ISSN 2079-8024 (print)

UDC 62-83-027.236(045) doi: 10.20998/2079-8024.2020.4.11

M. MUKHA, A. DRANKOVA, I. KRASOVSKYI

THE EXPERIMENTAL INSTALLATION FOR THE STUDY AND RESEARCH OF ELECTROMECHANICAL SYSTEMS ENERGY-EFFICIENT MODES

A modern variable frequency drive (VFD) is becoming an integral part of ship systems and complexes, where energy-efficient and resource-saving technologies are widely used. Therefore, the study and research of such electric drives for various applications with a typical load of ship mechanisms is an actual task. This paper presents an experimental setup designed to study and test methods and laws of VFD control, evaluate power quality indicators and energy-efficient modes of an electromechanical systems operation with a typical ship load. Used unit for measuring parame-ters (124 parameters) of electricity ME96SS ver. A, through MODBUS® RTU and the corresponding software for data collection, EMU4-SW1 allows you to display and record data in real time, and then present the results in the form of tables, graphs, etc. FR-Configurator 2 software of parameterization and adjustment allows to explore the various laws of controlling of ship mechanisms and systems. The typical nature of the loads for the studied motor for such mechanisms is simulated by a load DC generator, in the anchor circuit of which the steps of the resistors are switched as a function of speed (speed sensor signal) using a programmable controller. The proposed experimental setup, the available hardware and software testing, commissioning and diagnostics tools allow to develop and implement energy-saving technologists in ship's electromechanical systems, improve the methods of their technical operation based on the analysis of the technical condition. Used experimental research methods, modern energy-saving technologists are of great importance for the educational process.

Keywords: experimental installation, electromechanical system, study and research of energy-saving modes, variable frequency drive, hardware and software tools.

М. Й. МУХА, А. О. ДРАНКОВА, І. І. КРАСОВСЬКИЙ

ЕКСПЕРИМЕНТАЛЬНА УСТАНОВКА ДЛЯ ВИВЧЕННЯ І ДОСЛІДЖЕННЯ ЕНЕРГОЕФЕКТИВНИХ РЕЖИМІВ ЕЛЕКТРОМЕХАНІЧНИХ СИСТЕМ

Сучасний частотно-регульований привод (ЧРП) стає невід'ємною частиною суднових систем і комплексів, де широко використовуються енергозберігаючі та ресурсозберігаючі технології. Тому вивчення і дослідження таких електроприводів різного призначення з типовим навантаженням суднових механізмів є актуальним завданням. У даній роботі представлена експериментальна установка, яка призначена для вивчення і тестування методів і законів управління ЧРП, оцінки показників якості електроенергії та енергоефективних режимів роботи електромеханічних систем з типовим судновий навантаженням. Використовуваний блок вимірювання параметрів (124 параметри) електроенергії ME96SS ver. A, через MODBUS® RTU і відповідне ПО для збору даних EMU4-SW1 дозволяє в режимі реального часу відображати і записувати дані, а потім представляти результати у вигляді таблиць, графіків і т.п. ПО параметрування і налагодження частотних перетворювачів FR-Configurator 2 дозволяє досліджувати різні закони управління судновими механізмами і комплексами. Типовий характер навантажень для досліджуваного асинхронного двигуна для таких механізмів імітується навантажувальним генератором постійного струму, в якірному колі якого комутуються ступені резисторів в функції частоти обертання (сигналу датчика швидкості) за допомогою програмованого контролера. Запропонована експериментальна установка, наявні апаратно-програмні засоби тестування, налагодження та діагностики дозволяють розробляти і впроваджувати енергозберігаючі технології в суднові електромеханічні системи, удосконалювати методи їх технічної експлуатації на основі аналізу технічного стану. Використовувані експериментальні методи досліджень, сучасні енергозберігаючих технологи мають велике значення для навчального процесу.

Ключові слова: експериментальна установка, електромеханічна система, вивчення і тестування енергозберігаючих режимів, частотно-регульований при-вод, апаратно-програмні засоби.

