XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

IN THE SEARCH OF THE EFFECTIVE ASSESSMENT METHOD OF ELECTRIC POWER QUALITY ON SHIPS

Tomasz Tarasiuk[1], *Janusz Mindykowski*[2]

[1,2]Gdynia Maritime University, Department of Ship Electrical Power Engineering,
Gdynia, Poland,
[1]totar@am.gdynia.pl
[2]janmind@am.gdynia.pl

Abstract: This paper concerns the problem of proper evaluation of power quality in naval networks. Two aspects of the problem have been addressed. Firstly, the appropriate choice of power quality parameters for the aim has been discussed. Secondly, the methods of their estimation especially concerning aggregating of measurement intervals have been discussed. These considerations will be based on the basis of the original authors' research carried out in ship electrical power systems and relevant examples from this work will be given. Presented paper is a continuation and complementary part of the earlier works carried out by the same authors [1], [2].

Keywords: electric power quality, ship electric power systems, methods of measurement.

1. INTRODUCTION

The proposed paper concerns the problem of electric power quality. It is based on authors' original research of the current state of power quality on ships and current practice in dealing with the problem, or rather lack of a comprehensive approach. During the above-mentioned research all known kinds of the power quality disturbances have been observed. In particular a notorious supply voltage quality deterioration has been noticed. The voltage dips, voltage and frequency deviations, voltage unbalance, harmonics and interharmonics, transients and notching, all are present in ship's networks. These disturbances could affect the ship exploitation processes by inducing additional operational cost or diminishing ship safety. On the other hand, the proper recognising of the power quality problem increases a predictability of the malfunction or failure of important electrical energy receivers and systems and at the same significantly contributes to the marine safety improvement. So, the problem of the electric power quality should be taken into account when designing the ship's electric power system and afterwards during the system exploitation.

At the same time there are simple and relatively cheap tools for the discussed phenomena evaluation, based on the digital signal processing technique. So, the above-mentioned disturbances should be controlled and can be controlled during ship exploitation. But a few obstacles persist. The evaluation of the current state of electrical power quality has to be done during the different stages of vessel operation by her crew and during the periodical classification surveys. The consequences of misinterpretation of a measured information can prove fatal for ship operation as the whole. The best method of such misinterpretation avoiding is to evaluate the given parameters of electrical power against set of the reference parameters. However, such a set of reference parameters hardly exists in the field of the marine engineering. Obviously there are rudimentary requirements in the rules of ship classification societies or some IEC rules lately but these are obsolete or of any use at least. They do not deal with some existent in reality and easy-to-measure phenomena or impose improbable strict permissible level for some disturbances. So the rules of ship classification societies should be completed and amended. It is worth to add, that some new proposals were formulated and included in the current rules of Polish Register of Shipping [3].

To make matter worse, there are any rules concerning methods of respective parameters measurement in ship systems and the relevant IEC standards [4], [5] have not been mentioned in rules of ship classification societies. Moreover, some methods laid in above mentioned IEC standards should not be applied in ship networks, for example the analysis of previously carried out by the authors led to the conclusion, that only the method of frequency measurement should be discarded altogether [2], because IEC 61000-4-30 standard frequency definition is entirely inconsistent with the with the requirement of duration of short-term frequency deviation under ship conditions.

In the presented paper the authors' proposal of the problem solution and some guidelines for dealing with power quality is laid, mainly referring to the problem of power quality parameters under steady-state and non-steady-state conditions, defined by appropriate rules. The authors are convinced that different time of aggregation should be taken into account, dependently on the task and conditions of power quality indices.

2. SET OF REFERENCE PARAMETERS

According to IEC 61000-4-30 Standard [4] the term “power quality” means “characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters”. So, a defining such set of reference parameters is basic task when dealing with problem of electrical power quality in given electrical system. In the authors’ opinion, concerning ship systems the best try till now is IEC Standard 60092-101. *Electrical installations in ships. Definitions and general requirement* [6]. In this standard many power quality parameters have been defined but many ambiguities have remained. As an example the problem of harmonic components and harmonic subgroups can be mentioned. The comparison of chosen harmonic components and corresponding harmonic subgroups for chosen voltage registered in ship network (Fig. 1) has been laid in Table 1 [1]. The results in this table are mean values of appropriate analysis carried out for 200 measurement intervals during steady-state conditions.

