A VI-based Measurement Instrument for Detection and Analysis of Power Quality Disturbances in Power Systems Using Wavelets

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Abstract: - This paper presents a VI-based measurement instrument for detection and analysis of electrical power quality using wavelets. The virtual instrument developed can operate in two different working modes: detection and analysis of transient power quality disturbances and analysis of stationary or quasi-stationary disturbances. Depending on the working mode selected, different wavelet analysis, discrete or packet wavelet transform, with different mother wavelet, decomposition tree and sampling rate are performed in the input signal. The results obtained show a good performance of the method in the detection and analysis of different power quality disturbances in voltage supply.

Key-words: Harmonics, Power quality, Wavelets

1 Introduction

Electrical power quality is a general term used to designate a number of electromagnetic phenomena that cause voltage supply to deviate from its constant magnitude and frequency ideal sinusoidal waveshape. Two main groups of power quality disturbances can be defined: stationary (or quasi-stationary) and time-varying disturbances. Harmonic and interharmonic distortion, voltage fluctuation and voltage imbalance make up the first group, whereas voltage transients, voltage dips, swells, interruptions and other high-frequency disturbances constitute the latter group.

The root mean square magnitude is the most common signal processing tool used for estimation of voltage and current magnitude in power systems. Although this magnitude is defined for sinusoidal and periodic signals, it is also used in international power quality standards for estimation of non-periodic and time-varying signals such as voltage dips and swells or interruptions in voltage supply [1].

The discrete Fourier transform (DFT) should be used when we want to know the magnitude and phase-angle of the different frequency components of a periodic and stationary voltage or current waveform. IEC 61000-4-7 [2] proposes the use of rectangular sampling windows of 10-cycles' width in 50-Hz power systems and the grouping of the output bins of DFT analysis to compute the harmonic distortion in voltage and current waveforms. DFT only provides information in the frequency domain with a resolution depending on the time window width used. No time information about the signal is provided.

Wavelets are short-duration oscillating waveforms with zero mean and fast decay to zero amplitude, especially suited to analysis of non-stationary signals. The use of wavelet analysis allows the simultaneous evaluation of a signal in the time and frequency domains with different resolutions, making it very attractive for the analysis of electrical power quality disturbances. An interesting review on the use of wavelets in power quality can be seen in [3].

The discrete wavelet transform (DWT) is the digital representation of the continuous wavelet transform. The use of DWT produces a discrete number of logarithmic frequency bands of the input signal. High time resolution is provided in higher frequency bands whereas low time resolution is provided in the lower frequency bands of the signal.

Using the wavelet packet transform (WPT) instead of DWT and adequately selecting the sampling frequency and the wavelet decomposition tree, the uniform output frequency bands can be selected to correspond with the frequency bands of the different harmonic groups, as defined in the IEC standard 61000-4-7, in the input signal [4,5].

This paper presents a VI-based measurement instrument for detection and analysis of electrical power quality in power systems. A virtual instrument has been developed, using the LabVIEW 8.2 graphical programming environment, to monitor power quality disturbances in voltage supply in a low voltage distribution system.

2 VI measurement instrument

The instrument developed is made-up of a LEM LV 25-P Hall-effect voltage transducer with an overall accuracy of ±0.6%, a NI USB-6009 with eight single-end analog input channels, 14-bit, 48-kHz data acquisition board, a phase-locked loop (PLL) and a laptop computer (Fig. 1).

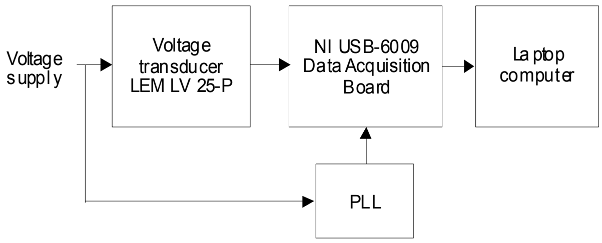


Fig. 1. Hardware structure of the VI-based instrument developed.

