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INCREASE OF ELECTRIC POWER QUALITY IN AUTONOMOUS ELECTRIC POWER SYSTEMS

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With the constant development of electronics for control and monitoring of the work for significant and important elements of electric power systems, the requirements to the quality of electric power also increase. The issues of increasing the quality of electricity are solved in the field of power supply systems, which are the backbone of any electric network, because of their wider distribution and usage, unlike the autonomous electric power systems. In turn, with the development of the marine and river fleet, as well as appearance of such a promising direction for mining operations, like the Arctic zone, the autonomous electric power plants become especially important. One of the main problems of such systems is an insufficient research of the problem of the quality of electric power. The article presents a model of an autonomous electric power system. To simulate such systems, the MathLab package with the Simulink application is being widely used. The developed model provides an assessment of the quality of electricity in it, a comparison of the assessment obtained in existing systems, and a modern solution is proposed to improve the quality of electricity.

***Key words*:** Simulink model, autonomous electric power system, electromagnetic compatibility, quality of electric power

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Introduction. Ensuring the quality of electricity in the supply networks is currently an urgent topic, that is evidenced by the increased requirements for the quality of electricity, which came into effect with the new GOST 32144-2013 [6, 16]. Especially it concerns autonomous electric power systems, which include ship (SEES) and drilling electric power systems (DEPS). The experience of their operation shows that the task of maintaining the proper level of voltage and frequency on the distribution frame strips of the main switchboards in different modes of operation, as well as the load asymmetry coefficients, is solved in modern autonomous electric power systems (AEPS) without any problems. This cannot be said of such a quality indicator as the coefficient of nonlinear voltage distortion, which shows how much the actual shape of the voltage differs from the sinusoidal one.

The distortion of the form of the supply voltage is connected with the presence of non-linear consumers in the autonomous electric power systems, including controlled and uncontrolled rectifier units, frequency converters, lighting equipment, etc. The consumption of non-sinusoidal current by nonlinear receivers, results in the generation of higher harmonics of current into the network, which distorts the form of the main voltage. The size of the voltage distortion in the autonomous electric power plant is determined by the power of static converters, their circuitry, the inductive resistance of the generator and the network to higher harmonics, the depth of voltage regulation, etc. The presence of higher harmonics of voltage in the ship's network adversely affects the work of both consumers and sources electric power, which in the autonomous electric power plant are diesel-generator sets [1, 8, 9, 20, 21].

The harmonics affect the generator in a negative way, worsening both its operation and the work of the entire autonomous power plant as a whole. If the level of harmonics is higher than the normal one, false alarms and incorrect operation of control systems occur, which can disable the entire electrical equipment. The equipment control systems, in particular power drives, are not able to work properly due to distortions, since they distort the sinusoid of current and voltage, as a result of which the equipment either turns off or breaks down, which at major and important autonomous electric power plants is unacceptable because of the importance of the functions they perform.

The aim of the work is to determine the level of harmonics in existing autonomous electric power plants, to assess their influence on the generator and to develop a modern method of reducing the level of harmonic components in the network of the operating autonomous electric power plant.

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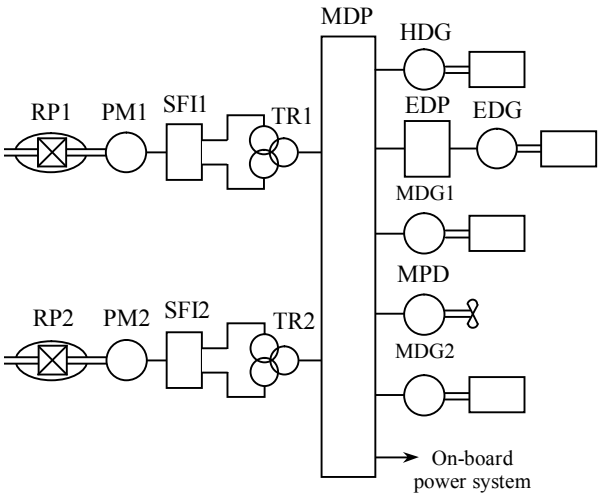


Fig.1. The structural layout of electric power plant system of a ship

To achieve these goals, it is necessary to simulate the work of the autonomous power plant. The use of modern software products for mathematical modeling makes it possible to significantly simplify the task of creating a model of the electro-energy system. Some modern software products, among which the leading position is occupied by MathLab with the Simulink application, have a fairly large library of standard devices and virtual measuring devices, which are necessary for computing experiments in the system [7, 15, 19].

