Wavelet decomposition algorithms for PQ measurements

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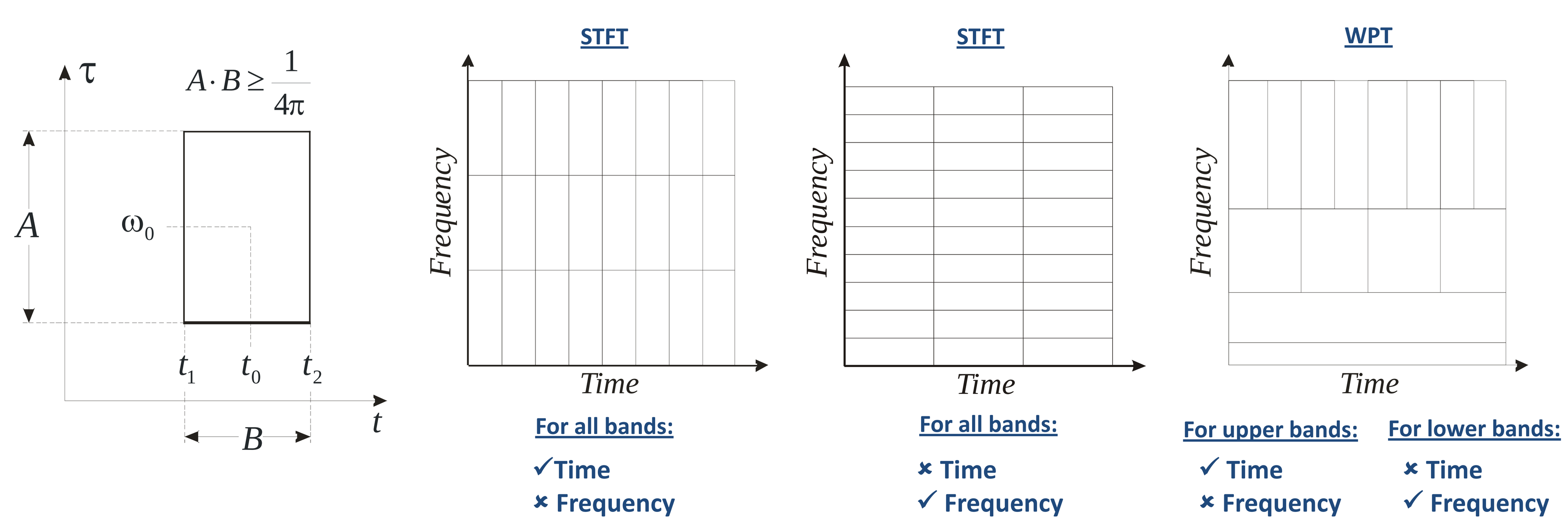
Why Wavelets?

Traditional expansions such as Fourier and Laplace transforms are commonly used in many applications, but when an accurate characterization in both time and frequency domains is needed other solutions must be taken into account.

Wavelet theory overcomes the principal limitations of traditional transforms. Depending on the application to be used for, Wavelet Transform provides benefits compared with Fourier transforms for the following relevant aspects:

1. Accurate edge detection for events
2. Localization in time of transient phenomena and presence of specific frequencies contents

Limitation: Heisenberg's inequality in frequency and time relation



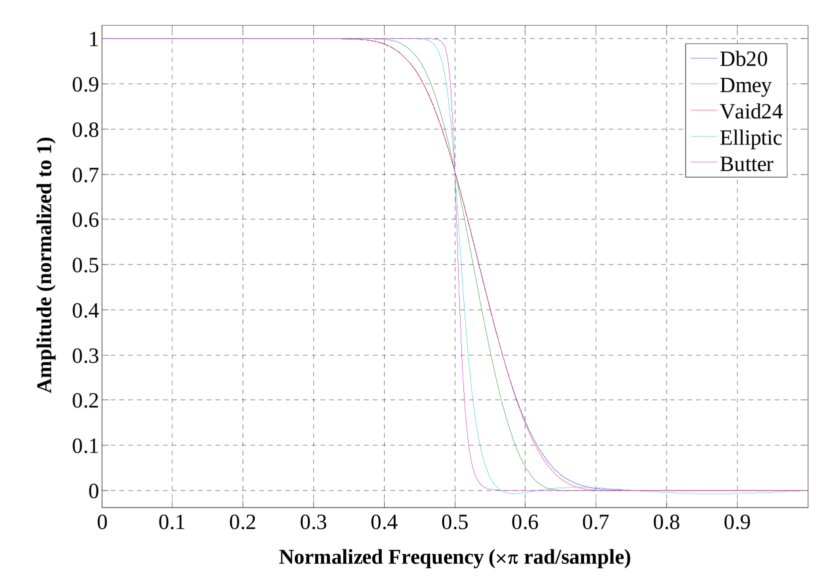
Digital filters: The families

The Wavelet process is performed by means of digital filters. They allow obtaining the necessary information from the input waveform to analyse both frequency and time when they are properly chosen.

