Vertical axis wind power plant

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Abstract. The issue of developing technologies using alternative renewable energy sources today is a very urgent task both around the world and in Russia, which is explained by economic, technological, and, most importantly, environmental factors. The climatic and geographical features of our country create all the necessary conditions for the use of such areas as solar energy, small hydro energy, wind energy, etc. But the most promising in terms of energy potential is wind energy, as many regions of our country are located in areas with high average wind speeds. However, there are a number of problems that impede the development of wind energy in Russia, the most important of which is the almost complete absence of wind generators designed and manufactured in our country that could compete with foreign models. The product proposed in the article is an attempt to solve this problem through the use of a new design of a wind wheel and an electric generator, as well as the use of magnetic suspensions.

1. Introduction

Today, energy conservation issues around the world are becoming more and more important; the reasons for this are the constant increase in energy prices and the complexity of relations between countries, and, most importantly, the issue of depleting easily accessible deposits of organic fuels (oil, coal, gas). In this regard, energy conservation is currently very relevant, and alternative, in particular, renewable energy sources and technologies for their use are in the spotlight.

Unfortunately, the Russian energy sector is seriously lagging behind European countries in the introduction of alternative technologies, and if in a number of developed and developing countries wind energy, photovoltaic and hydroelectric power plants produce up to 50% of all electric energy, in Russia this indicator does not reach 1% [1].

In recent years, the issue of the necessity of developing alternative energy in Russia is being discussed at all levels, but, unfortunately, at this point in time, this direction is seriously hindered by the almost complete absence of competitive domestic units produced in series; all we have is either experimental constructions or ones produced in a single copy.

Talks about the need to develop this energy sector are regular at all levels, but government investments are negligible, and the private sector has little interest in projects with long payback periods.

Nevertheless, interest in wind power plants in our country is increasing due to the resumption of projects for the development of remote areas, and a number of enterprises of various profiles are developing in this direction [2-5]. One of such enterprises is the Baltic Machine-Tool Plant (St. Peters-
burg), by order of which, in 2010-12, the Department of Electromechanical Systems and Power Supply of Voronezh State Technical University, together with the Department of Electric Power of International Institute of Computer Technologies (Voronezh), put into practice the project of wind-driven electric plants (WDEP) with a capacity of 10 kW. The orientation to the indicated power was adopted based on the analysis of the world practice of power supply of autonomous objects based on wind turbines with capacities from 1 to 15 kW [6].

2. The concept of a wind-driven electric plant
A reliable and inexpensive wind-driven electric plant for use in areas with severe climatic conditions should have the following qualities: simple design of the aeromechanical part with a minimum number of moving elements (absence of regulation of angles of attack and pointing to the wind), bearing units with long service life and minimal maintenance, a simple rotation frequency control system depending on wind speed. These requirements are met by a WDEP with a vertical axis of rotation, which allows one to use unconventional solutions for the generator and bearing units. In particular, the main shaft of the WDEP carries a generator rotor, and to reduce friction losses and increase the service life of bearings, a magnetic suspension of the rotating part can be used, which receives most of its weight.

To verify the technical solutions adopted in terms of the magnetic suspension and the automatic control system, we made a working model (figure 1) with a power of 1.5 kW, developed at the calculated (most often repeated in the region of possible use) wind speed.

![Wind-driven electric plant design](image)

Figure 1. Wind-driven electric plant design.

To convert wind energy into mechanical energy, we used a specially developed and patented wind turbine with a vertical axis of rotation (figure 1) [9].

In accordance with the requirements specification for the project, when developing a prototype, we used consumers that have low requirements for most of the quality indicators of electric energy, namely, accumulator batteries and illuminators based on incandescent lamps.

