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SIMULATION OF ONBOARD POWER SUPPLY SYSTEM FOR SMALL HYDROGRAPHIC VESSEL «VAYGACH»

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Computer simulation is a method resorted to more and more frequently for the development of the prospective power supply systems, in particular the vessel power supply system. It provides valuable insights into the transient processes and indicators of electric power quality in the system without building its physical model, thus significantly improving the efficiency and quality of the physical model.

Nowadays MathLab package with Simulink application is used with increasing frequency for simulation of such systems.

The paper presents a model of the power supply system of small hydrographic vessel 'Vaygach' built in MatLab environment. The system vulnerabilities and their remedies have been identified. Changes in sinusoid before and after the non-linear load on the network have been demonstrated and solutions for improving the non-linear distortion factor are proposed. The model developed for the vessel power supply system can be used for building models of different vessels.

Key words: «Vaygach», Simulink model, vessel power supply system, EMC, electric power quality.

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Introduction. Ensuring high quality of electric power in the supply lines today is the pressing challenge, as evidenced by more stringent requirements to the quality of electric power, which came into effect with enactment of new GOST 32144-2013. This applies in particular to autonomous power supply systems, to which the vessel power supply systems (VPSS) belong. These systems operating practice shows that the task to maintain proper voltage and frequency on the buses of main switchboard (MSB) in different modes of operation and values of load unbalance factors is addressed in the modern VPSS without much trouble. Though it is not the case of such quality indicator, as a non-linear voltage distortion factor, which shows how much the actual voltage curve differs from the sine wave. Distortion in the feeding voltage waveform is caused by non-linear consumers in VPSS, such as controlled and uncontrolled rectifiers, frequency converters, lighting equipment, etc. Frequency converters are used on the vessels to feed and control electric motors of electric propulsion plants (EPP), vessel electric drives, process mechanisms and equipment, etc. Consumption by non-linear consumers of non-sinusoidal current leads to generation of high-order current harmonics, which distort the system voltage waveform. Amount of VPSS voltage distortion depends on the power and circuit of static converters, inductive resistance of the generator and the network to the high-order harmonics, voltage control profoundness, etc.

The presence of high-order harmonics in the voltage of the vessel network impacts the performance of both power sources and consumers. In electric machines the high-order harmonics cause additional losses, leading to overall increase in temperature and local heatings, as well as to the elevated vibrations. In cable lines the high-order harmonics lead to acceleration of isolation wear processes and additional losses in the lines. Under the impact of high-order harmonics the normal operation of protection system and automatics may be disrupted, there can be false alerts, failures in the systems of synchronization and automatic distribution of loads during parallel run of generators, etc. The high-order harmonics also exert negative impact on the converters, commutation conditions worsen, failures occur in the control system, which can lead to higher ripples of the rectified current [1, 7, 8, 18, 19].

Due to this the requirement is imposed to limit the non-linear distortion factor to the permissible values as established by GOST 32144-2013, and for the vessels the requirements of the Russian Maritime Register of Shipping and Russian River Register shall be abided by [15].

The objective of this work is to build a model of the power supply system of small hydrographic vessel «Vaygach». The task is to identify problems with the quality of electric power in the system and possible ways to eliminate those.

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Research Method. Computer mathematical simulation is a method resorted to more and more frequently to design the power supply systems. The use of modern software for mathematical simulation allows to simplify essentially the task of building a model of the power supply system. Some modern software products, the leading position among which is held by MathLab with Simulink application, have quite a large library of standard devices and virtual instrumentation necessary for carrying out computational experiments in the system. By way of example the mathematical model of synchronous generator in MathLab environment is given, which is used within VPSS as a main source of electric power [6, 13, 17].

The synchronous generator model is based on a system of Park-Gorev equations [4, 5, 11, 12]. The model was built on the following assumptions: temperature dependencies of active resistance and iron losses are not taken into account, stator windings are symmetrical. Figure 1 shows an equivalent circuit of a synchronous machine in the coordinate system connected with the rotor (*d*-*q*-axes), all parameters and variables of which have been reduced to stator.