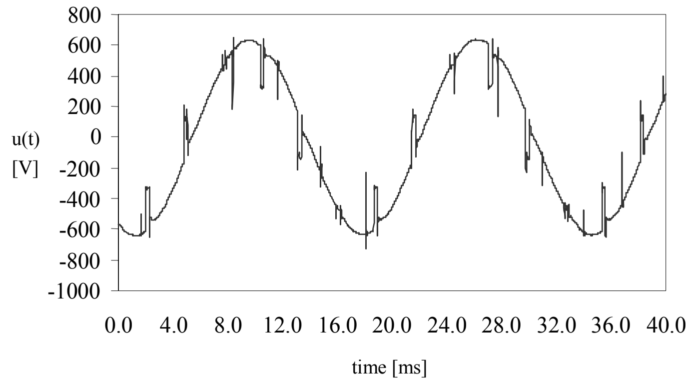

Fig 1. Exemplary voltage waveforms in ship systems of chemical tanker; notching in subsystem with rated voltage equal to 440 V, *THD* factor equal to 10.76%.

Table 1. Results of harmonic components and subgroups analysis

Harmonic component and subgroup order	Harmonic component [V]	Harmonic subgroup [V]
1st	435.98	436.04
5th	20.59	20.73
7th	18.35	18.56
11th	15.71	15.95
13th	15.39	15.75
17th	13.00	13.48
19th	13.29	13.93

Taking into account the results in Table 1, one can discern that the impact of phenomena of spectrum leakage to adjacent bins. It is due to the very features of ship systems, namely voltage and frequency significant fluctuations. The effect of leakage relatively increases for harmonics of greater order. However, the method based on harmonic subgroups for waveform disturbance estimation seems the most useful in ship systems, it has not been mentioned in discussed standard [3], [6].

Another problem concerning the harmonic analysis is related to time of aggregation of measurement results of both, singular harmonics and their total measure expressed by THD coefficient. In the first case, the authors are convinced, based on their original research results, that for analysis of power quality indices behaviour during long duration under non-steady-state conditions the time of aggregation of measurement results of respective components should be many times longer than duration of basic measurement window but their limit value should be lower than in the case than for short-time observation. The current IEC standard for ships does not address the matter [6]. Finally, the authors suggested for newly elaborated rules of Polish Register of Shipping to assume limit of short-time values for considered harmonics and THD coefficient as 150% of those values corresponding to aggregated values for 10-minutes time intervals. It corresponds to one of proposed the aggregation time intervals laid in IEC standard 61000-4-30, which can be understood as the square root of the mean of the squared input values [4]. The input values are the values of respective parameters calculated for basic measurement windows. The proposal has been accepted by respective body of Polish Register of Shipping.

To illustrate a relation between a value of respective parameters and a time of aggregation of measurements results, some examples are shown and discussed below. The analysis has been carried out for the voltage registered in ship network (Fig. 2) of vessel with electric propulsion system equipped with two PWM converters.

a)