Н. И. МУХА, А. О. ДРАНКОВА, И. И. КРАСОВСКИЙ

ЭКСПЕРИМЕНТАЛЬНАЯ УСТАНОВКА ДЛЯ ИЗУЧЕНИЯ И ИССЛЕДОВАНИЯ ЭНЕРГОЭФФЕКТИВНЫХ РЕЖИМОВ ЭЛЕКТРОМЕХАНИЧЕСКИХ СИСТЕМ

Современный частотно-регулируемый привод (ЧРП) становится неотъемлемой частью судовых систем и комплексов, где широко используются энергосберегающие и ресурсосберегающие технологии. Поэтому изучение и исследование таких электроприводов различного назначения с типичной нагрузкой судовых механизмов является актуальной задачей. В данной работе представлена экспериментальная установка, предназначенная для изучения и тестирования методов и законов управления ЧРП, оценки показателей качества электроэнергии и энергоэффективных режимов работы электромеханических систем с типовой судовой нагрузкой. Используемый блок измерения параметров (124 параметра) электроэнергии ME96SS ver. A, через MODBUS® RTU и соответствующее ПО для сбора данных EMU4-SW1 позволяет в режиме реального времени отображать и записывать данные, а затем представлять результаты в виде таблиц, графиков и т.п. ПО параметрирования и наладки частотных преобразователей FR-Configurator 2 позволяет исследовать различные законы управления судовыми механизмами и комплексами. Типовой характер нагрузок для исследуемого АД для таких механизмов имитируется нагрузочным генератором постоянного тока, в якорной цепи которого коммутируются ступени резисторов в функции частоты вращения (сигнала датчика скорости) с помощью программируемого контроллера. Предложенная экспериментальная установка, имеющиеся аппаратно-программные средства тестирования, наладки и диагностики позволяют разрабатывать и внедрять энергосберегающие технологи в судовые электромеханические системы, совершенствовать методы их технической эксплуатации на основе анализа технического состояния. Используемые экспериментальные методы исследований, современные энергосберегающих технологи имеют большое значение для учебного процесса.

Ключевые слова: экспериментальная установка, электромеханическая система, изучение и исследование энергосберегающих режимов, частотно-регулируемый привод, аппаратно-программные средства.

Introduction. The marine fleet provides most of the transportation for the global market of goods and raw materials. Reducing energy costs per unit of cargo by increasing the energy efficiency of marine vessels allows, on the one hand, lowering the cost of shipping, and on the other hand, prevents air pollution from ships and provides to reduce the amount of emissions into the atmosphere.

Reducing operating costs is one of the main concerns of the shipping industry today. The requirement that vessels must obtain an international certificate of energy efficiency establishes new rules for managing the vessel's energy efficiency and ways to reduce energy consumption on water transport.

Therefore, the development of an energy-efficient strategy for the operation of sea and river transport is a priority and relevant investigation. In our opinion, the effectiveness of the vessel should be a part of the design and construction criteria for ships.

Problem analysis. At Present in the ship's complex "generation - consumption of electricity" the potential for improving energy efficiency was used only to a small extent. The specificity of improving energy efficiency in this complex is the significant saving of primary fuel resources by reducing power consumption.

One of the ways to increase the energy efficiency of ship operation and reduce energy consumption is to develop methods for managing electricity flows. Unwanted losses occur in the generation, distribution, transformation and use of electricity in a ship's autonomous electricity system.

In addition, ship consumers of electricity are mainly active-inductive load, i.e. the total current of generators, transformers and cable lines should increase in relation to the required active load by a value that is inversely proportional to the value of the power factor, which is proportionally to the increase electrical consumers. Therefore, generating installations must provide additional jet power, which in turn reduces their efficiency due to the increased fuel consumption of the prime move drives.

Thus, as mentioned earlier, one of the ways to increase the energy efficiency of the ship's operation and reduce the power consumption along with improving the operation modes of the ship's propulsion and optimizing the operation of an auxiliary equipment and mechanisms is a develop rational methods of managing electrical energy flows of the shipboard power plant.

In our opinion, there are two ways to solve this problem. This determines two areas of research into this problem: 1) optimal control of the electrical energy flow at the stage of its generation and distribution; 2) optimization of energy flows at the consumption stage, i.e. at the stage of electromechanical electricity conversion. The main research results associated with the 1-st area presented in our papers [1, 2]. The biggest benefit of designing a newbuild in a more energy efficient way is the potential for reducing the size of the shipboard power plant, which can operate with power factor close to unity.

The problem of increasing the energy efficiency of ship generation systems is urgent and rather complicated due to the restrictions due to the laws of physics.

Based on the given values of the generating plants efficiency [3], we can conclude that saving one unit of electricity at the consumption stage allows saving up to five units of conventional primary fuel.