Convolution and decimation operations are the most important part of the process, halving time resolution and doubling frequency resolution.

Depending on filter nature, the filter sequence can be finitely or infinitely supported. This leads to have FIR or IIR filters respectively. The type of the filter will entail more or less mathematical complexity for similar results. For this, 53 different filters were tested for determining the best one for each application.

The 29th order-Butterworth filter was chosen for its low spectral leakage compared with others.

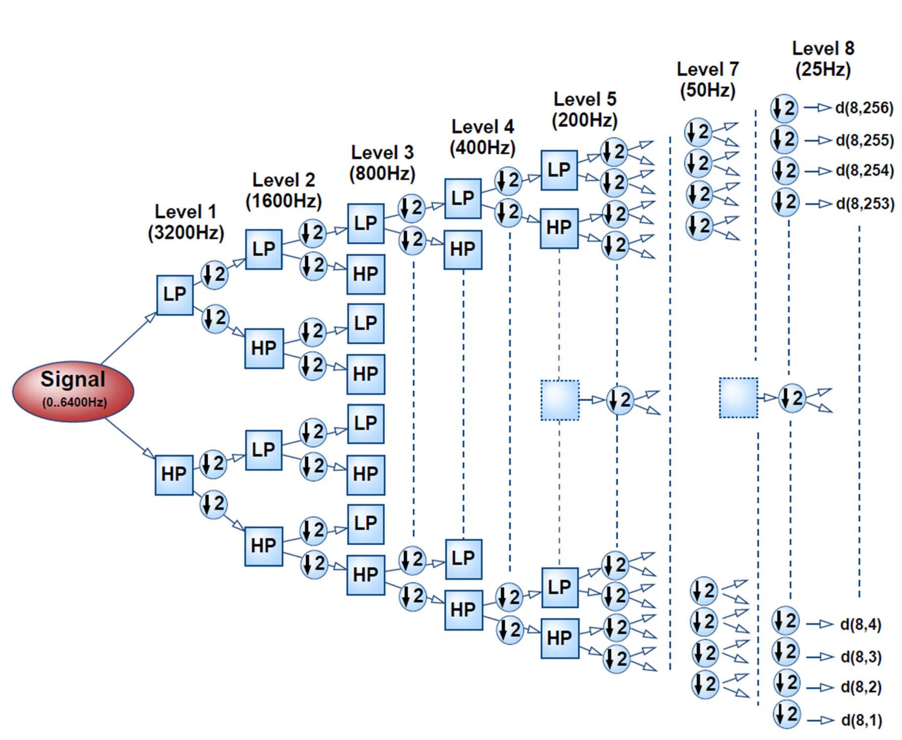


Normalized frequency response

FILTER	COEFFICIENTS NUMBER	FILTER	COEFFICIENTS NUMBER	FILTER	COEFFICIENTS NUMBER
Haar	2	Coif1	6	Bior2.6	14
Db2	4	Coif2	12	Bior2.8	18
Db3	6	Coif3	18	Bior3.1	6
Db4	8	Coif4	24	Bior3.5	10
Db5	10	Coif5	30	Bior3.7	6
Db6	12	Sym2	4	Bior3.9	20
Db7	14	Sym3	6	Bior4.4	10
Db8	16	Sym4	8	Bior5.5	12
Db9	18	Sym5	10	Bior6.8	18
Db10	20	Sym6	12	Vaid	24
Db11	22	Sym7	14	Elliptic ★	8
Db12	24	Sym8	16	Butterworth ★	29
Db13	26	Sym9	18		
Db14	28	Sym10	20		
Db15	30	Dmey	102		
Db16	32	Bior1.1	2		
Db17	34	Bior1.3	6		
Db18	36	Bior1.5	10		
Db19	38	Bior2.2	6		
Db20	40	Bior2.4	10		