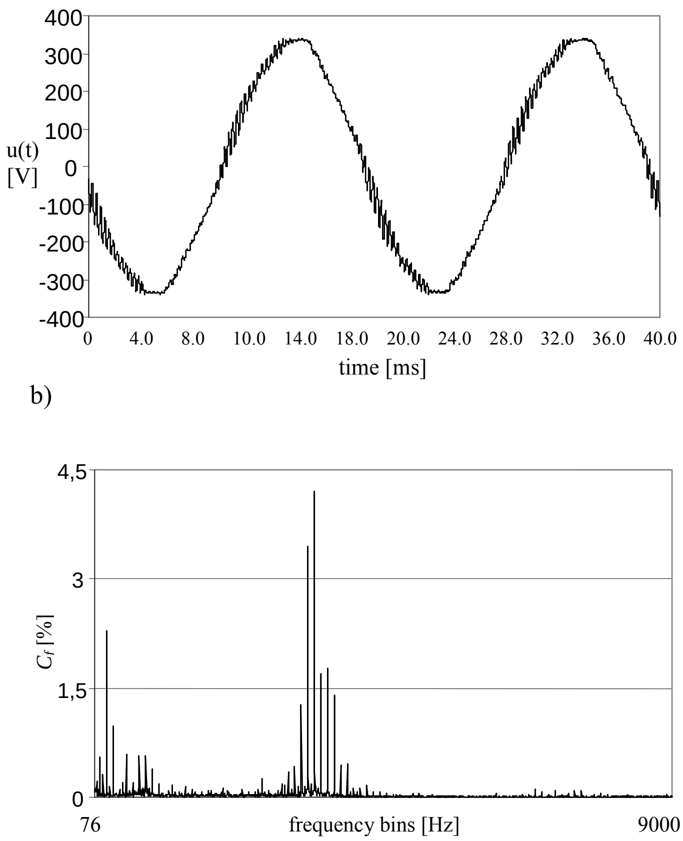

Fig. 2. Exemplary voltage waveform (a) registered in ship electric power subsystem with rated voltage equal to 230 V and rated frequency equal to 50 Hz and corresponding spectrum (b)

The waveform distortion has varied significantly during observation period. Although the prevailing components have remained the very same, but their magnitudes have changed. To exemplify the phenomenon, the variations of high frequency component of approximately 3360 Hz (dominant component) has been chosen for detailed analysis. However, the adjacent frequency bins have been taken into account as well. Namely, the group of this component has been calculated by following formula:

$$GC_{3360} = \sqrt{\frac{C_{k-5}^{2}}{2} + \sum_{i=-4}^{4} C_{k+i}^{2} + \frac{C_{k+5}^{2}}{2}} \qquad (1)$$

where: GC_{3360} – group of the 3360 Hz component, k=663.

The mean value of voltage frequency has assumed value equal to 50.67 Hz during observation period. The measurement has been carried out at sea voyage as well as manoeuvring of the ship.

The GC_{3360} group has been calculated in similar way like harmonic groups according to IEC 61000-4-7 standard [5], albeit the very frequency is not harmonic frequency in usual meaning. The distortions in frequency band in proximity of 3360 Hz have been caused by switching of the PWM converters harnessed for ship propulsion drives. Nevertheless, the method have been applied for minimising the influence of system frequency fluctuation during measurement period (approximately 25,5 minutes).

The results of the analysis has been shown for 3 different times of measurement: 10-period measurement windows as well as aggregated values for 150 periods and 10-minutes. In the last case (10-minutes) the aggregated value has been refreshed each 10-period measurement window. The results of such an analysis has been shown in Fig. 3.

Other problems like: interharmonics,, lack of unbalance definition, problem of simultaneous different disturbances occurrence [7] and especially imprecise THD definition seems also very important in the context of power quality assessment on ships. Especially, the latter problem (THD definition) is interesting since the authors have found out that typical THD definition do not enable correct or even rough evaluation of all cases occurred in ship systems. The problem of appropriate definition of total harmonic distortion factor THD, it means traditional approach based on a sum of higher harmonics up to 50-order versus formula covering whole spectrum up to 9 kHz (including subharmonics and interharmonics as well) has been presented in the work [2]. But the definition of THD does not close the matter because the problem of time intervals of aggregation is also very important, especially in the context of the threshold values of power quality parameters under steady-state and non-steady-state conditions, respectively. To show relation between an interval of aggregation and the value of defined quantity some examples concerning the THD determining are shown in Fig. 4. The aggregation intervals are the very same like in the case of 3360 Hz component, it means 10-cycles, 150-cycle and 10-minute refreshed each 10-cycle measurement window.

a)

