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# MEASUREMENT SYSTEM OF LOW FREQUENCY RANGE INTERFERENCE IN LOW-VOLTAGE POWER SUPPLY 50 Hz

***B. Palczyñska [1], L. Spiralski [2] and A. Konczakowska [2]***
[1] Gdynia Maritime Academy, ul. Morska 83, 81-225 Gdynia, Poland
[2] Technical University of Gdañsk, ul. Narutowicza 11/22, 80-952 Gdañsk, Poland

*Abstract: The following paper is a presentation of the digital system used for measuring interference in low frequency range that occurs in low-voltage power supply. It discusses how the hardware of the system, controlled by graphical programming environment LabVIEW v.4.0 National Instrument, has been realised. Furthermore, it presents basic functions, which the virtual part of the system performs. The paper gives special attention to the methods used in determining quantities, which describe deterministic as well as stochastic types of interference. Additionally, the paper defines the conditions deciding about inaccuracies of the evaluation of estimators.*
*Keywords: interference, virtual instrument, measurement of electrical quantities*

## 1 INTRODUCTION

By swapping particular parts of hardware with the blocks of signal processing and analysis of digital data, one can achieve effective decrease in inaccuracies in the evaluation of estimators of the measured quantities that describe interference.

In the presented system, the acquisition of measuring digital data is performed in accordance with the requirements accepted in defining factors, parameters and characteristics of interference in low frequency range in low-voltage power supply. Software of the measurement system allows multiple repetitions of calculation procedures as well as modification and altering processing algorithms. This is essential for the analysis of interference in very low frequency range, where determining estimators requires the signal observation time ranging from hours to days. But the digital signal processing depends exclusively on the speed of the processor located in the software part of the system.

Analogue-digital conversion is performed at high resolution, because of the much lower level of interference as compared with 50 Hz frequency signal.

Cut-off frequency of the analogue antialiasing filters used in the hardware part of the system changes according to the analysed frequency band. Such a solution enables us to analyse, with comparable inaccuracy, interference in many frequency decades [1].

## 2 DESCRIPTION OF THE SYSTEM

The measurement system contains two main parts (Figure 1): the hardware part (data acquisition block) and the virtual part (consisting of signal processing and analysing block and graphic interface block). The hardware part is responsible for converting the quantities of the measured waveform [2]. This involves proportional decrease of all the quantities of the waveform without changing its shape. The aim is to match the measured signal level with the input of optoisolation amplifiers - the amplifiers separate high voltage signal. The initial conditioning follows and is realised through the low-pass filter module (antialiasing). The formation of the output digital signal from the analogue signal takes place in the A/D converter with 16-bit resolution and sampling rate up to 20 kS/s. Using three channels at the same time allows the maximum sampling rate of 6,6 kS/s. This ensures the measurement of interference in the frequency band up to 2,2 kHz. The frequency of analysed interference was limited by the frequency of cutting-off antialiasing filters.

The dynamics (DR) of 16-bit A/D converter is:

$$DR = 20\log 2^{n} = 6{,}02n = 96{,}3\ \text{dB} \quad (1)$$

where n=16 is the number of converter bits.

The change of real values of the analogous course on the converter input with the use of the appropriate quantisation levels leads to errors. In case of ideal conversion the error will be steady in

