

DEFINITION AND MEASUREMENT OF A NEW ELECTRICAL POWER QUALITY INDEX FOR POWER SYSTEM MANAGEMENT PURPOSES

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Abstract – This work deals with the purpose of a new measurement methodology and a new quality index to evaluate quality of the signal, particularly of electrical ones, valid also when these signal are non-stationary.

A new quality index, named *Wavelet Harmonic Distortion* (WHD), is here suggested, taking origin from the theory of the *Wavelet Transform*, very useful to on-line evaluate the well-known *Total Harmonic Distortion* (THD) of the voltage and current signals relevant to power systems.

Keywords: Power Systems, Measurement Systems, Wavelet Transform, Harmonic Distortion, Quality Indices, Electrical Power Quality

1. INTRODUCTION

Nowadays, both the industrial factories and the technical users are attracted by the concept of “quality” of an industrial product. Electrical energy may be considered as a “processed material”, having an immediate delivery in a continuous flow [1].

Actually, an electrical system is characterized by a non-sinusoidal system, being generally distorted and unbalanced, and healthy carrier of disturbances.

Modern-life depending on continuous supplying of electrical energy caused a great increase of importance and significance of all the problems related to reliability and quality of the electrical power system. In fact, in last years, the problem concerning the *power quality* became an important and serious discussion matter in a lot of international Conferences and Congresses: particularly, definition and measurement of electrical energy are become more and more attention and investigation matters [2].

A number of indexes defined and carried out to evaluate harmonic pollution in power systems and, in other terms, its “quality”, suffer from a serious restraint: they are defined only in steady-state conditions [3].

Starting from the assumption that in a transmission and distribution system there are transits and exchanges of energy in terms of transient waveforms, in this work the Authors focus their attention to the definition of a new quality index which can be used also for non-stationary waveform analyses [4].

This new index, named *Wavelet Harmonic Distortion* (WHD), is based on the multiresolution analysis via *Wavelet Transform* of the input signal, applied to the classical definition of the *Total Harmonic Distortion* (THD). It can be con-

sidered a THD version valid also for non-stationary signals.

The proposed methodology has been developed on the basis of both the *Wavelet Transform* theory and the multiresolution analysis applied to a monodimensional signal [5].

To filter the acquired signals we utilized four “*quadrature mirror*” filters, very useful for signal decomposition and reconstruction. These digital filters, shown in Fig. 1, operate at high and low frequencies, being all determined as function of the *mother wavelet “Coiflet5”*, shown in Fig. 2.

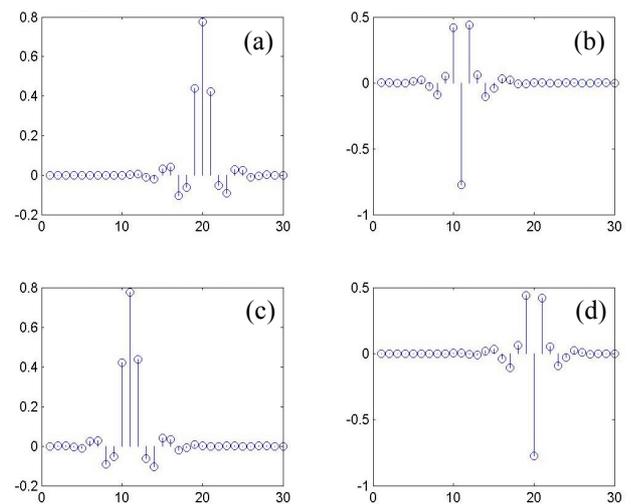


Fig. 1. Low-pass (a) and high-pass (b) decomposition filters; low-pass (c) and high-pass (d) reconstruction ones

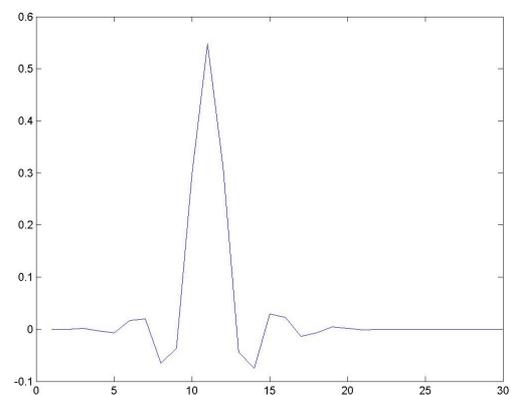


Fig. 2. Mother wavelet “Coiflet5”

