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Investigation of SEPS electric power quality indicators based on mathematical simulation models

A. Vyngra[1,3], S. Chernyi[1,5,*], B. Avdeev[2,4]

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ABSTRACT

The analysis of the electric power quality indicators for electrical power system on board ship is made. Electric power quality refers to the various properties of electric power, which together ensure the normal operation of ship consumers. Any ship electrical power system (SEPS) is characterized by limited capacity and the presence of a full cycle of generation, transmission, distribution and consumption of electric power. The consequences of deviations in the quality of electric power indicators are determined. Ways to improve the quality of electricity on board the ship are considered. A simulation model of the ship's electric power system has been developed to analyze the harmonic components of the voltage and current of the busbars of the main switchboard. A carried-out simulation showed the presence of interharmonic current components during the operation of reciprocating compressors' powerful electric drives. Methods for eliminating distortion by using boosters and active current filtering systems are proposed.

1. Introduction.

Improving the quality of electricity on a ship is a very urgent task due to the requirements of the Russian Maritime Register of Shipping (RMRS) and the International Association of Classification Societies (IACS) regarding the indicators of the sinusoidal current and voltage of SEPS in any operating modes. Various methods are being taken and new methods and devices are being created to solve this problem.

[1]St. Petersburg State Marine Technical University, St.Petersburg, (Russia).

[2]Kerch State Maritime Technological University, 298309, Kerch, (Russia).

[3]Lecturer of ships electronic of the Department of Ships Electrical Equipment and Automation. Tel. (+79788596496). E-mail Address: elag1995@gmail.com.

[4]Assistant professor of theoretical foundations of electrical engineering of the Department of Ships Electrical Equipment and Automation. E-mail Address: dirigeant@mail.ru.

[5]Assistant professor of cyber-physical department. E-mail Address: segiiblack@gmail.com.

*Corresponding author: S. Chernyi. E-mail Address: segiiblack@gmail.com.

2. Problem formulation.

The quality of electricity for operation in different modes is one of the most important characteristics on which the efficiency of SEPS operation depends [1-2].

Electric power quality refers to the various properties of electric power which together ensure the normal operation of ship consumers. The widespread use of various devices with non-linear and asymmetric loads significantly reduces the electric power quality indicators on ships. Therefore, it is necessary to perform a parametric analysis of the causes of current and voltage sinusoidal distortions in ship electric power systems. Indicators of the quality of electric power will be the deviations of certain parameters from the nominal

Any SEPS is characterized by limited capacity and the presence of a full cycle of generation, transmission, distribution and consumption of electric power. Requirements for the operation of ship electrical equipment are defined by the Russian Maritime Register of Shipping (RSRS) in the Rules for the Classification and Construction of Sea Vessels.

Table 1: Permissible deviations of power supply parameters.

Parameters	Deviations of parameters from the nominal		
	Long	Short-term	
	%	%	Time, s
Voltage (AC)	+6…-10	±20	1,5
Frequency (frequency range of a power plant with a variable frequency of the main source of electric power)	±5	±10	5
Voltage (DC)	±10	5 10	Cyclic ripple deviations

Source: Authors.

3. Consequences of deviations in power quality indicators.

Deviations in the values of certain indicators can affect the operation mode of electric power consumers. For example, if the grid's voltage is reduced by 5%, this will lead to a decrease in the induction motor (IM) torque by 10%, at the same time, the consumed current will increase by 11%. Such oscillations can cause false operation of protective devices that are designed to operate at rated voltage [3,4,5].

As for oscillations in the current frequency, they almost proportionally affect changes in the rotational speed of a three-phase induction motor that also has a negative effect on other joined mechanisms.

Ways to improve the quality of electric power on board. Various devices and schemes can be used to improve electric power quality on ships. One of these devices is the regulator of excitation current, which, in turn, stabilizes the voltage at the generator terminals. The generator voltage decreases when the stator current increases with an active-inductive load in normal mode. A compounding device is used to restore the voltage at the generator stator terminals. This device automatically increases the excitation current, and as a result, the generator rotor current.

One of the most effective means to ensure voltage stabilization can be boosters. Such devices are effectively used both for the groups of consumers that are particularly critical of supply voltage oscillations, and for voltage stabilization in the entire ship grid as a whole [6].

Energy storage devices can be used to significantly reduce the power of boosters. Among them are high-capacity capacitors, or small-capacity batteries, but for high voltages of 300 V and above.

