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A measurement method of voltage properties on main switchboard busbars - tools and preliminary results

SUMMARY

In this paper preliminary and exemplary results are presented of voltage analysis on busbars of the main switchboard. Special attention was paid to voltage and its frequency deviation from their nominal values as well as to different voltage waveform distortions. The research contains measurement results of two electrical power systems : of a ro-ro ship and ferry ship. The analysis was carried out off-line on the basis of voltage samples from different states of ship exploitation. The analyzed electrical power systems and measurement devices are also described.

INTRODUCTION

An appropriate quality of supply voltage on main switchboard busbars of the ship electrical power system is necessary for correct operation of the entire ship. Therefore the quality significantly contributes to ensuring the safety to ship and human life as well. The voltage quality can be described by its properties such as: rms value, frequency and waveform distortions. These properties should be taken into account during steady state and non-steady-state periods. Especially waveform analyses enable to detect and estimate determined and stochastic interference occurring in the electrical power systems. So far proper estimation of voltage quality is practically impossible because of lack of suitable measurement devices. However the development of microprocessor technique enables to increase quantity and quality of measurement information. Usefulness of this technique was tested during computer simulation [1]. The next research stage was to analyze real-life signals.

The presented analysis was carried out on the basis of voltage samples. The off-line mode was chosen to get better precision. This made it possible to apply different conversion methods in post-measurement stage.

ELECTRICAL POWER SYSTEMS UNDER CONSIDERATION

The research was carried out on two different ships: a ro-ro and ferry ship. Each of the ships had a three-phase, three-wire electrical power system. The electrical power plants of both systems consisted of free-standing generating sets and shaft generators. The configuration of the ro-ro ship electrical power system is sketched in Fig.1.

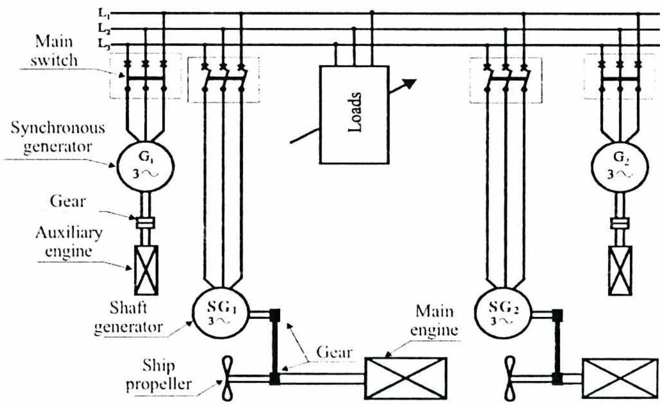

Fig.1. The electrical power plant configuration on the ro-ro ship

The system consisted of two free-standing generators of 1000 kVA each and two shaft generators of 1500 kVA each. The nominal voltage on the main switchboard busbars was 400 V at 50 Hz frequency. 220 V voltage was obtained by means of a transformer. During manoeuvring and re-loading operations the two free-standing generators were used. During sea voyage a single shaft generator was used as well as during manoeuvring as the energy source for bow thruster. As the bow thruster was supplied from the separate energy source, its influence on the remaining electrical power system can be omitted. Each of the shaft generators could not work in parallel with other electrical energy sources, excluding short switching period (roughly 2 seconds). The shaft generators were connected to the remaining system only by means of a simple circuit breaker. It was possible due to appropriate adjusting the screw propellers in operation.

The main difference between the above described electrical power system and that of the ferry ship was the number of free-standing generators. The ferry ship was equipped with three 1400 kVA generators and two 1375 kVA shaft generators. The nominal voltage on the main switchboard busbars was 380 V at 50 Hz frequency. The free-standing generators served as the main electrical energy source. Parallel work of each shaft generator with the free-standing generators was possible, especially during calm sea voyage. Additionally, each of the bow thrusters was supplied from one shaft generator, usually in a configuration separated from the main electrical power system.

MEASUREMENT SYSTEM

In the ship electrical power system such phenomena occur that hardly can be noticed by means of the ship measurement equipment used so far. The correct estimation of voltage properties in the system under consideration requires wide range of data on steady-state and non-steady-state disturbances [2]. It seems that the only method to achieve this goal is to apply microprocessor technique. It enables to cover broad range of quality and quantity of information about voltage properties.

The digital measurement system contains two main parts (Fig.2): the hardware part (data acquisition block) and the virtual part (consisting of signal processing and analyzing block and graphical interface block). The analyzing block can contain another software, e. g. Mathcad.