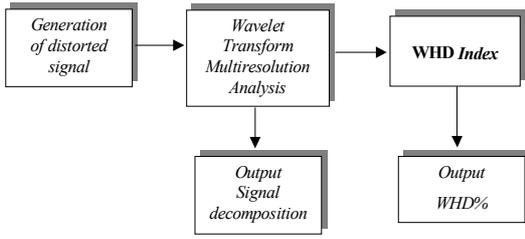


Fig. 3. Block diagram of WHD measurement system

2. WAVELET HARMONIC DISTORTION INDEX

Index WHD measuring can be executed according to the functional architecture shown in Fig. 3. It uses a pair of digital filters (low- and high-pass, respectively) for each level step in the analysis, as Fig. 4 shows.

The proposed methodology has been implemented to analyze a signal characterized, at network frequency, also by a superimposed noise, generally non-stationary. With reference to the period of the non-distorted signal and similarly to THD definition for stationary signals, the new index is defined in the following way:

$$WHD = \frac{\sqrt{\sum_{i=L}^{J-1} W_i^2}}{W_{L-1}}$$

where:

- W_{L-1} is the rms value of the signal at level $L-1$;
- W_i is the rms value of wavelet components of the signal relevant to the i -th level, with $i=L, \dots, J-1$.

For stationary signals, WHD index is constant and equals the well-known THD value:

$$THD = \frac{\sqrt{\sum_{i=2}^{+\infty} V_i^2}}{V_1}$$

where:

- V_i is the rms value of the i -th harmonic component of the analysed signal; V_1 is the rms value of the fundamental component of the signal under test.

We simulated the WHD measurement on signals with harmonic contents variable in a large frequency range. In our analysis we chose windows of length equal to one cycle of the fundamental frequency ($t=0.02$ s, for $f=50$ Hz), or 8 ($t=0.16$ s), or 16 ones ($t=0.32$ s), in order to compare the relevant measurements with the expected values and the evaluation of the quality index carried out by means of the traditional Fourier analysis-based measurement methodology. It has to be outlined that the last two investigations were performed according to the regulations in force.

It is possible to obtain a WHD continuous against time by choosing as analysis window a cycle of the fundamental

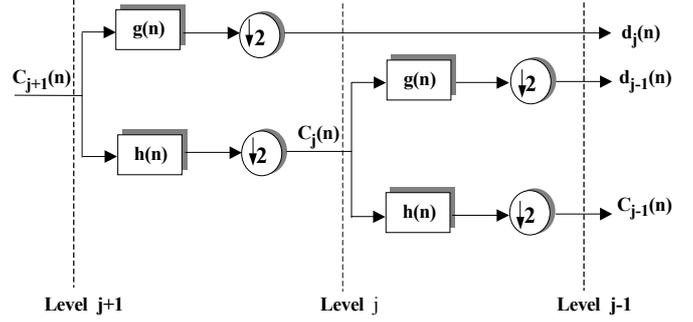


Fig. 4. Flow diagram of the iterative filtering algorithm

component of the signal and by iterating the measurement for all its duration.

The signal in input to the processing block comes from a synchronous sampling, being represented by a N -length sequence per period, with $N=2^J$, $J \in \mathbb{N}$.

The value of the parameter J determines also the number of resolution levels of the output signal.

3. EXPERIMENTAL APPLICATION

The suggested technique has been verified by means of a series of elaborations in Matlab programming environment, consisting in WHD measurements on stationary and non-stationary waveforms, suitably simulated and constructed, in order to verify reliability, accuracy and capability of this here-proposed electrical power quality index. For this purpose, in the work the results relevant to the WHD-based measurements and those relevant to an index STHD-similar based on the Fourier classical theory, have been compared. These comparisons have been executed also with the STHD index suggested in [6].

The disturbances considered in this work are those reported in the Table I and II.

