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STUDY OF ELECTRO-PHYSICAL PARAMETERS OF WIND TURBINES

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The article discusses the results of research on the effectiveness of wind-driven power plants of small and medium power. The results of tests of two different models of wind turbines combined with a specially designed low-speed electric generator under the conditions of natural wind are discussed. A description of the device and technical parameters of wind turbines is presented. The dependences of electro-physical characteristics on the speed of natural wind during a long time are obtained. It is shown that the power generated by an electric generator with a wind wheel with cylindrical blades is greater than the power of a generator with a sail-type wind wheel.

Keywords: wind turbine, sail blade, rotating cylinder, Magnus effect, electric generator.

Introduction

Wind energy as an environmentally friendly source of energy has great potential in reducing dependence on traditional resources such as oil, gas and coal. One of the most important features of development at the present stage is the increased attention of the world community to the problems of rational and efficient use of energy resources, introduction of energy saving technologies and the search for renewable energy sources (RES).

The growing need of mankind for energy resources leads to the demand for searching and broader use of alternative sources of energy supply. These include primarily wind power engineering. Due to the large territory, the potential of renewable energy sources (hydropower, wind and solar energy) in Kazakhstan is very significant. The development and introduction of wind-driven power plants (WPP) to obtain electrical energy from wind energy is constantly developing, and industrial production of this environmentally friendly energy source can be a new stage of power industry development [1, 2].

In addition to the fact that wind energy does not pollute the environment, it is also capable of producing clean, inexhaustible energy in a local remote area. Moreover, in Kazakhstan there are many remote areas where there is a shortage of electric energy, where it is expensive, and sometimes it is technically impossible and economically impractical to build power lines. The development and production of WPP as an autonomous source of electrical energy for the needs of economic and domestic activities in the field environment, at testing grounds or defense facilities is a very topical issue of modern power industry. Autonomous WPP of small and medium power can provide with electricity a separate building, small farms or military defense facilities, remote from sources of centralized electricity supply. The increased interest in wind-driven power plants (WPP) for the conversion of clean and renewable wind energy necessitates a more thorough analysis of not only their aerodynamic parameters, but their energy characteristics as well. In the framework of project number 0109 PK01319, a special electric generator for small WPP was designed and manufactured. Tests of the developed low-speed electric generator for two types of WPP were carried out at the training and testing ground of the Faculty of Physics and Technology to identify the energy conversion efficiency of low-speed low level wind.

1. Technical characteristics of WPP experimental models

1.1 Experimental model of sail-type WPP

The principle of operation and design of the WPP under study were developed and constructed at the Laboratory of Hydrodynamics and Heat Exchange of the Department of Engineering Thermophysics named after Professor Akylbayev Zh.S. under the guidance of Professor K. Kussaiynov [3,4]. Later various modifications of original models were made, which were installed and successfully function at the testing ground of the Faculty of Physics and Technology.

The first model of the sail-type WPP is a multi-blade wind turbine with a dynamic variable blade shape, made in the form of a triangular "sail". For aerodynamic testing under natural wind conditions, a prototype of a 6-blade sail-type wind turbine with a wind wheel with the diameter of 3 m was constructed, Fig.1. The distinctive novelty of this WPP model is in use of blades made in the form of a triangular flexible sail with a moving end. Sail-type wind turbines have a unique feature - they work equally effectively both at low wind speeds and at high wind speeds. Due to the dynamic changeable shape of the working surface, sail-type wind turbines react quickly to changes in the wind direction [4, 5].

Based on the results of preliminary tests to ensure maximum thrust force of the sail blades, 15 cm elongation of the moving yarn was chosen. The sail-type wind turbine shaft is made of a metal cylinder with a diameter of 30 mm and a length of 1750 mm. The diameter of the metal disk coaxially attached to the shaft is 150 mm, the disk thickness is 10 mm. The pulley has a diameter of 400 mm, and a thickness of 40 mm, intended for a belt drive with a generator. The support rods and frame rods of the wind turbine are 25 mm diameter metal tubes, which are fixed to the disk. The length of each frame rod of the wind turbine is 1570 mm, and the length of the support rods of the wind wheel is 2100 mm. The prototype of the sail-type wind turbine is installed at a height of 5 meters in the prevailing direction of the local wind flow.

1.2 WPP model using the Magnus effect

The second model is that of a WPP with blades in the form of rotating cylinders, as shown in Fig.2.



Fig.1. General view of an experimental sail-type WPP model



Fig.2. General view of an experimental model of WPP with cylindric blades

It is known that when a transverse air stream flows past a rotating cylinder, a lateral force arises due to the Magnus effect [3, 6]. This physical phenomenon is used when designing this model. Cylinders, like propeller blades, rotate the axis of the wind turbine connected to the electric current generator, providing a number of unique properties of the WPP:

- steady work at low and medium wind speeds;
- increased utilization factor of low speed winds;
- the ability to automatically support the constancy of the revolutions of the axis of the wind turbine when the wind speed changes.