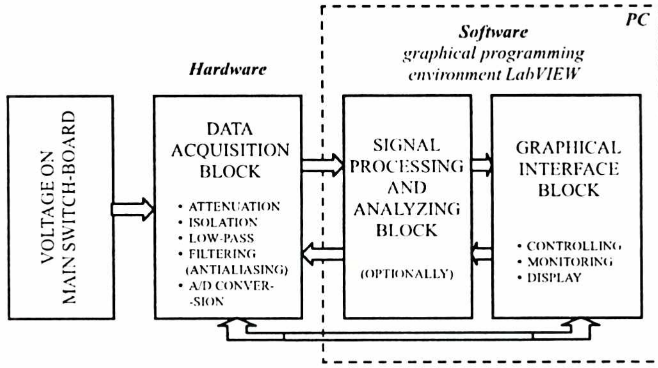

Fig.2. Block diagram of the digital measurement system

The hardware (Fig.3) is responsible for converting the quantities of the measured waveform. It makes it possible to process analogue input voltage into digital form without changing its shape. The measured signal level is matched with the input of the isolation amplifiers which separate high voltage signal. The initial conditioning is carried out 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 of 16-bit resolution and sampling rate up to 20 kS/s [4]. The analogue-to-digital conversion is performed at high resolution because of a much lower level of interference in comparison with 50 Hz frequency signal. Using three channels at the same time allows for the maximum sampling rate of 6.6 kHz. This ensures