Based on the presented equivalent circuits a synchronous salient-pole generator can be described by the following system of equations:

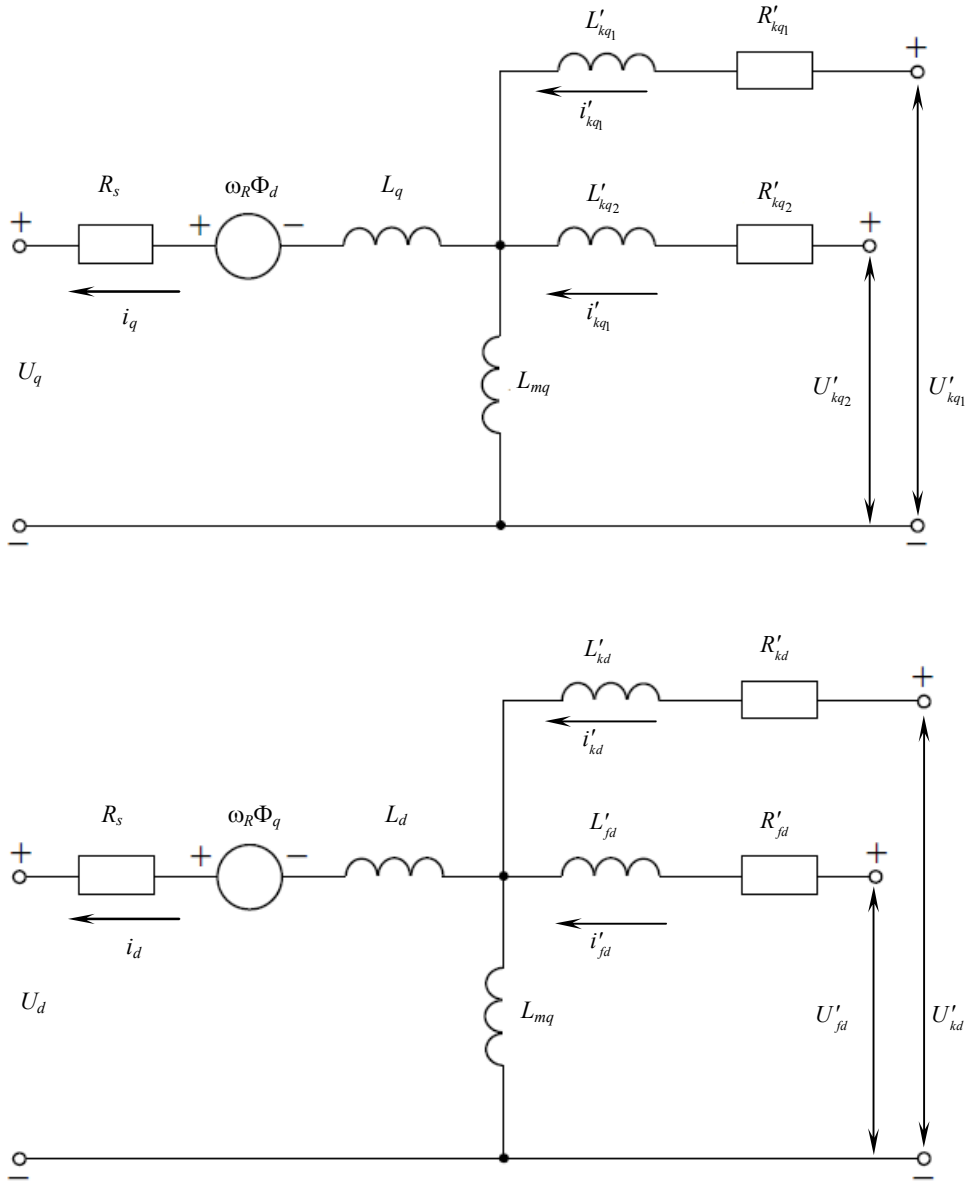


Fig.1. Equivalent circuit of synchronous machine in the coordinate system connected with the rotor (*q*-*d*-axes)