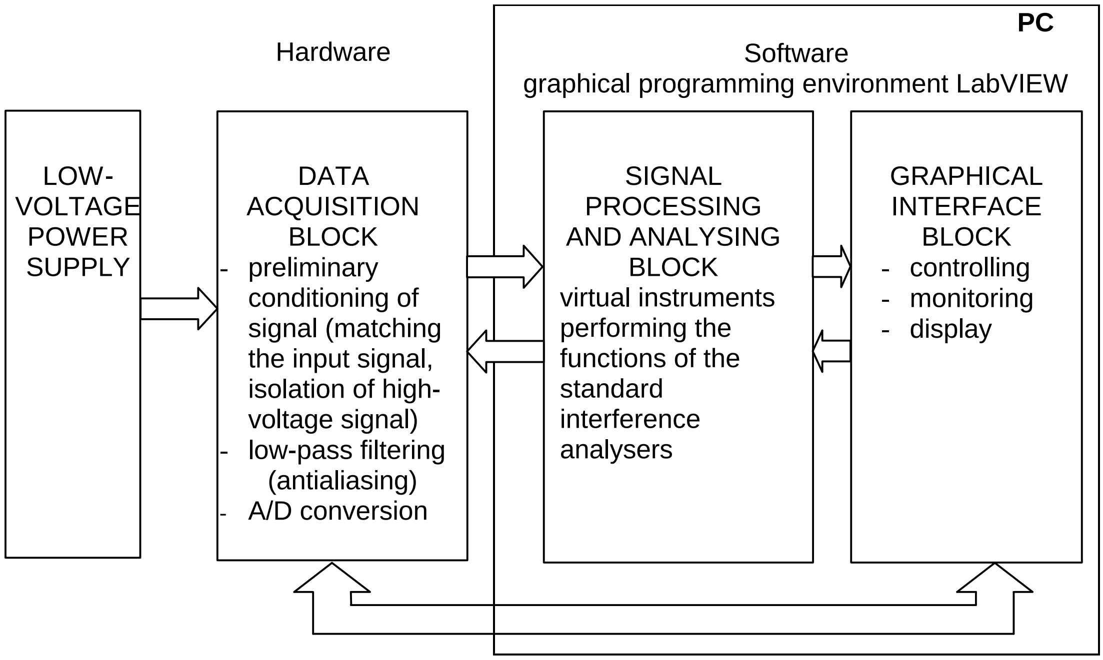


**Figure 1.** Block diagram of the digital measuring system of interference in low frequency range

the range *(-Q/2, Q/2)* with the standard deviation (*Q /12*) (where *Q* is the quantisation range). Thus, quantisation can be regarded as equal to the sum-up of input course x (t) with the independent noise n(t). Then, the percentage proportion of effective quantisation noise $Y_n$ to the rms value $Y_x$ of the waveform on the quantised input may be regarded as the quantisation error:

$$\frac{\Psi_n}{\Psi_x} = \frac{1}{2^n \sqrt{12}} \qquad (2)$$

The parameters connected with the accuracy card for the input voltage range ±10V are presented in the table 1.

**Table 1.** The accuracy of measurement card PCI-MIO-16XE-50 National Instruments [5].

| Absolute accuracy | | | | | | | Relative accuracy resolution [µV] | |
|---|---|---|---|---|---|---|---|---|
| % of reading | | | offset [µV] | Noise+quantization [µV] | | drift temp. [%/°C] | | |
| 24 Hrs. | 90 days | 1 year | | single pt. | averaged | | single pt. | averaged |
| 0,0058 | 0,0078 | 0,01 | 397,2 | 526,4 | 45,8 | 0,0002 | 602,7 | 60,3 |

The use of the 16-bit resolution card for the signal on input of the measurement system of a few hundreds V ensures the accuracy of the system on the level of several dozens mV.
Table 2 presents the measured noises level of the measuring process for three channels.

**Table 2.** The noises level of measuring process in bandwidth 0-2,2 kHz.

| No channel | DC offset [mV] | $V_{rms}$ [µV] |
|---|---|---|
| 0 | 175 | 270 |
| 1 | 231 | 400 |
| 2 | 44 | 260 |

The measured constant component (DC offset) results from the presence of offsets brought about by the isolating amplifiers in the set of preliminary conditioning of the system.

## 3 THE EVALUATION OF INACCURACY OF ANALYSED INTERFERENCE

The virtual part of the system is realised in graphical programming environment LabVIEW v.4.0 [6]. Signal processing and analysing block is responsible for performing functions of the standard interference measuring instruments and stochastic analyser. The sampled signal is processed in several virtual instruments, which are included in the main application as sub-VIs.

