

Frequency characteristic of transients and notching disturbances – case study

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Abstract- This paper is focused on the problem of transient and notching recognition. Especially, a problem of frequency characteristic of real impulses are considered. Aim of the paper is to determine a minimum covered frequency bandwidth, when dealing with this kind of disturbances. Parameters of the selected transient and notching disturbances are determined, after extracting disturbances by pass-band filters with various corner (cut-off) frequencies. Finally, some remarks regarding these disturbances measurements are presented.

I. Introduction

The IEEE 1159-1995 standard [1] defines various kinds of power quality disturbances, including transients and notching. According to the standard transients can be divided into two groups: impulsive and oscillatory. The former term means “a sudden non-power frequency change in steady-state conditions of voltage, current or both, that is unidirectional in polarity” [1]. The later term means “voltage or current whose instantaneous value changes polarity rapidly” [1]. These disturbances usually contain high frequencies (from few hundred hertz up to a few MHz) and their duration varies from below 50 ns up to few dozens ms [1]. Similar kind of disturbance is notching. This is “a periodic voltage disturbance” caused by power electronics devices operation [1]. Frequency components characterising notching can be quite high, similarly like in the case of transients. Sometimes this kind of disturbance is called “periodic transient” [2]. Summing up, frequency components associated with these disturbances are significantly higher than usually covered by power quality analysers. They require a wide bandwidth of measurement circuit and high sampling frequency [3]. But typical power quality analysers are optimized for measurement of components up to 40th or 50th harmonic (maximum 3 kHz in case of 60 Hz systems) or sometimes up to 9 kHz. The latter value results directly from IEC 61000-4-7 standard [4]. According to this standard a sampling frequency of measuring device should be sufficient for analysis of power quality disturbances up to 9 kHz. Obviously, sampling frequency sufficient for low-frequency components measurement up to 9 Hz would be insufficient for transient and notching analysis. Nevertheless, many commercial and scientific power quality analysers are capable of transient analysis. However, their data sheet can make some confusion and methods of detecting and characterizing transients are often undisclosed [3]. Sampling frequencies declared by power quality developers equal e.g. 38.4 kHz [5], 50 kHz [6] or 200 kHz (Fluke 435). Obviously, these sampling frequencies are insufficient for covering all notching and transients as defined in IEEE standard [1], but would they be sufficient for common ones?

The transients can be evaluated with or without fundamental component. In the latter case some kind of high-pass filtration is required. E.g. in the case of measurement instrument described in ref [5], 6th order IIR filter was used, with cut-off frequency 100 Hz. One of the most popular tools for transients and notching analysis is discrete wavelet transform DWT [7], [8]. Application of this tool do not require additional high-pass filtering. However, the number of implemented decomposition stages should be determined. In some respect, it can be treated as proper choice of the cut-off frequency of high-pass filter.

This paper presents results of selected disturbances analysis after band-pass filtering with various corner frequencies. The aim is to determine a minimum sampling frequency required as well as a minimum required level of wavelet decomposition for selected impulses evaluation. The analysis were carried out for transients and notching registered in real power systems. This paper is an extension of previous author’s paper on the subject [9]. New examples were added (registered after ref. [9] publication – in previous paper only one example of notching was analysed), pass-band filtering was implemented (in previous version only DWT was considered) and changes of lower cut-off frequency were considered.

II. Signals under research

The phenomena discussed in this paper are hard to detect and register due to limited capabilities of typical measurement devices for power quality phenomena monitoring. So, the number of transients and their

characteristics described in literature is limited [3]. Authors of the paper carried out a research of power quality in electric power networks (mainly ship networks) for quite a few years. During this time dozens hours of power signals were registered with various sampling frequencies. Fortunately, during this research some examples of transient and notching were registered. The examples selected for this paper were shown in Fig. 1. They were registered by means of DAQ PCI703-16/A Eagle Technology equipped with 14-bit A/D converter. The isolation amplifiers ISO 124 of Burr Brown were used as well. The maximum bandwidth of these amplifiers was equal to 50 kHz. So, the presented below analysis are valid for this particular frequency band. Applied sampling frequency was equal to 150375 Hz.