Research method. The structure of the main diesel-electric power plant (Fig. 1) includes two main diesel-generator sets with a capacity of 1000 kW (MDG1, 2), a harbor diesel generator (HDG), two asynchronous propulsion motors of 550 kW (PM1, 2), two semiconductor frequency inverters (SFI1, 2) with a power of 700 kV·A, two triple-winding step-up transformers with a power of 800 kV·A (TR1, 2), a main distribution panel (MDP), two rudder-propellers (RP1, 2). In the head part of the vessel there is a maneuvering propulsion device (MPD). The ship has an emergency diesel generator (EDG) with a capacity of 100 kW with emergency distribution panel (EDP) to supply power to the most critical consumers in emergency situations [2, 3, 12, 18].

Within the framework of this paper we have considered and researched a case of emergency, which one main diesel generator has failed and the power of the two propulsion motors is supplied by one remaining diesel generator. The scheme of SEES in the MathLab environment is presented in Figure 2.

The «Diesel engine» block [22] simulates the operation of the diesel internal combustion engine, the «Synchronous generator» - synchronous motor block (in the presented model the «Synchronous Machine pu Standard» block from the Simulink library was used), the «Frequency-controlled drive» – block with a transformer, frequency converter and propulsion motor [7]. To evaluate the performance of the system in abruptly changing loads, the units that model the drive with frequency control are set for a constant sharp increase in load on the shaft.

Research results. The resulting current sine wave is shown in Fig.3. As you can see, its shape is different from the reference one. The analysis of harmonic components shows that the coefficient of non-linear errors in the system is about 25 %, which is unacceptable for normal operation of the equipment.

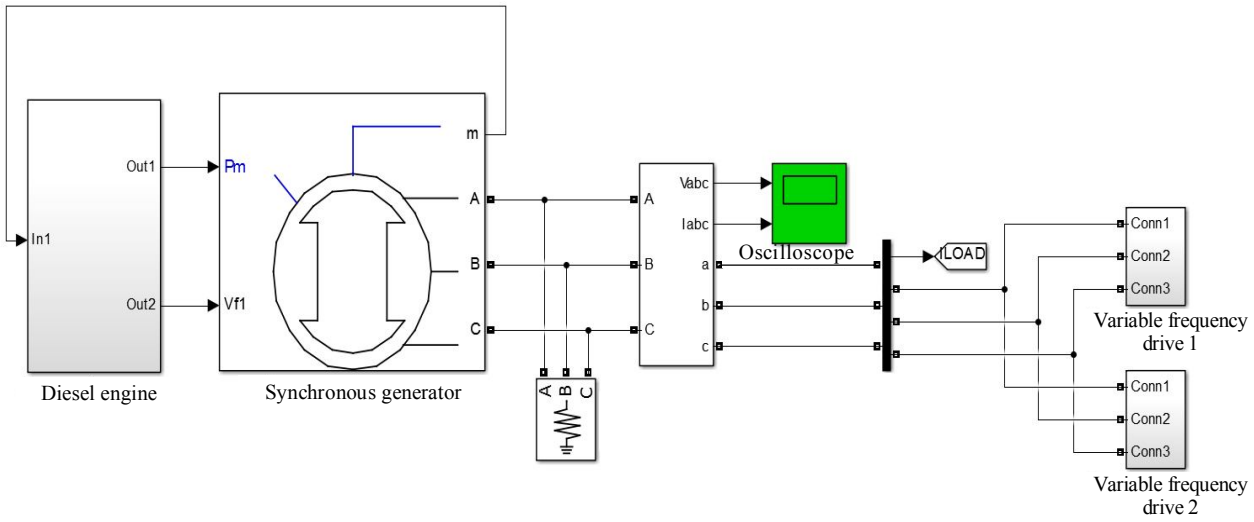


Fig.2. The layout of electric power system of a ship

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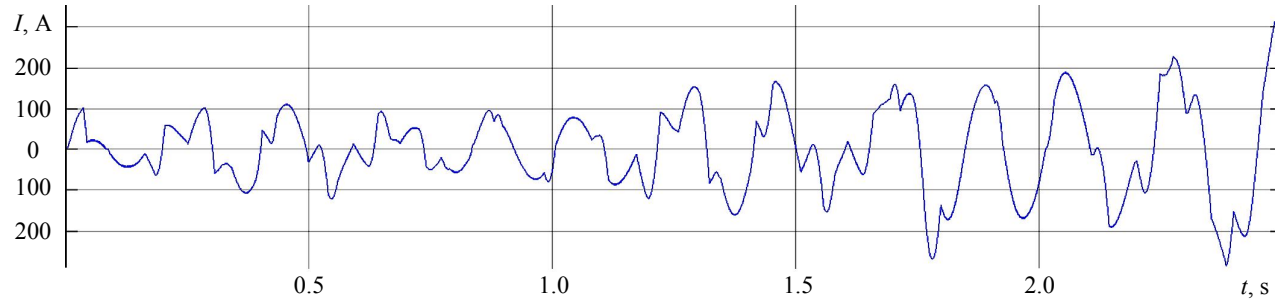