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$$\begin{cases} U_d = R_s i_d + \dfrac{d\Phi_d}{dt} - \omega_r \Phi_q; \\ U_q = R_s i_d + \dfrac{d\Phi_d}{dt} - \omega_r \Phi_d; \\ U'_{fd} = R'_{fd} i'_{fd} + \dfrac{d\Phi'_{fd}}{dt}; \\ U'_{fd} = R'_{fd} i'_{fd} + \dfrac{d\Phi'_{fd}}{dt}; \\ U'_{kd} = R'_{kd} i'_{kd} + \dfrac{d\Phi'_{kd}}{dt}; \\ U'_{kq_1} = R'_{kq_1} i'_{kq_1} + \dfrac{d\Phi'_{kq_1}}{dt}; \\ U'_{kq_2} = R'_{kq_2} i'_{kq_2} + \dfrac{d\Phi'_{kq_2}}{dt}; \end{cases}$$

$$\begin{cases} \Phi_d = L_d i_d + L_{md}(i'_{fd} + i'_{kd}); \\ \Phi_q = L_q i_q + L_{mq} i'_{kd}; \\ \Phi'_{fd} = L'_{fd} i'_{fd} + L_{md}(i_d + i'_{kd}); \\ \Phi'_{kd} = L'_{kd} i'_{kd} + L_{md}(i_d + i'_{fd}); \\ \Phi'_{kq_1} = L'_{kq_1} i'_{kq_1} + L_{mq} i_q; \\ \Phi'_{kq_2} = L'_{kq_2} i'_{kq_1} + L_{mq} i_q, \end{cases}$$

where U_d, U_q is the voltage armature winding along the longitudinal and transverse axes; U'_{fd} is the voltage of excitation winding; U'_{kd}, U'_{kq_1}, U'_{kq2} is the voltage of the damper windings; i_d, i_q are the currents of the armature winding along the longitudinal and transverse axes; i'_{kd_1}, i'_{kd_2}, i_{kd} are currents of synchronous machine damper winding along the longitudinal and transverse axes; i'_{fd_1} is the current of excitation winding; Φ_d, Φ_q is the magnetic flux along the longitudinal and transverse axes of the synchronous machine; Φ'_{kd}, Φ'_{kq_1}, Φ'_{kq_2}, Φ'_{fd} is the magnetic flux of damper windings and excitation winding of the synchronous machine; ω_r is the angular speed of the rotor; L_d, L_q is the inductance of the synchronous machine armature winding along the longitudinal and transverse axes; L'_{kq_1}, L'_{kq_2}, L'_{kd} - is the inductance of the synchronous machine damper winding along the longitudinal and transverse axes; L'_{fd_1} is the inductance of excitation winding of the synchronous machine; R'_{kq_1}, R'_{kq_2}, R'_{kd} is the active resistance of the synchronous machine along the longitudinal and transverse axes; R_s is the active resistance of the armature winding; R'_{fd} is the active resistance of the excitation winding; L_{md}, L_{mq} is the mutual inductance between the windings along the longitudinal and the transverse axes.

The model of synchronous machine 'Synchronous Machine pu Standard', presented in Matlab package with Simulink application, corresponds to the above description [6].

As a rule the vessel power station includes several diesel generators servicing the common network. Their parameters in a general case can differ from each other. That's why in order to simplify the process of VPSS parameters calculation and VPSS simulation it makes sense to replace multiple generators with a single equivalent generator.

Figure 2 shows a block diagram of the vessel power supply system. The main diesel electric power supply unit of the vessel includes: two main diesel generators (MDG 1, 2) rated 1000 kW, two electric propulsion motors of asynchronous type (EPM 1, 2) rated 500 kW, two semiconductor frequency converters (SCFC 1, 2) of the supply mains with frequency of 50 Hz rated 700 kVA, two three-winding stepup transformers rated 800 kVA (TR 1, 2), the main switchboard (MSB) and two rudder propellers (RP 1, 2). At the vessel front there is the bow thruster (BT). The vessel has an emergency diesel generator (EDG) rated 100 kW with emergency switchboard (ESB) to feed the most critical consumers in case of emergency.

