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DEVELOPMENT AND RESEARCH OF A SMALL ELECTRIC-POWERED VESSEL USING PHOTOVOLTAIC CELLS

The article reflects the research of the possibility of using solar panels on small-class vessels in order to improve environmental safety. A mathematical model and algorithm for calculating the elements and characteristics of «small» passenger ships with various types of electric solar power plants have been developed. Scope of application: uninterrupted supply of electric energy to the consumer on ships. The results obtained in the work can be used for the development of renewable energy projects. To justify the rationality of using an electric motor and electrochemical energy sources, extensive field tests were carried out on the Irtysh River, during which the composition of equipment, passenger capacity, operational speed and the length of the line of operation varied.Based on the enlarged flowchart, the authors develop a program that allows for a quantitative analysis of the impact on the characteristics and elements of a «small» passenger vessel of various complexes of an atypical rowing rig using an electric motor as the main one. The program provides for the calculation of such economic indicators as the payback period of the vessel, the cost of transportation of one passenger, profit from the operation of the vessel.

Keywords: «small» ships, vessel, solar panels, electric motor, battery.

Introduction

The transition to a «green economy» is largely due to increased emissions requirements and rising fuel prices. Currently, Western shipbuilders have implemented vessels with both combined drive and fully electric. The latter are, in our opinion, very promising for river transport. The development of the photovoltaic cell market and technological progress in the production of batteries contribute to the implementation of bold innovative projects.

The advantages of using solar panels include:

– prospects, availability and inexhaustibility of an energy source in conditions of constant growth of prices for traditional types of energy carriers;

– complete safety for the environment.

However, this energy source is characterized by such disadvantages as dependence on the weather and time of day; seasonality in mid-latitudes and the discrepancy between the periods of energy production and demand for it, unprofitability in high latitudes; the need for energy accumulation; high cost of construction associated with the use of rare elements; the need for maintenance (periodic cleaning of surfaces from contaminationheating of the atmosphere above the power plant; low power density.

The issue of using atypical energy sources may be relevant for “small” passenger ships providing local and intra-city transportation.

Materials and methods

Employees of the Faculty of Engineering of Toraighyrov University are working on the creation of environmentally friendly small vessels with an electric power plant and solar power panels (Fig. 1). The projected pontoon vessel has an electric motor with a capacity of 10 kW, 8 solar panels and a battery voltage of 48 V.

The main problem in the design of such vessels is the justification of the spheres and conditions for the use of combined or autonomous non-typical energy sources for electric propulsion systems.

Figure 1 – Prototype of a vessel with photocells

The solution of the task can be achieved based on the analysis of the mathematical model of the vessel, which, when calculating with its use of the main characteristics, elements, economic indicators and criteria, should take into account the main aspects of the creation and life cycle of a vessel using an atypical complex of electrical equipment.

Article [1] defines that electromechanical solar panels are constructed using a motor-screw-slider-rack-and-pinion design in combination with solar panels.

The article [2] shows a new design of a small autonomous ground vehicle powered by solar energy. The vehicle was made of composite materials of natural origin. It was equipped with an electric motor powered by an ultralight photovoltaic panel.

In [3] a simplified ship size optimization base on the existing ship design for obtaining minimum propulsion power by using golden search section algorithm has been applied.

The paper [4] illustrates the practical new technologies (naval architecture small craft design, mechanical and electrical design), rational design and engineering approach, safety and reliability methods used in solar boats. In our project, the boat is powered by lithium-ion batteries that can be charged at any time by the photovoltaic generator placed on a flat top structure.

The paper [5] aims to analyze the possibility of applying renewable energy sources, particularly solar and wind energy, on an existing vessel by conducting technical and economic analysis. Data for the solar hour's number and wind distribution are gathered from the six locations in the Adriatic Sea over 32 years period.

The peculiarity of the mathematical model of a vessel with an autonomous electric rowing unit (AERU) is related to the characteristics of electric power sources reflected in it, which ensure the operation of the rowing electric motor (EM) and makes up the second part of the model. If the obtained characteristics change the mass-dimensional characteristics of the vessel as a whole, then the latter are corrected and only economic indicators are calculated based on them.

