

ELECTRICAL ENERGY QUALITY UNDER SHIP'S CONDITIONS

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Abstract: The goal of the presented paper is to sum up the author's past activities in the field of electrical energy quality on ships. General problems connected with quality are shown, then, its measurement aspect is broadly described. It consists of measured quantities choice, methods and appropriate instrumentation. The idea of new means is based on microprocessor techniques. Particularly, it contains specialized analyser of electrical energy quality as well as additional devices. The proposed analyser is designed as distributed measurement system. It means autonomous measurement modules and redundant structure. All considerations are carried out with the help of different records of ship's supply voltage waveform on the main switchboard bus bars. Final remarks focused on further project frameworks (going beyond measurement range) and new challenges are included.

Keywords: electrical energy quality, sea vessels, digital signal processor

1 INTRODUCTION

The presented paper concerns quality of electrical energy in ship power systems. Electrical power system is a very important part of ship engineering system, because of it influences all remaining vessel systems. This way, it affects safety and economic efficiency of the whole ship operation. Thus, the importance of electromagnetic compatibility of ship environment is not to be underrated. It can be concluded that worsening of electrical energy quality under ship conditions diminishes the margin of ship safety. It often means great risk to human life and environment. The reasons of disturbances are complex and of unexplained nature. In Table 1 the casualty statistics related to IMO data have been shown [1]. This data contains 93 cases of electrical failures, classified by place of occurrence and 27 others unknown or operational failures. Of course, this data is not comprehensive and contains only information which brought attention of the relevant authorities.

Table 1. Summary of failures caused by electrical installations on ships [1]

| Cause of failure | Number of incidents | Share by percentage |
|-------------------|---------------------|---------------------|
| Prime Mover | 20 | 16.7 |
| Alternator | 16 | 13.3 |
| Electrical system | 31 | 25.8 |
| Auxiliaries | 18 | 15 |
| Others | 27 | 22.5 |
| Fire/flood | 8 | 6.7 |

In many cases the failures occurring in auxiliaries are due to mechanical causes. However, some events do not have explicitly determined reasons, except for the place of occurrence. Especially, the unknown and operational cases (others) take up significant part of all the phenomena specified in Table 1. There is a possibility that its considerable part is connected with electrical energy quality.

The international classification societies take an attempt to cope with the above mentioned problems. But it should be firmly stated that this attempt is not sufficient. It means, these societies inflict strict boundary levels of some important electrical energy quality factors but they neglect the necessity of those factors' control during the period of ship exploitation. The number of important

factors contained in these rules is too small as well. So far, the lack of asymmetry of three-phase supply voltage aspect has been observed.

The proposed solution is to emphasize the problem of electrical energy quality in the system under consideration. This quite new approach means new understanding of this problem as a complex and distinct phenomenon. It requires measurements of electrical quantities under ship conditions. A suitable choice of a set of the measured quantities as well as methods and appropriate instrumentation are necessary.

2 SET OF ELECTRICAL ENERGY QUALITY FACTORS FOR SHIP USE

The electrical energy quality in ship electrical power system should be mainly understood as supply voltage quality. It allows to describe phenomena such as: voltage waveform, rms value, frequency as well as asymmetry. They are to be divided into steady-state and non-steady state phenomena [2] and they should be analysed separately. Now, especially the problem of suitable estimation of voltage waveform seems still underestimated [3, 4].

There are other problems as well. Amid these, proportional distribution of active and reactive power between generating sets working in parallel has an utmost significance. An appropriate set of electrical energy quality factors under ships conditions was proposed in the authors' previous papers [5]. It consists of: voltage and its frequency deviations coefficients, active and reactive power distribution coefficients as well as total harmonic distortion coefficient as shown in (1):

$$THD = \sqrt{\frac{U_{rms}^2 - U_{1rms}^2}{U_{rms}^2}} \cdot 100 [\%] \quad (1)$$

where: U_1 – the rms value of the basic harmonic, U_{rms} – the rms value of whole waveform, taking into account also higher harmonics

and also voltage asymmetry coefficient as shown in (2):

$$C_{va} = \frac{\Delta u}{U_a} \cdot 100 [\%] \quad (2)$$

where: Δu - biggest voltage deviation of any phase from the voltage average value
 U_a - voltage average value