The normal operation of large power electrical equipment and other ship receivers is adversely affected by the voltage unbalance of the three-phase system. For example, induction motors are subjected to additional heat, increase in vibrations, which leads to significant reduction in speed and other losses. Synchronous generators also experience increased rotor heating, stator heating and increased generator vibration. For single-phase receivers, unbalance manifests itself in an increase or decrease in the voltage level. Voltage unbalance in three-phase rectifiers leads to low-frequency ripples in the output voltage.

4. Simulation model design.

The model was designed in the Simulink environment (Fig. 1). Since the main source of electricity on the ship is a synchronous generator, the model uses a block of a synchronous machine.

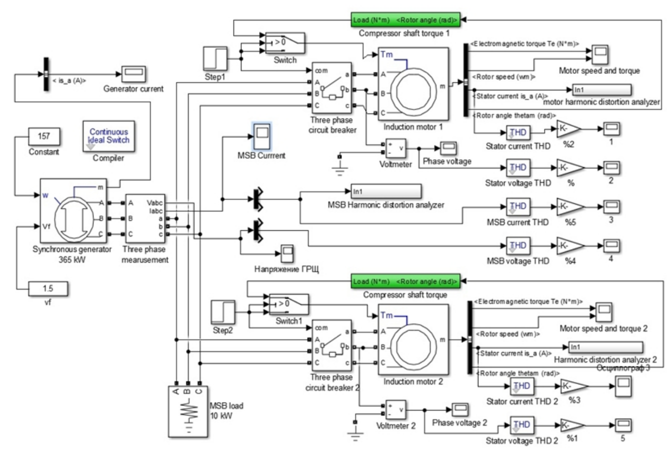
The rated active power of the generator is 375 kW. The rated power of the IM compressor is 11 kW, the constant load on the busbars of the main switchboard (MSB) is 10 kW.

The block of the synchronous machine can operate in the modes of the generator or the engine. The operating mode is determined by the sign of the mechanical power (positive for generator mode, negative for motor mode).

The electrical part of the synchronous generator unit is represented by a model based on the Park-Gorev differential equations [7]. Fig.2. shows the electrical circuit of the synchronous machine block in the axes d, q.

The model takes into account the dynamics of the stator windings, excitation windings and damper ones. The equivalent circuit of the model is represented in the rotor reference frame (d,q). All rotor parameters and electrical values are normalized to the stator windings.

Figure 1: Simulation model of SEPS with electric drives of high power compressors.



Source: Authors.

5. Results of mathematical and simulation modeling.

Modeling was carried out for three stages - start-up of the synchronous generator, connection of the first and second IM. The dip of the voltage sinusoid when the first IM is connected is shown in Figure 3.

The voltage dip was 13.7%, which meets the requirements of RMRS. However, according to [2], the compressor is an unbalanced load on the IM shaft, which makes interharmonic components of the stator current. Therefore, a voltage dip provides insufficient information about meeting the power quality requirements for the nonce. Figure 4 and figure 5 show an analysis of the selected interharmonic current components of the MSB busbars [8-10].

The amplitudes of the IC current of the busbars of the main switchboard when operating two reciprocating compressors are about 1.5 A, and THDi is 15%, which significantly affects the distortion of the voltage sinusoid. Thus, the THDu of the busbar voltage in the main switchboard rises up to 1.5%.

Therefore, there is a need for a systematic study of the problem of voltage distortion during the operation of powerful electrical appliances of reciprocating compressors as part of a SEPS of limited power.

Figure 2: The equivalent circuit of the electrical model of a synchronous machine in the axes d, q.

