Features of the complex power unit for mobile robotic

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Abstract. This article discusses the prospects for the use of power units based on renewable energy sources for additional and emergency power supply of surface robotic systems. This kind of complex power unit can be built on the basis of renewable wind and solar energy and generate at least 10-15% of all the electrical energy required for a vessel. Considered one of the main problems of designing this type of complex power unit - the creation of a promising wind power systems (windmills). The windmill under development should meet a number of necessary criteria regarding reliability, power, noise level, and design constraints of the surface platform itself. The rationale for the design of the windmill is given. Further, the design of the windmill is optimized by the criteria of aerodynamic power, taking into account these limitations. The aerodynamic comparison shows the superiority of the proposed design of a windmill in relation to analogues on all the most important quality criteria. The features of the implementation of the electrical connection scheme of a windmill, solar panels and a diesel generator set into a single complex power unit are considered. For a robotized ship with a given power of the propulsion system, the complex power unit has been developed, which allows generating at least 10% of the power consumption.

1. Introduction
Currently, there is a large group of offshore facilities, stationary and mobile, including robotic complexes, which need auxiliary autonomous energy sources. Diesel generators used as such energy sources are quite expensive. Also, the fuel that is used by such units is quite expensive. In addition, these units are highly polluting.

Many international companies are developing and introducing alternative energy sources on offshore surface platforms to reduce their overall fuel consumption. [1,2].

One of the approaches to significantly reduce the consumption of conventional fuel (more than 10%) is the use of a complex power unit consisting of a windmill and solar panels.

The key challenges are: selection of a windmill type suitable for installation on a fixed/mobile platform as an element of a complex power unit; development of optimal configuration of solar panels and windmill; selection of types and relevant parameters of solar panels and a windmill, allowing to optimize the operation of a complex power unit by the criterion of the maximum power generated under severe restrictions imposed by the requirements of safety and reliability of operation of all ship systems.

2. Problem statement
It is necessary to develop a comprehensive power unit based on renewable energy sources. The unit should produce at least 10% of the nominal power \( P_{\text{engine}} = 10 \text{ kW} \) of propulsion boats of small displacement (\( L_{\text{max}} = 10 \text{ m} \) long).
We take the standard system of solar panels, so we will further focus on the necessary requirements for the design and features of the windmill.

From the requirements of safety and efficiency of the functioning of a surface ship follow certain restrictions imposed on the used design of the windmill:
1) compactness. Installing a windmill on the ship should not greatly increase the windage due to the flow of wind;
2) exceed power output. The windmill should surpass all similar designs at the same wind speeds;
3) reduced noise level. The windmill should have a lower noise level compared with the considered analogues;
4) sufficient structural strength;
5) independence from the direction of the air flow relative to its moving part;
6) efficient rotor stop system when critical speed is reached;
7) simple assembly, disassembly and repair.

The requirements of 1, 3, 4 and 5 classic horizontal-axis windmills do not satisfy. Requirements 1 and 4 and 7 also do not meet vertical-axial windmills with strongly elevated blades of the movable part. The requirements correspond to the design of vertical-axial windmills, which have a movable part of the rotor with a minimum ratio of the height of the rotor to its diameter. To meet the requirements of 1 and 4, it is advisable to use windmills with special static elements that protect the rotor from damage.

It is necessary to develop a structural electrical circuit of an integrated power unit, taking into account the features of the operation of a windmill that meets the specified requirements, in conjunction with solar panels.

3. Synthesis and justification of the design of a promising windmill, which can be integrated into a complex power unit

In works [3-9] one of the possible designs of a windmill of a vortex type is presented that satisfies all the above conditions. shows the advantages of the proposed windmill in terms of the power generated and the level of noise compared with analogues, including those presented in [7-13].

The proposed design is patented, and its mechanical part includes the following main elements [5, 6, 16]: a special-shaped turbine with eight blades, the upper part of the stator is a bell, the lower part of the stator is a guide structure; the rack-holder of the socket and the rotor; rotor shaft (Figure 1).

The electrical part of the integrated power unit includes: power generator based on synchronous machine, output voltage stabilization system, power converters, energy conversion control system, batteries, backup source - diesel generator.