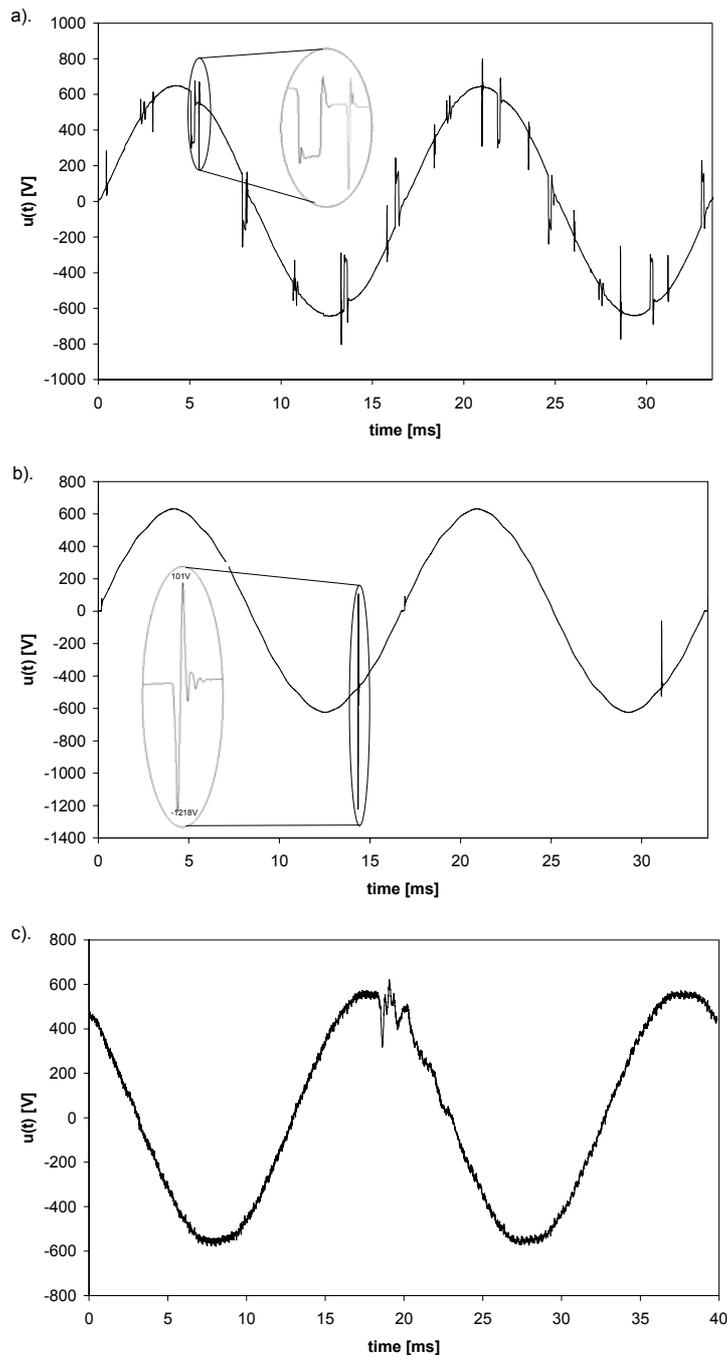


Fig. 1. Examples of transient and notching registered in ship networks: a). notching (marked in Fig. 2 as a *notch*), b). impulsive transient (marked as a *imp*) and c). oscillatory transient (marked as a *osc*)

III. Research results

A. Pass-band filtration by means of IIR filters with various cut-off frequencies

Results of preliminary analysis of selected disturbances have been depicted in Fig. 2. The presented in Fig. 2 results shows chosen parameters of transients evaluation, namely energy and peak-to-peak amplitude. Energy of the transient was calculated as follows [13], [14]:

$$E_t = \int_{t_1}^{t_2} u_t^2(t) dt \approx \frac{1}{f_s} \cdot \sum_{k_{t1}}^{k_{t2}} u_k^2 \quad (1)$$

where: $u_t(t)$ - impulse signal, t_1 - start of impulse, t_2 - end of impulse, f_s - sampling frequency, k_{t1} - first sample of the transient impulse, k_{t2} - last sample of the transient impulse.