Table I. Driven phenomena at low frequencies

Harmonics and inter-harmonics
Signalling voltages
Voltage fluctuations
Interruptions and reductions of the voltage
Voltage unbalance
Frequency fluctuations
Induced voltages at low frequency
d.c. components in an a.c. network

Table II. Driven phenomena at high frequencies

Induced continuous waveforms of voltage and current
One-way transient waveforms
Oscillating transient waveforms

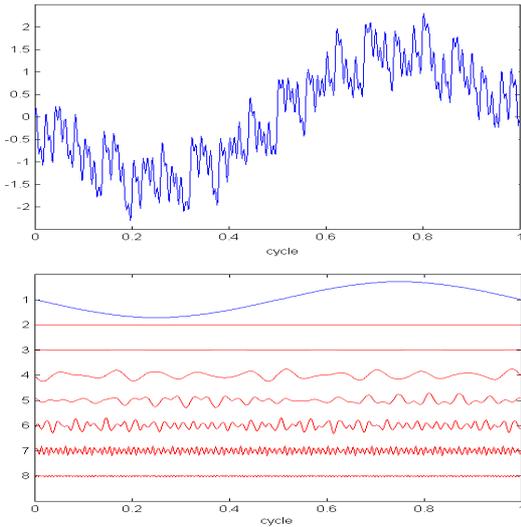


Fig. 5. Analysed distorted signal (a) and its 8-levels multiresolution analysis (b)

An example of analyzed signal and its relevant multiresolution analysis are shown in Figs. 5a and 5b, respectively.

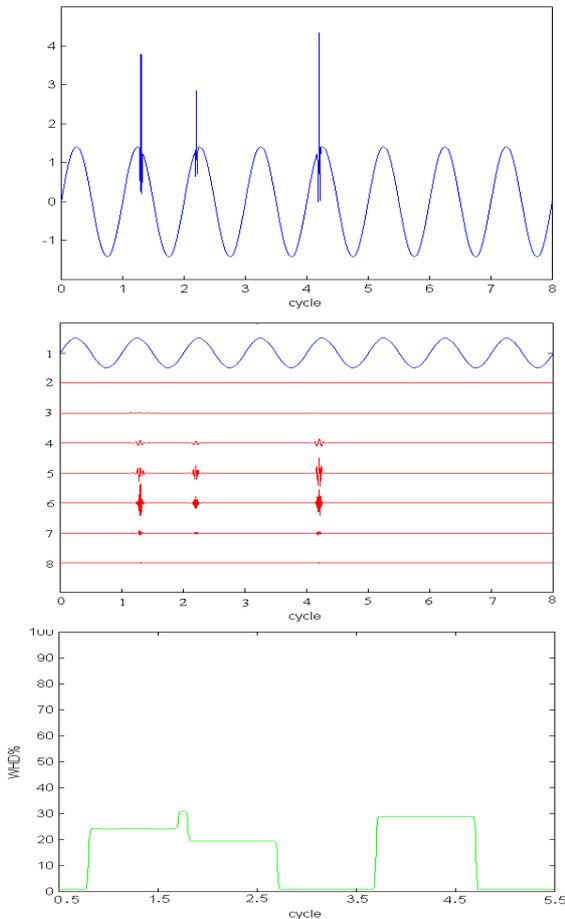


Fig. 6. Analysed distorted signal with disturbances(a); its 8-levels multiresolution analysis (b) and its WHD % evaluation (c)

Table III. WHD measurement on the signal of Fig.5

	Number of signal samples				
	2048	1024	512	256	128
WHD	0.2731	0.2733	0.2731	0.2675	0.2649
Exp. value	0.2732	0.2732	0.2732	0.2732	0.2732
$\epsilon_{\text{WHD}} (\%)$	0.01	0.01	0.01	0.57	0.83

The stationary signal under test (with a fundamental frequency of 50 Hz) was distorted by five harmonic components of order $k=5, 7, 11, 13$, having amplitude ratio with respect the fundamental equals to $1/5, 1/7, 1/11$ and $1/13$, respectively.