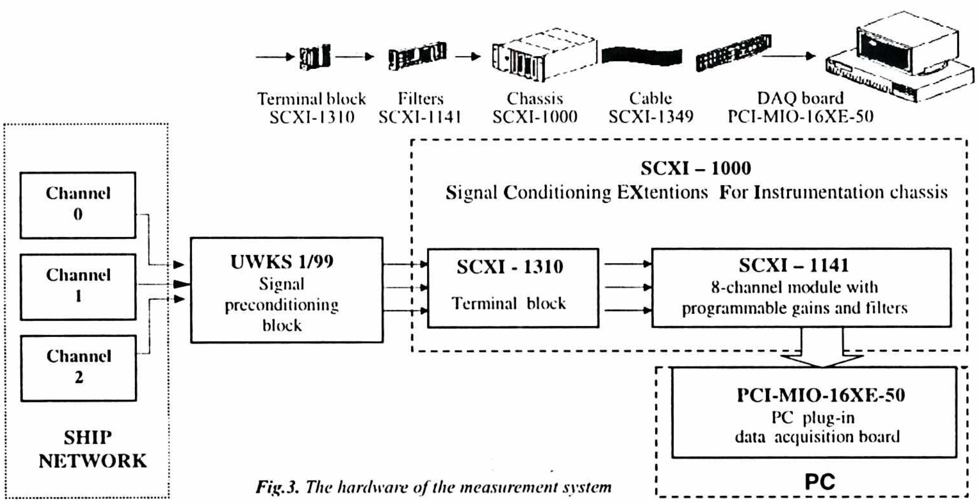

Fig.3. The hardware of the measurement system

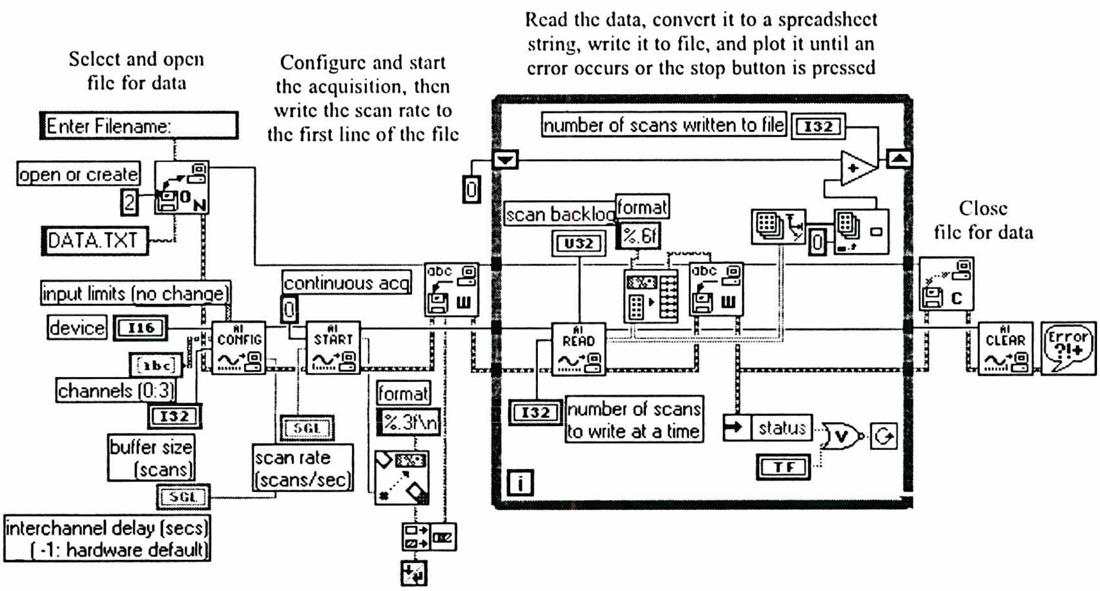

Fig.4. The measurement system software - diagram of LabVIEW virtual instrument

the measurement of interference in the frequency band up to 2.2 kHz. The latter value results from setting the antialiasing filter.

The system hardware is controlled by LabVIEW v.4.0 , graphical programming environment of National Instrument [5]. The Virtual instrument VI (Continuous Acquire to Spreadsheet File) is used to acquire data (Fig.4). It works with the use of the circular buffer technique of data acquisition whereby data is continuously acquired into a circular acquisition buffer at the same time that the VI reads the acquired data and processes it. The program creates the file and on each iteration it reads „number of scans to write at a time" scans from the acquisition buffer, converts the data to a spreadsheet string, and writes it to the hard disc.

EXEMPLARY RESULTS

Voltage and frequency deviations

The deviations of voltage and its frequency from their nominal values are the broadly known phenomenon which occurs in the ship electrical power systems. First of all its reason is switching off and on large receivers as well as generators. The variations of rms value of voltage and its frequency in result of replacing the shaft generator by diesel generator as an energy source on the ro-ro ship are shown in Fig.5. The greatest recorded deviations during such operation on the ro-ro ship were 17% of steady-state voltage value and 4% of steady--state frequency value. These extreme voltage and frequency deviations did not occur simultaneously. As far as the ferry ship is concerned the same kind of operation revealed voltage deviations hardly exceeding 2% and frequency deviations 1.5%.

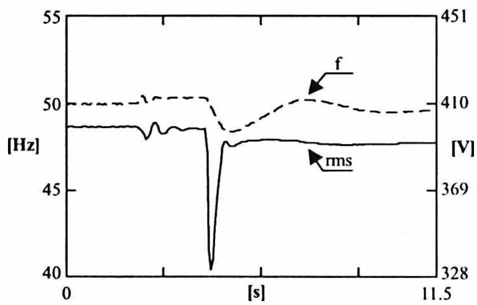

Fig.5. Exemplary voltage and frequency deviations on the ro-ro ship due to changing the electric power plant configuration

Another source of voltage and frequency deviations is switching on large receivers. For example, the deviations recorded on the ro- ro ship due to switching on the hold fans were equal to 4.8% and 2.8% of steady-state values of voltage and frequency, respectively. The deviations on the ferry ship recorded during operation of a bow thruster were 3.5% and 2% of steady-state values of voltage and frequency, respectively.

Continuous fluctuations of the voltage rms values also occur in the ship electrical power systems. They are due to sudden changes in power demand of high power receivers, and electronically controlled devices as well as changing the rotational speed of generator drives. The fluctuations cause undesirable effects in various electrical apparatuses. The most common effect of the voltage variations is the change of the illumination intensity of light sources, which is known as the voltage flicker.

The flicker is caused by low amplitude modulation of 50/60 Hz frequency, whose spectrum is limited within 0.5÷25 Hz range. The presence of interharmonics and modulation of high harmonics also can cause the flicker to appear.

An example of the voltage rms value fluctuations which produce flicker is shown in Fig.6. It was caused by heavy sailing conditions (wind and rough seas).

The aim of flicker measurements is to assess the value which expresses directly the degree of irritation of human beings. Therefore, the voltage flicker is measured with respect to the human eye sensitivity.