The analyses were carried out for various frequency bands (in the range from 200 to 50000 Hz). There were two stages of research. Firstly, the research consisted in changing a upper cut-off frequency of band-pass filter with constant lower cut-off frequency equal to 200 Hz. Secondly, it consisted in changing a lower cut-off frequency of band-pass filter with constant upper cut-off frequency equal to 50 kHz. The results are presented in relation to respective values calculated for the maximum considered frequency band 200-50000 Hz. It means that the value calculated for the whole frequency band is 100%.

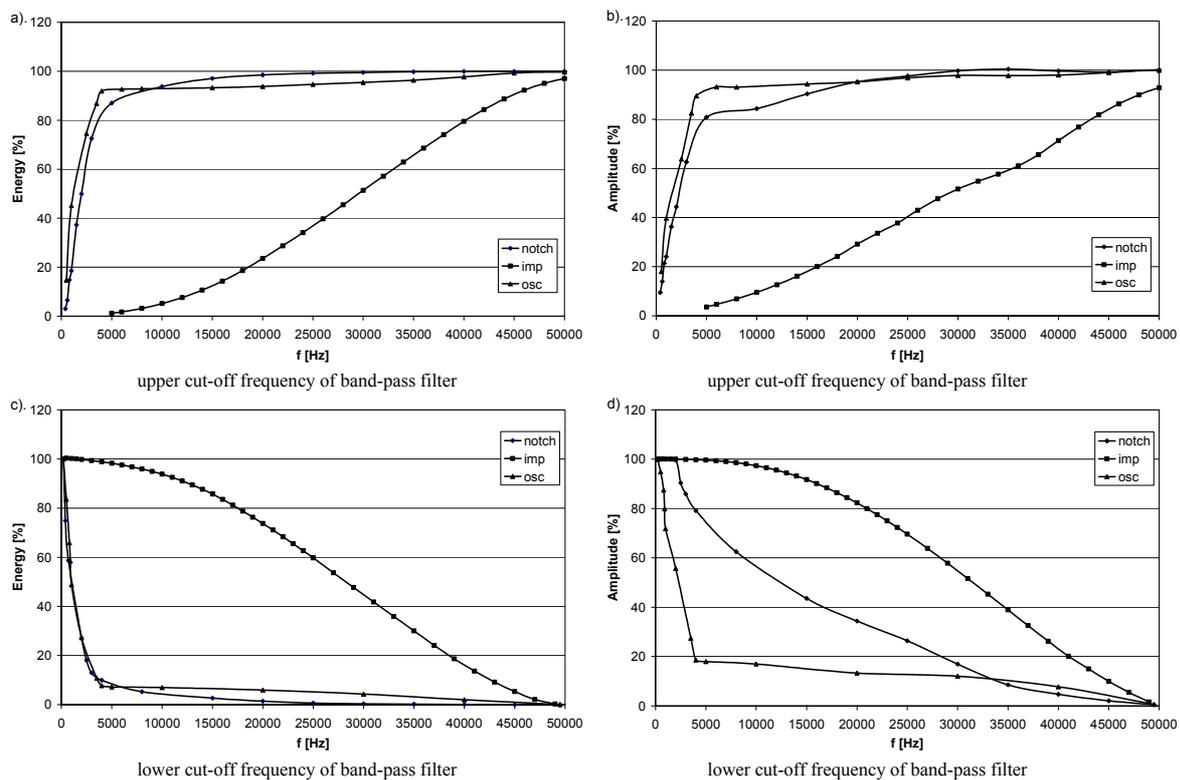


Fig. 2. Results of selected disturbances analysis after band-pass filtering with various corner frequencies: a). – b). values of impulses energy and amplitude measured with constant lower cut-off frequency of band-pass filter equal to 200 Hz and various upper cut-off frequencies; c). – d). values of impulses energy and amplitude measured with constant upper cut-off frequency of band-pass filter equal to 50 kHz and various lower cut-off frequencies