The instrument can operate in two different working modes: firstly, detection and analysis of transient power quality disturbances and secondly, analysis of stationary or quasi-stationary disturbances. Depending on the working mode selected, different sampling rates and wavelet analysis are performed. The instrument developed has been tested in simulation and with real signals using an a.c. programmable power source [6].

2.1 Transient disturbances

In this working mode discrete wavelet transform (DWT) is performed using the two-level wavelet decomposition tree in Fig. 2, with Daubechies with 4 coefficients as the mother wavelet. The sampling rate selected is 12.8 kHz obtaining the output frequency bands in Fig. 3.

The coefficients of the highest frequency band of the decomposition tree in Fig. 2 ($d_1(n)$, frequency band 6.4 – 3.2 kHz) are insensitive to a steady-state signal but show a high variation in magnitude associated with high-frequency transients in voltage waveform. If these coefficients have sharp and short peaks in magnitude, then the disturbance is a short duration voltage event, such as a voltage dip, swell or short interruption. Otherwise, if they present a long series of peaks then it corresponds to a repetitive high-frequency transient. In both cases the occurrence of the disturbances is determined with high time resolution. The same can be applied to the 3.2 – 1.6 kHz band for low-frequency transients.

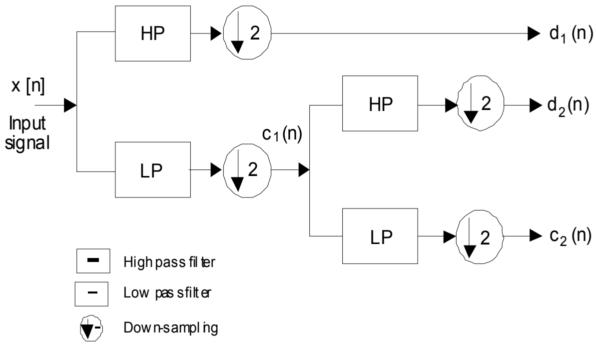


Fig. 2. Two-level wavelet decomposition tree for DWT analysis of transient power quality disturbances.

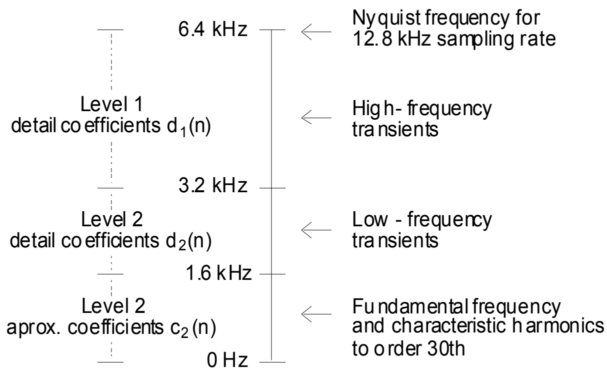


Fig. 3. Output frequency bands of the wavelet decomposition tree in Fig. 2 for 6.4 kHz sampling rate.

In this working mode, the two-level discrete wavelet transform is implemented in real time using the method proposed in [7].

2.2 Stationary disturbances

In this working mode harmonic distortion is computed applying the wavelet packet transform (WPT) to the voltage samples. The five-level wavelet decomposition tree in Fig. 4, with Vaidyanathan with 24 coefficients as the mother wavelet is used.

Selecting 1.6 kHz sampling rate and using sampling window widths of 10 cycles of the fundamental frequency, the output of the wavelet decomposition tree is formed by 32 bands of 25 Hz width, which are grouped in fifteen output bands of 50-Hz width centred on each harmonic component, making the algorithm compatible with the harmonic groups defined in IEC 61000-4-7. Furthermore, as is shown in [8], the method proposed enables the tracking of the time evolution of the odd harmonic frequency bands in the input signal using the outputs of the third-level of the same wavelet decomposition tree. In this third-level there are eight outputs bands with uniform 100-Hz width covering the frequency spectra from 0 to 800 Hz, with the odd harmonic frequencies form 1st to 15th order harmonic in the centre of each band.