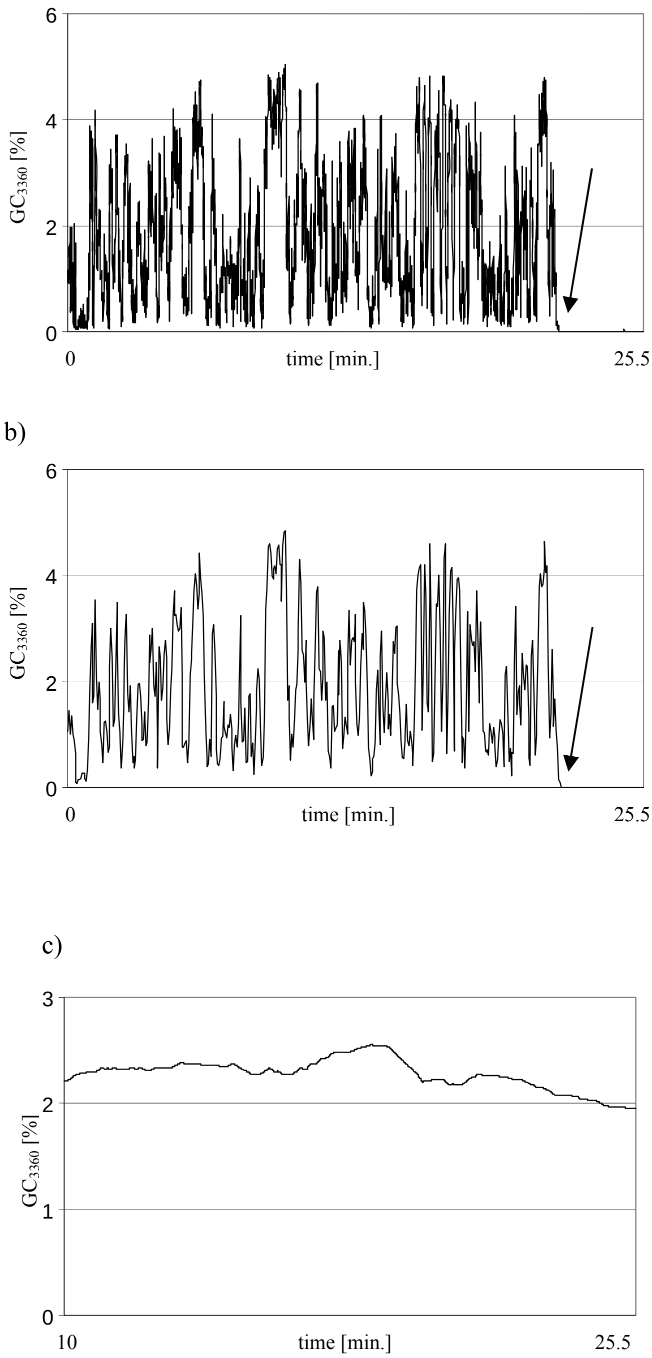

Fig. 3. Fluctuations of group of 3360 Hz component during sea voyage and ship manoeuvring: values measured for 10-periods (a), aggregated 150-period values (b), aggregated 10-minutes values (c); the arrow marks the moment of switching ship electric propulsion off