It is discernible that wrong choice of frequency band have adverse influence on the results of evaluation of selected disturbances parameters. For instance, disturbances such as impulsive transients (marked in this paper as a *imp*) requires analysis over wider frequency band than the band used during described research. In particular, the upper limit of the frequency band should be much higher than the cut-off frequency of applied antialiasing

filter, which equals to 50 kHz. But it seems that lower limit of the analysed frequency band equal to 10 kHz should be sufficient.

In the case of other two examples a frequency band up to 5-6 kHz is sufficient for proper evaluation of parameters of such disturbances like notching and low frequency oscillatory transient. But they require a significantly lower value of lower limit of considered frequency band. These two categories of transients and notching are the most frequently encountered in ship networks.

B. Wavelet decomposition

There are a few methods in dealing with discussed phenomena, e.g. subtracting the prevent steady-state waveform, high-pass filtering or notch filters [3]. However, it has been mentioned above that the often used tool for the phenomena analysis is DWT. Fortunately, the tool has some distinct advantages. DWT can be used concurrently for data compression [15], [16] or it diminishes a demand for DSP resources, by improving performance of methods of other parameters assessment. In Ref. [10] the original method of combined application of DWT and Fourier transforms for harmonics measurement was described. In shorthand, the method consists in application of tools for calculation of coefficients in Fourier series to wavelet coefficients representing lower frequencies. Since the wavelet coefficients are decimated after each decomposition stage, this method results in decrease of overall computational complexity.

Further, the method enables saving a needed RAM memory. Transients usually contain high frequency components from few hundred Hz up to a few MHz but their duration is up to 50 ms [1]. In real cases the transient duration is even lower. During abovementioned research, all observed transients lasted no longer than half cycle. But according to IEC Standard 61000-4-7, low frequency phenomena should be analysed on the basis of 10/12 (harmonics) or 5/6 cycles (from harmonic of 40th or 50th order up to 9 kHz) [4]. So, a information about low frequency components must be preserved for approximately 100 ms or 200 ms. It would be enormous burden in the case of high sampling frequencies required for transient analysis, if original signal samples would be stored. Fortunately, wavelet coefficients are decimated after each decomposition stage and only the coefficients representing lower frequencies should be preserved for the whole measurement window for low frequency parameters measurement. Then, the wavelet coefficients representing different frequency bands can be preserved for different time intervals. This results in saving RAM memory. E.g. authors of the paper developed the new measurement instrumentation called estimator-analyzer of power quality [12]. The device operates with constant sampling frequency equal to 148917.8 Hz. Due to application of discussed method, the requirement for RAM memory needed for data storage was reduced five times.

The wavelet decomposition of *imp* and *osc* signals were shown in Fig. 3 and Fig 4 respectively. In particular, Daubechies filters with 10 coefficients were used.