Fig.3. The current sine wave of the modeled SEES

The harmonic distortions revealed during the simulation are also confirmed during the operation of the autonomous electric power systems. The analysis of the operation of the electric power system of the jack-up drilling rig (JUDR) «Arkticheckaya» in different modes is given in the table.

The measurements results for JUDR «Arkticheskaya» for different modes of operation

Mode of operation	ΣP, kW	ΣQ, kVAr	cos ϕ	THDU1, %	THDU2, %	THDI, %
Drilling:	1780	2446	0.59	***12***	0	***16.5***
technology 1						
technology 2	1594	2158	0.59	***10***	9.8	***12.4***
Round trip operations:	1380	800	0.86	4	3.8	***10***
technology 1						
technology 2	1550	1700	0.67	8	9.2	***15.1***
Cementation	800	480	0.86	0.6	0	0.5

Note. The figures in bold italics are values going beyond the norm.

The measurements were taken at an exploration well of 2300 m, where: ΣP – active power in the electric power plant, in total by two inputs; ΣQ – reactive power in the power plant, in total by two inputs; THDU1 – coefficient of nonlinear distortion of voltage in the network with 660 V; THDU2 – factor of nonlinear distortions of voltage in a network with 400 V; THDI – coefficient of non-linear distortion of current in the electric power plant.

The currently existing methods of reducing the nonlinear distortions assume the use of both the layout changes or structural solutions, as well as various devices for suppressing higher harmonics. In particular, converters with increased phase, network inductance chokes and filters, DC chokes, resonance and sinus filters are used. The main disadvantage of these devices is their significant weight and dimension characteristics, which seems to be critical in autonomous electric power systems, as the increase in weight and size leads to an increase in operating costs. A modern tool being used at such power plants is the active filter [10, 17].

The active high-current harmonic filter is connected to the network in parallel with the load generating higher harmonics of the current. It contains IGBT-transistors and operates on the principle of the generator of «anti-harmonic» current to compensate for the higher harmonics of the nonlinear load current. The active filter has an automatic setting to compensate for the higher harmonics of sharply varying loads. It also completely controls the current of compensation according to the principle of the current source, which excludes the possibility of occurrence of resonance phenomena typical of passive filters. Together with the compact sizes of power transistors this provides small dimensions of the power part of the active filter [11].

A simplified model of the active harmonic filter is shown in Fig. 4 [5]. The main blocks of the active filter are the inventory and power storage devices – capacitors. The model uses a simplified control system for the active filter for generating inventory control signals, the reference signal