To reduce material costs at the first stage of the development of the WDEP, as an electric generator, we decided to use a 4MP 31.5 gear motor based on the AIR 100L6E2 asynchronous electric motor with a built-in electromagnetic brake with a capacitor excitation, the rotation frequency of which is practically unchanged and is a multiple of the 50Hz network frequency. The selected geared motor has a vertical design and a flange on the upper bearing shield, which makes it easy to mount it in the generator compart-
ment of the WDEP (figure 2). A feature of the selected gear motor is the presence of an integrated mechanical brake, which makes it possible to stop and fix the wind wheel during a WDEP shutdown.

Figure 2. Mounting the gear motor.

In accordance with the theory of wind engines, the maximum efficiency of converting wind energy into the mechanical energy of a rotating shaft corresponds to a certain ratio of specific speed and wind speed. For WDEPs with known dimensions of a wind turbine, it is fair to talk about a certain ratio of rotational speed and wind speed. The main feature of the developed wind wheel is the impossibility of regulating the torque and frequency of rotation during fluctuations in wind speed and generator load using aerodynamic means. To regulate the rotational speed of the wind wheel, on which the output voltage of the generator also depends, we made it possible to adjust the current in the load, which allows us to influence the braking torque on the shaft of the wind turbine, which is created by the electric generator [8].

3. The electrical part of a prototype WDEP

Figure 3. Scheme of the electrical part of the WDEP:

AG – the asynchronous generator; KET – the electromagnetic brake; C1 - C3, C4 - C6, respectively, the main and additional excitation capacitors; KV1 – the contactor for connecting additional capacitors; R1-R3 – the unit of ballast resistors; U1 - U3 – the opto-symistors; QF2 – the load switch; AC – the automatic charger; GB – the accumulator batteries.

To control the load current during the operation of the plant, we developed an automatic control system (ACS) that implements the principle of phase control of the load current distributed between the
active payload, accumulator batteries, and ballast resistors [8]. Thus, the electric part of the prototype WDEP consists of two parts: the power circuit and ACS (figure 3).

ACS consists of a microcontroller unit - A1, and a unit for interfacing the microcontroller with the power elements of the plant - A2. For visual control of the current state of the WDEP, the circuit used control and measuring devices PV, PF PA, as well as LED indication H1, H2.

To ensure the temperature regime of equipment mounted in an electrical cabinet, and, in fact, to cool opto-symistors and ballast resistors, we provided radiators and fans, which are not shown on the electrical circuit diagram for simplification (figure 4).

The bench tests fully confirmed the operability of the WDEP automatic control system.

Figure 4. General view and internal structure of the WDEP control cabinet.

4. Magnetic levitation suspension
An important part of the work on creating a promising WDEP was the development of magnetic levitation units that take up most of the vertical load on the WDEP shaft bearings in order to reduce mechanical friction losses and increase durability.

The developed permanent magnet levitation suspension (PMS) consists of several magnetic modules of the same design, the number of which varies depending on the amount of force that needs to be compensated (figure 5). This constructive solution is explained by the fact that the overall dimensions of the module are limited by the inner diameter of the hub into which it is mounted, as well as by the diameter of the axis of the wind wheel. In addition, in many respects, the geometric dimensions of the modules are determined by the dimensions of the permanent magnets and also depend on the distance between the bearing supports [11].

The proposed design of the magnetic suspension uses three magnetic modules (figure 5 b), each of which consists of two magnetic platforms. The upper platform (position 2) is fixed on the tubular axis of the wind wheel 4, the lower platform 3 is on the inner surface of the hub housing, which transmits torque from the wind wheel to the generator.

Magnetic platforms, in turn, consist of steel shells 9 and 10, on which permanent magnets of the brand N342/1.32/876/955 are placed (position 11). For ease of installation, the magnets were made in the form of segments, which allows us to assemble them in the form of a ring inside the shell (figure 5 a), each prototype platform contains 24 magnets.

In the course of the research, we found that in the places of contact of two adjacent magnets the uniformity of the magnetic field is violated, which results in a pulsation of the magnetic flux inside the module, which inevitably leads to eddy currents and, consequently, to additional losses. In order to
reduce the effect, a steel magnetic strip 14 was added to the platform design over a ring of magnets. In addition, platform cover 15 acts as a damper when the magnetic flux of the magnetic module changes since it is made of an aluminum alloy with high electrical conductivity.

