

Electric power quality and ship's safety

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1. Introduction

The issue of electric power quality onboard ships has seemed of utmost importance, in particular nowadays when a great progress in implementation of electric drives for ship's thrusters, propellers and other smaller drives is evident. Ship's electric power systems are isolated power systems. Similar systems are installed on aircraft, oil platforms and small islands, in industrial plants with seasonal character of operation and also as emergency electric supply systems in banks, hospitals, hotels, large supermarkets and skyscrapers [1], [2]. Characteristics of those systems are: scarce in other cases proportion of single consumer power to electric source power (some consumer powers are often comparable to generator power supplying them) [3] and relatively high short-circuit impedance of generators installed in the systems under consideration [1]. Finally, electromagnetic disturbances observed in isolated power systems are more serious than those observed in large connected systems in their normal operation. What is unique in ships power systems? Answer is simple. System is installed on mobile object – the ship - and simultaneously is deciding for its operational control. Effects of incorrect system operation can be very serious and consequences of ship's casualties are known very well from the news. Indeed, question of the electromagnetic disturbances determining electric energy quality in ship's power systems has not only technical aspect and / or vessel operational safety. Paltry quality of electrical energy on ships has also its economic dimension. In spite of relatively not big power (normally no more than few MVA) of a single electric plant, large number of ships (30 395 of 1000 gt and above as of 1.01.2003 [4]) shows the measure of presented problem excellently.

2. Electromagnetic disturbances in ship's power networks

Wide spectrum of electromagnetic disturbances, radiated and conducted, is present in the ship's electric networks causing disorder in their element operation. Typical conducted, and particularly prolonged disturbances, as:

- voltage and frequency variations;
- voltage asymmetry;
- distortions caused by harmonics, inter-harmonics, transient pulse disturbances;
- improper distribution of active and reactive power between generating sets working in parallel.

The disturbances introduce many difficulties into operation of the ship's crew and owner's technical service, independently on basic value - the ship's safety. Electric and electronic devices, the power network elements are the "causes" of disturbances and at the same time the "victims" of the waveform distortions. Ragged design and carrying out of installation give rise to the EMC disturbances, often causing the asymmetry and voltage level changes. Switching process in distribution switchgears and electrical consumers and also overvoltage during fuse blow out were traditionally causes of signal distortion in power network. Presently distortions are caused by still more popular power electronic converting systems used in machinery auxiliary drives, but not only. Drives consisting of power converters are applied to thrusters, big technological consumers and main propellers of the vessels. Marine generating sets are "weak" power sources (with 15-20 % impedance) compared to "stiff" sources (4-6 % impedance) more common in land industrial applications.

Converters of electrical power in co-operation with so weak power sources generate harmonic and inter-harmonic distortions causing inadmissible disturbances in power system. Distortions 15% and even 20% and above were observed onboard ships many times [5], [6], [7].

The examples of all above mentioned disturbances, i.e. voltage and frequency deviations, voltage asymmetry and distortions of voltage waveform are shown in Fig 1 to 5. Presented examples are the original results of some tests which were carried out on ships by personnel of Marine Electrical Power Engineering Department of Gdynia Maritime University. The test purpose was to settle the real voltage parameters (in fact its quality), supplying Main Distribution Boards of examined ships.

Fig. 1 represents variations of voltage rms value during the start-up and running of the thruster driven by 1,3 MW electric motor, when two generators with power 1,75 MVA each operated parallel. In that case overload of ship's electric power plant had caused automatic switching off a less important services and next switching on the third generator with the same power, for parallel operation. Fig. 2 shows frequency variations for that case accordingly.

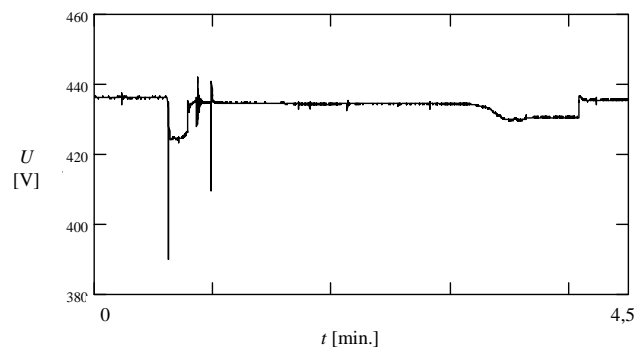


Fig. 1 Voltage variations during starting and running of the thruster [3]