Expression (1) defines the required power, mass-dimensional characteristics and the possibility of placing the main equipment of the ship's electrical power plant of the vessel. The system describes the requirements for sufficient capacity of batteries and the number of their elements, the condition for placing modules of photovoltaic cells and a set of equipment in the hull of the vessel.

$$\left.\begin{array}{c} C_{bat} \geq \dfrac{N\left(v, P_e, t, \eta_p, \eta_{\text{в}}, \eta_{\text{п}}\right)}{bat} - (C_{sb}(L, B) + \Omega \\ n_{el} \geq n_1^{el}(U_{bat}; C_{bat}) + n_2^{el}(U_{bat}; C_{bat}) \\ S_{sb}^{el}(L, B) \leq S_{SD} \end{array}\right\} \quad (1)$$

where C_{bat} is the total capacity of the battery, Ah;

U_{bat} – voltage of the main electrical network, V;

$C_{sb}(L, B)$– the capacity of photovoltaic cells, Ah;

Ω – is the total capacity obtained when recharging during the parking of the vessel;

n_{el} – the number of elements that provide the necessary mains voltage and the required capacity for the vessel to move at a given speed during a certain voyage parameters, time;

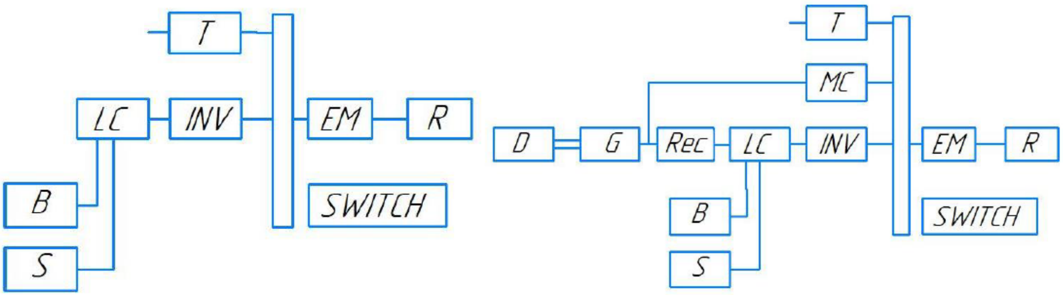
n_1^{el} – the number of elements connected in series;

n_2^{el} – the number of elements connected in parallel;

S_{sb}^{el} – total area of photovoltaic modules;

S_{SD} – the area of the superstructure deck designed to accommodate the solar array;

The structure of the complex of electrical equipment significantly depends on the type of autonomous electric rowing unit. Figure 1 shows the schematic diagrams of the AERU. The power source of the propeller electric motor in both cases is the battery, but the first scheme provides for the possibility of parallel supply of current to the EM from the battery and diesel generator (DG). As an option for working under this scheme, the DG is used only for charging the elements.



a b

Figure 1 – Schematic diagram of an electric power plant (a); schematic diagram of a combined power plant (CPP) (b)

D – diesel engine; G – generator; B – batteries; S – photocells; Rec – rectifier; LC – load controller; MC – mode controller; INV– inverter; SWITCH – main switchboard; EM – electric motor; R – reducer; T – transformer.

The subtask representing the design component is connected with the determination of the composition of the necessary equipment and operational modes of the vessel, which significantly depends on the type of the ship's power propulsion system and determines its configuration.

The calculation of the mass-dimensional characteristics of the battery cells is based on the calculated required capacity for a given driving time on electric traction. The total capacity is determined depending on the set mains voltage and the required total capacity of the vessel, which is according to the methodology given in [6].

According to the total capacity, the number of battery cells providing the required mains voltage is calculated by the formula

$$n_{el} = {}^{U_{bat}}/_{U_{el}}, \quad (2)$$

where n_{el} is the number of cells interconnected according to the calculation scheme;

U_{bat}, V – voltage of the electrical installation;

U_{el}, V is the average voltage of one element.

The power output of the battery can be found by the expression

$$P_{bat} = \frac{(P_e + N_{EC})}{\eta_c},$$

where P_{el}, kW is the required power of the propeller to ensure the movement of the vessel at a given speed;

N_{eC}, kW – estimated capacity of the power plant;

η_c is the total efficiency of the system.

