based on Wavelet Technique using Disturbance Recorders," FDA'07