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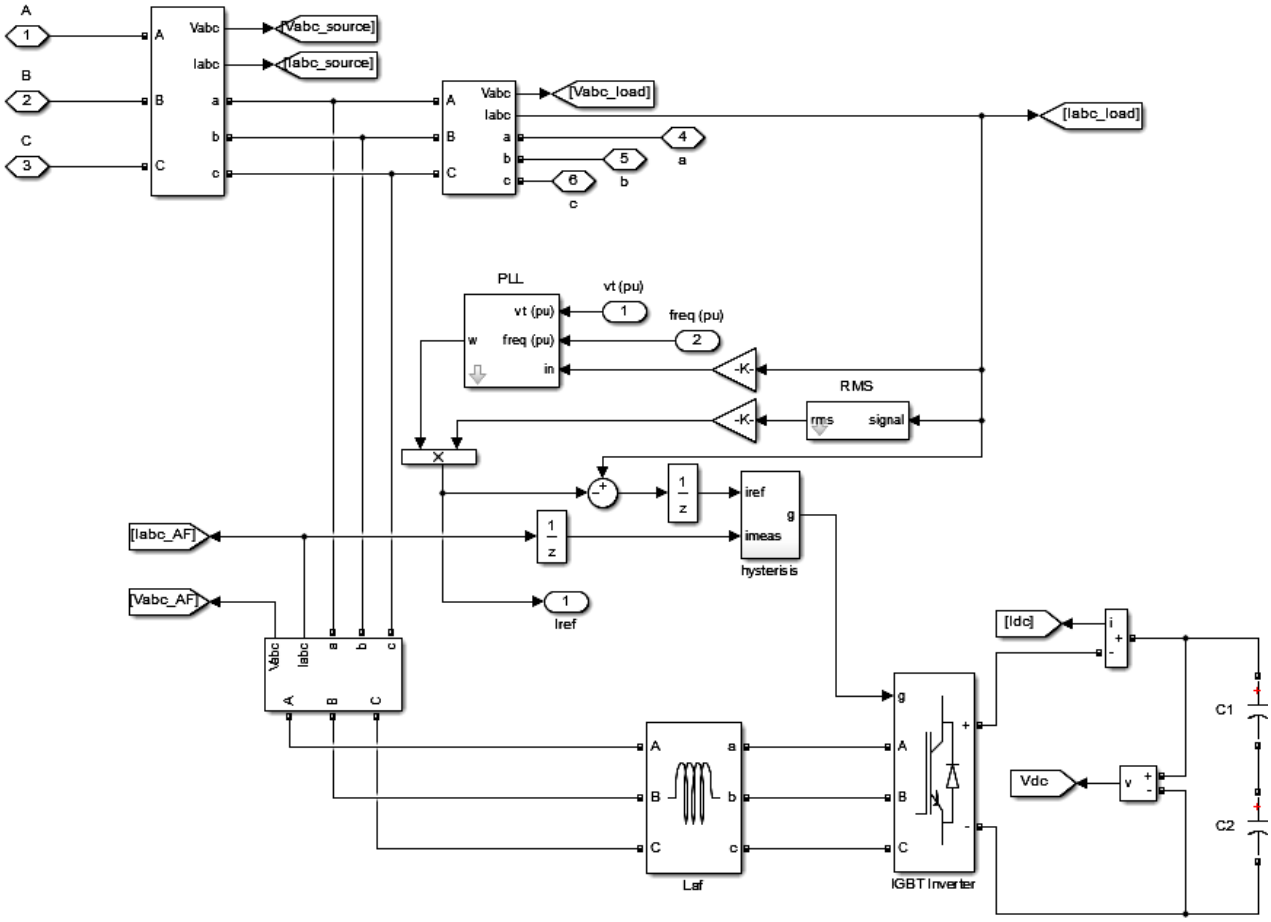


Fig.4. The simplified model of active filter for high-harmonics

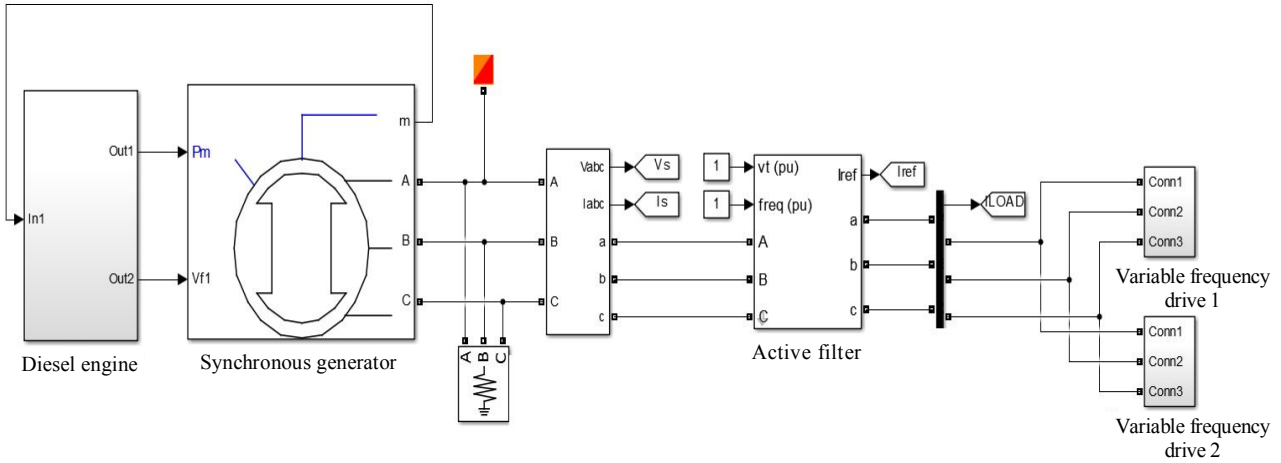


Fig.5. The layout of electric power system of a ship with included active filter

generation unit is used, the effective value and frequency of which correspond to the measured values of the nonlinear load current.

Unlike the above-mentioned model, the active filters of the world's leading manufacturers are built on the basis of powerful microprocessor systems with the use of special processors for digital signal processing, which allows achieving high rates of dynamic compensation of reactive power and filtering of nonlinear distortions in the system. The model of a autonomous electric power plant with an active filter is shown in Fig.5.