The capacity of the batteries is determined by the expression

$$C_{bat} = \frac{P_{bat} \cdot 1000}{U_{bat} \cdot h_p}, \quad (4)$$

where is the permissible depth of battery discharge.

The operating time of an electric motor from batteries is calculated by the formula

$$t_p = \frac{C \cdot U_{bat} \cdot h_p}{P_e}, \quad (5)$$

For the CPP, the share of energy accounted for by the main sources of electrical energy is a given value. When distributing the shares of energy between the DG and battery, it is worth following not only the parameters of the voyage (the estimated operating time of the vessel on battery), but also the fact that when determining the power of the generator, it is necessary to take into account the energy needs of other consumers for the operation of the vessel in the current operational mode.

To calculate the mass-dimensional characteristics of the battery, taking into account the features of their design, as well as a significant proportion of the mass, in order to avoid large errors, it is preferable to take technical characteristics for specific manufactured equipment.

The efficiency of using photovoltaic cells as an additional power source of the vessel is largely due to the indicators of insolation for the region of operation of the vessel during the entire navigation . The total capacity of the modules installed on the deck of the superstructure is determined by the formula

$$\sum P_{SB} = \frac{E_{ins} \cdot (P_{SB} \cdot n_{el}^{SB})}{\lambda} \cdot k_{SB} \quad (6)$$

where k_{SB} is a correction factor that takes into account the efficiency of the system and the operating conditions of the batteries; is the power of the photovoltaic module. Determined by the technical characteristics; n_{el}^{SB} – the number of modules located on the deck of the superstructure; E_{ins}, – the average value of insolation for the current period for a given region of operation of the vessel (horizontal platform; λ – the power of insolation on the earth's surface per square meter, 1000 W/m^2.

Similarly to the battery, the mass-dimensional characteristics of solar cells are calculated for specific equipment.

In the case of an electric ship power plant, the operation of the vessel is provided by one main engine – electric. With this approach, the following operational modes that determine the operation of a particular equipment at the moment can be enlarged for the CPP.

The beginning of movement. The need for maximum energy causes the simultaneous supply of electricity from the battery and the DG.

Standby mode. This mode is used during the parking period at the bus stop. In this mode, the diesel generator works to power the ship's power grid and charge the batteries.

Also, the use of this mode is possible to activate the EM and move at a minimum speed without using battery power.

Electric mode. In this mode, the vessel moves at cruising speed exclusively with the help of EM. At the same time, the battery charge level is constantly monitored.

Boost. The mode is designed to move (if necessary) at maximum speed. This contributes to high dynamics and rapid acceleration. The power supply is supplied to both the screw and the consumers.

Coastal mode. This mode is used when the ship is in port to connect to shore power to charge the battery.

This approach makes it possible to quantify the operating time of the vessel using a specific energy source and calculate accordingly the need for a particular type of energy.

All of these tasks are closely related to each other, so their division into groups is rather conditional. At the same time, their solution occurs within the framework of probabilistically uncertain information (the duration of a particular operating mode, data on the required amount of a specific type of energy). These factors determine a certain conditionality of the solutions obtained, which are only close to the actual operating conditions of the vessel [8].

In Block 1, the initial data is set.

Block 2 contains the optimal values at the stage of solving the optimization problem for the vessel as a whole for diesel-mechanical SPP.

In Block 3, depending on the specified type of AERU, the composition of the SPP equipment is determined.

Block 4 controls the presence or absence of photocells in the task with a given utilization factor of the superstructure deck.

In Blocks 5, 6, the mass-dimensional and capacitance characteristics of photovoltaic modules are calculated.

Unit 7 calculates the required battery capacity depending on a given fraction (combined version) or for a fully electric power plant. This parameter depends on the full capacity of the vessel, which consists of the required energy to ensure operational speed, internal ship needs, power reserve, taking into account losses during conversion and transmission of energy in the system, as well as the time of operation of the vessel from the battery during the day.

In Block 8, the mass-dimensional characteristics of the entire complex of installed equipment and the minimum required dimensions of the machine room and the room for the placement of the battery are determined.