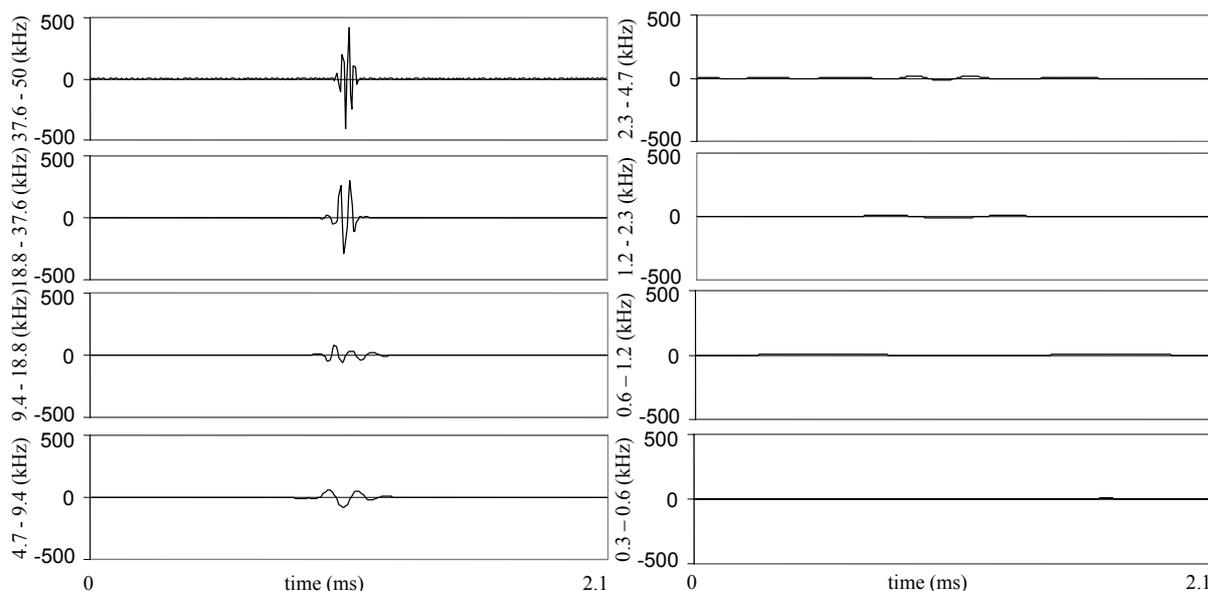


Fig. 3. Wavelet decomposition of the impulsive transient *imp* into eight frequency sub-bands

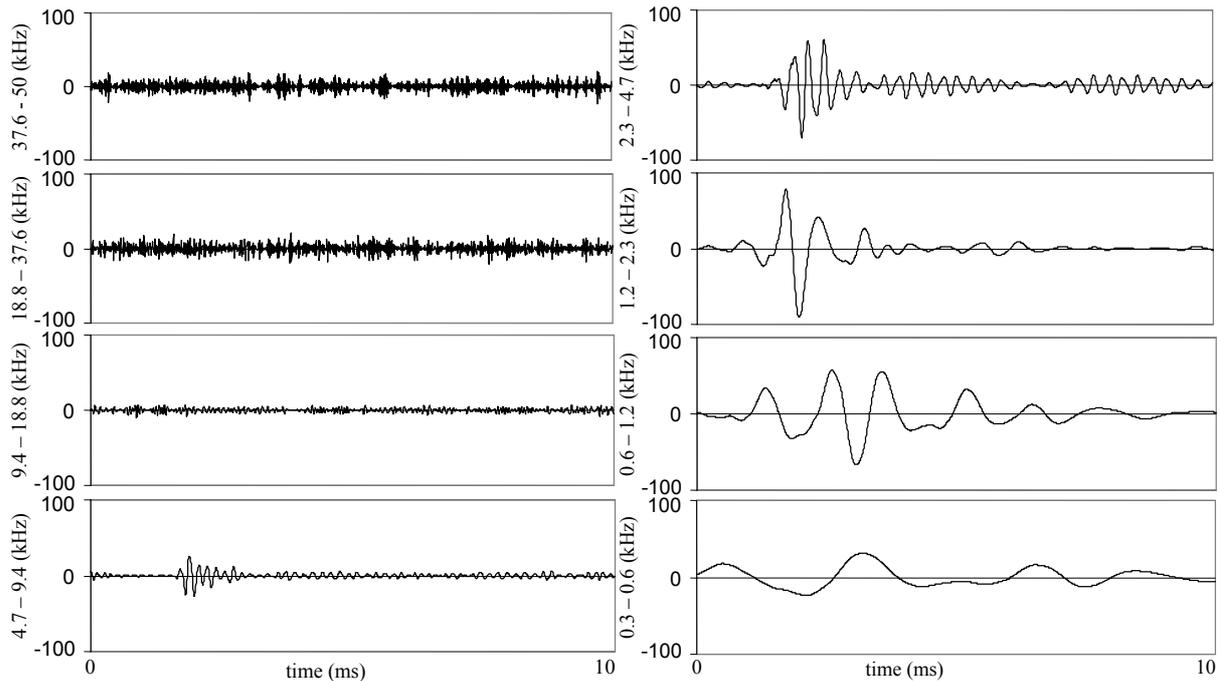


Fig. 4. Wavelet decomposition of the oscillatory transient *osc* into eight frequency sub-bands