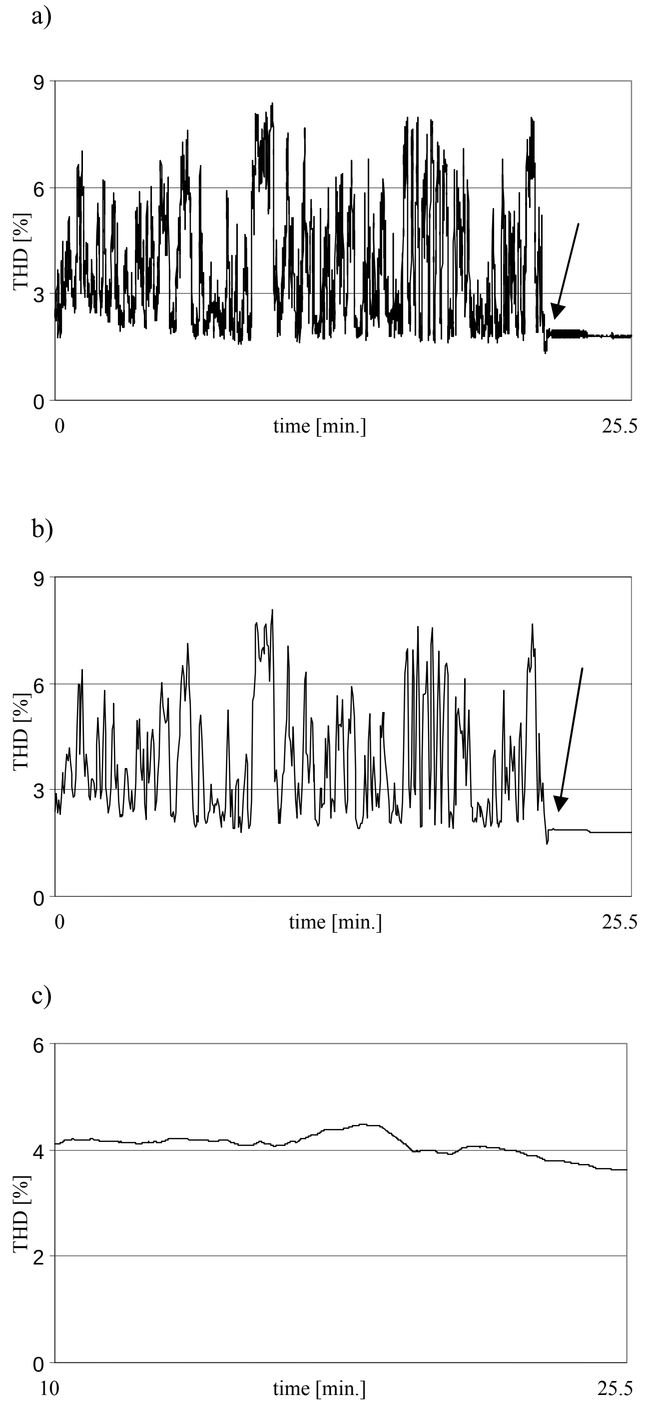

Fig. 4. Fluctuations of THD coefficient during sea voyage and ship manoeuvring: values measured for 10-periods (a), aggregated 150-period values (b), aggregated 10-minutes values (c); the arrow marks the moment of switching ship electric propulsion off

Careful analysis of presented examples lead to conclusion that in the considered ship system higher frequency components can vary significantly. These changes concern not only relatively short-time analysis for approximately 200 ms time span, but the aggregated values for 150-period time intervals have changed in similar scope and span. However, is has been quite different story for 10-minutes aggregation time. In this case the value of considered component has varied only slightly. So, the above mentioned amendment of Polish Register of Shipping rules seems justified.

It is worth noting that the observed waveform distortion occurred only when the ship electric propulsion has been operating. It can be clearly discernible in Fig. 3a, Fig. 3b, Fig, 4a and Fig.4b where the switching the electric drives off has been marked by arrow.

3. METHODS OF POWER QUALITY PARAMETERS MEASUREMENT

Apart from proper definition of a set of reference parameters, the effective assessment method of electric power quality requires the clear definitions measurement techniques. However, such techniques have not been defined for ship systems. Moreover, the respective rules for ships have not refer to existing standards [4], [5]. In the authors' opinion, the best solution should be explicitly to apply methods defined in these standards with two exceptions.

The first exception concerns the method of frequency measurement. According to IEC 61000-4-30 Standard [4] "the fundamental frequency output is the ratio of the number of integral cycles counted during the 10-s time clock interval, divided by the cumulative duration of the integer cycles". But frequency values shall be obtained in relatively short periods of time in ship systems since its deviation from rated value shall be within the limit of ±10% during the time not longer than 5-s (the steady-state deviation should not exceed ±5%) [6]. The authors' proposal is to align the measurement windows for frequency observation with these for r.m.s. value of voltage measurement. It was be discussed on the basis of real examples from ship systems in the paper [2], when the authors have proposed to calculate frequency by two ways. Firstly, to calculate frequency as reciprocal of one cycle refreshed each half cycle for short-term frequency deviation analysis, similarly like the measurement of rms value of voltage $U_{rms(1/2)}$ for voltage dip and swell evaluation [4]. Secondly, to calculate frequency over basic measurement time interval [4] equal to 10 cycles for systems with rated frequency equal to 50 Hz and 12 cycles for systems with rated frequency equal to 60 Hz. The last option is to evaluate the steady-state frequency deviations.

