



# A virtual measurement instrument for electrical power quality analysis using wavelets

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## ABSTRACT

This paper presents a virtual measurement instrument for detection and analysis of power quality disturbances in voltage supply using wavelets. The instrument developed can operate in different working modes depending on the type of power quality disturbance to be detected and analyzed. In each mode different wavelet analysis (discrete or wavelet-packet transform), with different mother wavelet, decomposition tree and different sampling rate is performed on the input signal either in real-time or off-line. The instrument also permits the partial implementation of a wavelet decomposition tree when we are only interested in a specific frequency band in the input signal. The results obtained in simulation and using real signals demonstrate the good performance of the instrument developed for the detection and analysis of different power quality disturbances in voltage supply.

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## 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 transient disturbances. Harmonic and interharmonic distortion, voltage fluctuation, voltage flicker and voltage unbalance make up the first group, whereas voltage transients, voltage dips, voltage swells, short interruptions in voltage supply and other high-frequency disturbances constitute the latter group.

The root mean square magnitude (rms) is the most common signal processing tool used for estimation of voltage and current magnitude in power systems. Although the rms 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 short 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 (12 cycles in 60-Hz systems) and the grouping of the output bins of DFT analysis to compute the harmonic distortion in voltage and current waveforms. DFT analysis only provides information in the frequency domain with a resolution that depends on the time window width used in the analysis (5 Hz resolution using the standard method for measurement of harmonics). 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. Contrary to the use of DFT analysis, the use of wavelets 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. Wavelets are used in power quality when it is not important to know the exact frequency of a disturbance in voltage or current waveforms, but the time information is

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important. An interesting review on the use of wavelets in power quality can be seen in [3–5].

The discrete wavelet transform (DWT) is the digital representation of the continuous wavelet transform (CWT). DWT can be implemented using a multi-stage filter bank with the wavelet function as the low-pass filter (LP) and its dual as the high-pass filter (HP), as is shown in Fig. 1 for a two-level decomposition tree. Downsampling by two at the output of the low-pass and high-pass filters scales the wavelet by two for the next stage. The output coefficients of the low-pass filter (the approximation coefficients) are again decomposed to produce a new representation of the signal and so on, producing a logarithmic decomposition of the frequency spectra of the input signal as is shown in Fig. 2 for the wavelet decomposition tree in Fig. 1 ( $f_s/2$  is the Nyquist frequency for  $f_s$  sampling rate). High time resolution is obtained in higher frequency bands whereas low time resolution is provided in the lower frequency bands of the signal.

The wavelet-packet transform (WPT) can be used to overcome the limitations of the DWT and to obtain a uniform frequency decomposition of the input signal. In the WPT, the output of both, the low-pass and the high-pass filters (the detail and the approximation coefficients) are decomposed to produce new coefficients, as is shown in Fig. 3 for a two-level wavelet decomposition tree, in this way enabling a uniform frequency decomposition of the input signal (Fig. 4).

Using the wavelet-packet transform 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 in the input signal, as defined in the IEC standard 61000-4-7 [6].

Two main factors affect the successful application of wavelets in power quality applications: first, the extraction of specific features for detection and identification of the different power quality disturbances and second, the selection of the most adequate wavelet mother function and the selection of the decomposition tree and sampling frequency to obtain the time–frequency resolution required. In general, WPT provides more information for signal discrimination than DWT.

This paper presents a virtual measurement instrument for detection and analysis of power quality disturbances in voltage supply in a low-voltage distribution system using wavelets. Three main characteristics presents the instrument developed: (1) different wavelet analysis can be applied on the input signal depending on the type of power quality disturbance under study, (2) real-time or

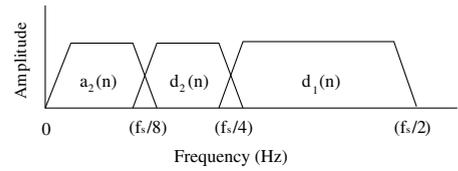


Fig. 2. Output frequency bands of the wavelet decomposition tree in Fig. 1 for  $f_s$  sampling rate.

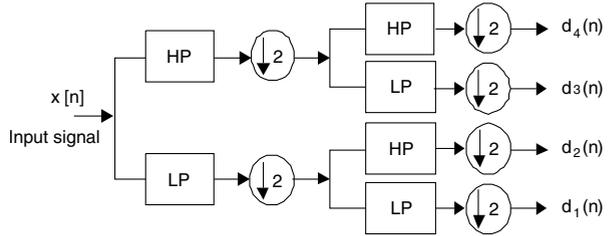


Fig. 3. Two-level wavelet decomposition tree for WPT analysis.

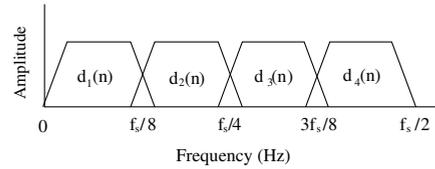


Fig. 4. Output frequency bands of the wavelet decomposition tree in Fig. 3 for  $f_s$  sampling rate.

off-line application of wavelet transforms can be applied and (3) a partial implementation of wavelet transforms can be used to study only the time–frequency characteristics of the specific frequency band in the input signal selected by the user.

The organization of this paper is as follows. Section 2 describes the hardware structure of the instrument and its different working modes depending on the power quality disturbance to be detected and analyzed. Section 3 presents the performance of the instrument under different measurement conditions using a programmable AC voltage supply and real voltage waveforms obtained from a low-voltage distribution system. Finally, Section 4 presents the conclusions of the paper.

## 2. Virtual measurement instrument

The single-phase version of the instrument developed is made up of a LEM LV 25-P Hall-effect voltage transducer, a NI USB-6009 and a laptop computer (Fig. 5). The voltage

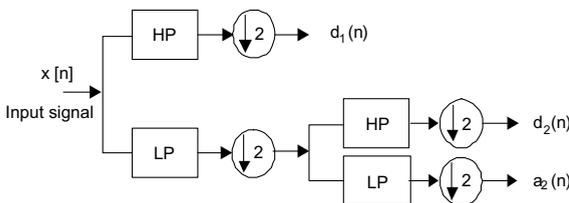


Fig. 1. Two-level wavelet decomposition tree for DWT analysis.

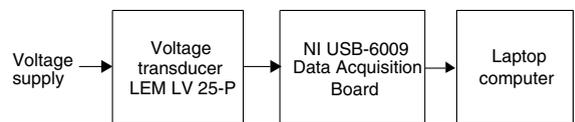


Fig. 5. Hardware structure of the virtual instrument developed.

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