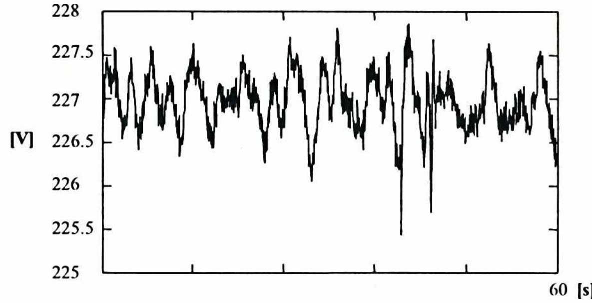

Fig.6. Fluctuation of the voltage rms value in 220 V network supplied by a shaft generator on the ro-ro ship

The instantaneous flicker sensation level S(t) obtained from the output of virtual instrument [3] (included in the Signal Processing and Analyzing Block of the measurement system) is presented in Fig.7.

The virtual flickermeter corresponding to the existing standards is responsible for performing the measurements based on the simulation of behaviour of the lamp-eye-brain system. The absolute value of the instantaneous flicker sensation level is divided by a corresponding value of the perceptibility threshold to express the level in perceptibility units (p.u.). Finally the short-term flicker severity level P_{st} is statistically evaluated, which directly expresses the degree of irritation, and P_{st}=1 p.u. means the disturbance limit, i.e. irritability threshold. This P_{st} value is based on a short-term observation period (ten minutes) and calculated as the root sum of weighted percentiles of the instantaneous flicker sensation level S(t).

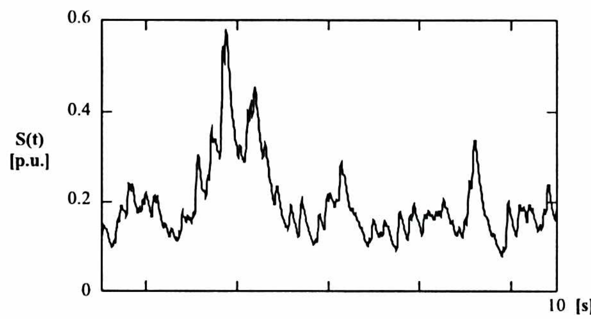

Fig. 7. The instantaneous flicker sensation level in 220 V network of the ro-ro ship, supplied by a shaft generator

A significantly higher flicker level was observed in the ferry ship network during operation of the bow thrusters (Fig.8). The short--term flicker severity level P_{st} was equal 2.03, i.e. well above the perceptibility level.

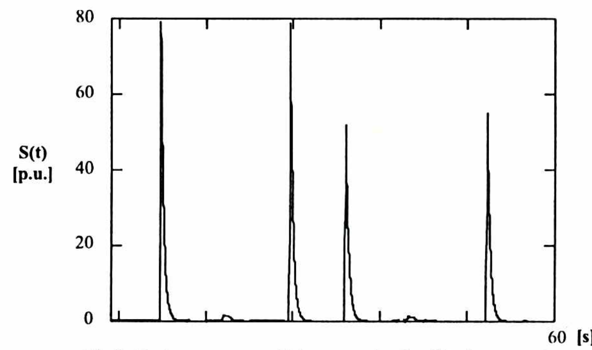

Fig.8. The instantaneous flicker sensation level in the network of the ferry ship during operation of the bow thrusters

Waveform distortions

The appropriate measurement and evaluation of voltage waveform is not yet resolved. However, new tools for waveform analysis appear such as wavelet transform, which can be useful in analyzing non-steady phenomena. An example of the transient state caused by switching processes is shown in Fig.9. This example relates to the same process as that shown in Fig.5.

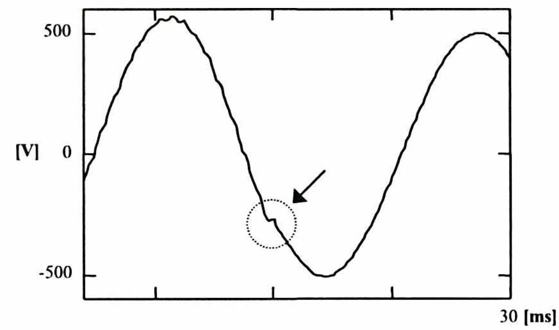

Fig. 9. Examplary waveform transient distortion of 400 V voltage rms value on the ro-ro ship

Besides non-steady phenomena, steady-state ones also can occur, like harmonic and notching distortions. In the research in question only the harmonic distortion was observed, shown in Fig.10 and 11.

