

Study on a generator and turbine designed for an efficient wind power plant in low speed wind currents

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Abstract. This article presents the advantages of improving and developing new types of turbines and generators designed for the production of electricity from low-speed wind and free-flowing water, at a time when the environment is deteriorating and there is a shortage of electricity. It has been analyzed that low-speed micro-hydroelectric power plants and wind power plants bring great benefits to the environment and economy through their mass use in meeting the needs of the population and businessmen for electricity. For this purpose, the effective structure of low-speed generators, micro-hydroelectric power plants and wind power plants were considered, and the issues of improving them so that they work efficiently at low speeds were considered. Mathematical equations of a low-speed generator designed to obtain electricity from low-speed wind and free-flowing water are presented. At the same time, scientific research was conducted to study, improve, and develop new types of micro-hydroelectric and wind power plants suitable for low-speed generators. As a result of scientific research, an improved wind power device designed for small speed was developed and the results of research were analyzed.

1. Introduction

Today, in the Republic of Uzbekistan, using renewable energy sources, that is, wind or water energy, scientifically based, high-quality, durable, relatively cheap low-speed generators that can be maintained by our specialists, and based on innovative ideas, development, research, is one of the urgent tasks. For this, the structure and principle of operation of the low-speed generator, electromagnetic processes are studied and analyzed based on the information obtained on the basis of scientific research.

Based on scientific calculations, the structure of the turbine is being researched into a new efficient structure adapted to low-speed wind and water. The effective value of the angle of exposure of the small speed turbine blades to the wind or water flow is selected and the structure of the turbine is analyzed based on scientific calculations. The main magnetic field of the low-speed generator considered in this article is created using neodymium permanent magnets, while additional built-in excitation coils are also used when necessary [1]. The auxiliary drive is supplied with a constant current source by means of accumulator batteries. This device protects the generator from malfunctions by increasing the power of the generator at the right time and calming the electromagnetic processes in the generator in the modes of symmetrical loading and short circuit [2-4]. This low-speed generator differs greatly from its closest analogues in its structure and the fact that the main magnetic field is controlled together with excitation coils and permanent magnets. When changing the speed of the generator, permanent magnets and additional excitation coils are used together, which makes it possible to use them in small-power wind power plants and micro-hydroelectric plants.

Great work is being done on the development and improvement of turbines and generators used to convert low-speed wind and free-flowing water energy into electrical energy [5-10]. Therefore, technological study of their structure, properties of materials used in making the working wheel, blades, stator and rotor is of great importance. In several leading universities in the world, practical scientific and technical research works, improvement of devices that

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convert wind and water energy into electricity, development of new types, development of effective technologies for their use and adaptation to local conditions, and the use of renewable energy sources are carried out. Research works are being carried out on the development and creation of the technology of production of technical devices and materials used [2, 4, 5].

The rotor of the generator, which is being studied in the scientific article, is made in two disc-shaped forms. Excitation windings and neodymium permanent magnets are placed on the rotor along longitudinal and transverse axes, and the stator is made of composite material and contains single or three-phase windings. Based on this scientific and innovative idea, the use of an alternative material instead of electrotechnical steel, which is the main material of generators, the use of a permanent magnet along with the excitation coil is scientifically and technologically based. The turbine is designed in a design adapted to small speeds. It is shown that the structure of the working wheel and the angle of influence of the blades, its shape and materials are made according to scientifically based conclusions, and it can work effectively with a low-speed generator [11-14].

"The energy sector is being developed on a large scale in the Republic of Uzbekistan. Not limited to hydrocarbons such as oil and gas, solar, wind and hydroelectric power generating facilities are being built. In particular, in 2017, the joint-stock company "Uzbekhydroenergo" was established by presidential decree. In the past period, 11 new hydroelectric power plants were built and 8 were modernized. As a result, 244 MW of additional capacity was created. However, only 50% of Uzbekistan's hydropower potential has been used. Therefore, 21 large projects with a total capacity of 740 MW have been developed. In particular, it is planned to implement 7 projects of 170 MW next year, 12 projects of 150 MW in 2023-2024, and 2 projects of 420 MW in 2025-2026.