The results presented in Fig. 3 confirm previous conclusions that the investigated impulsive transient contains high frequencies. In practical terms, only the wavelet detail coefficients from first and second decomposition stages are required for the case rough assessment. The opposite is true for the oscillatory transient (see Fig. 4). Its rough assessment requires at least seven stages of wavelet decomposition, although detailed analysis of the wavelet coefficients from fourth to seventh decomposition stage seems enough.

C. Estimator-analyser of power quality – exemplary results of research

The above-mentioned estimator analyser of power quality is a multi-parameter measurement device. The device determines power quality parameters defined in the respective IEC standards [4], [17]. But it is capable of transient detection and evaluation as well. Its sampling frequency is 148917.8 Hz and the cut-off frequency of used antialiasing filters is 60 kHz. Following transient parameters are recorded for each basic measurement window (equal to 10 cycles of the input signal): number of impulses detected during the window, sum of all impulses energy ΣEn , their combined duration Σt , maximum peak-to-peak magnitude of singular impulse V_{p-p} and maximum energy of singular impulse $maxEn$. The transients are detected and extracted by means of DWT. Further two threshold were applied for extracted impulse samples: first for the samples absolute values and second for differences of two consecutive samples. Details of the algorithm were described in Ref. [9]. The device was investigated under laboratory conditions for several testing signals. For this paper purpose the results of investigation of a sinusoidal signal containing a one cycle triangle wave was described. Results of the above-listed parameters measurement and respective setting values were set out in Table I. For testing signal 1500 measurement were carried out. For the research a waveform arbitrary generator was used. Since the generator maximum output is ± 10 V, a voltage divider of measurement instrumentation was bypasses and setting values were re-calculated according to the voltage divider ratio.

Table I. Results of chosen transient parameters measurements; mean values μ , standard deviations σ , maximum registered value max and minimum registered value min.

	number of impulses				ΣEn (V^2s)				Σt (μs)				V_{p-p} (V)			
	μ	σ	max	min	μ	σ	max	min	μ	σ	max	min	μ	σ	max	min
Setting value	10	-	---	---	399	---	---	---	3727	---	---	---	1098	---	---	---
Results of measurement	10	0	10	10	387	0.83	388	385	3690	8.1	3720	3666	1099	1.9	1103	1093

The analysed transient contains frequencies above 2.6 kHz and obtained results seem satisfactory. Unfortunately, results gradually worsens for transients containing components below 1 kHz, although seven wavelet decomposition stages were utilized. Probably, the problem concerns assumed thresholds values. It will be investigated in a future research.

IV. Final remarks

Various transient and notching disturbances have different frequency characteristics. In the case of *notch* and *osc* examples more wavelet signal decomposition stages are required in order to properly evaluate these phenomena parameters. But applied sampling frequencies have not to be especially high. However, high sampling frequency is required for impulsive transient estimation. Unfortunately, higher sampling frequencies create large number of samples, which have to be analysed. It consumes a lot of resources of used digital signal processor DSP, especially computational power and RAM memory. Such high sampling frequencies are needless for another power quality parameters measurement. Therefore many commercial power quality analysers use rather low sampling frequencies, despite a constant progress in digital signal processor technique. These power quality analysers have only limited capacity for proper transient assessment or sometimes even detection.

However, an application of appropriate algorithms for all power quality measurements can improve a measurement instrumentation performance in terms of computational complexity and requirement for RAM memory. Such algorithms were proposed by the authors [10], [11] and positively implemented in the new instrumentation for power quality assessment. Time of computation of parameters in low frequency range up to 9 kHz (as defined in IEC Standard 61000-4-7 and IEC Standard 61000-4-30) concurrently with transient monitoring did not exceed 41 ms for one phase signal and 200 ms measurement window. (Core clock of used digital signal processor is 333 MHz). So, some spare computational power remained for further device development, e.g. increase in sampling frequency.