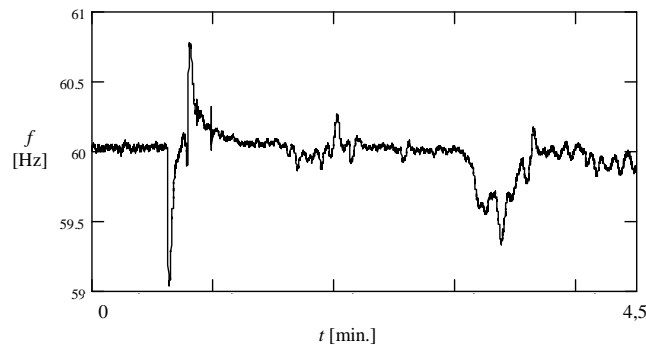
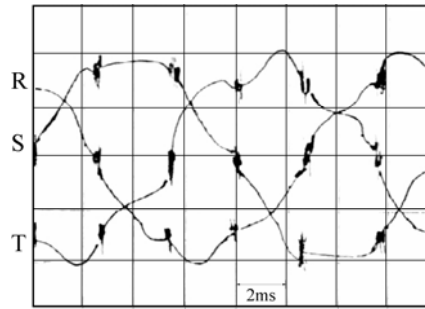


Fig. 2. Frequency variations during starting and running of the thruster [3]

Voltage asymmetry in the system with nominal parameters $U_n=440$ V and $f_n=60$ Hz is shown in Fig. 3. Presented voltage asymmetry is so interesting because one can see harmonic distortion and pulse interference, too. Phenomena observed in that example were caused by shaft generator with power converter working on ship's network with simultaneous failure of harmonic filter (3-phase LC passive filter).



Rys. 3 Voltage asymmetry (3,7%) [8]

Next two presented samples are also from the ship equipped with shaft generator working in network through power converter. However in that case all system components were operating correctly. Fig. 4 shows voltage inter-harmonic and harmonic distortion, e.g. interharmonic quantity is ca. 0,4% at frequency ca. 150 Hz when total harmonic distortion THD amounts 4,4% on Main Distribution Board 220 V bus-bars. It means that between power converter and the connection point of measuring apparatus, transformer attenuating commutation over-voltage was present. Fig. 5 shows the same measurement however measuring instrument was connected directly to 440 V bus-bars. In that case one can see the notching caused by commutation over-voltage in power converter. The THD coefficient amounts 13,5% for that case.

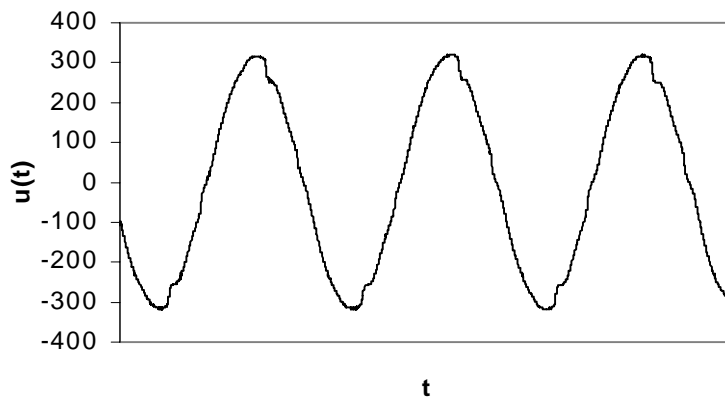


Fig. 4. $U_n=220V$ voltage inter-harmonic and harmonic distortion [9]

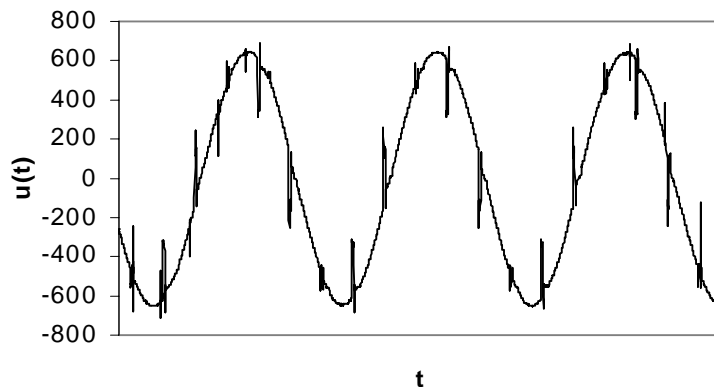


Fig. 5. $U_n=440V$ voltage pulse interference [9]

Finally, it is worth to present an example of distribution of active power between generating sets working in parallel. Such an example registered during ship manoeuvring has been shown in Fig. 6. There have been two generating sets working in parallel during analysed phenomenon. The active power load of generating set no 2 (P_{G2}) has been depicted by bold line.