A detailed description of WPP with cylindric blades is given in [7]; we just note that in WPP model under study the surface of cylindric blades is smooth. The blades themselves are made of durable material in the form of cylinders with flat ends, Fig.2. The diameter of the cylindric blades is 150 mm, the diameter of the flat end discs is 250 mm, and the height of the supporting tower is 5 m. The main technical parameters of the WPP models under study are shown in table 1.

Table 1. Technical parameters of prototypes of wind turbines.

WPP type	Sail-type WPP	WPP with cylindric blades
Wind wheel diameter, m	3	3
Number of blades, pcs.	6	3
Nominal power kW	1	1
Operating wind speed, m/s	7	7
Starting wind speed, m/s	3	3
Operating speed range, m/s	3-12	3-12
Critical wind speed, m/s	14	15
Nominal rotation speed, rpm	150	180
Weight of wind turbine with support, kg	100	80

Test and measurement of volt-ampere characteristics were carried out throughout the year under natural wind conditions. Then, according to the test results, the effectiveness of the developed low-speed electric generator for two WPP models was evaluated.

2. Experimental technique

A prototype of an electric generator (EG) was developed for converting wind energy into electrical energy and WPP trial. The most convenient for the constructive combination of the wind-wheel with the electric machine is the EG variant with inductor synchronous generator, assuming a windingless rotor. The specific consumption of materials and the cost of a gearless EG are about the same as the total indicators of a WPP with a high-speed EG increasing gearbox.

A distinctive feature of this EG is that it begins to produce an emf at relatively low speeds of air flow. In addition, the developed version of the EG has a reliable contactless excitation system and starts to generate electricity at frequencies from 50 to 350 revolutions per minute.

The study of the electro-physical characteristics of the low-speed EG depending on the speed of rotation of the generator shaft shows that the changes introduced into the design lead to an increase in the efficiency, which promises the prospect of further improvement. In particular, it was established that the use of two-discs with neodymium magnets as rotors in the design of a low-speed EG makes for noticeable increase in the efficiency of WPP.

To measure the natural wind speed, GEOS #11 anemometer was used, which can be used as a stationary weather station. To measure the angular velocities of the rotating shafts, the AT-8 contact-noncontact digital photo-tachometer was used in the range of 0.1-10,000 rpm. The principle of operation of the AT-8 digital photo tachometer is based on measuring the speed resulting from

the interaction of the rotating magnetic field of a permanent magnet. Rotation from the shaft of the unit, with induction currents induced by this field in a solid metal rotor, provides fast and accurate readings of rotational speed. Measurements of the electro-physical characteristics of WWP on natural wind speed were carried out during the year with seasonal climate changes. The measurement error does not exceed 3-4%.

3. Discussion of the test results

In order to study the electrical and physical parameters of two types of WPP testing models using low-speed electric generator with neodymium magnets as rotors, aerodynamic tests were carried out at the testing ground in natural wind conditions.

Volt-ampere characteristics of WPP testing models were determined at a fixed value of the pulley diameter. 5 and 21 W lamps with powers of were used as a load to determine the current-voltage characteristics. Volt-ampere characteristic of the WPP with rotating cylinders is shown in Fig. 3. The operating point of the generator connected to the load coincides with the maximum power point. Connecting loads can shift the operating point of the system to the area of minimum or even zero power. Therefore, important components of the system are voltage converters capable of matching the wind module with the load.

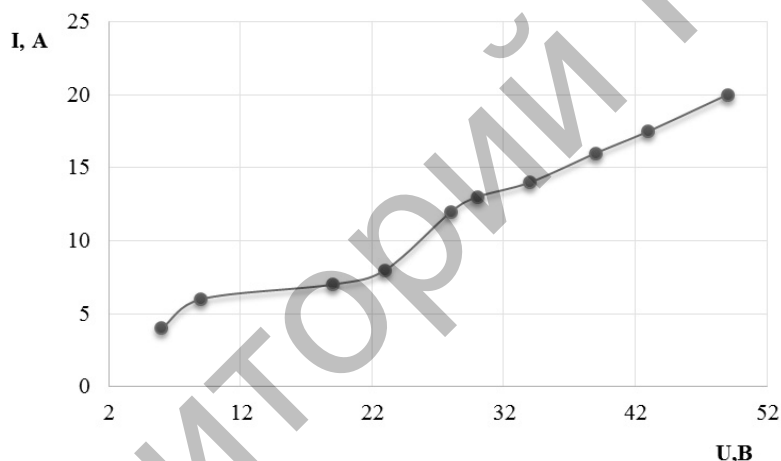


Fig.3. Volt-ampere characteristic of the WPP with rotating cylinders

On the base of the test results, the dependences of the electro-physical characteristics of two prototypes of WPP on shaft rotation speeds at various natural wind speeds were obtained during the year. An increase in wind speed leads to an almost linear increase in the number of revolutions of the wind wheel per minute. This is due to the fact that with increasing wind speed, incident on the wind wheel, almost linearly increases the pressure force acting on the sail blades.

The efficiency of the EG also rises as a result of increasing cross section of the winding wire, which, in turn, determines the amount of generated current. Tests show that when connected to the wind wheel of the WPP with rotating cylindrical blades, EG begins to produce electric current at a lower value of the number of the shaft revolutions. It has been established that for WPP with cylindrical blades the maximum value of the generated electric current I is achieved with a smaller value of the number of revolutions of the wind wheel N , Fig. 4.