According to the President's decision "On measures to further reform the hydropower sector", it is envisaged to increase the hydropower capacity to 4999 MW by 2030, including the creation of additional 2311 MW and 615 MW with the participation of private investors. The following additional prospective projects will be implemented in Uzbekistan from 2023:

Construction of Upper Pskem, Korongitogay, Toldiksoy HPPs, Oygain HPP cascade and Upper Pskem hydroelectric power station with a total capacity of 876 MW in Bostonliq district of Tashkent region;

- Construction of the Norin HPP cascade with a total capacity of 225 MW on the Norin River, Namangan Region;
- Construction of the Yuqoritopolang HPP cascade with a total capacity of 264 MW in Sariosia district of Surkhandarya region;

The program of additional measures for the further development of hydropower in 2023-2030 was approved. Followings are main points:

- Updated target indicators of further development of hydropower and increasing the level of use of hydropower in 2023-2030;
- List of 9 investment projects with a total capacity of 748.5 MW included in the investment program of Uzbekistan for 2023-2025 and implemented in 2023-2027;
- In 2024-2030, a list of 47 investment projects aimed at increasing the level of use of existing hydropower, creating new capacities of hydropower plants and modernizing existing ones;
- Includes a list of equipment, components and spare parts necessary for the construction and use of small hydroelectric power plants and proposed for localization on the basis of cooperation in 2023-2025.

2. Materials and Methods

In this article, the structure and working principle of a small speed turbine and generator were analyzed based on the data obtained on the basis of scientific experiments. It is important to develop turbines and generators in accordance with low-speed wind and free-flowing rivers and canals, to reduce their speed according to demand and to reduce the cost of electricity due to technological development. Therefore, it is very important to study their structure, the properties of materials used in making the impeller, stator and rotor, and the principles of operation. In the article, based on scientific calculations, the structure of the turbine, i.e., the shape of the inner and outer blades of the working wheel, the angle of placement, and the co-location of the excitation coils with the neodymium permanent magnets in the two disk-shaped rotors of the generator, the stator is a single or three-phase stator coil. It is considered to be made of fixed composite material. In this, parameters such as wind power plant and micro-hydropower plant operating modes, electromagnetic processes in them, efficient operation, useful work coefficient, unit cost were analyzed. Using an alternative anisotropic material instead of electrotechnical steel, which is the main material of the stator of generators, and the rotor is made in the form of a disk of ordinary steel instead of electrotechnical steel, and the use of excitation coils together with neodymium magnets. By controlling the main magnetic field, measures have been taken to increase the power of the wind power plant. If we create the main magnetic field of the low-speed generator of the low-speed wind electric device with the help of neodymium permanent magnets, the possibility of

controlling it through an additional excitation coil when necessary is taken into account. As a result of this, it was possible to increase the power of the low-speed generator through the additional excitation coil, as well as to calm down the electromagnetic processes in the generator in various operating modes such as salt, load, and short-circuit modes, and protect the generator from malfunctions. This low-speed wind turbine produces either single-phase or three-phase alternating current. A low-speed generator consists of one shaft, two disc-shaped rotors, one disc-shaped stator, bearings and housing. The rotor is made of steel in the form of two disks, and neodymium permanent magnets are placed at opposite poles on their inner side facing each other. Additional excitation coils are placed next to the magnets. The rotor discs are fixed so that they rotate together with the shaft. The shaft is fixed to the housing with bearings. A disk-shaped stator (5) is placed between the rotating rotor disks (1) and fixed to the housing.

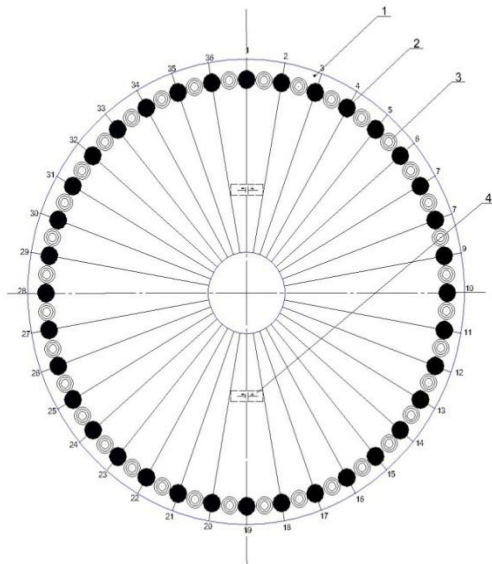


Fig. 1. Rotor: 1- rotor disk, 2- neodymium permanent magnet, 3- additional coil on the transverse axis, 4- battery