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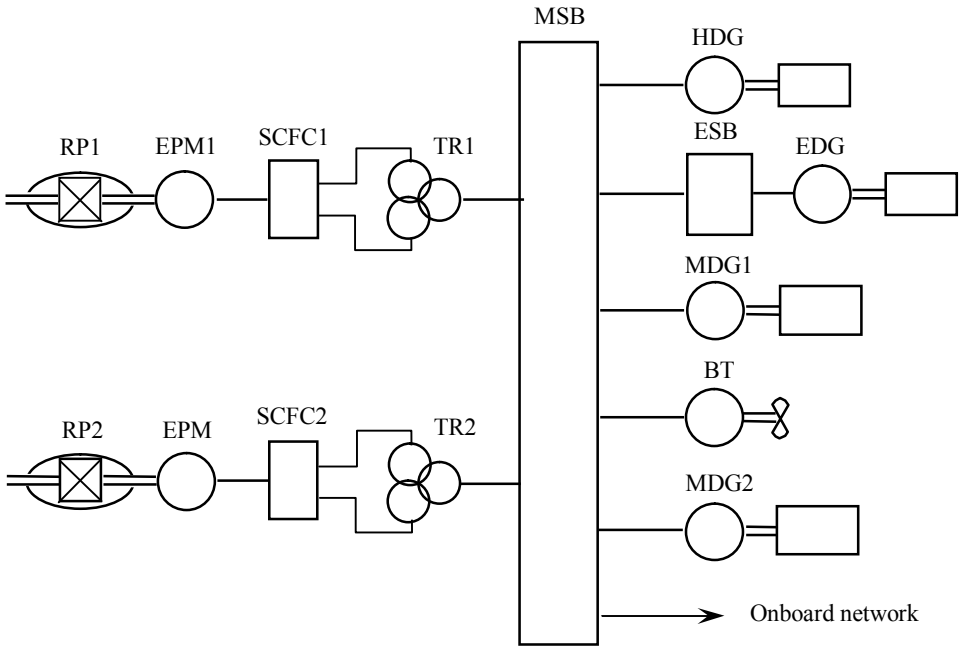