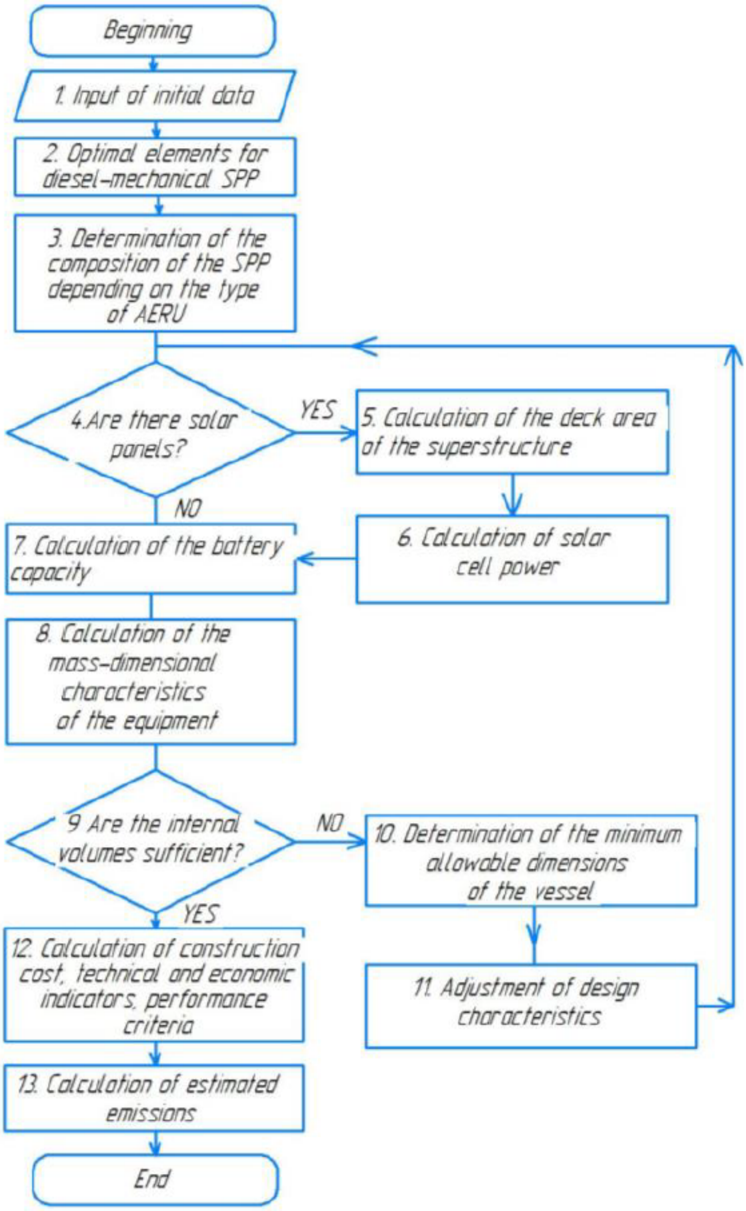


Figure 2 – Block diagram of the problem of designing «small» passenger ships with various types of electric SPP

In Block 9, the dimensions of the engine room determined at the previous calculation step are compared with those calculated for a vessel with a diesel-mechanical SPP.

As a result of the inspection in Blocks 10, 11, if necessary, the main dimensions of the vessel are adjusted (to meet the requirements for the placement of equipment) and the characteristics depending on them.

In Block 12, the construction cost, the performance indicators of the vessel on the line and the economic efficiency criteria for the selected variant of the vessel are calculated.

Block 13 examines the impact of the type of SPP on the environment at the initial design stage. The calculation is reduced to determining the amount of estimated emissions of pollutants into the atmosphere during the period of operation under consideration. The calculation is performed using averaged indicators according to generally accepted methods for operated river vessels [7-10].

In Block 14, the comparative economic indicators of a vessel with an atypical SPP complex and a vessel with a diesel-mechanical installation are calculated.