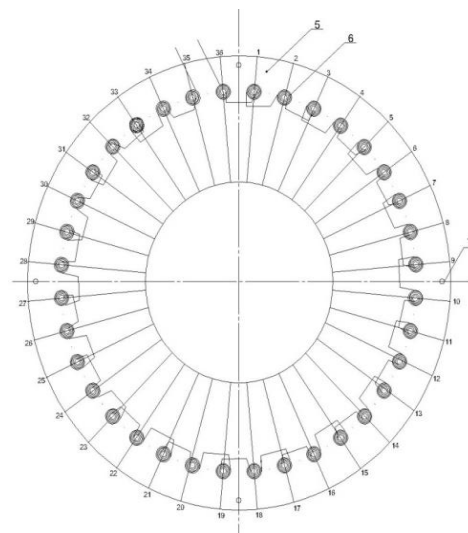


Fig. 2. Stator: 5- stator disk, 6- stator sleeve, 7- fastening place

The weight and size of a low-speed synchronous generator is determined by its stator and rotor diameter D and length l [1, 2]:

$$D^2 \cdot l = C_A P_{\text{his}} / n \quad (1)$$

Arnold's constant for a generator is found using the formula $C_A = 6.1 \cdot 10^7 / \alpha_i \cdot k_F \cdot k_O \cdot A \cdot B_\delta$.

here:

P_{his} – calculated power [W];

n – rotor rotation speed [r/min];

α_i – the calculated closing coefficient of the pole;

k_F – field shape curvature coefficient;

k_O – chulgam coefficient;

A – linear load [A/cm];

B_δ – the maximum induction value in the air gap at nominal load [Tl].

The calculated power is determined using the following formula:

$$P_{\text{his}} = k_e \cdot P_n / \cos \varphi \quad (2)$$

Here: $k_e = E_i / U_n$ – Coefficient that characterizes the electromotive force of the armature coil.

A low-speed synchronous generator with a permanent magnet and an additional excitation winding located along the transverse axis is characterized by high energy efficiency due to the small internal power losses ΔP . Generator internal losses are calculated using the following formula:

$$\Delta P = \Delta P_{\text{copper}} + \Delta P_{\text{steel}} + \Delta P_{\text{additional}} \quad (3)$$

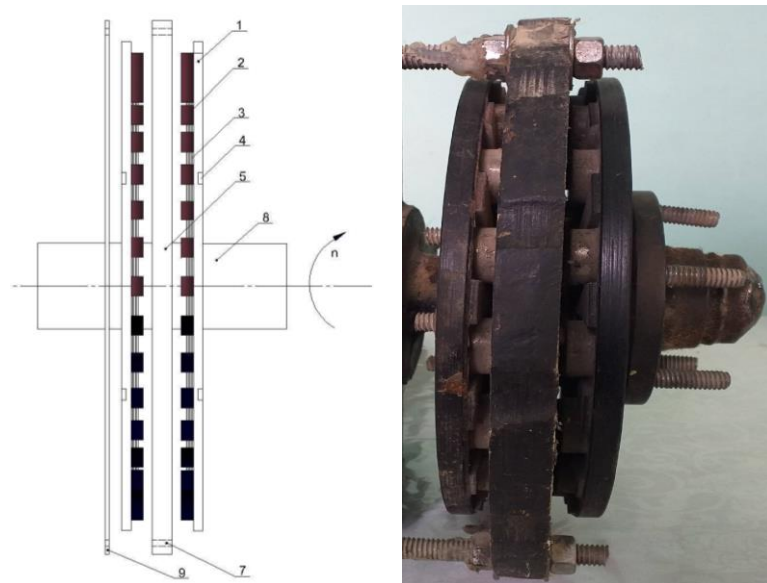


Fig. 3. General view of the generator. 8 - shaft, 9 - body

It is possible to review and analyze the micro-hydroelectric and wind power plants that correspond to the technical dimensions of the low-speed generator.

The technical dimensions of a small-speed synchronous generator with a permanent magnet and an additional are given in Table 1.