In relation to use of independent control systems of voltage and rotational speed on ships, respectively, it is necessary to supervise mainly the quotient value of voltage to frequency under static conditions. This parameter has an important influence on magnetic flux magnitude in electrical devices, especially engines, and at the same time on optimum conditions of their operation. The factor characterizing the U/f relation deviation from its nominal value may be determined as a magnetic flux deviation coefficient and described by means of the following expression:

$$\delta\Phi = \frac{U/f - U_n/f_n}{U_n/f_n} \cdot 100\% \quad (3)$$

Continuous control of electrical energy quality by the servicing personnel, often with limited qualifications, is significantly difficult by a great number defined electrical energy quality factors. Because of this reason, it is necessary to compress measurement information for this quality control processes improvement. It seems that the best solution is a presentation of the basic part of measurement information as one joint synthetic factor. This new synthetic factor allows fast and easy estimation of voltage quality by servicing personnel and crew. This factor has been widely described in [6]. The most important aspects of this issue may be summarized as follows:

- Mathematical formula describing this criterion is based on the quantities which are determined by properties of supply voltage on the bus bars of main switchboard, it means THD, C_{va} and $\delta\Phi$, where $\delta\Phi$ covers the δU and δf influences;
- Mathematical function chosen as a description of criterion should be sensitive to small changes of quantities which have an influence;

- For exceeding permissible limits by any partial quantity (simple factor) the value of synthetic factor should be equal to zero and the value equal to one corresponding with the optimum of electrical energy quality
- Mathematical formula describing a synthetic factor of electrical energy quality should be easily interpretable in the area or in the space (dependent on the chosen axis system), because of the visualization needs.

3 SHIP'S VOLTAGE WAVEFORM ANALYSIS

All analyses have been conducted with the help of exemplary voltage waveforms. Part of these waveforms registered on the bus bars of gas carrier power network are depicted in Fig. 1 [3].