Conclusions

On the basis of an enlarged flowchart, a program is being developed that allows a quantitative analysis of the impact on the characteristics and elements of a «small» passenger vessel of various complexes of an atypical rowing rig using an electric motor as the main one. The program provides for the calculation of such economic indicators as the payback period of the vessel, the cost of transportation of one passenger, profit from the operation of the vessel.

In order to substantiate the rationality of using an electric motor and electrochemical energy sources, extensive field tests were carried out on the Irtysh River, during which the composition of equipment, passenger capacity, operational speed and length of the line of operation varied.

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ФОТОЭЛЕКТРЛІК ЭЛЕМЕНТТЕРДІ ҚОЛДАНАТЫН ШАҒЫН ЭЛЕКТР ЖЕТЕКТІ КЕМЕНІ ӘЗІРЛЕУ ЖӘНЕ ЗЕРТТЕУ

Мақалада су көлігінің экологиялық қауіпсіздігін арттыру мақсатында шағын класты өзен кемелерінде күн батареяларын пайдалану мүмкіндігін зерттеу көрсетілген. Электр күн электр станцияларының әртүрлі типтері бар «шағын» жолаушылар кемелерінің элементтері мен сипаттамаларын есептеудің математикалық моделі мен алгоритмі жасалды. Қолдану саласы: шағын көлемді кемелерде тұтынушыны электр энергиясымен үздіксіз қамтамасыз ету. Жұмыста алынған нәтижелер жаңартылатын энергия көздері саласындағы су көліктерін дамыту үшін пайдаланылуы мүмкін.

Электр қозғалтқышы мен электрохимиялық энергия көздерін пайдаланудың ұтымдылығын негіздеу үшін Павлодар облысындағы Ертіс өзенінде кең далалық сынақтар жүргізілді, оның барысында қолда бар жабдықтардың құрамы, жолаушылар сыйымдылығы, пайдалану жылдамдығы, сондай-ақ пайдалану желісінің ұзақтығы өзгерді. Үлкейтілген блок-схема негізінде авторлар Электр қозғалтқышын негізгі ретінде пайдаланатын типтік емес есу қондырғысының әртүрлі кешендерінің «шағын» жолаушылар кемесінің сипаттамалары мен элементтеріне әсерін сандық талдауға мүмкіндік беретін бағдарлама әзірлейді. Бағдарлама кеменің өтелу мерзімі, бір жолаушыны тасымалдау құны, кемені пайдаланудан түскен пайда сияқты экономикалық көрсеткіштерді автоматтандырылған есептеуді көздейді.

Кілтті сөздер: «шағын» кемелер, кеме, күн панельдері, электр қозғалтқышы, батарея.

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РАЗРАБОТКА И ИССЛЕДОВАНИЕ НЕБОЛЬШОГО СУДНА С ЭЛЕКТРИЧЕСКИМ ПРИВОДОМ, ИСПОЛЬЗУЮЩЕГО ФОТОЭЛЕКТРИЧЕСКИЕ ЭЛЕМЕНТЫ

В статье отражено исследование возможности использования солнечных панелей питания на речных судах малого класса с целью повышения экологической безопасности водного транспорта. Разработана математическая модель и алгоритм расчета элементов и характеристик «малых» пассажирских судов с различными типами электрических солнечных электростанций. Область применения: бесперебойное снабжение электрической энергией потребителя на маломерных судах. Результаты, полученные в работе, могут быть использованы для разработки водных транспортных средств в области возобновляемых источников энергии.

Чтобы обосновать рациональность использования электрического двигателя и электрохимических источников энергии, были проведены обширные полевые испытания на реке Иртыш в Павлодарской области,, в ходе которых варьировался состав имеющегося оборудования, пассажировместимость, эксплуатационная скорость, а также протяженность линии эксплуатации. На основе укрупненной блок-схемы авторы разрабатывают программу, позволяющую проводить количественный анализ влияния на характеристики и элементы «малого» пассажирского судна различных комплексов нетипичной гребной установки, использующей электродвигатель в качестве основного. Программа предусматривает автоматизированный расчет таких экономических показателей, как срок окупаемости судна, стоимость перевозки одного пассажира, прибыль от эксплуатации судна.

Ключевые слова: «малые» суда, судно, солнечные панели, электродвигатель, аккумулятор.

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