Therefore, in our opinion, the 2-nd strategic direction of research, which is associated with a more efficient use of electrical energy, is reasonably arguable.

Moreover, if you keep in mind that the component of the total generated energy, which converted using vessel's electromechanical systems, is more than 90%.

Thus, the introduction of energy-efficient electromechanical systems has the potential to reduce electricity consumption by more than 10-15% of the total generated and is one of the priority areas for increasing the vessel's energy efficiency.

A modern variable frequency drive (VFD) is becoming an integral part of ship systems and complexes [4], where energy-efficient and resource-saving technologies are widely used. Therefore, the study and research of such electric drives for various applications with a typical load of ship mechanisms is an actual task.

The aim of this work is to create a laboratory installation for studying and testing a control laws, evaluating the energy parameters of an adjustable electric drive of ship's electromechanical systems with a typical load.

Research materials. In Fig.1 presented the laboratory setup for the study and research of control laws, indicators of the electric energy quality and assessment an energy efficiency of asynchronous electric drives with frequency converters FR-F840, FR-A740 and voltage converter (soft starter) of type RVS-DN-8-400.

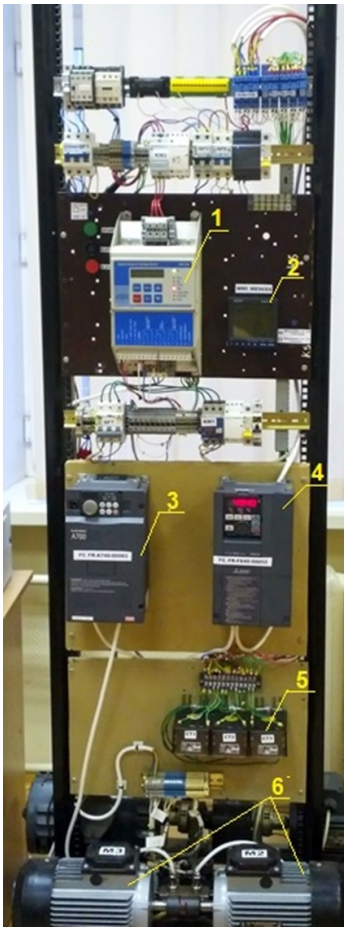

Fig. 1 – Voltage and frequency converters with asynchronous motors aggregate: 1 – Digital Voltage Soft Starter; 2 – Electronic Multimeasuring Instrument ME96SSRA-MB; 3 – Frequency Converter FR-A740; 4 – Frequency Converter FR-F840; 5 – Current Transformers; 6 – Two-machine Aggregate with 1.5 kW Asynchronous Machines