Table 1. excitation coil located on the transverse axis

P [W]	800
U [V]	24
I [A]	34
n [r/min]	167
m [kg]	6
l [mm]	110
D [mm]	175
2p	18
τ [mm]	29
cos ϕ	0,8

For the above generator, it will be necessary to adapt the production of a scientifically based, low-speed, high-quality, durable, relatively inexpensive turbine that can be maintained by specialists. For this, the structure and working principle of the small speed turbine, which is supposed to be developed, will be analyzed on the basis of scientific experiments. The type, structure, and materials of such a low-speed turbine, the number of blades, and the shape of the impeller were scientifically studied and analyzed. The analysis of wind and hydropower potentials in Uzbekistan showed that the use of small power turbines is effective. Based on this, the wind turbine in Fig. 4 was developed based on our scientific research on improving the structure of low-speed, small-power turbines. This wind turbine was adapted to a generator, a wind power device was developed and scientific research was carried out. The developed vertical axis wind electric device is important for its noiseless operation even in low-speed wind currents.

Structure of wind power plant:

1,4 - rings that hold the guide wings; 2 - guide bars; 3 - working wheel blades; 5 - holding legs; 6,7 - discs holding the blades of the working wheel; 8 - generator; 9 - frame holding the generator; 10 - consists of a shaft. Since it is possible to change the angle of action of the turbine, impeller vanes (3) and guide vanes (2) of this wind turbine, it is placed at the desired angle depending on the speed of the wind flow. In order to ensure the efficient operation of the wind electric device, wind deflectors are placed and they perform the task of diverting the wind flow to the blades of the working wheel. In addition, the angle of the guide vanes can be changed depending on the speed of the wind

flow. The ability to change the angle of exposure of the blades of the working wheel of the wind turbine and the guide blades depending on the speed of the wind flow ensures the efficient operation of the wind power plant.



Fig. 4. Wind power plant. 1,4 - rings that hold the guide wings; 2 - guide bars; 3 - working wheel blades; 5 - holding legs; 6,7 - discs holding the main wings; 8 - generator; 9 - frame holding the generator; 10 - shaft

The turbine structure adapted to the small speed generator of the wind power plant, which produces electricity efficiently even in low wind flow, has been improved. Therefore, it allows to produce the necessary electricity even in low current wind.

Table 2 shows the dimensions of the wind power plant.

Table 2. Dimensions of the wind power plant

Wind power plant technical dimensions	Weight (kg)	Height (sm)	Width (sm)	Number (piece)	Power (kW)
Inner wheel blades	40	89	50	9	0.8
Referral page	25	97	50	6	0.8
Generator	6	Ø17,5	11	1	0.8
Legs	20	80	6	4	-
Val	4	160	3	1	-
A ring that holds the guide blades	30	Ø120	-	2	-
Ring that holds the inner wheel spokes	10	Ø 62	-	2	-

3. Results

It is possible to determine the main parameters of the wind electric device by means of experiment, to study its unique important features.

The effective size and power of the generator, which is the main part of the wind power device, is calculated by mathematical expressions for small wind currents. A wind turbine with an adapted turbine for this generator was made and research was carried out at different wind speeds. The study of the physical experimental device of the wind power plant was carried out in the regions of Tashkent region with different wind speeds. Based on the results of the research, the electrical parameters of the wind power plant were measured and analyzed.

When the wind speed is changed from 1 m/sec to - 4 m/sec by 0.5 steps, the rotation speed (n), current (I), voltage (U), power (P) of the wind electric device was measured in the experimental device. The dimensions of the wind power plant measured as a result of research are given in Table 3.

It can be seen that the proposed wind power plant has the possibility of efficient production of electricity even in low-speed wind. Various operating modes were studied and electrical quantities were measured and analyzed through the wind power device under study. The researches and scientific research carried out on the wind power device, the nominal sizes of the generator and turbine under consideration, that is, when the wind speed is 4 m/s, the rotation frequency of the wind power device is 167 rpm, the power is 0.8 kW, the load current is 34 A and indicated that the rectified voltage at the load would be 24V. Based on the values in Table 3, which are given the values

measured as a result of the research, **U, I** - characteristics (Fig. 5) and **P, n** - characteristics (Fig. 6) were obtained at different values of the wind speed v of the wind power device. It can be seen that the proposed wind electric device clearly characterizes the modes of operation and loading.