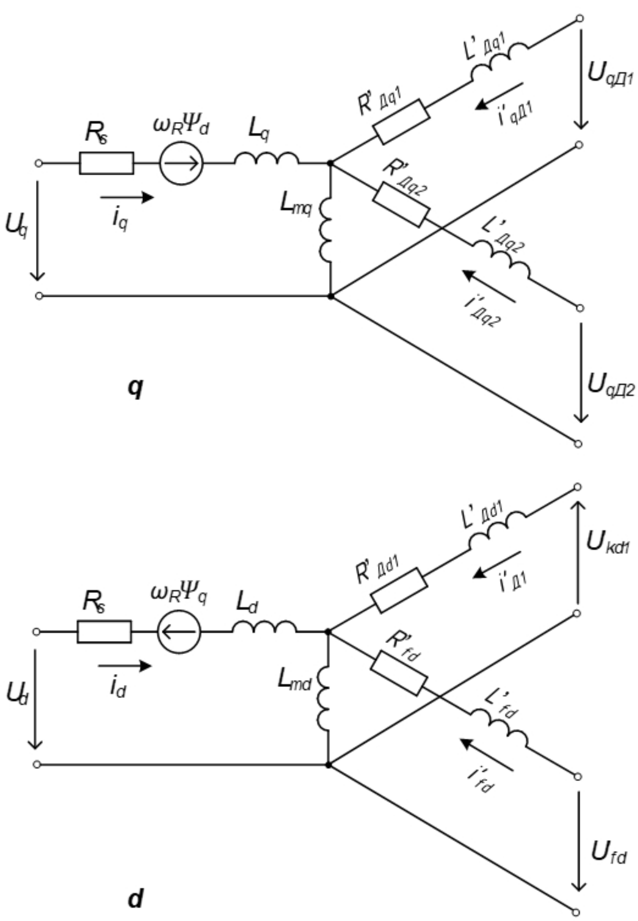


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Figure 3: MSB voltage when connecting the first IM.

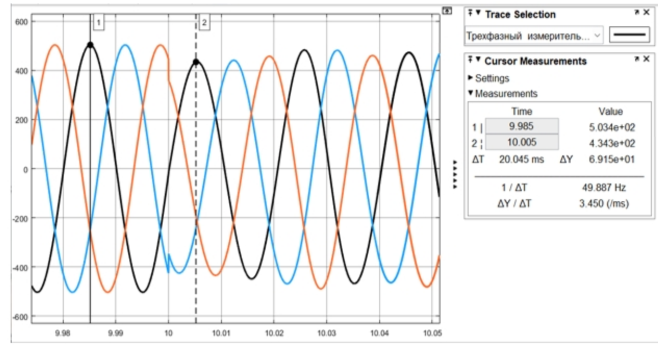

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Figure 4: Analysis of the interharmonic components (IC) of the main switchboard current during the operation of one IM.

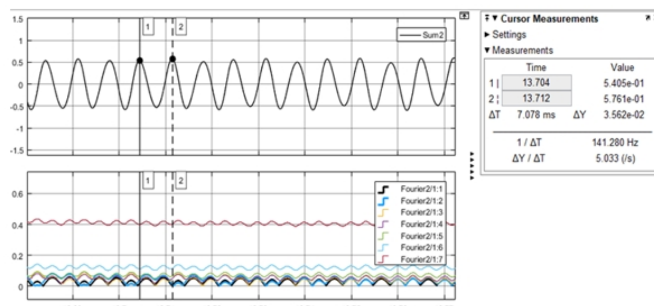

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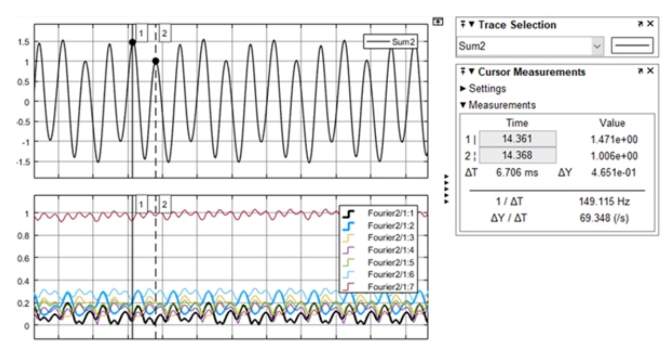
Figure 5: Analysis of the IC of the current during the operation of two IM.



Source: Authors.

Based on this, it is necessary to use devices that allow compensating for asymmetry and distortion, automatically adjusting the changing parameters [11-13]. In order to realize this, they use a system based on the principle of voltage boost which in its action is similar to the voltage stabilization system in the ship's network during its drawdowns and jumps.

Conclusions.

As a result of the research and modeling, it was revealed that the current sinusoid of the main switchboard is distorted and the IC occurs when operating a powerful electric drive of a reciprocating compressor as part of the SEPS. The voltage dip during the start of the IM does not violate the requirements of the RMRS, however, the harmonic distortions determined by THDi, THDu, and the IC amplitudes show a significant effect of the variable load of the IM on the voltage sinusoidality and current sinusoidality of the MBS.

In the course of the analysis, a solution to the problem of the presence of current IC was proposed through the use of filter-compensating devices in the circuits of compressor electric drives.

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