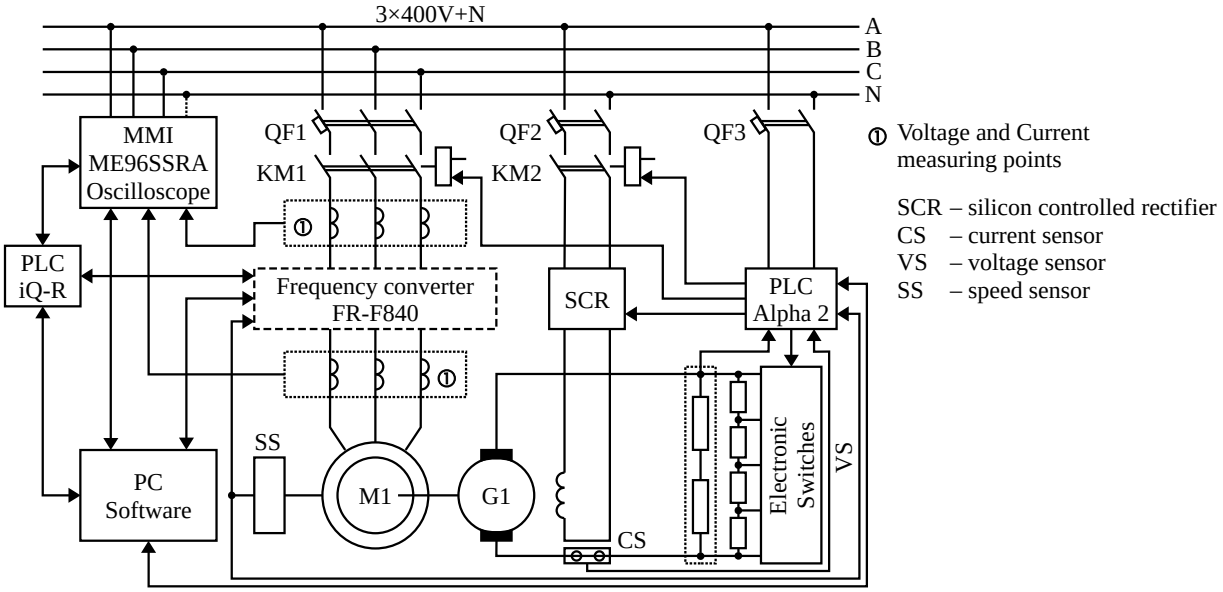

Fig. 2 - Functional diagram an experimental installation of the electromechanical system with VFD

The functional diagram of the VFD research complex shown in Fig. 2. The measuring equipment of the laboratory complex is a good tool for research work, and the available software provides convenient opportunities for receiving and presenting research results.

The MMI block consists with an electronic multi-measuring instrument ME96SSRA-MB (ME96SS – A Ver.) and an oscilloscope ExtechMS420, which measure and record electrical energy parameters, power quality indicators and their time and phase dependencies. We are used this Energy Measuring Unit ME96SS Ver. A series unit with MODBUS® RTU (using RS-485 - USB conversion adapter) and corresponding Data Acquisition Software EMU4-SW1 for remote real-time monitoring system of an electrical energy parameters.

Data acquisition function can acquire the data from measuring terminals at constant intervals: 1 minute or 1 hour. In the “Report output” function, is create, for example, a detailed report by pasting the data measured at any constant interval to the master file (Excel file). Measured parameter's values are updated one-second intervals at shortest and save it as CSV file. The result file of data acquisition is stored in the user folder.

Data Sheet for ME96SSRA-MB is shown in table below. In Fig. 3 is shown the connection diagram of the device ME96SSRA-MB for measuring the electricity parameters. Using the ME96SSRA-MB instrument it is possible to measure the input power source parameters of the converter and the load parameters [11, 12] (at the converter output) by entering the measured values from the secondary windings of voltage transformers and current transformers and display the values of these measurements. Measuring type: instantaneous or integration value. Measuring elements are phase or linear currents, phase or linear voltages, active power, reactive power, apparent power, power factor and frequency.

In addition, it can measure harmonics (current and voltage) [10] and count active energy (imported and exported) and reactive energy (imported lag, imported lead angle, exported lag, exported lead angle).

Measuring Items	ME96SSRA-MB
Current (A)	±0.2%
Demand Current (DA)	
Voltage (V)	±0.2%
Active Power (W)	±0.5%
Reactive Power (var)	±0.5%
Apparent Power (VA)	±0.5%
Power Factor (PF)	±0.5%
Frequency (Hz)	±0.1%
Active Energy (Wh) (IEC62053-21,22)	Class 0.5S (Import/Export)
Reactive Energy (varh)	Class1S
Apparent Energy (VAh)	±2.0%
Harmonics Current (HI)	Max.19th,±1.0%
Harmonics Voltage (HV)	Max.19th,±1.0%

It can expand the remote input/output function to the ModBus RTU communication, that is provide for visualization on HMI (GOT). This allow to efficiently operate, monitor and control of an investigational processes. GOTs can be seamlessly integrated to other Mitsubishi Electric devices like PLCs, inverters, or motion systems for a total automation and studying solution [5-7].

Simulation of the typical load of asynchronous electric drives was performed with the help of load-type direct-current (DC) generators, which are connected by a coupling with an asynchronous electric motor. The load of the generators, in turn, varies or discretely from idling to 1.25 of the generators rated current with a constant excitation of the generator or smoothly while regulating the excitation voltage of the generator (see Fig. 2).