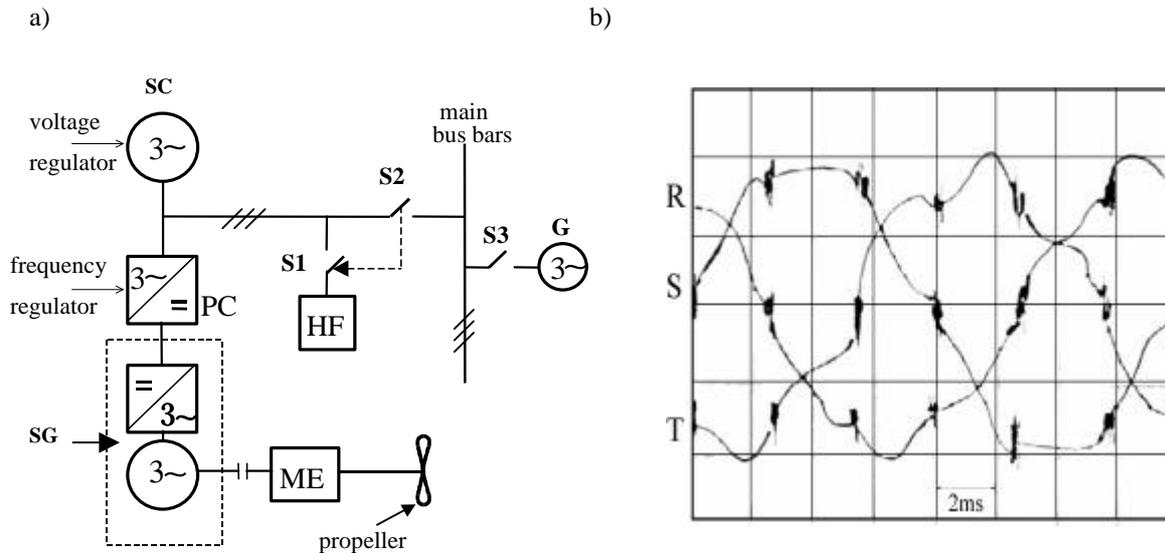


Fig.1. Gas carrier power network: a) simplified configuration b) exemplary three-phase voltage waveform on bus bars of ship switchboard; S₁ - switches, SG - shaft generator, PC - power converter, G - synchronous generator, ME - main engine, HF - harmonic filter, SC - synchronous compensator

The main problem of these waveforms is perceptible at the first blush. Of course, there is a wide range of distortions (harmonic and notching), including the low- and high frequency effect. However significant asymmetry is also included albeit less discernible. It should be stressed that there is the lack of any classification societies rules related to voltage asymmetry. The observed disturbances have been caused by malfunction of harmonic filter in the system under consideration. The thorough measures of important factors have been laid in Table 2.

Table 2. A few electrical energy quality factors for supply voltage waveforms shown in Fig. 2.

| | Phase R | Phase S | Phase T |
|---------------------|---------|---------|---------|
| THD [%] | 15.4 | 9.3 | 17.2 |
| C _{va} [%] | 1.5 | 3.7 | 2.2 |
| δΦ [%] | 3.7 | 1.4 | 4.3 |

Most classification societies require the value of THD less than 10%. However, the distortions exceeded by 20% often may be noted [4]. At the same time, the level of distortions is practically not recorded neither on- nor off-line. But the total harmonic distortion coefficient is insufficient in the estimation of voltage waveform even on steady-states, what has been noticed in experimental results. Moreover, it can calm crew vigilance of harmonic problem if assumes a relatively small value. There have been recorded examples of voltages over thorough research of voltage properties on two ships that yield only low level of THD but contain one significant harmonic [7]. The exemplification of this problem has been depicted on Fig. 2.

