USE OF AUTONOMOUS ENERGY SOURCES: DEVELOPMENT OF A ROTARY WIND FARM

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Abstract

In our study, we proceeded from the need of finding the efficient systems of renewable energy sources that could meet the needs of remote regions without the participation of backbone networks. In this regard, the use of wind turbines, of which there are several types, is promising. However, the use of a vertical-axis rotary wind power plant, in our opinion, is still not explored much and such installations are rarely found in work practice, in particular in agriculture. When choosing to use a vertical-axial rotary wind power plant, they are based on the independence of operation from the direction of the wind and the simplicity of the structure in comparison with horizontal-axial ones. Vertical-axis rotary wind turbines have a number of advantages, including mechanisms located at the base and accessible for maintenance and repair. When developing the design of the rotor of a wind power plant, in which the blades are a part of a cylindrical surface, and the torque is created due to the difference in resistance to the wind flow of convex and concave surfaces, the main tasks are to determine their geometric dimensions and relative position on the rotor. As a result of the study, we came to the conclusion that predominantly vertical-axial wind power plants can be used on isolated energy consumers remote from power grids, including livestock mini-dairy farms, farms and other subjects of the agro-industrial complex.

Keywords: Energy supply, Mini-farm, Wind farm, Renewable, Diesel power plant

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Introduction

At present, it is becoming increasingly urgent to accelerate the introduction of developments of rotary wind power plants for autonomous use to the stage of mass production [1-3]. The lack of state attention to this direction in small-scale wind energy has led to a significant slowdown, or rather a complete absence of its use by isolated energy consumers remote from the power grid, which include such economic entities as livestock mini-farms of the dairy direction, farms, sheep farms, and others, which are called small remote individual consumers of various types of energy, or combine small "autonomous remote energy consumers" in the agro-industrial complex [4-7].

An attempt to provide energy to small remote energy consumers with the help of powerful horizontal-axial wind turbines did not lead to positive results due to the need to lay hundreds of kilometers of electric lines and organize the service infrastructure in the form of mobile teams with appropriate equipment and equipment [8, 9].

The performance of wind power plants (wind turbines) is estimated by the wind flow power utilization factor, also called the power factor or the Betz-Zhukovsky criterion. Its maximum value can theoretically not exceed 0.593 [10].

The theory according to which it was determined led, at one time, to incorrect theoretical conclusions that the maximum possible wind energy utilization coefficient of vertical-axis rotary wind turbines is much lower than that of horizontal-axis wind turbines.

As a result of this theory, vertical-axis rotary wind turbines were practically not developed for forty years. Only in the 60s – 70s of the twentieth century, it was experimentally proved that the power factor of both wind turbines is approximately the same.

Wind turbines with a vertical-axial rotor began to be intensively developed only from the beginning of the 80s. Today, many countries operate wind turbines with vertical-axial rotors. In practice, their service life is on average twenty years. As the horizontal-axial wind turbines are used and worn out, they will gradually be replaced by vertical-axial rotary wind turbines.

Powerful wind turbines of both types cannot operate separately. For horizontal-axial wind turbines, an external source of energy is needed to orient the wind wheel to the wind after a lull, and its mass together with the gondola is significant.

Vertical-axial wind turbines must be unwound after a lull. They themselves do not start even in the presence of wind. Therefore, both are connected to the power supply system. Thus, in the future, large wind power will be based on vertical-axis rotary wind turbines, and the United Kingdom, the Netherlands, Canada, and the United States are already reaching this level. In Russia, vertical-axis wind turbines are engaged in the design Bureau "Raduga", LLC "Vertical" and other companies [11].

When choosing a vertical-axial rotary wind turbine, they focus on the independence of its operation from the wind direction and a simpler design compared to horizontal-axial ones. Vertical-axial rotary wind turbines also have a number of advantages. The main ones are that all their mechanisms are located at the bottom at the base and are available for maintenance and repair [2,12]. The annual electricity generation at the same swept area of a vertical-axial wind turbine is 1.5...3.0 times greater than that of a horizontal-axial wind turbine. These advantages of vertical-axial wind turbines attract the attention of many manufacturers.

In addition to large wind power, there is a small wind power with the capacity of individual wind turbines up to 10 kW. Low-power wind power is especially needed by individual energy consumers, who are formed in territories remote from power supply lines and represent livestock mini-farms, koshars, field-growing, horticultural, vegetable-growing and other objects of the agro-industrial complex, which need electric energy for production activities and everyday life [4,13]. It would be too expensive to run power lines to them. Of course, for such farms, the use of low-power wind turbines is a rational way out of the energy problem.

Currently, horizontal-axial wind turbines of low power up to 10 kW are produced, but they are practically not widely used in remote farms due to the complexity of installation, maintenance and repair, since all their mechanisms are at a considerable height and are inaccessible without dismantling the entire installation [14, 15].