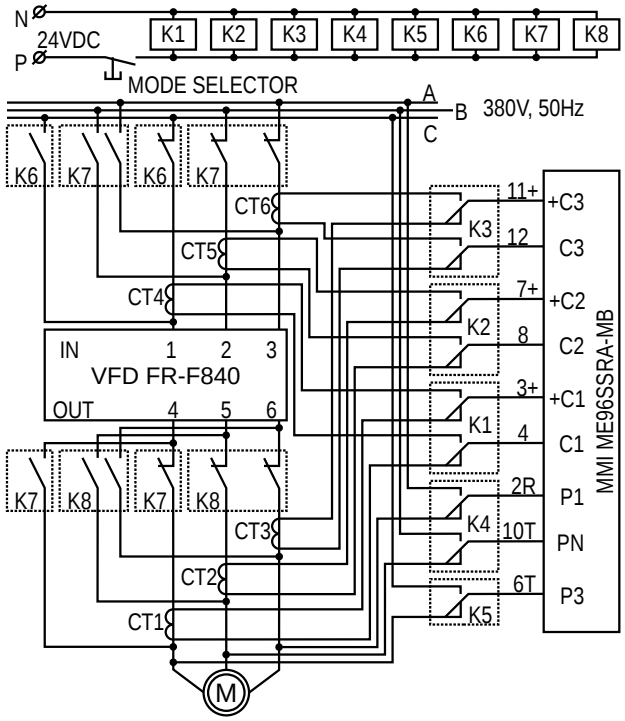

Fig. 3. The connection diagram of the ME96SSRA-MB device

The law of the load torque changing on the motor shaft can be formed by means a PLC in automatic mode as a function of changing the speed of the motor shaft (analog feedback signal from the speed sensor, which is fed to the PLC input, see fig. 2). Typical mechanical characteristics of ship mechanisms (fans, centrifugal pumps, lifting mechanisms, conveyors, etc.) are preprogramed for the PLC. These laws are determining an algorithm for connecting the corresponding resistors to the armature circuit of the generator.

Schematic diagram of the speed sensor for the automatic mode of the load torque formation of typical ship mechanisms is shown in Fig. 4.

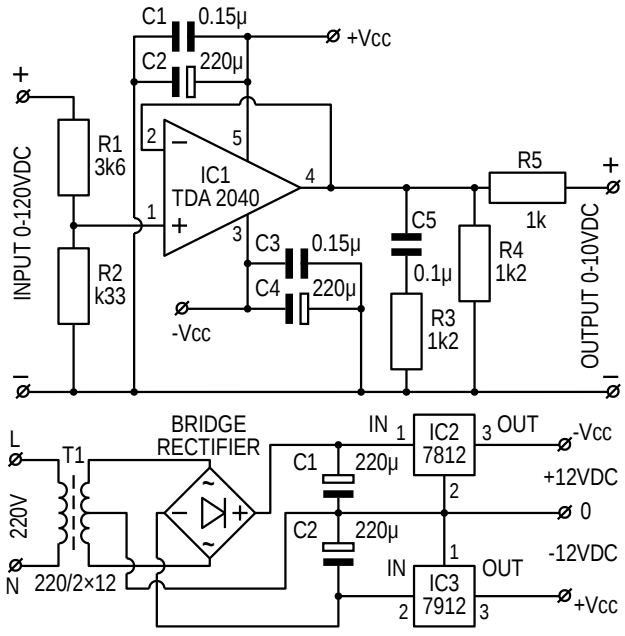

Fig. 4. Speed sensor for PLC-controlled load

Conclusions.

The developed experimental setup allows us to study and test various operation modes of the shipboard electromechanical systems based on a frequency-controlled electric drive [3]. VFD control laws, indicators of the electric energy quality and assessed the modes an energy-efficiently electromechanical systems with typical ship's load can be investigated with the help of mentioned equipment.

A short list of the main tasks which can be solved with the help of laboratory equipment:

Development and implementation of energy-saving technologies in the control system of a marine electric drive based on diagnostics and determination of their energy characteristics [8, 12] using the theory of instant power.

Development of monitoring and evaluation systems for the operational life of electrical machines.

Development of methods for the technical operation of ship electromechanical systems based on an analysis of their technical condition.

The use of modern energy-saving technologies used on ships, on the examples of frequency-controlled electric drives of various ship mechanisms and systems for educational process.

In finally, it should be noted that modern higher education should be aimed at teaching students in accordance with the constantly updated technical base and with the growing needs of employers. In order to meet these objectives, it is necessary to introduce new technologies in the process of education and training of specialists, which not only helps to increase the level of training, but also to orient the educational process to the real problems of maintenance, parameterization of modern shipboard electromechanical systems with PLC control.