The harmonic distortion is usually described by means of the total harmonic distortion (THD) factor or/and harmonic content factors of respective harmonics. The factors concerning the distortions shown in Fig.10 and 11 are presented in Tab.1.

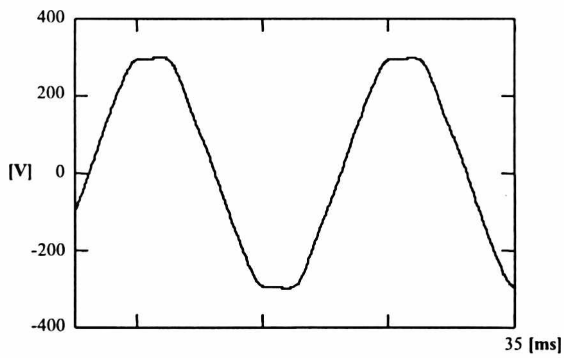

Fig. 10. Voltage waveform in 220 V network on the ferry ship

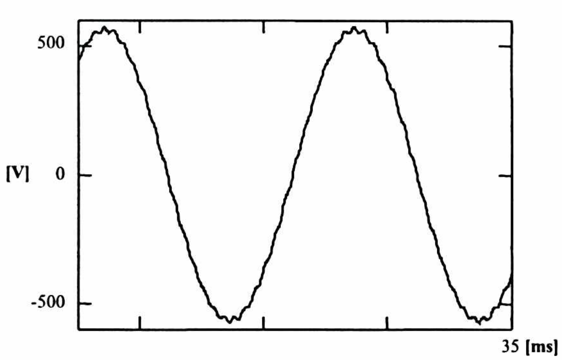

Fig. 11. Voltage waveform in 400 V network supplied by a shaft generator on the ro-ro ship

Tab. 1. Harmonic content of the signals shown in Fig.10 and 11

Harmonic order	Harmonic content of signal from Fig.10 [%]	Harmonic content of signal from Fig.11 [%]
2	0.2	0.0
3	0.1	0.0
5	2.9	0.1
7	1.7	0.3
11	0.2	0.1
13	0.1	0.2
23	0.0	0.5
25	0.0	1.6
THD factor	3.4	1.8

The harmonics not included in Tab.1 can be neglected because of their small values.

FINAL REMARKS

Various kinds of voltage disturbances on the main switchboard busbars were observed.

The highest deviations of voltage rms value and its frequency were recorded on the ro-ro ship in question. The maximum voltage dip related to 380V was 13%. However, an additional decrease of the voltage on cables between receivers and main switchboard should be also taken into account. In the Rules of Polish Register of Shipping [6] 6% voltage decrease of its nominal value is permitted. Simultaneously the requirements regarding the electrical energy receivers impose that they be able to withstand ±20% deviations of rms voltage from its nominal value. Therefore the recorded voltage dips verge on the maximum permissible level.

Steady-state deviations of voltage rms value, i. e. low-frequency interference has an impact on luminance of light sources (causing flicker). The short-term flicker severity level P_{st} exceeded the limiting value only during manoeuvring period, i.e. that of highly variable loads.

The next problem is voltage waveform distortion. The aforementioned rules require the THD factor to be less than 10%. The observed THD factor was significantly lower than the limiting level, and the dominant role of one of the harmonics was recorded on both ships. On the ro-ro ship it was mainly 25-order harmonic. Its content was equal to 1.6% of the fundamental harmonic. It should be stressed that the permissible level of this harmonic content is 1.5% of voltage in the networks of class 1 and 2, according to standards [7]. At the same time the rules of ship classification societies do not refer to the problem of content of respective harmonics. So, it can be stated that THD factor is an insufficient measure for assessing the voltage waveform quality.

The proposed method consisting in sampling the measured signals and further processing them by means of digital signal processing tools, proved effective. It makes possible to obtain the highest efficiency as well as to apply various processing tools.

Another problem is choice of measurement periods. Casual surveys do not provide full information. The occurrence of various kinds of interference is strictly related to different stages of ship exploitation. So it is necessary to carry out research over a relatively long period of ship exploitation under conditions of different electric power plant configurations.

Appraised by Janusz Mindykowski, Assoc.Prof.,D.Sc.

NOMENCLATURE

f	-	frequency
p.u.	-	perceptibility unit
rms	-	root-mean-square value
s	-	second
t	-	time
P_{st}	-	flicker severity level
S	-	flicker sensation level
THD	-	Total Harmonic Distortion
V	-	voltage

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