As noted earlier, horizontal-axial wind turbines are not suitable for farms for the above reasons. Therefore, there are prospects for vertical-axis rotary wind turbines for their use in mini-farms [16].

Therefore, the focus of our study was directed to the study of the vertical-axial rotary wind turbine, operating on the Savonius rotor principle.

The main advantage is that it does not require promotion, such as the vertical-axial Darye rotor, runs independently at wind speeds ranging from 2.5 m/s, is operable at all its speeds up to 35 m/s and has a power factor of 0.3...0.4, not inferior to horizontal-axial wind turbines [10].

Until recently, it was believed that the wind energy utilization coefficient of rotary wind turbines could not even theoretically be greater than 0.22. However, experimental studies conducted in recent years have refuted this statement and proved that the Savonius type rotary installations are not inferior to horizontal-axial ones, and in a number of other parameters even surpass them and are the most rational for use in peasant farms and other agricultural enterprises, remote from power supply lines [17, 18].

The power factor of wind turbines of various designs is determined on models blown in a wind tunnel, in which the air flow and its direction do not change.

In real conditions, the wind flow acting on the wind turbine constantly changes both in the direction of up to 10 degrees or more, and in gusts, in which its speed can change by 2...3 times.

In practice, it is not possible to determine the power factor for different wind turbines, since horizontal-axial wind turbines cannot respond to these changes due to their inertia and the presence of a gyroscopic effect that occurs on a rotating wind wheel.

Rotary wind turbines of the Savonius type do not have these disadvantages, because they use the wind from any direction at any speed. Logically, rotary wind turbines are more efficient, which is confirmed by the test results – the amount of energy generated by a rotary wind turbine of the Savonius type is 1.5...3.0 times more than horizontal-axial ones.

The purpose of our study was to develop an optimal power plant, which will be based on a vertical-axis rotary wind turbine.

Materials and methods

Rotary wind power plants, in which the working bodies (blades) are part of a cylindrical surface fixed around a vertical shaft, attract specialists by the simplicity of their design, the ability to use the wind flow from any direction, the availability of maintenance and repair, since all their working mechanisms – pulleys, clutches, gearboxes and an electric generator are located at the ground surface. Another attractive feature is that the mechanical energy of the vertical rotating shaft can be used directly to drive various technological mechanisms (**Figure 1**).

Figure 1 General view of the design of a two-rotor wind power plant.

These features of rotary wind turbines are more attractive to energy consumers who are far from power supply systems. The required power of wind turbines for remote energy consumers does not exceed 3 ... 5 kW, and could solve many problems in the field of their individual production activities. However, the solution to the problem of energy supply to remote farms is not included in the state program.

In such conditions, the farmers themselves are forced to develop and manufacture rotary wind turbines. Without a theoretical basis and the necessary practical experience, production workers in the manufacture of rotary installations repeat the same mistakes, and their efforts eventually end in failure.

The most common mistake is the manufacture of a cantilever rotary wind turbine. When the wind flow affects the rotor of a cantilever rotary wind turbine, the shaft bends and, as a result, when it rotates, a dynamic unbalance appears, leading to a crack in the shaft body at the place of its attachment in the lower bearing of the support, and the shaft breaks.

Trying to eliminate this drawback, the upper end of the shaft is fixed in a bearing with a bearing support, which is installed on the crosspiece, and the crosspiece is attached to the ground by stretch marks. This method does not solve the problem, since the stretch marks are not able to rigidly fix the crosspiece.

There is only one way out that we have come to, namely, the upper and lower ends of the rotor shaft must be attached together with the bearings in the bearing housings in a rigid support truss on the support platforms installed in it [19]. The support truss must have at least three supports.

The second drawback-in an effort to simplify and facilitate the design, the rotor shaft is mounted in a two-support frame, which does not save the rotary wind turbine from the above-mentioned defects.

In an effort to increase the power of rotary wind turbines, they are made with two, three and a large number of rotors. In this case, all the rotors are fixed rigidly on one shaft. Of course, the rotors and the support truss itself will deform under the influence of wind pressure and cause bending of the shaft and struts, which also leads to an unbalance of the entire structure of the rotors – the shaft, the ends of which are fixed in bearings in the bearing supports on the upper and lower support crossbars. An attempt to secure the shaft in the intermediate bearing supports only caused additional pinching.

These, and a number of other reasons, make a rotary installation with a vertical rotating shaft unreliable in operation. This has led to the fact that many researchers are currently engaged in improving its design.

Analyzing the causes of unreliable operation of many designs of rotary wind turbines, it can be concluded that the causes that cause unreliable operation of rotary wind turbines can be eliminated in certain ways.