The leakage effects was limited by using the windowing technique, i.e by applying the Hanning window to acquired signal [7]

In Table III the different WHD values are reported, as obtained for different number of signal samples. The resultant accuracy of the algorithm was about 99,99%.

Moreover, another signal under test, characterised by some disturbances, is shown in Fig. 6a, with its relevant multiresolution analysis (Fig. 6b) and its WHD%, carried out by using the suggested algorithm. (Fig. 6c).

As well known, a lot of disturbances with negative effects on the electrical energy quality are largely nonstationary. For this, our analysis investigated about different nonstationary distorted signals, in order to evaluate their relevant “instantaneous” WHD. Also in this case, Hanning windows were chosen, with a length variable against the number of signal samples.

The following examples are relevant to classic nonstationary power-system signals, concerning firstly a signal at network rate, distorted by two harmonic components, the 17th and the 33th ones. This signal presents a linear increase of its amplitude versus time (from 0 to 100 V), as shown in Fig. 7.

The second example is relevant to a distorted signal like the previous one, having constant harmonic amplitudes, and a fundamental frequency variable linearly versus time (from 0 to 100 Hz). This last signal, named *chirp signal*, is shown in Fig. 9.

In Figs. 8a-f and 10a-f the multiresolution analyses of the examined signals are shown, respectively. In these figures, also the approximated versions and the detailed ones relevant to the signals under analysis are shown.

Moreover, in Tables IV and V the characterisation of both the examined signals is reported, for different number of signal samples. Particularly, the WHD measured and expected values are illustrated, jointly with the relevant algorithm percentage errors in WHD measurement. As it is easy to be noted, these errors decrease as the sample array size increases, and the errors relevant to the variable-amplitude case are greater than the variable-frequency one. In fact, the accuracy of the method is more sensitive to the frequency changes than to the amplitude ones.

In both the examined examples, the collected samples were weighted by the Hanning window (having a low ENBW), and were analysed via wavelet transform, applied to the multiresolution analysis.

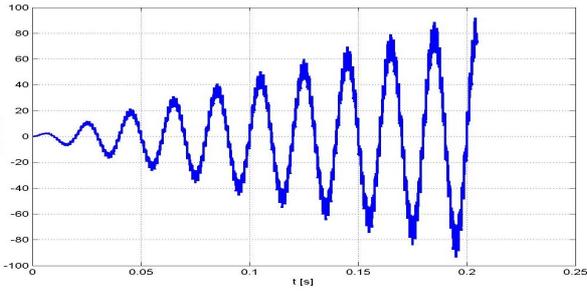


Fig. 7. Examined nonstationary signal, having an amplitude linearly variable from 0 to 100 V

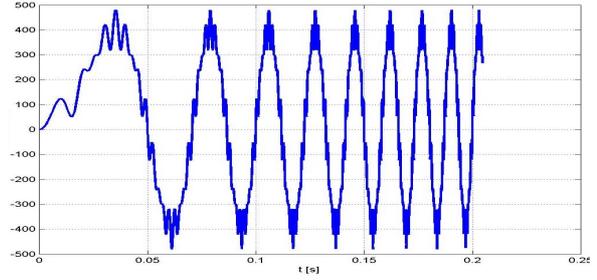


Fig. 9. Examined chirp signal, having a frequency linearly variable from 0 to 100 Hz