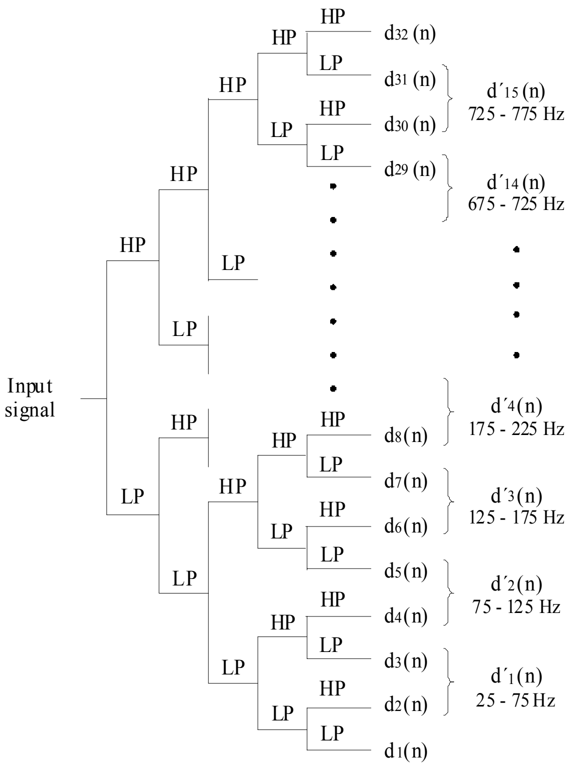


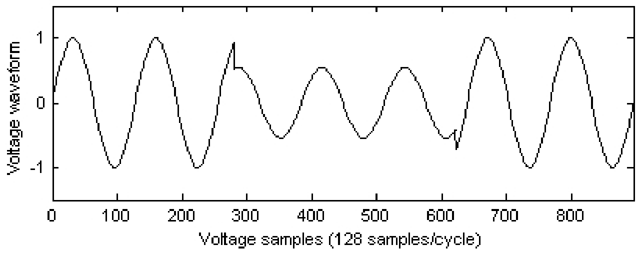
Fig. 4. Five-level wavelet decomposition tree for time-frequency analysis of harmonics

3 Experimental results

Three different examples are considered in this section to show the performance of the method proposed in the detection and analysis of transient and stationary disturbances in voltage supply.

Fig. 5 shows the waveform of voltage supply with a 45% magnitude and 53 milliseconds duration voltage dip and the magnitude of the detail coefficients of the first level of the wavelet decomposition tree in Fig. 2, $d_1(n)$, obtained applying DWT with Daubechies with 4 coefficients to voltage samples.

As can be seen these coefficients are insensitive to the steady-state magnitude of voltage supply but show sharp variation in magnitude corresponding to the beginning and end of the voltage dip. Therefore, using these coefficients the beginning and end of a voltage dip can be accurately detected.



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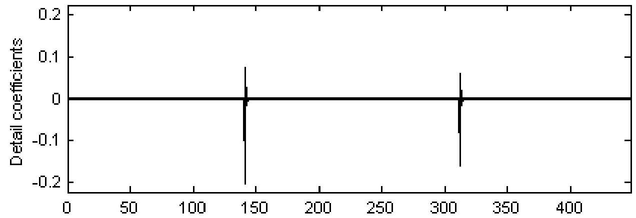
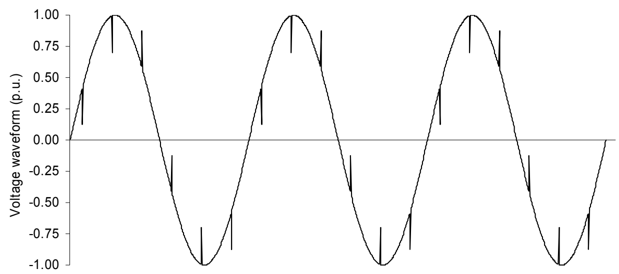