As a result of the aerodynamic optimization of the shape of the windmill, the design was obtained according to the criterion of the maximum of the aerodynamic moment of the rotor [5-6] (Figure 2). This form is more than 2 times more efficient in power compared to horizontal-axial windmills, and more than 30% superior to some modern types of vertical-axial windmills in power, with other things being equal (Table 1).

| Types of windmills | Wind swept surface area, m² | Torque at 5 m/s, N*m | Torque at 2.5 m/s, N*m |
|--------------------|------------------------------|---------------------|----------------------|
| Proposed windmill  | 0,70263                      | 1.8                 | 0.87                 |
| Horizontal classic windmill | 0,70263           | 0.223               | 0.071               |
| Vertical spiral windmill | 0,70263          | 0.757               | 0.316               |
| Vertical windmill with bell | 0,70263         | 1.242               | 0.577               |
The principle of operation of the vortex wind power unit is based on the useful aerodynamic interference between the static and rotor parts of the unit and the use of a special twisted shape of the rotor blades [3-7, 14-16] (Figure 2).

Let us consider the main technical characteristics of the complex power unit being developed with the vortex type windmill proposed above for a boat with a length of L = 10 m.

For wind speed acting on a windmill \( V = 3 \) m / s, the average power of a complex power unit is \( P_{CP} = 2 \) kW, which is 14% of the power of the propulsion unit \( P_{PU} = 10 \) kW. The windmill generates \( P_{WM} = 0.1 \) kW, and the solar panel \( P_{SP} = 1.3 \) kW. This ratio is calculated on the basis that a solar panel generates an average power of 190 W per 1 m\(^2\), which corresponds to a solar panel efficiency of 19%. The power of the windmill and the complex power unit with a wind speed of \( V = 10 \) m/s are respectively equal to: \( P_{WM} = 3.7 \) kW, \( P_{CP} = 5 \) kW, which, taking into account the \( P_{SP} \), is already 56% of the power consumption of the propulsion unit.

Dimensions of the windmill are 2.4x1.6x2.4 m, solar panels – 2.2x2.5x2.9 m. The vertical size of the windmill can be reduced by using existing structural elements of the boat as the lower part of the stator (Figure 3).

### 4. Electromechanical control circuit of complex power unit

Consider a generalized structural electromechanical scheme of a complex power unit including a windmill a block of solar panels and a backup diesel generator (DG).

To combine the windmill, solar panels and DG in a single integrated power unit can be used classical scheme (Figure 3). The circuit consists of a synchronous generator with permanent magnets, a low-pass filter, AC/DC converters, DC/AC inverter, a charge controller and batteries. The solar panel module (SP) uses its own charge controller supplying the battery; the DG can connect to the load using a software-controlled key 2.

When the wind speed is greater than the minimum \( V_{min} \) value required to start the windmill and less than the maximum \( V_{max} \) value, controlled key 1 should be in position 1 if the battery is already fully charged. In this case, a output voltage from the synchronous generator is rectified, and then it is inverted to produce a three-phase sinusoidal voltage and then it goes to the load. If under the same conditions the battery is not fully charged, the key 1 is transferred to position 2, and the load begins to be powered by the battery through the inverter.

If the speed \( V \geq V_{min} \), then controller starts to limit the current from the rectifier and the voltage on the generator increases, the electromechanical moment of resistance to the rotation of the rotor decreases, contributing to an increase in the speed of rotation. To prevent such a situation, two options are provided: a) emergency braking of the propeller; b) switching generator to ballast load. If key 1 was in position 2, then a command is given to the braking devices of the rotor for its forced braking. In case \( V > V_{max} \) is detected in position 1 of key 1, first the key 1 is moved to position 2, and then the battery is disconnected from the generator and the rotor is braked.

A special feature is the aerodynamic braking of the rotor, for which the variable geometry of the elements of the windmill is applied to regulate its output characteristics [4-6]. This braking is proposed to be carried out by means of controlled pull-up of the rotor, i.e. by regulating the wind-blown surface...
of the rotor. It uses two controlled parameters of the variable geometry of the elements of the windmill: the distance from the lower part of the rotor to the upper edge of the lower stator \( h^1 \), and to the edge of the upper stator \( h^2 \), respectively (Figure 3). Geometry changes are carried out through the deviation of actuators from their normal positions for the implementation of a given interaction of wind flow with a windmill. For the implementation of feedback on the management of variable elements of the geometry used sensors deviation. Control signals for actuators are generated in the control pulse generation unit for variable geometry elements.

![Diagram of a windmill and solar panel system](image)

**Figure 4.** Generalized classical electromechanical circuit of an complex power unit.

The battery must supply the load and, accordingly, be designed for one of two possible modes: 1) supply the consumer after the loss of power from renewable energy sources as long as the capacity of the battery allows; at the same time, the indicated capacity should be as high as possible at a given limit of the cost of the battery; 2) consumer supply before turning on the diesel generator.