References

1. Муха М.Й. *Динамічна компенсація реактивної потужності у суднових автономних електроенергетичних системах: монографія*. Саарбрюккен: LAP LAMBERT Academic Publishing, 2019. 381 с. ISBN: 978-613-9-99561-5.
2. Mukha M. A Full Mission Simulator of the Ship's Automated Electric Power System for Training and Competence Testing of Marine Engineers. *Journal of Shipping and Ocean Engineering*. 2017. Vol. 4. pp. 153 – 160. doi 10.17265/2159-5879/2017.04.002.
3. Загірняк М.В., Клепіков В.Б., Ковбаса С.М., Михальський В.М., Пересада С.М., Садовой О.В., Шаповал І.А. *Енергоефективні електромеханічні системи широкого технологічного призначення: монографія*. Київ: ІЕД НАНУ, 2018. 310 с. ISBN 978-966-02-8403-6.
4. Jan-Erik Rasanen, Eric W Schreiber. Using Variable Frequency *Drives (VFD) to save energy and reduce emissions in newbuilds and existing ships. Energy efficient solutions*. London: Lloyd's Maritime Academy, ABB, 2012. 11 p.
5. Drankova A., Mukha M., Mikhaykov S., Krasovskyi I. Electromechanical Laboratory Complex for Power Quality Studies of the Ship Electrical System. *IEEE 20th International Conference on Computational Problems of Electrical Engineering (CPEE)*. Lviv-Slavske: Lviv Polytechnic National University, Ukraine, 15-18 September, 2019. PS2, N15. doi: 10.1109/CPEE47179.2019.8949147.
6. Mukha M., Drankova A. About practical preparation of marine engineers on the electromechanical systems laboratory. *Computational problems of electrical engineering*. 2018. Vol. 8, №2. pp. 66 – 72.
7. Mukha M., Drankova A., Bousher V., Shestaka A. PLC-based ship's electromechanical systems laboratory. *Proceedings of the 13th International Conference on the Engine Room Simulators*. Odessa:

National University «Odessa Maritime Academy», Ukraine, 20-21 September, 2017. pp. 183 – 190.
8. Загірняк М.В., Мамчур Д.Г., Калінов А.П., Чумачова А.В. *Діагностика асинхронних двигунів на основі аналізу сигналу споживаної потужності: монографія*. Кременчук: ПП Щербатих О.В., 2013. 208 с. ISBN 978-617-639-037-4.
9. Петрушин В.С. Коэффициент мощности электрических нагрузок в автономных деформированных системах. *Известия высших учебных заведений. Энергетика*. Минск: БГПИ. 1990, №4. С. 41 – 43.
10. Электромагнитная совместимость (ЭМС). Часть 4-30. Методы испытаний и измерений. Методы измерений качества электрической энергии: ГОСТ IEC 61000-4-30-2017. [введен в действие от 01.12.2018]. Москва: Стандартинформ, 2018. 56 с.
11. Электромагнитная совместимость (ЭМС). Часть 4-7. Методики испытаний и измерений. Общее руководство по измерениям и приборам для измерения гармоник и промежуточных гармоник для систем энергоснабжения и связанного с ним оборудования: IEC 61000-4-7:2002/Amd.1:2008. [введен в действие от 08.08.2002]. International Electrotechnical Commission, 2002. 13 с.
12. Загирняк М.В., Родькин Д.И., Ромашихин Ю.В., Черный А.П. Энергетический метод идентификации параметров асинхронных двигателей: монография. Кременчуг: ЧП Щербатых А.В., 2013. 164 с.

References (transliterated)