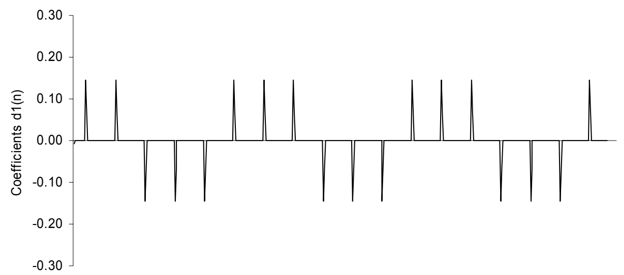
b)

Fig. 5. a) Waveform of voltage supply with a voltage dip and b) magnitude of coefficients $d_1(n)$ obtained applying DWT.

As another example of the performance of the method proposed in the detection of transient disturbances, Fig. 6 shows the waveform of voltage supply with voltage notches due to the conmutation of a six-pulse converter and the magnitude of the detail coefficients of the first level of the wavelet decomposition tree in Fig. 2 obtained applying DWT with Daubechies with 4 coefficients to voltage samples.



a)

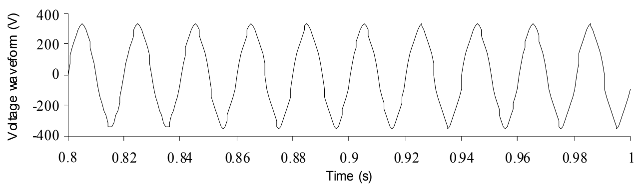


b)

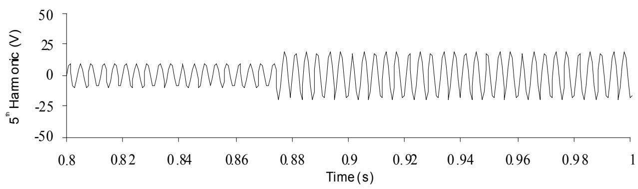
Fig. 6. a) Voltage notches in voltage supply due to a 6-pulse converter, b) magnitude of coefficients $d_1(n)$ of the wavelet decomposition tree in Fig. 2.

As can be seen the magnitude of coefficients $d_1(n)$ shows a long series of peaks (six peaks/cycle) exactly corresponding to the notches in voltage supply.

Finally, as an example of the time-frequency characteristics of the method proposed in the analysis of stationary or quasi-stationary disturbances, Fig. 7.a shows ten cycles of a 3-second record of voltage supply measured in a low-voltage distribution system, with a predominant fifth order harmonic of 3.15% magnitude. A change in magnitude of this harmonic component from 3.15% magnitude to 6% magnitude (compatibility level for low-voltage supply distribution systems according to European standard EN50160) is produced at instant 0.875 seconds of the record.



a)



b)

Fig. 7. Voltage waveform with a 5^{th} order harmonic fluctuation and time evolution of the corresponding output coefficients in level three of the wavelet decomposition tree in Fig. 4.

On the other hand, Fig. 7.b shows the magnitude of the output coefficients of level three of the wavelet decomposition tree in Fig. 4 corresponding to the output band from 200 to 300 Hz. As can be seen the change in magnitude of the fifth order harmonic can be accurately detected using these coefficients.

4 Conclusion

The paper presents the performance of a VI- based measurement instrument for detection and analysis of power quality disturbances in power systems. In the working mode of detection of transient disturbances the instrument implements a two-level DWT algorithm and uses the detail coefficients of the first level for detection and discrimination of different types of transient disturbances. In the working mode of stationary disturbances the instrument simultaneously uses different levels of a five-level WPT algorithm for time-frequency analysis of harmonic components in the input signal.

Acknowledgement

The authors wish to thank the Spanish Ministry of Science and Technology, Plan Nacional de I+D+I (2004-2007), for its support of this research project under grant DPI2006-15083-C02, of which the present paper is a part.

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