Results and discussion

As a result of our analysis, we propose a conceptual framework consisting of certain requirements for the design of a rotary installation with a vertical rotating shaft (**Figure 2**):

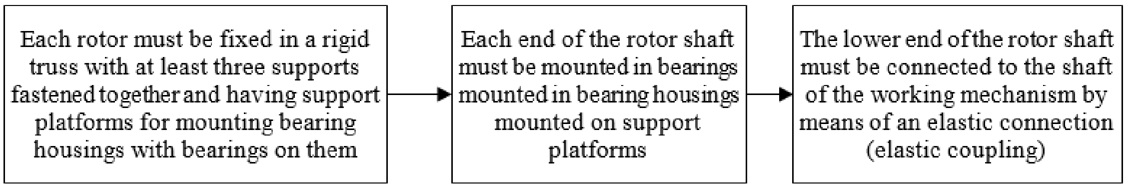

Figure 2 Requirements for the design of a rotary installation.

Compliance with the accepted requirements allows you to eliminate the bending of the shaft and avoid dynamic unbalancing of the rotor.

In the manufacture of a rotary wind power plant with multiple rotors, in order to increase its power, it is also necessary to meet the following requirements (**Figure 3**):

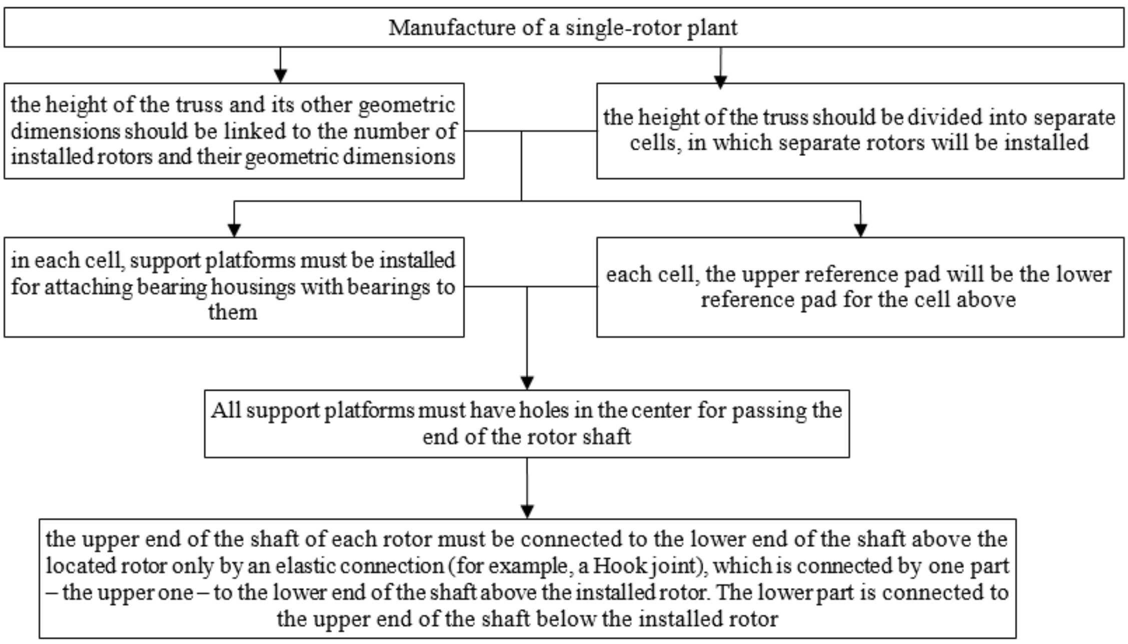

Figure 3 Requirements for the manufacture of a rotary wind power plant with multiple rotors.

The implementation of the specified design requirements in the development of rotary wind turbines will avoid many obvious design errors.

When developing the design of a wind turbine rotor, in which the blades are part of a cylindrical surface, and the torque is created due to the difference in wind flow resistances of convex and concave surfaces, the main issues are the determination of their geometric dimensions and their relative position on the rotor [20].

The design dimensions of the elements of the rotary wind turbine obtained as a result of the conducted research allowed us to start developing and manufacturing a prototype of a two-rotor wind power plant that meets the technical and energy characteristics of the requirements determined by the nature of production activities of decentralized energy consumers remote from the energy supply systems in the agro-industrial complex.

Conclusion

Tests of a two-rotor wind turbine for 9 years at wind speeds from 2.5 m/s to 25 m/s, and in gusts up to 35 m / s showed the correctness of the choice of a constructive approach, since no failures of individual nodes were observed during its testing.

The reliability and operability of the proposed vertical-axis rotary wind power plant allows us to recommend the developed design for mass production in order to supply energy to remote autonomous energy consumers, including livestock mini-farms of the dairy sector of the agro-industrial complex.

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