★ IIR filter

The Wavelet Decomposition Structure

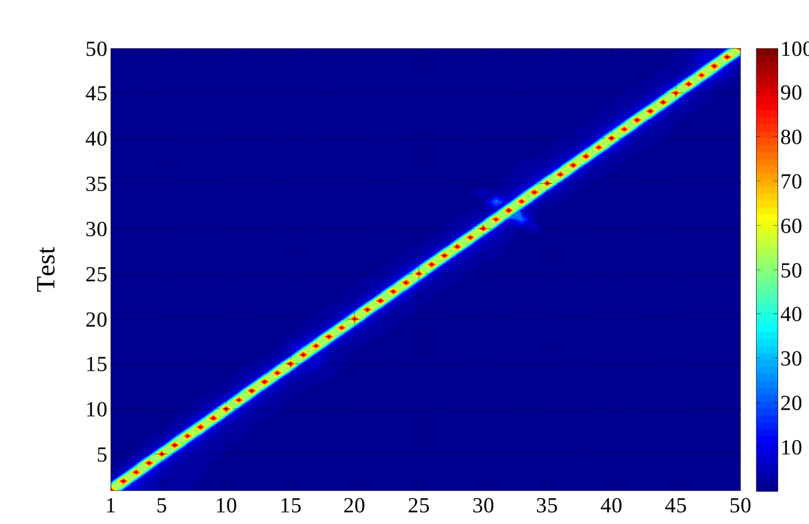


Decomposition tree

The dyadic filters bank is formed by 8 levels of decomposition. This number of levels was chosen to have precise information of time (1st level) and frequency (8th level). The sampling frequency of the system was set to 12.8 kS/s to have a resolution of Δt=78.125 μs and Δf=25 Hz respectively.

With these premises, a very flexible decomposition scheme was made for event detection and harmonics measurements up to 63rd order.

Harmonic Wavelet Calculation



IIR-filter spectral leakage

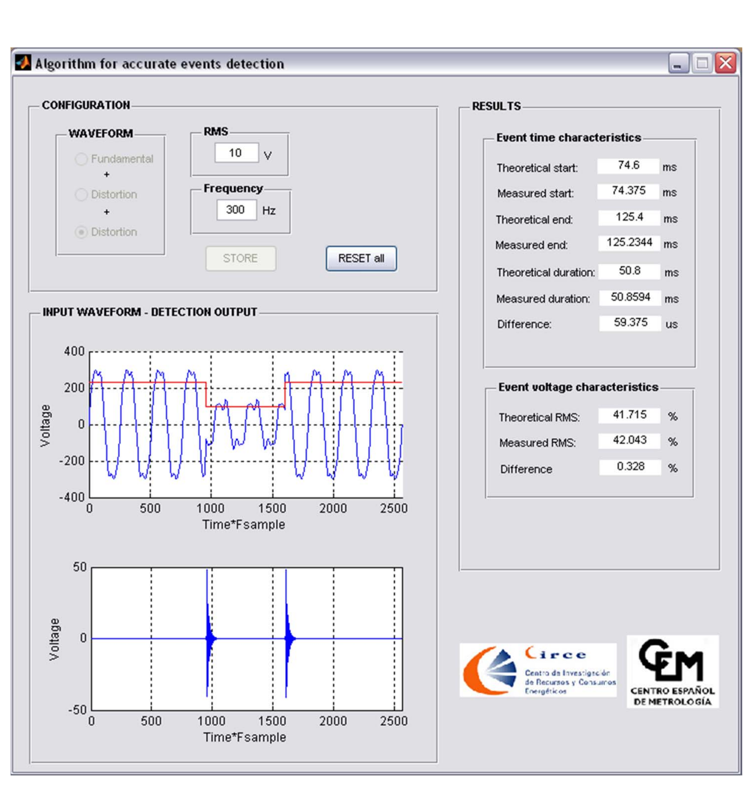
The harmonic calculation methodology was strictly followed as IEC 61000-4-7 requirements. The RMS content is quantified with the information extracted from the 8th level. These data are conveniently grouped to obtain the compound harmonic response (h 25 Hz):

$$x_{rms}(j,p)=\sqrt{\frac{\sum_k \left(d_{j,k}^{p}\right)^2}{N}} \qquad x_{rms}(j,p+q)=\sqrt{\frac{\sum_k \left(d_{j,k}^{p}\right)^2+\sum_k \left(d_{j,k}^{q}\right)^2}{N}}$$

This method offers promising results when fluctuating harmonics are evaluated.

Event Wavelet Detection

With the extracted information from the 1st level of decomposition, an algorithm for event detection was implemented. The main characteristic of this development is its sensibility to small voltage changes within the measurement window.



Event detection interface

A large set of tests were simulated consisting of one input waveform with 3 different voltage harmonics: a fundamental harmonic wave where the event (dip, swell or interruption) appears plus 2 other harmonics during the 200 *ms*-window. It was observed that the system always properly detects with errors lower than 1 *ms* from the theoretical measured duration.

Besides, a 0.5-cycle RMS calculation was performed to get the most accurate RMS value during the event duration.

CONCLUSIONS

A novel method for harmonics either event detection has been developed. The flexibility of the dyadic structure makes possible to extract accurate information of time and frequency depending on the level it is fetched from.

The harmonic algorithm provides even and odd harmonics RMS values similar or even better to the ones obtained from FFT algorithm in certain cases.

The event detection algorithm shows a very good behaviour under all tested cases. RMS and time differences meets the strictest requirements from theoretical values.

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