References

- [1] IEEE Std. 1159-1995. IEEE Recommended Practice for Monitoring Electric Power Quality.
- [2] J. Arrillaga, N. Watson., S. Chen, *Power system quality assessment*. John Wiley & Sons Ltd, 2000.
- [3] M. H. J. Bollen, I. Y. H. Gu, *Signal processing of power quality disturbance*, Wiley-Interscience 2006.
- [4] IEC Std. 61000-4-7:2002. *General Guide on Harmonics and Interharmonics Measurements for Power Supply Systems and Equipment Connected Thereto*.
- [5] P. Bilik, J. Zidek, "PC Based Power Quality Analyser – Suite of SW and HW Products for Power Quality Monitoring", *Proceedings of 8th Electrical Quality an Utilisation Conference*, 21-23 September 2005, Cracow, Poland, pp. 261-265.
- [6] P.M. Ramos, T. Radil, F.M. Janeiro, A. Cruz Serra, „DSP Based Power Quality Analyser using New Signal Processing Algorithms for Detection and Classification of Disturbances in a Single-phase Power System”, *Metrology and Measurement Systems* vol. XIV, no 4, 2007, pp. 483-494.
- [7] S. Santoso, W. M. Grady, E. J. Powers, J. Lamoree, S. C. Bhatt, "Characterization of Distribution Power Quality Events with Fourier and Wavelet Transforms", *IEEE Trans. on Power Delivery*, vol. 15, no 1, January 2000, pp.247-254.
- [8] L. Angrisani, P. Daponte, M. D'Apuzzo, A. Testa, "A measurement method based on the wavelet transform for power quality analysis," *IEEE Trans. PowerDelivery*, vol. 13, Oct. 1998, pp. 990-998.
- [9] T. Tarasiuk, M. Szweda, "A few remarks about notching analysis - case study". *Proceedings of 13th IMEKO TC4 International Symposium*, Greece 2004, pp. 504-509.
- [10] T. Tarasiuk, "Hybrid Wavelet-Fourier Method for Harmonics and Harmonic Subgroups Measurement – Case Study", *IEEE Trans. Power Delivery*, vol. 22, No 1, pp. 4-17, January 2007.
- [11] T. Tarasiuk, "The Method Based on Original DBFs for Fast Estimation of Waveform Distortions in Ship Systems – Case Study", *IEEE Trans. Instrum. Meas.*, to be published.
- [12] T. Tarasiuk, "A few remarks about assessment methods of electric power quality on ships – present state and further development", *Measurement, Elsevier*, doi:10.1016/j.measurement.2008.02.003 , to be published, available on-line at www.sciencedirect.com.
- [13] Szabatin J.: *Podstawy teorii sygnałów*. WKŁ, Warszawa 2000 (in Polish).
- [14] J. Mindykowski, T. Tarasiuk, "Ocena jakości energii elektrycznej w okrętowym systemie elektroenergetycznym – metody i narzędzia". *Electrical Power Quality and Utilization*, vol. 8, no. 1/2, 2002, pp. 53-62 (in Polish).
- [15] S. Santoso, E.J. Powers, W.M. Grady, "Power Quality Disturbance Data Compression Using Wavelet Transform Methods", *IEEE Transactions on Power Delivery*, Vol. 12, No. 3, pp. 1250-1257, July 1997.
- [16] E.F. Hamid, Z.I. Kawasaki, "Wavelet-Based Data Compression of Power System Disturbances Using Minimum Description Length Criterion", *IEEE Transactions on Power Delivery*, Vol. 17, No. 2, pp. 460-466, July 2002.
- [17] *Testing and Measurement Techniques – Power Quality Measurement Methods*. IEC Std. 61000-4-30, 2003.