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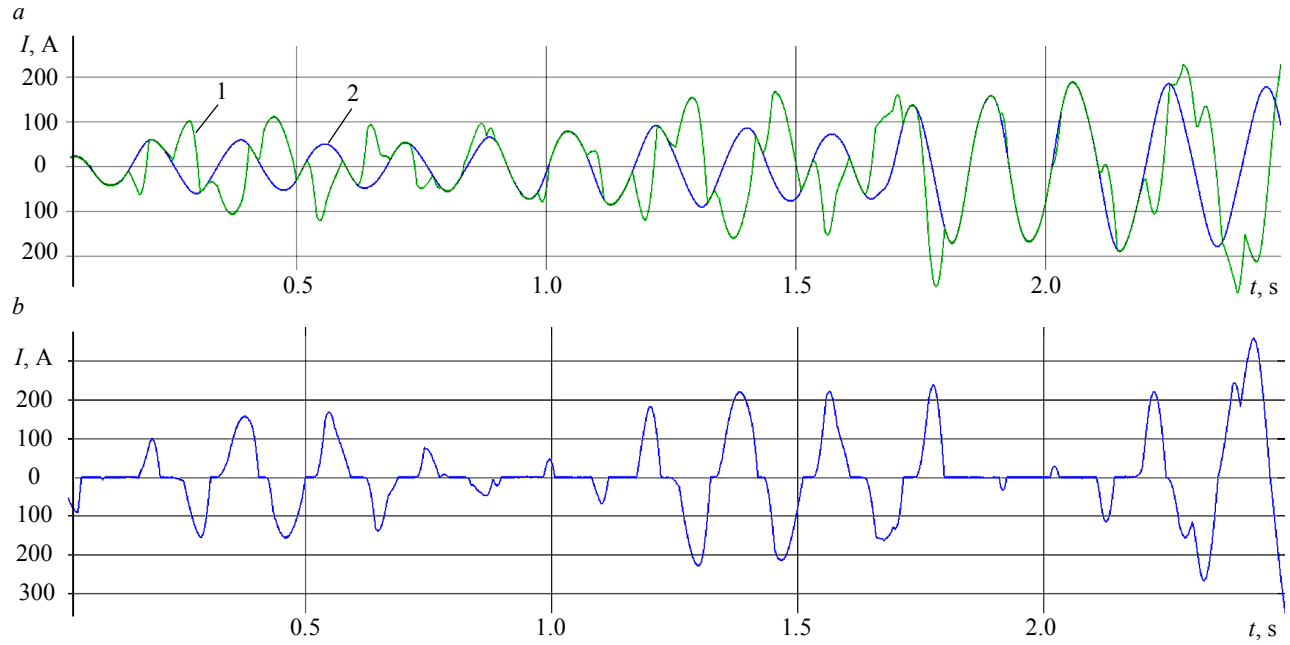


Fig.6. The results of active filter application

Research results. For comparison, the diagrams in Fig. 6 *(a)* show the results with a working active filter (1) and without it (2). The diagram in Fig. 6 *(b)* shows the corrective signal of the active filter.

Conclusion. The active high-harmonics filter is a modern tool for dealing with non-linear distortions. However, its work in autonomous electric power systems, which include ship and drilling power systems in particular, has not been studied, so this line of research will remain relevant. This is due to the growing importance in these days of such a strategically important direction for oil and gas production, like the deposits located in the Arctic area. Production in this region is provided with the help of sea-based drilling rigs, which use power rectifier units and frequency converters, which, in turn, worsen the operation of the power system of the drilling rig and are able to put it out of action, which is almost unacceptable in severe conditions Arctic climate and large remoteness of drilling rigs. In particular, in order to reduce the nonlinear distortions in the operation of the power system of the JUDR «Arkticheskaya», the results of which are given in the table, it is necessary to install two active filters of 375 A.

The analysis of existing passive methods and devices to reduce nonlinear distortions of voltage showed their insufficient effectiveness, large weight and dimensions of units or practical uselessness to be installed and operated at the autonomous electric power plant. Active filters allow to purposefully influence the nonlinear voltage distortions, provide high efficiency of reactive power compensation in smaller mass and size parameters and simultaneously reduce the coefficient of nonlinear distortion created by the work of nonlinear consumers. Thus, the use of active filters in autonomous electric power systems, which include marine vessels and autonomous drilling rigs, can lead to resource savings through the implementation of a wide range of works in relatively small dimensions.

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