The software contains also the algorithms enabling the evaluation of inaccuracy of determined estimators depending on the observation time of the measured signal, linear range of the measurement system and frequency requirements of the system (Fig. 2). Interference are analysed in the following virtual instruments:

- THD.vi, which calculates total harmonic distortion THD, harmonic ratio (expressed as a percentage of the ratio of the rms value of a harmonic component of order n to the rms value of the fundamental component of the same wave).
- Flicker.vi, which determines the value of short-term $P_{st}$ and the long-term $P_{lt}$ flicker severity [3].
- Stochast.vi, which evaluates estimators of mean square (root-mean square) values, probability density function, probability distribution function taking instantaneous values, interference power spectral density, correlation function).
- Off-lineJTFA.vi, which performs joint time - frequency analysis.

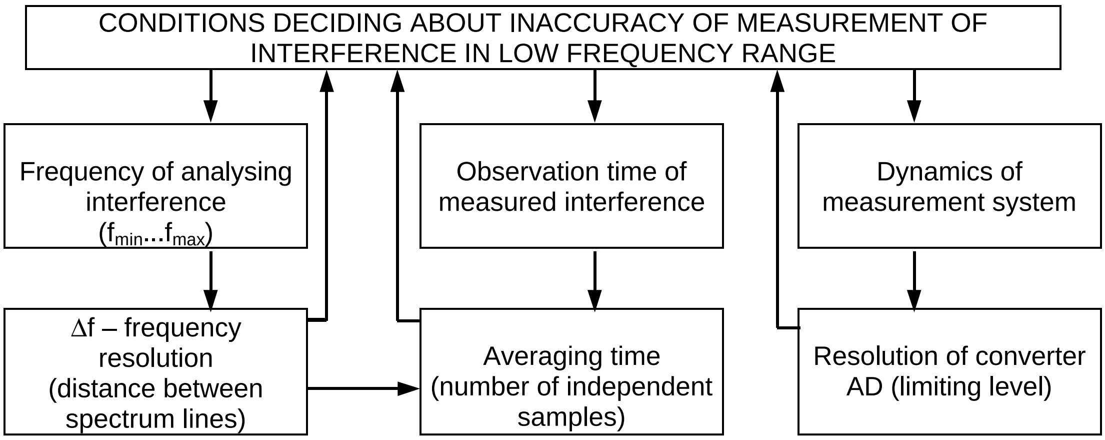


**Figure 2.** Basic conditions deciding about measurement inaccuracy of interference in low frequency range.

The frequency analysis was made with the use of FFT for the time frame of $N_r$=2048 samples. The data were multiplied by Hanna window function. The use of the time window causes FTT resolution to become worse (the relative bandwidth increases about 1,5 times). Because of the necessity to decrease the spectrum estimation errors (tab. 3), the calculated Fourier transforms complex components were averaged with the use of section averaging method ($q$=10).

In the analysis of stochastic parameters connected with the mean value and the mean square value, the statistic error of these values measurement depends on the independent number of samples $N$ (tab. 3).

## 4 EXEMPLARY RESULTS OF INTERFERENCE ANALYSIS

The measurement system was used for acquisition of measurement data in the ship switchboard of low voltage of frequency 50 Hz. Research was carried out on two different ships: ro-ro and ferry. Each ship contained three phase, three wire ship electrical power systems. The sources of electrical power were three-phase synchronic generators driven by auxiliary combustion engines diesel powered. Additionally, shaft generators were used; they were driven by the propeller shaft of the main engine. The characteristic feature of the electrical power networks of low voltage used on ships is that there must be two parallel electricity generating sets working during the ship’s manoeuvring and reloading operations when there is an increased demand for electrical power. The electrical power of a ro-ro type ship consists of two freestanding generators of 1000 kVA each and two shaft generators of 1500 kVA each. The nominal voltage on bus bars of the main switchboard was 400 V. the main difference between the ro-ro and ferry electrical power systems has been the number of freestanding generators. The ferry was equipped with three generators of this kind of 1400 kVA each. There were also two shaft generators of 1375 kVA each. The nominal voltage on bus bars of main switchboard was 380 V.