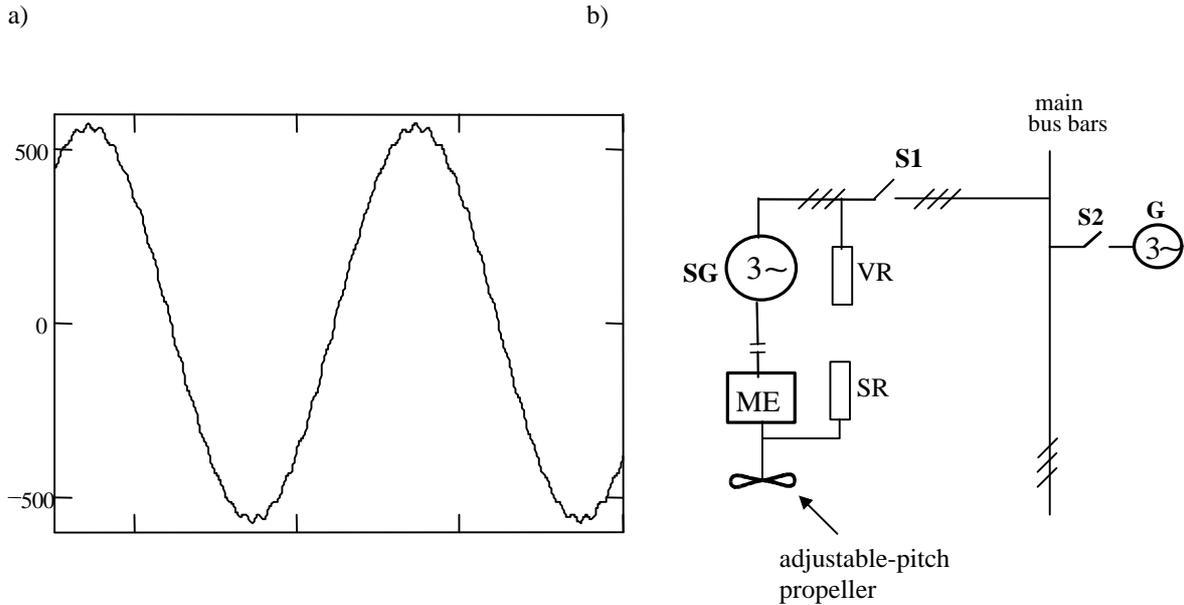


Fig. 2. Ro-ro ship power network: a) simplified configuration b) exemplary voltage waveform on bus bars of ship switchboard; S_i - switches, SG - shaft generator, G - synchronous generator, ME - main engine, VR – voltage regulator, SR – speed regulator

The cause of the disturbance observed in Fig. 2. Was the operation of gear between main engine and shaft generator. There have been two shaft generators and two main engines in that system but only one shaft generator has been connected with system at any time. The above depicted voltage has a THD equal to 1.8%. But the dominant role of harmonic of 25 order is observed. Its content can be described as ratio of rms value of its harmonic to rms value of fundamental harmonic and it is equal to 1.6%. It is higher than boundary level for this harmonic in some class of network that is imposed in some rules [8]. At the same time, the rules of ship classification societies don't refer to the problem of respective harmonics content.

4 INSTRUMENTATION FOR ELECTRICAL ENERGY QUALITY ESTIMATION

Proper estimation of electrical energy quality in ship electrical power system involves the measurement of a wide range of different and difficult-to-measure factors. Taking into account the present progress in microprocessor measurement technique scope [9], it is proposed as a solution to this problem. A specialized analyser of electrical energy quality (in fact the distributed measurement system) was shortly described in [10]. This analyser is still in the course of construction, but in the meantime the autonomous microprocessor analyser-ammeters are proposed as complementary devices, which are also being designed. This microprocessor current analysers should enable to match disturbances observed in supply voltage with proper reasons, e.g. start of electrical drivers. The exemplary deviations of voltage's rms value and its frequency caused by switching on the hold's fans have been depicted in Fig. 3.

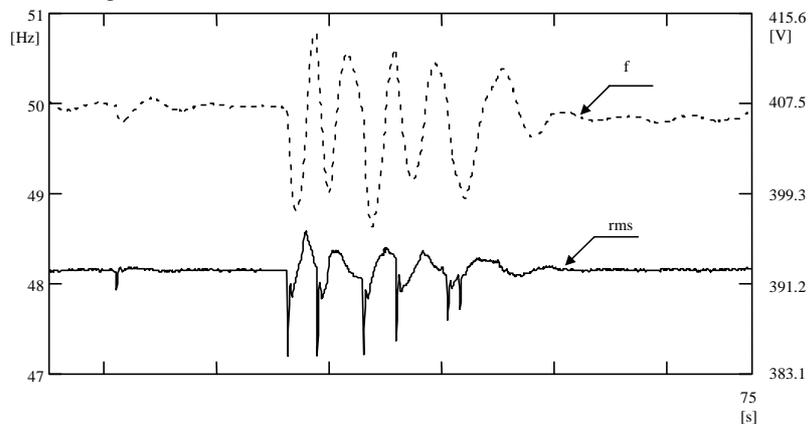


Fig. 3. Exemplary deviations of voltage's rms value and frequency over switching on large loads

The limited number of large receivers in the system under consideration enable to harness autonomous microprocessor analysers of current of these receivers. This relatively low-cost solution will develop microprocessor analyser of voltage's quality into full electrical energy quality analysis and diagnosis system, such as shown on Fig. 4. Software and hardware structure of the microprocessor analyser of electrical power quality have been carried out by taking into account the specific character of ship electrical power system, namely an autonomous, flexible system. This device carries out at first measurement functions and converts measurement information into commands for control systems of voltage and frequency as well as the main switch of respective generators and alarm signalling of marine power plant [10].