Second exception is the methods of spectrum estimation. The suggested method is Fourier transform and rectangular window [5]. However, usually applied algorithm is Fast Fourier Transform FFT. The method should not be used in the case of ship systems, because it could lead to significantly flawed results [8]. The best solution seems ordinary Discrete Fourier Transform DFT, despite its greater computational complexity. A capacity of current digital signal processors e.g. ADSP 21364 enables such technique [9]. By the way, application of Hanning window is not a good solution as well and in some cases could lead to even worse results than rectangular window [8], [11]. The interesting solution seems the complementary application of wavelet transform and Fourier transform [10], [11]. It could be very efficient tool especially when the wavelet transform is to evaluate transients and/or notching concurrently. It is often applied for the task [12].

Finally, the authors have proposed following solutions concerning mathematical tools within considered area:

- discarding FFT algorithm as a basic tool for spectrum estimation,

- implementing complementary application of discrete wavelet transform DWT and discrete Fourier transform DFT for time-efficient transient as well as harmonics detection and evaluation, although the FFT can be used in some limited cases.

4. FINAL REMARKS

The progress in the field of power quality assessment in ship networks has been observed. But some ambiguities and prominent omission persist. The authors have introduced some proposals to amend these shortcomings. The proposals have been mainly based on original authors' research carried out in ship systems for quite a few years. Especially, the specific features of ship systems have been taken into account. These proposals are to avoid the ambiguities and should lead to increased safety of ship networks exploitation.

Summing up, the authors have proposed for ship systems following solutions:

- defining new measurement time intervals for frequency estimation,

- improving THD definition,

- defining different time of aggregation and threshold (limit) values for power quality parameters under steady-state and non-steady-state conditions respectively,

- introducing more parameters for transient and notching evaluation and to take into account only harmonic subgroups (instead of harmonic components),

- practically discarding FFT algorithm and introducing complementary application of both discrete transform, wavelet DWT and Fourier DFT.

It should be also added that all methods of discrete Fourier transform estimation can be applied in the area of isolated power networks complementary with wavelet transform, depending on input signal character and attainable computational power of measurement device.

ACKNOWLEDGMENTS

This work was financially supported by The State Committee for Scientific Research, in Poland, in years 2004-2007 (Project No 3T10C02027)

REFERENCES

[1] J. Mindykowski, T. Tarasiuk "Power Quality Assessment in the Wake of Ship Technology Development", Proceedings of 14th IMEKO TC4 International Symposium, Poland, pp. 358-363, Gdynia/Jurata 2005.

[2] T. Tarasiuk, J. Mindykowski "How to Measure and Estimate the Power Quality Parameters in Ship Systems?", Proceedings of the 23th IEEE Instrumentation and Technology Conference, pp. 1608-1613, 24-27 April, Sorrento, Italy, 2006.

[3] Technical requirements for ship power converters. Polish Register of Shipping, Gdańsk, 2006.

[4] IEC Std. 61000-4-30 Electromagnetic Compatibility (EMC): Testing and Measurement Techniques – Power Quality Mesurement Methods.

[5] IEC, Std. 61000-4-7 "General Guide on Harmonics and Interharmonics Measurements for Power Supply Systems and Equipment Connected Thereto.

[6] IEC Std. 60092-101. *Electrical installations in ships. Definitions and general requirement.*

[7] P. Gnaciński, J. Mindykowski, T. Tarasiuk "Influence of electrical power quality on induction cage machine durability", Proceedings of 7th International Conference „Electrical Power Quality and Utilization", pp. 455-462, Cracow September 17-19,2003.

[8] T. Tarasiuk **"**Problems of Spectrum Estimation in Ships' Electric Power Networks", Proceedings of 8th International Conference „Electrical Power Quality and Utilization", pp. 241-246, Cracow September 21-23, 2005.

[9] Analog Devices ADSP 21364 SHARC Processor. Preliminary Technical Data.

[10] T. Tarasiuk "Hybrid wavelet-Fourier spectrum analysis", IEEE Trans. on Power Delivery vol. 19, No 3, pp. 957-964, July 2004.

[11] T. Tarasiuk "Hybrid Wavelet-Fourier Method for Harmonics and Harmonic Subgroups Measurement – Case Study", to appear in Trans. on Power Delivery (accepted for future publication).

[12] L. Angrisani, P. Daponte, M. D'Apuzzo, A. Testa, "A measurement method based on the wavelet transform for power quality analysis," IEEE Trans. Power Delivery, vol. 13, pp. 990-998, October 1998.