**Table 3.** The relative standard errors of estimating of mean, mean square value and power spectral density.

| Estimator | The relative standard error: correlated samples | The relative standard error: noncorrelated samples τ<<h |
|---|---|---|
| mean value: $\tilde{m}_x = \frac{1}{N}\sum_{i=1}^{N} x_k(ih)$ | $\frac{e}{m_x} = \sqrt{\frac{1}{Nm_x^2}[1+2\frac{C_x(ih)}{C_x(0)}]}$ | $\frac{e}{m_x} = \frac{s_x}{m_x}\frac{1}{\sqrt{N}}$ |
| mean square value: $\tilde{\Psi}_x^2 = \frac{1}{N}\sum_{i=0}^{N-1} x^2(ih)$ * | $\frac{e}{\Psi_x^2} = \sqrt{\frac{2}{N}[1+2\frac{C_x^2(ih)}{C_x^2(0)}]}$ | $\frac{e}{\Psi_x^2} = \sqrt{\frac{2}{N}}$ |
| power spectral density: $G_k = \frac{1}{q}[G_{k,1}+G_{k,2}+...+G_{k,q}]$ $\Delta f = \frac{q}{T} = \frac{q}{Nh} = \frac{1}{T_S}$ | $e_r = \frac{1}{\sqrt{q}}$ $q = N/N_r$ | |

*Assumption: mean value equal 0*

*$s_x$ – variance, $C_x(t)$ - covariance, $T_S$=$N_r h$ – time duration of time segment, $h$ - time interval between two successive samples, Df – the analysis resolution.*

Both ships were capable of generating the voltage of 220 V, and after transformation - 400 V and 380 V as well. The measurements were done in three modes: the ships were standing still, manoeuvring and sea sailing. The figure 3 presents frequency analysis of the signal of nominal voltage of 220 V.

The measurements were taken while the ferry was sailing at sea. The total harmonic distortion THD did not exceed 4 %.