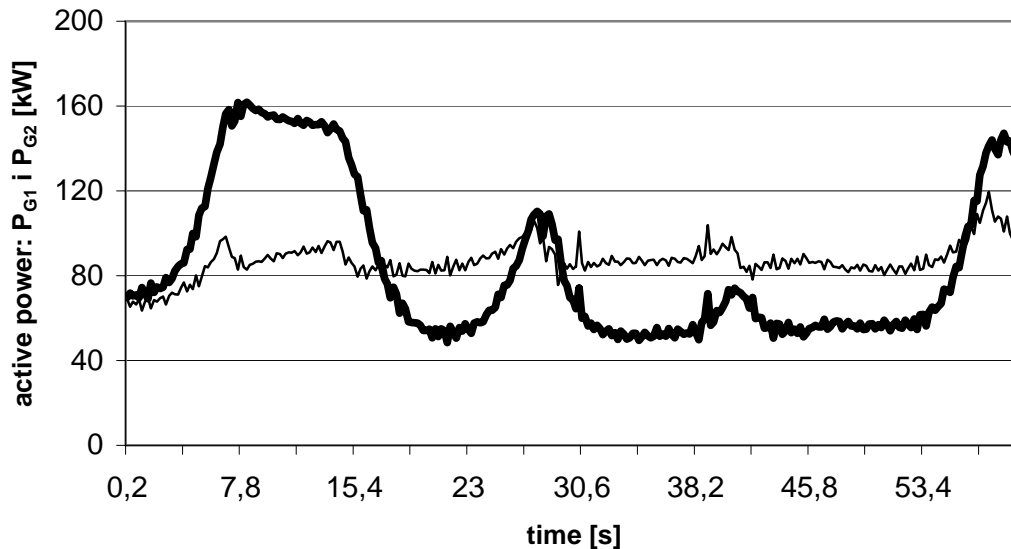


Fig. 6. Exemplary changes of active power load of respective generating sets working in parallel during ship manoeuvring.

It should be stressed that improper distribution of the active (as well as reactive) load can be hazardous. It may cause artificial overload and real collapse of whole supply system (switching operating generators off). The possible risk, especially during manoeuvring, can be hardly overstated.

The last of presented examples (Fig. 6) results from joint research of Marine Electrical Power Engineering Department of Gdynia Maritime University and Electrical and Automation Department of Polish Register of Shipping.

3. Harmonic distortions cause a lot of damages in electrical power system

Harmonic distortions can cause following typical damages to and malfunction of most elements and units of ship's power network [10]:

- **Electric power sources:**
 - Overheating and, in result, damage to bearings, winding and sheets packages of generators, because of a premature thermal ageing of insulation.
- **Electrical power consumers:**
 - Overheating of the stator and rotor of fixed speed electric motors, risk of bearing damage because of the motor high temperature, additional rises of insulation temperature and its premature thermal ageing. A special hazard is present in the case of explosion proof motors operating in explosion hazardous areas. Unintentional tripping of circuit-breaker protections, interference with all control, electrical and electronic systems including radio-navigation and communication equipment, lighting, etc.
- **Electrical energy networks:**
 - Overheating of cables as result of decreased ability to carry rated current because of reduction of effective cable cross section area by so called skin effect, also risk of cable damage due to resonance.

- Overheating and premature thermal ageing of transformer sheets packages and winding insulation.

It is important that harmonic distortion are present together with voltage and frequency variation and also voltage asymmetry, most frequent. Fig. 3 shows it. Negative synergy effect of above mentioned phenomena can be expected for many power consumers. That kind of interference synergy was discovered in tests of temperature rises in induction motor windings at different supply conditions [11].

4. Harmonic distortion – the past and the present time

Ian C Evans, author of “Harmonic Mitigation for AC Thruster & Small Propulsion Drives”, advises that one of the classification societies have noted 24% voltage distortion (U_{THD}) in an offshore installation tested. He also says that voltage distortion of 12 – 19 % is relatively common, albeit not continuous in these installations, where up to 85% of the electrical load consists of electric drives [6, 7]. Distortion level measured on ships' bus-bars by Department of Marine Electrical Power Engineering of Gdynia Maritime University are described in [3, 9, 11] and confirm international observations. However, the classification societies determined harmonic distortion limit on 5-10% level recognising possibility of serious faults of the electric network and, in result, general safety of the ship [14, 15].