1. Mukha M.I. *Dynamichna kompensatsiia reaktyvnoi potuzhnosti u sudnovykh avtonomnykh elektroenerhetychnykh systemakh: monohrafiia* [Dynamic Compensation of Reactive Power in Ship Autonomous Power Systems: monograph]. Saarbriukken: LAP LAMBERT Academic Publishing, 2019. 381 p. ISBN: 978-613-9-99561-5.
2. Mukha M. A Full Mission Simulator of the Ship's Automated Electric Power System for Training and Competence Testing of Marine Engineers. *Journal of Shipping and Ocean Engineering*. 2017. Vol. 4. pp. 153 – 160. doi 10.17265/2159-5879/2017.04.002.
3. Zahirniak M.V., Klepikov V.B., Kovbasa S.M., Mykhalskyi V.M., Peresada S.M., Sadovoi O.V., Shapoval I.A. *Enerhoefektyvni elektromekhanichni systemy shyrokoho tekhnolohichnoho pryznachennia: monohrafiia* [Energy-efficient electromechanical systems of wide technological purpose: monograph]. Kyiv: IED NANU, 2018. 310 p. ISBN 978-966-02-8403-6.
4. Jan-Erik Rasanen, Eric W Schreiber. Using Variable Frequency *Drives (VFD) to save energy and reduce emissions in newbuilds and existing ships. Energy efficient solutions*. London: Lloyd's Maritime Academy, ABB, 2012. 11 p.
5. Drankova A., Mukha M., Mikhaykov S., Krasovskyi I. Electromechanical Laboratory Complex for Power Quality Studies of the Ship Electrical System. *IEEE 20th International Conference on Computational Problems of Electrical Engineering (CPEE)*. Lviv-Slavske: Lviv Polytechnic National University, Ukraine, 15-18 September, 2019. PS2, N15. doi: 10.1109/CPEE47179.2019.8949147.
6. Mukha M., Drankova A. About practical preparation of marine engineers on the electromechanical systems laboratory. *Computational problems of electrical engineering*. 2018. Vol. 8, №2. pp. 66 – 72.
7. Mukha M., Drankova A., Bousher V., Shestaka A. PLC-based ship's electromechanical systems laboratory. *Proceedings of the 13th International Conference on the Engine Room Simulators*. Odessa: National University «Odessa Maritime Academy», Ukraine, 20-21 September, 2017. pp. 183 – 190.
8. Zahirniak M.V., Mamchur D.H., Kalinov A.P., Chumachova A.V. *Diahnostyka asynkhronnykh dvyhuniv na osnovi analizu syhnalu spozhyvanoi potuzhnosti: monohrafiia* [Diagnosis of asynchronous motors based on the analysis of the power consumption signal: monograph]. Kremenchuk: PP Shcherbatykh O.V., 2013. 208 p. ISBN 978-617-639-037-4.
9. Petrushin V.S. *Koefficient moshchnosti elektricheskih nagruzok v avtonomnyh deformirovannyh sistemah* [Power factor of electric loads in autonomous deformed systems]. *Izvestiya vysshih uchebnyh zavedenij. Energetika* [Energetika. Proceedings of higher education institutions]. Minsk: BGPI. 1990, №4. pp. 41 – 43.
10. *Elektromagnitnaya sovmestimost' (EMS)*. CHast' 4-30. Metody ispytanij i izmerenij. Metody izmerenij kachestva elektricheskoj energii: GOST IEC 61000-4-30-2017. [vveden v dejstvie ot 01.12.2018] [Electromagnetic compatibility (EMC). Part 4-30. Testing and measurement techniques. Power quality measurement methods: IEC 61000-4-30-2017 from 01.12.2018]. Moskva: Standartinform, 2018. 56 p.
11. *Elektromagnitnaya sovmestimost' (EMS)*. CHast' 4-7. Metodiki ispytanij i izmerenij. Obshchee rukovodstvo po izmereniyam i priboram dlya izmereniya garmonik i promezhutochnyh garmonik dlya sistem energosnabzheniya i svyazannogo s nim oborudovaniya: IEC 61000-4-7:2002/Amd.1:2008. [vveden v dejstvie ot 08.08.2002] [Electromagnetic compatibility (EMC). Part 4-7. Testing and measurement techniques. General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto: IEC 61000-4-7:2002/Amd.1:2008 from 08.08.2002]. International Electrotechnical Commission, 2002. 13 p.
12. Zagirnyak M.V., Rod'kin D.I., Romashihin YU.V., CHernyj A.P. *Energeticheskij metod identifikacii parametrov asinhronnyh dvigatelej: monografiya* [The energy method of identifying the parameters of induction motors: monograph]. Kremenchug: CHP SHCHerbatyh A.V., 2013. 164 p.

Received 09.02.2020

Відомості про авторів / Сведения об авторах / About the Authors

Муха Николай Иосифович (Муха Микола Йосифович, Mykola Mukha) – доктор технічних наук, професор, Національний університет «Одеська морська академія», завідувач кафедри суднової електромеханіки і електротехніки; м. Одеса, Україна; e-mail: n.mukha52@gmail.com

Дранкова Алла Олеговна (Дранкова Алла Олегівна, Alla Drankova) – кандидат технічних наук, доцент, Національний університет «Одеська морська академія», доцент кафедри суднової електромеханіки і електротехніки; м. Одеса, Україна; e-mail: drankova64@gmail.com

Красовский Игорь Игоревич (Красовський Ігорь Ігорович, Igor Krasovskyi) – суднова компанія Minerva Marine, електромеханік; м. Одеса, Україна; e-mail: garrakrass@gmail.com