Consider the second mode, since it will determine the lower limit of the battery capacity in the general case. Thus, the battery unit should provide power to the load, powered by a complex power unit, during short-term drawdowns of its power (due to unstable primary energy flow of renewable energy), the idle state of the windmill and solar panels for a time before the diesel generator is commissioned. Set the power of the complex power unit \( P_{CP} = 5 \text{ kW} \), suitable wind \( V = 10 \text{ m/s} \).

The time of putting the diesel generator into operation, depending on the power, is from 2 to 15 seconds. Thus, the choice of battery capacity is determined by the time during which the consumer may need power only from batteries. Choose a 5-minute interval with a maximum load power of 5 kW. Consider a battery, according to the passport data, the voltage of which will be 12V with a capacity of 200 Ah, providing 5352 W for 5 minutes with a voltage drop of 20%. A deeper discharge of the battery is impractical and can reduce its service life.

The use of additional solar panels requires the connection of an appropriate charge controller. Note that the use of a single charge controller for windmills and solar panels is impossible, since the transistors used in the solar panels charge controller, failure when the voltage on the generator is close to the open circuit voltage at a high rotor speed. This limitation can be overcome by using a hybrid controller for windmill / solar panels [17-19]. The introduction of a hybrid controller allows you to abandon one of the charge controllers and electronically controlled key 1 in the classical scheme.
The hybrid controller controls additional external charging / discharge currents by automatically limiting them. Thus, the problem of exceeding the permissible charge current in the classical scheme is solved, since the instantaneous currents from the controller of the windmill and the solar panels cannot be taken into account simultaneously. In addition, the use of a hybrid controller has a number of advantages: a) application of MPPT technology (maximum power point tracking); b) detection of excess speed of rotation of the windmill rotor (alarm indicating the need to use an aerodynamic brake); c) current and voltage control from two sources (windmill and solar panel); d) application of solar panel protection against reverse, reverse polarity; and battery from idle, reverse polarity, overload, lightning, overcharge; e) dynamic correction of battery charge/discharge parameters.

Depending on the specific hybrid controller, different circuit solutions can be applied. Analysis of serially-produced hybrid controller showed that there are three main options for connections: 1) The windmill and solar panels feed the battery through a hybrid controller, and the battery feeds the load; 2) Windmill and solar panels through a hybrid controller supply battery and load in parallel, and the battery feeds the load directly; 3) Windmill and solar panels through the hybrid controller in parallel feed the battery and the load, and the battery is connected to the load through the hybrid controller.

Since we preferred to use the battery exclusively to maintain the required total capacity of the complex power unit, the third option is the best in terms of ensuring maximum battery control.

Thus, the classical scheme of connection of a windmill, solar panels and a diesel generator is presented in Fig. 4, can be converted to the view shown in Figure 5.

**Figure 5.** Generalized block diagram of a complex power unit using a hybrid controller

5. **Conclusion**

In this paper, the substantiation of the design of windmills which can be a structural element of a complex power unit to be used on surface ships of small displacement in order to save fuel, including on robotic platforms.

The analysis of the specific shape of a windmill with a vertical axis of rotation, axisymmetric stator and rotor, special forms of which and their layout are obtained as a result of aerodynamic optimization by the criterion of the maximum torque of the rotor is carried out. The paper shows that the proposed design of windmills meets all the key requirements for ensuring safety, reliability and efficiency, dictated by the use of an complex power unit on a ship with a small displacement including a robotic surface platform. The proposed design significantly exceeds the analogs in the generated power - by at least 30% for the best types of vertical-axial windmills from the comparison list.

For a boat with a small displacement with the power of the propulsion unit $P_{CP} = 10$ kW, a generalized design of an integrated power plant has been designed, which produces at the accepted minimum wind speed $V = 3$ m/s not less than 14% of the energy from the $P_{PU}$.

The structural electric scheme of the complex power unit including solar panels and diesel generator in addition to the windmill is considered; the diesel generator can be derived from the scheme at short-term failures of the generated energy. Also the scheme with use of the hybrid controller is considered, the choice of the main equipment of this scheme is proved.
The commonality of consideration of the electrical part of the complex control system, containing a diesel generator in its composition, allows the use of the proposed circuit solutions for the organization of both the main and backup power supply of medium displacement vessels.

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