Table 1. Results of voltage distortions measured in different vessels [5], [6], [7], [9]

Kind of parameter	Voltage harmonic distortions range permitted by rules of classification societies	Mean instantaneous values of voltage harmonic distortions measured on ships	Max. instantaneous value of voltage harmonic distortions measured on ships
Result of observation/the measurement	5 – 10 %	12 – 19 %	24%

It shows, a gap is between ships practice and classification societies attitude. Problem is that, classification societies determining harmonic level limits did not assign the method of their testing onboard. However, the limits of electric power disturbances were stated when the risk caused by power-electronic elements and systems was not present. DC driving systems not generating so serious interference had dominated on ships at that time.

5. Harmonic mitigation – the present time and the future

Global forecasts give information about several times growth of power electronic (measured in the million USD of installed “electric” propeller value or “electric” ship’s number) [7]. It enhances the issue.

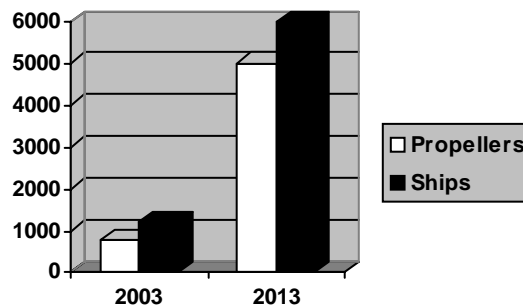


Fig. 7 Global forecast of ship's electric drives application

Individual classification societies have to revise their rules in connection with the fast development of the AC drives introducing many of harmonic and inter-harmonic distortions. These is the opinion of classification societies, marine electricians and electrical equipment producers. Recently some modifications of industrial standards were done. Many of the IEC and IEEE standards concerning permissible levels of electrical power parameters determining its quality and measuring methods are present now [16], [17], [18]. Polish and international standard PN-IEC 60092-101 “Electrical installations in ships – Part 101: Definitions and general requirements” has also set up many limits of quality parameters of electrical power [19]. Some exemplary parameters of that standard are placed in Table 2

Table 2. Chosen quality parameters of electrical power stated by PN-IEC 60092-101 standard

Parameter	Value
Steady voltage deviations	+6% -10%
Steady frequency deviations	±5%
Voltage asymmetry	3 %
Transient amplitude	5,5 U _n
Increase / decrease time of transient	1,2 μs / 50 μs
Total harmonic distortion THD	≤ 5 %
A single distortion (any harmonic greater than)	≤ 3 %

However none of classification societies have implemented many of that parameters into their rules up to now. Continuous monitoring of electric power quality is not also carried out onboard, presently. Sometimes some observations, occasional measurements are being carried out but they are not adequate solution because of large variation of power quality parameters during ship’s operation. It is worth to note that some producers of power system control devices are introducing some means of power quality verification but it can not be considered as a global solution.

The expected development of electric drives for ship propulsion is the next and new challenge for marine specialists. Therefore, it is necessary to introduce special requirements for electromagnetic interference prevention (by correction of energy parameters in ship’s electrical power system) and their effects (by increasing of consumers immunity) and also to monitor power quality in ship’s networks. Possibility of current control has appeared with the development of transducer technology and advanced method of electrical signal processing and also specialised devices for real time data processing. High yet prices of suitable systems are decreasing continuously (cost of signal processor amounts from a few to a several hundred dollars) [10].

6. Conclusion

Tests, studies and analysis carried out during research onboard ships indicate necessity of complex solution of power quality problem in ships power systems, unequivocally. Specific means to prevent against electromagnetic disturbances and their effects are required. It may be done by correction of power quality in ship’s power systems and improvement of the electric consumers' EMC immunity. On the other hand monitoring of electrical power quality is needed. Therefore problem of electrical power quality and its assessment should be one of priority in designing, construction, classification and utilisation of ship’s electric systems, now and in the future. It is evident that on the one hand the matter applies to shipyards and ship’s owners and on the other to classification societies surveying ships production and exploitation processes [20].

Suitable solution of that problem requires sufficient knowledge and experience. The preparation of appropriate staff for shipyards, owners and classification societies, as well as research of new methods and ways to limit the influence of poor power quality on the effective economically and safe operation of ships are the tasks of maritime universities.

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