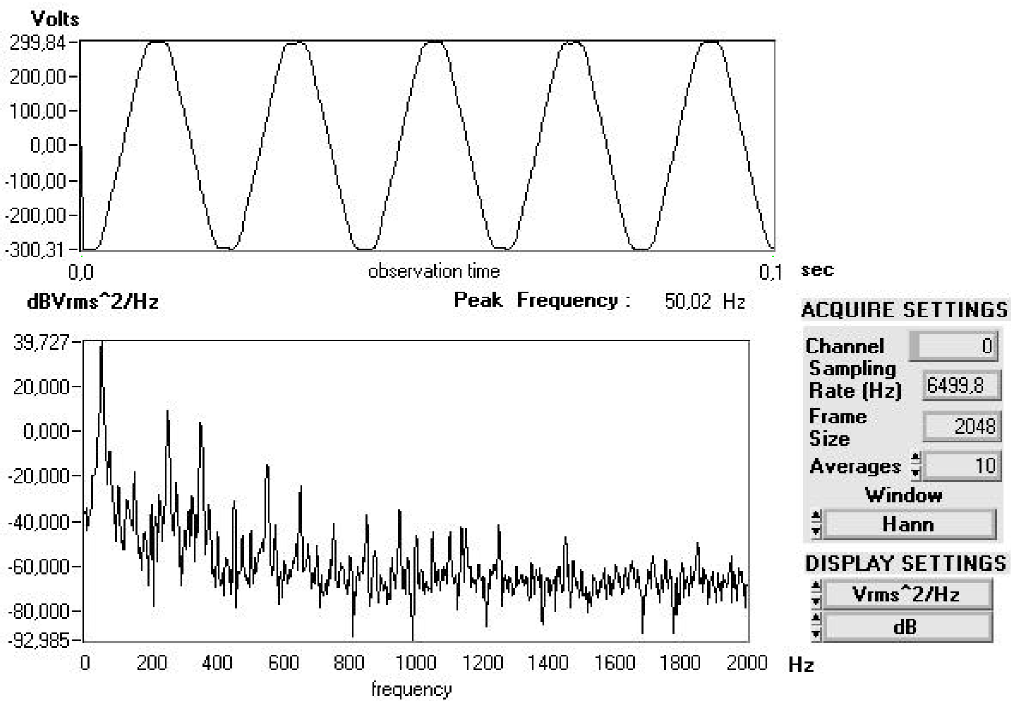


**Figure 3.** Time waveform signal and power spectrum density of the signal of nominal voltage 220 V.

Using the designed virtual device Flicker.vi, it was possible to make the analysis of the voltage changes in the switchboard that result in flickering of light luminance. The aim of flicker measurement is to assess a value expressing directly the degree of irritation of human beings caused by light flickering. Therefore, the voltage flicker is measured with respect to the sensitivity of a human eye. The instantaneous flicker sensation level S obtained on the output of virtual instrument [3] (included in Signal Processing and Analyzing Block of measurement system) was presented in Fig. 4.

The structure of a virtual flickermeter, corresponding to the existing standards, is responsible for performing the measurements, which are based on the simulation of the lamp-eye-brain behaviour. The absolute value of the instantaneous flicker sensation level is divided by the corresponding value of the perceptibility threshold in order to be expressed in terms of perceptibility units. On the ro-ro ship the short-term flicker sensation level of the voltage did not exceed the perceptibility threshold. On the other hand, the temporary considerable values of the instantaneous level of flicker sensation were observed on the ferry during overloads (Fig. 5). The final statistical evaluation calculates the short-term flicker severity level $P_{st}$, which directly expresses the degree of irritation, with $P_{st}$ =1 p.u. meaning the limit of disturbance (threshold of irritability). One Pst value is based on a short-term observation period (ten minutes) and calculates as the root sum of weighted percentiles of the instantaneous flicker sensation level.

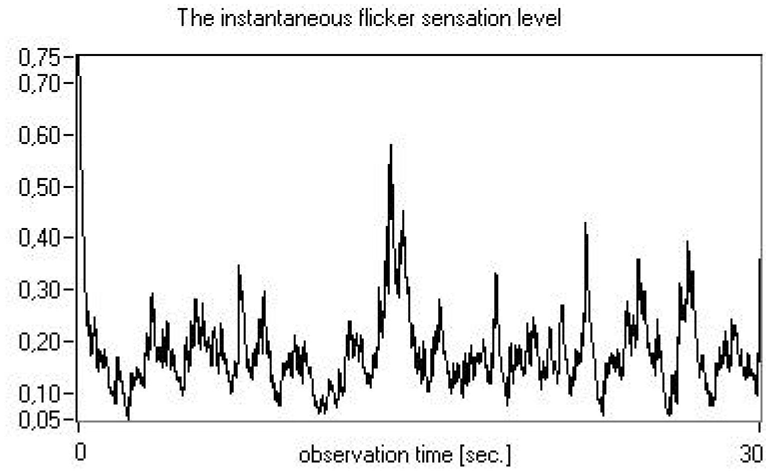


**Figure 4.** The instantaneous flicker sensation level in the 220 V network supplied by a shaft generator on a ro-ro ship.

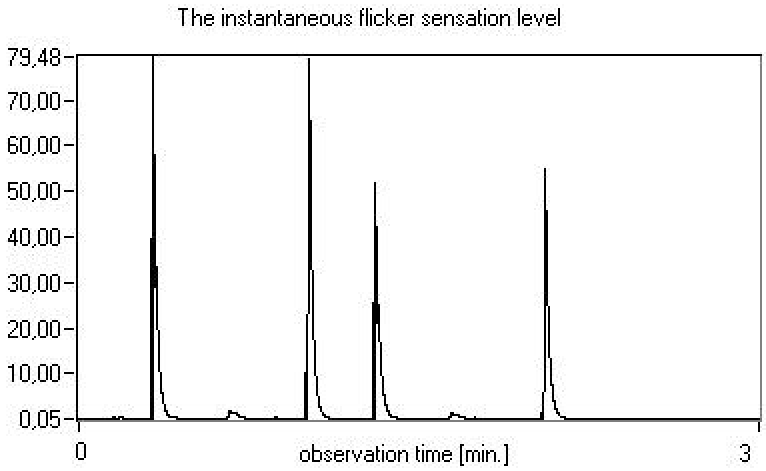


**Figure 5.** The instantaneous flicker sensation level in the network of a ferry ship during the bow thrusters operation [4].