Table 3. Dimensions of the wind power plant measured as a result of research

Units	Wind speed, v (m/sec)						
	1	1.5	2	2.5	3	3.5	4
n (rpm)	40	65	81	102	124	147	170
I (A)	4	6.8	10.5	15.6	21.7	27.5	34
U (V)	3	4.8	8.1	11.2	15.1	19.3	24
P (W)	12	33	85	175	328	531	816

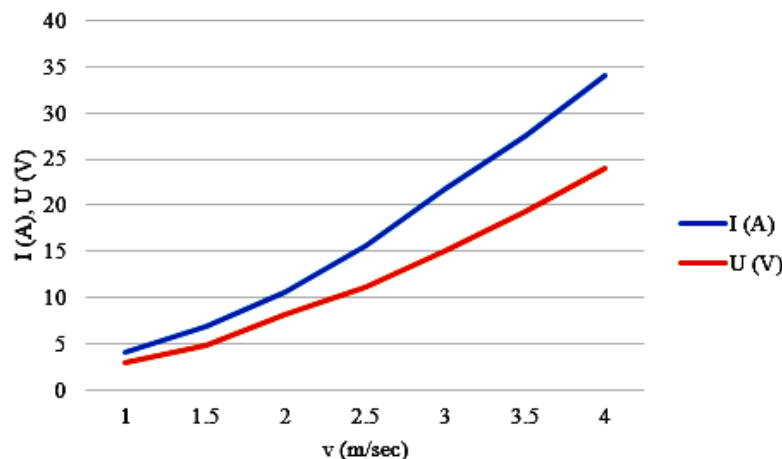


Fig. 5. **U, I** characteristics of the wind power device at different values of the wind speed v at the physical experiment stand

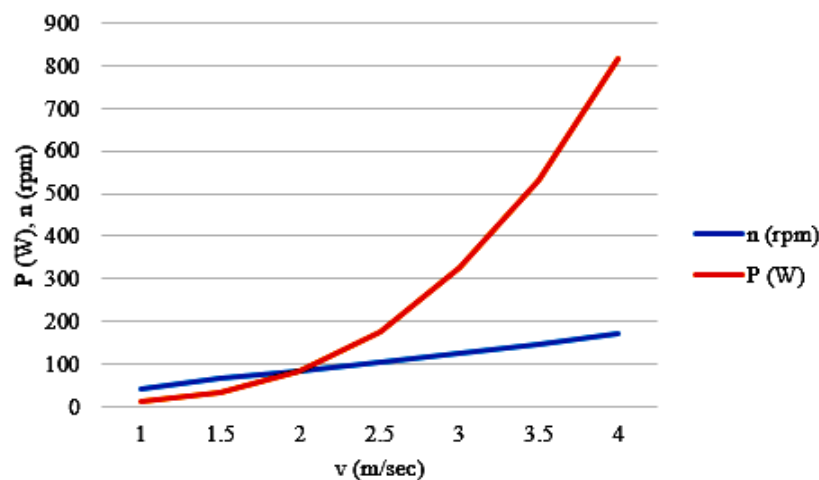


Fig. 6. Characteristics of **P, n** at different values of wind speed v of the wind power device at the physical experiment stand

With the help of such a low-speed turbine and generator, it is possible to launch a serial production of wind power devices that produce efficient electricity in low-speed wind currents.

This is important due to the fact that the generator and turbines in the wind power plant are different from other analogues, and the excitation coils are controlled together with permanent magnets, and the blade exposure angles can be controlled, and the useful work coefficient is relatively high. In this case, the whole part of the stator winding of the generator of the wind electric device works usefully in the production of electricity, that is, all the stator windings are active and the magnetic field lines of force are crossed. Due to this, the coefficient of useful work is also high. Another advantage of this low-speed generator is that it can operate at low and high wind speeds.

4. Conclusions

The main parts of the wind power plant presented in the article are new low-speed turbines and generators, the price of which is 50% cheaper than foreign analogues, they are light, simple in structure, and the useful work coefficient is relatively high.

Produces efficient electricity even in 1-4 m/sec wind flow.

The structure of the synchronous generator has been improved, that is, as a result of the use of an additional coil together with a permanent magnet, it allows efficient production of electricity in low-speed wind currents.

It is possible to increase the power of the generator by controlling the main magnetic field, symmetrical loading with the help of an additional excitation coil when necessary, calms the electromagnetic processes in the generator during short circuit times, and protects against malfunctions in the generator.

The presence of vanes of the working wheel in the turbine and the vanes that direct the wind flow to the working wheel, the possibility of controlling them depending on the speed of the wind flow, are preferred because of their efficient operation in small wind flows.

One of the important indicators is the possibility to reduce the speed of the wind power plant according to the demand due to the technological development of the wind power plant.

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