Figure 5. Magnetic suspension design:

a - lower platform with magnets installed during the assembly process; b – module assembled from unlike type platforms, prepared for transportation; c - design of the WDEP with magnetic suspensions.

The proposed module design reliably protects the permanent magnets from various external influences, including moisture. The possibility of condensation in the inner cavity of the hub housing is not excluded. In this regard, all the steel parts of the module are painted, the final painting is carried out after assembling the elements of the magnetic module, and to ensure complete proofness, the shell of the module is filled with epoxy compound.

To ensure reliable fastening of the magnetic modules, inner ring 12 and gussets 8 are welded to shell 9, and outer ring 13 and gussets 8 are welded to shell 10. Upper platform 2 is attached to inner fiberglass cylinder 5 with screws 17. Similarly, the lower platform is attached to outer fiberglass cylinder 5 with screws 17. In turn, inner fiberglass cylinder 5 is attached to the axis of the rotor 4 with bolts 21. Additional bond strength is provided by bolts 23. Outer fiberglass cylinder 6 is attached to hub housing 7 with bolts 18. Bolts 25 provide additional bond strength.

In order to reduce the scattering magnetic fields and increase the interaction force between the magnetic supports, the construction of the supports includes fiberglass cylinders that create a non-magnetic gap between the hub housing and the magnetic module.

A distinctive feature of the proposed PNMS is the possibility of using various combinations of magnetic modules, some of which work on attraction, and some on repulsion, which makes it possible to reduce the total mass of applied permanent magnets ”[11].

5. Special electric generator
As the studies showed, the realization of all the advantages of a vertical-axis wind turbine mentioned above can be fully achieved by using a special electric generator integrated into the design of the plant
An analysis of the available information showed that a synchronous generator with excitation from permanent magnets having a disk design can be most effective [7] for the realization of the tasks set.

In the course of the research, we developed and subsequently patented [10] a design scheme of a disk synchronous generator. Figure 6 shows a sketch of the layout of the developed generator used in the research.

The rotor design of the developed generator consists of two magnetic conductors mounted on a shaft. Magnetic conductors are in the form of disks, permanent magnets are assembled on one of them round the edge. As the research results showed, the cylindrical shape of the magnets is the most optimal, but it is possible to use the shape of the segments, as is the case with a magnetic suspension. The generator shaft is made in such a way that it can be rigidly connected to the wind wheel shaft, which makes it possible to exclude bearing assemblies from the generator design.

A distinctive feature of the proposed generator is that there is no steel magnetic conductor on the stator, it is a monolithic winding, which is made by pouring coils with a compound.

During the research we found that for this generator we can use different types of windings, the choice of winding depends only on the required parameters of the machine, and the best performance is given by the use of a single-layer coil or two-layer loop windings [12].

**Figure 6.** Design of the synchronous disk generator:

1 - the upper magnetic conductor of the rotor; 2 - a permanent magnet; 3 - shaft; 4 - lower magnetic conductor of the rotor; 5 - stator winding.

Thus, the proposed generator in comparison with machines of a similar purpose has a lower mass (due to integration into the design of the WDEP), a simpler structural scheme, and therefore it is easier to service and repair, and most importantly, it has a low cost. In addition, an important feature of the adopted concept is the modular principle of a magnetic suspension and generator, which allows one to build a range of WDEPs for a number of capacities by using a different number of generator blocks.

**6. Conclusion**

Thus, the complex of research and development work allowed us to formulate a promising concept of a vertical-axis WDEP for a power range from 1 to 15 kW. We tested a number of solutions and implemented them in the form of existing prototypes, for example, manufactured at the Baltic Machine-
Tool Plant (St. Petersburg) (figure 7). Unfortunately, it was not possible to carry out full tests and refinement of the product based on their results, since the work was suspended due to financing problems.

![Figure 7. Prototype WDEP.](image)

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