The ship network is characterised by the fluctuations in effective values of voltage and frequency. This is caused by the work of non-calm receivers (characterised by sudden changes of great power), but also the necessity of parallel work of at least two generating systems while manoeuvring and reloading operations when there is a greater demand for electrical power. In result of the statistic analysis of the parameters obtained from the measurements on the ferry while manoeuvring in the network of the nominal voltage 380 V it was possible to determine the basic statistic parameters for rms voltage and frequency (tab. 4). The instantaneous values of rms voltage and frequency were obtain for time frame equal 2048 samples during 40 min. time observation.

**Table 4.** The statistic properties of rms voltage and frequency.

| Statistics | rms voltage | frequency |
|---|---|---|
| mean | 389,097 V | 49,778 Hz |
| standard deviation | 2,337 V | 0,044 Hz |
| skewness | -2,43 | 0 |
| kurtosis | 6,859 | 8,647 |
| mode | 382,39 V | 49,78 |

The corresponding the probability density functions of assuming instantaneous values are presented in Fig. 6.

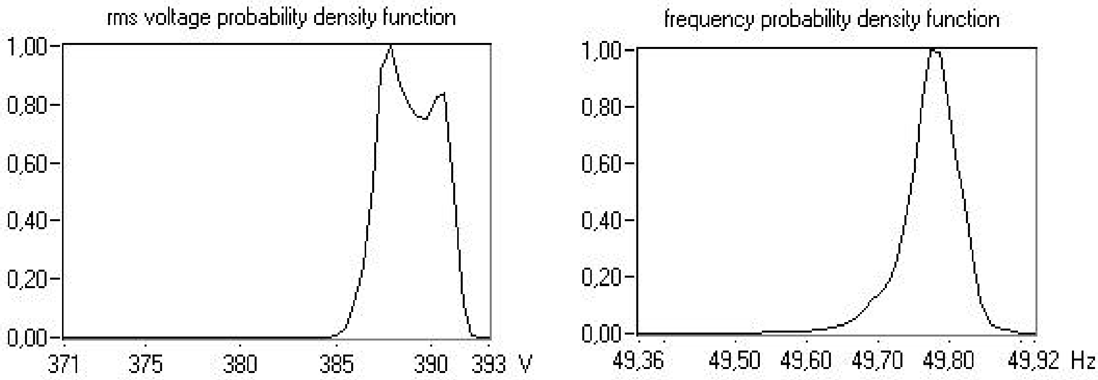


**Figure 6.** The probability density functions of rms voltage and frequency in the network of 380 V while the ferry was manoeuvring.

## 5 SUMMARY

The paper contains the exemplary results of interference analysis occurring in low voltage power supply of ships, obtained with the use of the presented system. A completely different problem is the detailed inaccuracy evaluation of the determined parameters taking into account the measuring method errors and the errors resulting from processing (analysis) of the signal. This instrument after slight modifications, especially in the hardware part, can be applied to measure and estimate signals, noises, conducted and radiated interference, which occur in various electrical and electronic devices.

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**AUTORS:** B. PA£CZYÑSKA, Gdynia Maritime Academy, Department of Marine Radio Electronics, Morska 83, 81-225 Gdynia, Poland, Phone +48 58 6289552, Fax +48 58 6217353
E-mail: palbeata@wsm.gdynia.pl
L. SPIRALSKI and A. KONCZAKOWSKA, Technical University of Gdañsk, ul. Narutowicza 11/22, 80-952 Gdañsk, Poland, E-mail: kapsz@sunrise.pg.gda.pl