Fig. 2. Block diagram of vessel power supply system

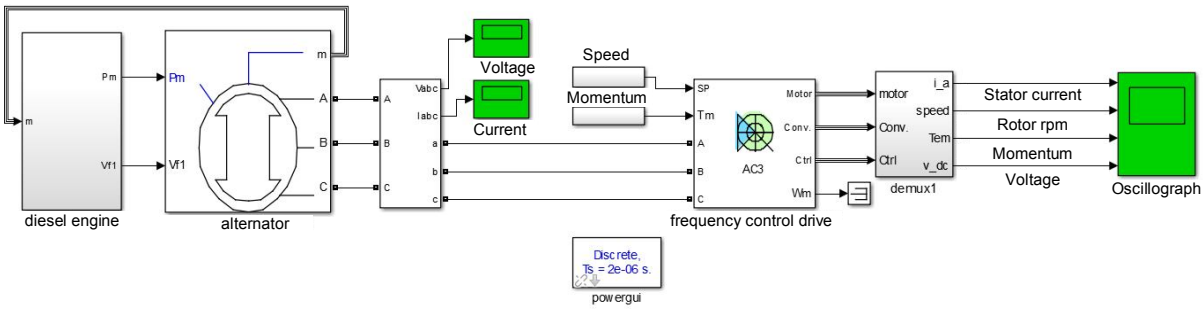


Fig.3. Diagram of vessel power supply system

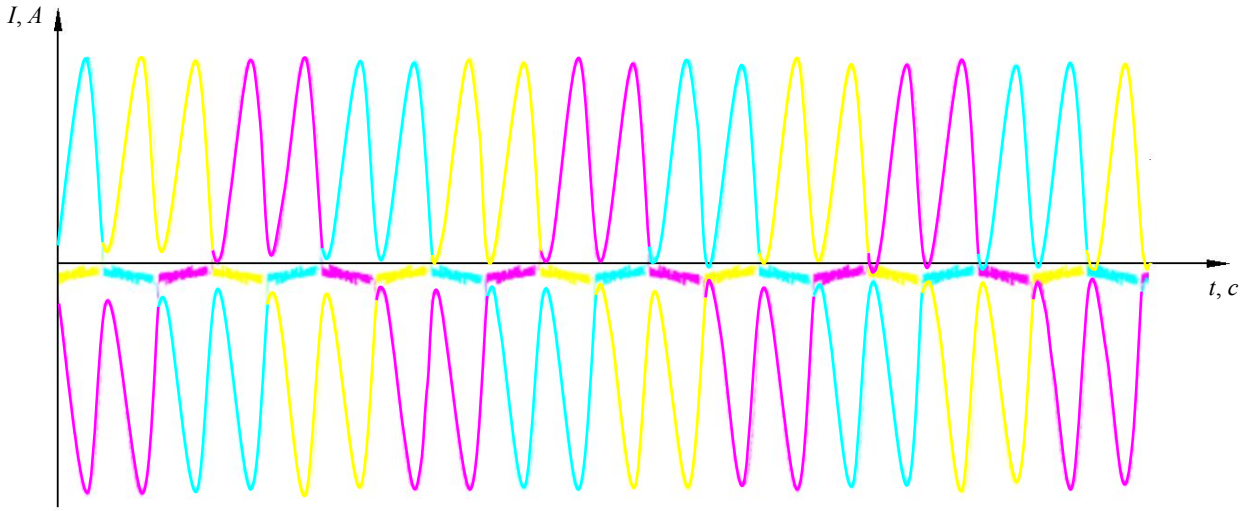


Fig. 4. Current sinusoid obtained by simulation

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In this research the work of one MSB section in the regular operation mode has been examined. VPSS diagram built in MathLab environment is presented in Figure 3 [2, 3, 10, 16].

Diesel Motor block [20] simulates the work of a diesel internal combustion motor, Synchronous Generator block simulates the operation of synchronous motor (the presented model is built using Synchronous Machine pu Standard block from Simulink libratory), drive with Frequency Control block simulates the block, including a transformer, a frequency converter and a propulsion motor.

When the parameters of vessel aggregates are known, this model can be adjusted for other vessels, and thereby necessary parameters of the power supply network can be obtained. Also this principle of building the models of autonomous electric power systems provides insight into the architecture of the autonomous electric power supply systems of offshore drilling rigs, which employ non-linear consumers of electrical energy, etc.

The current sinusoid obtained by simulation is presented in Fig.4.

Research Findings and Discussion. The obtained sinusoid is different from the reference sine wave. The main reason of changes in the sinusoid wave are the high-order harmonics, generated by drive frequency control. Negative impacts, which can result from the high-order harmonics are described above.

The existing ways to reduce non-linear distortions suggest the use of both network or structural solutions and different devices to suppress the high-order harmonics. These can include converters with increased number of phases, line throttles and filters, DC throttles, resonant and sine filters. The main drawback of the above devices are their considerable weight and overall dimensions, which is especially true for the autonomous power supply systems, to which VPSS belong. The modern device to filter out the high-order harmonics is the active filter [9, 14].

The high-order harmonics active filter shall be connected to the network in parallel to the load, generating the current high-order harmonics. It includes IGBT-transistors and works on a principle of ‘anti-harmonics’ generator for compensation of the current high-order harmonics of the non-linear load. The active filter has automatic control for compensation of the high-order harmonics of severely fluctuating loads. It also fully controls the compensation current by principle of the current source, thus eliminating a possibility of any resonant impacts as can be observed when passive filters are used. That coupled with the compact size of power transistors ensures small dimensions of the active filter power component [5], i.e. the use of active filters in autonomous electric power supply systems, which are used on the marine vessels, can bring about the resource saving due to the performance of a large range of works within comparatively small dimensions.

Thus the computer model we built has revealed a problem of high-order harmonics above the permissible level. The modern way to improve the non-linear distortion factor is the use of harmonics active filters.

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