The type of dependences of the change in current strength on the rotational speed of the wind wheel for two models of WPP is slightly different from each other. It can be seen that in the whole range of variation of the rotational speed of the wind-wheel, the value of the electric current I is 25-30% higher compared to the current produced by the sail-type WPP. This is probably due to the fact that in the generator the cross section of the winding wire, on which the generated current magnitude directly depends, exceeds the cross section of the wire of the sail-type generator.

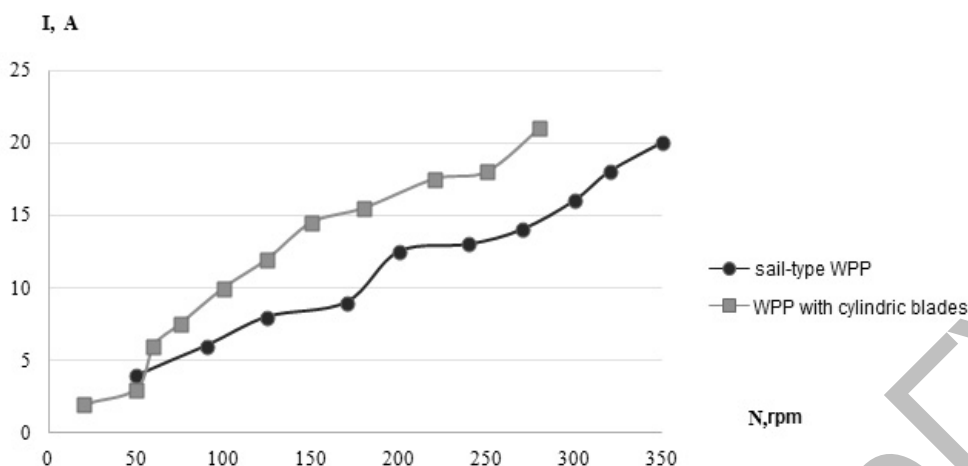


Fig.4. The dependence of the amount of the current produced by generators on the rotational speed of WPP

Analysis of the test results shows that in the entire rotational speed range, the power generated by the electric generator connected to the wind wheel of the WPP with rotating cylinders, exceeds the power generated by the sail-type WPP, Fig.5.

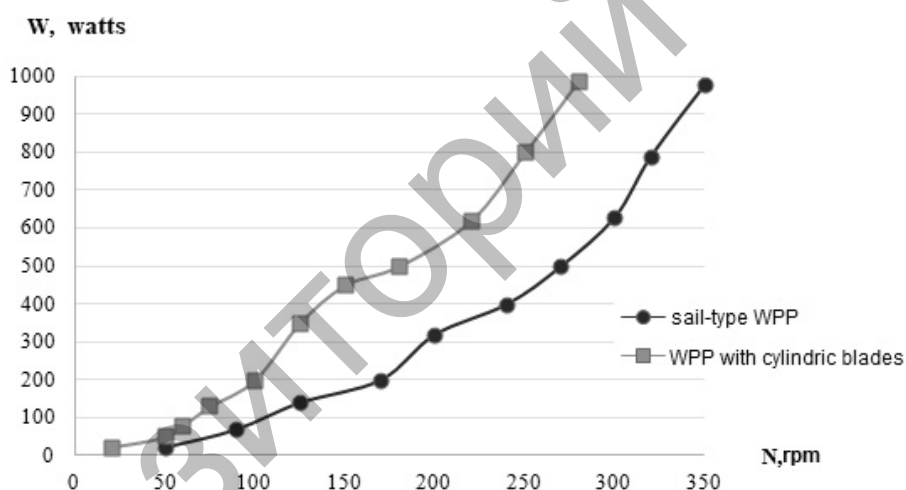


Fig.5. The dependence of the power of electric generators on the rotational speed of the wind wheels.

It can be seen that with an increase in wind speed, the generated power increases almost linearly. At a wind speed of 7 m/s, the wind power plant produces a nominal power of 330 Watts. The maximum generated power at a wind speed of 12 m/s is equal to 970 Watts.

A similar regularity was also obtained for the EMF that occurs on the windings of a generator operating with WPP with "rotating cylindrical blades", at a significantly lower value of the revolutions number of the wind wheel shaft. This is due to the low operating threshold of the generator, and its high efficiency coefficient as well.

Conclusion

The electrophysical characteristics of two models of WPP were studied using the developed low-speed electric generator. As a result of the tests performed for a long time, it was found that the use of gearless wind generators based on arc-type stator electric machines is advisable for low-speed WPP with high torque. This conclusion is due to the lower operating threshold of the

developed EG at a change in wind speed and its higher efficiency coefficient value. Due to its structural connection to the electric generator, it makes for most of the mechanical energy to be converted into electrical energy.

The practical significance of the considered low and medium power WPP also lies in the possibility of their autonomous use for driving various working devices and economic mechanisms at facilities remote from centralized power supply lines.

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