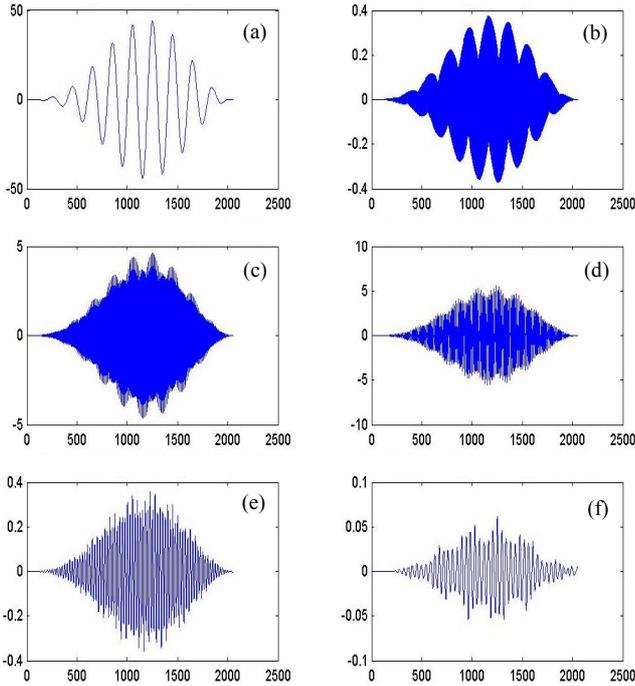


Fig. 8. (a) 5th-level approximated version, and (b) 1st-, (c) 2nd-, (d) 3rd-, (e) 4th-, (f) 5th-level detailed version of the signal under analysis of Fig. 7.

Table IV. Characterisation of the signal of Fig. 7 by means of the proposed technique

N	2048	1024	512	256	128
WHD	0.1414	0.1413	0.1415	0.1370	0.1382
Exp. Val.	0.1414	0.1414	0.1414	0.1414	0.1414
$e_{\text{WHD}}\%$	0.00	0.01	0.01	0.32	0.44

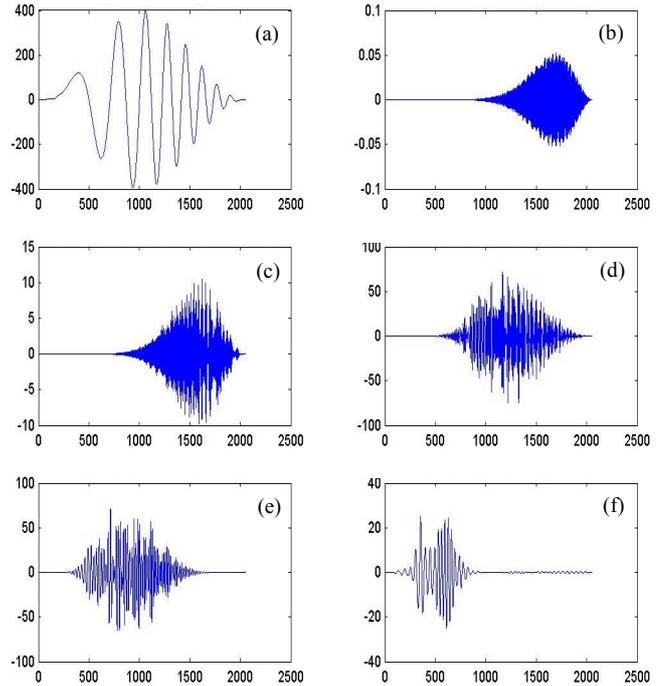


Fig. 10. (a) 5th-level approximated version, and (b) 1st-, (c) 2nd-, (d) 3rd-, (e) 4th-, (f) 5th-level detailed version of the signal under analysis of Fig. 9.

Table V. Characterisation of the signal of Fig. 9 by means of the proposed technique

N	2048	1024	512	256	128
WHD	0.1412	0.1365	0.0948	0.0525	0.0409
Exp. Val.	0.1414	0.1414	0.1414	0.1414	0.1414
$e_{\text{WHD}}\%$	0.02	0.49	4.7	8.9	10

4. CONCLUSIONS

The obtained results by applying the suggested technique on the different signal under analysis and for different length of sampling sequences evidenced the capability of the WHD in evaluating the whole energy content of the input signals.

The algorithm accuracy in measuring WHD characteristics of nonstationary signals was resulted

comparable with those relevant to stationary ones. It resulted less than 0,5 % for signals with variable amplitude (also for sequences of small length, i.e. $N \geq 128$), and less than 0,5 % for signals with variable frequency (with $N \geq 1024$). These results are always more accurate than those relevant to STFT analysis or other available algorithms.

The principal idea in the definition of the new electrical quality index WHD has been that consisting in

applying the techniques related to the multiresolution analysis and the Wavelet Transform to the classical definition of the Total Harmonic Distortion (THD). By following this procedure, the Authors have carried out an accurate measurement index, to detect the different and time-varying disturbances in an electric power system.

5. REFERENCES

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