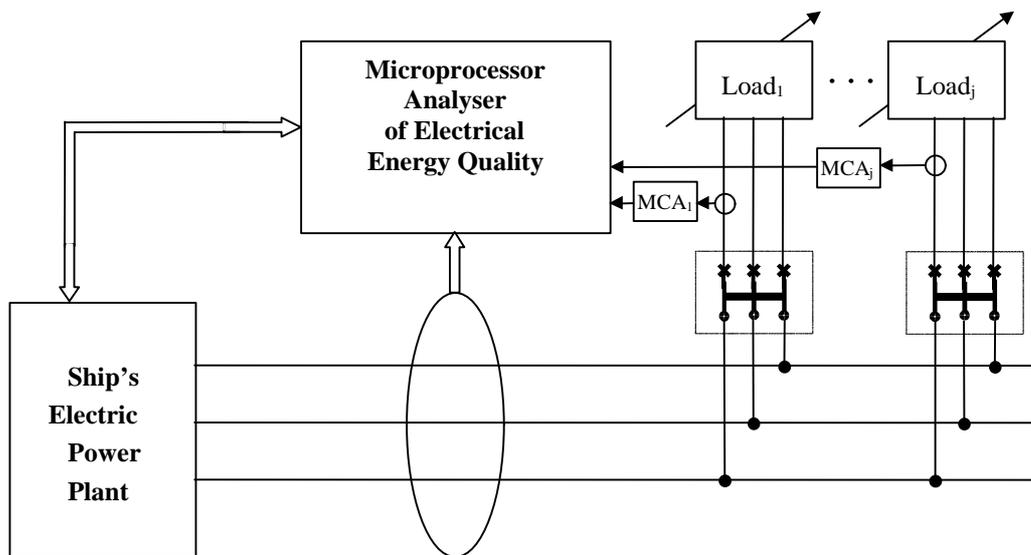


Fig. 4. System for analysis of electrical energy quality and diagnosis reasons of disturbances

The term MCA means a Microprocessor Current Analyser and implies both functions: measurement of current rms value in steady- and non-steady-states and analysis waveform of this current. Actually, the MCA device is under work. It is based on such tool as digital signal processor (same as microprocessor analyser of electrical energy quality) and involves simple and effective algorithms of digital signal processing as digital integration and Digital Fourier Transform with asynchronous sampling use.

5 CONCLUSIONS

The electrical energy quality on ships is of very complex concern, which consists of wide range of issues. But the voltage quality on bus bars of ship main switchboard should be taken into account at first. The disturbances of voltage quality occurred in ship electrical power system have an utmost level. The deviation of rms value of supply voltage often exceeds 20% of its nominal value [7]. Its frequency deviations also reach 10%. Add incredible voltage waveform distortions and asymmetry and there is a perilous compound. Therefore, because they are impossible to avoid completely, the importance and complexity of electrical energy quality problem in ship electrical power system need a suitable approach. Appropriate estimation of this quality is indispensable for solving the problems caused by voltage disturbances and necessitates measurement of important voltage parameters. It involves suitable tools based on digital signal processors. The requirement of high reliability imposes redundant and distribution structure of specialized measurement devices that consist of a few independent and interconnected modules. At this point significant role of complementary devices as Microprocessor Current Analysers should be stressed. These analysers enable fast and reliable localization of disturbance source as well as meet the classification societies rules which require measurement of important and large receivers currents.

At that point, the problem of classification societies' rules should be introduced. Changes of these rules in the aspect of electrical energy quality are advisable. So far, the lack of strict rules related to asymmetry of supply voltage has been observed. Moreover, there is a lack of any requirement concerning many important parameters of electrical energy control during the period of ship exploitation. For example, the present factors for estimation of voltage waveform are insufficient and should be complemented with factors of respective harmonic contents as in other rules [8]. Hitherto,

the present peremptory rules do not ensure electromagnetic compatibility in the ship electrical power system. More flexibility in these rules is advisable. Strict boundary levels of values of some electrical energy parameters should be superseded by appropriate configuration of the system under consideration.

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