Compact household wind generator

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Abstract. Nowadays, there is a problem of further development of alternative energy for power supply of residential consumers. One of the areas of alternative energy is wind power. Wind generators offered to the public do not fully meet the requirements for household wind turbines. They are characterized by high cost; large weight and dimensions; installation complexity; impossibility of installation in cramped conditions; high noise and vibration. The article presents a physical model of a household wind generator with a wind guide device. Mass, dimension and energy characteristics of this device are estimated. The presented construction of a household compact wind turbine can be used for power supply of residential consumers, small businesses, in the field of housing and communal services and in agricultural sector.

1. Introduction
The constantly growing tariffs for purchased electricity stimulate a further search for alternative ways of electricity supply to consumers, in particular, through the use of wind energy [1, 2]. Wind generators make it possible to convert wind energy into electrical energy of alternating current, which is necessary to power household electrical receivers. However, one should not forget about its shortcomings, which are; long payback period; relatively low efficiency; the presence of expensive equipment (battery and inverter), without which the station cannot work on windless days.

Industrial consumers have a fairly wide choice of wind generators with installed capacity from 30 kW to 7.5 MW [3,4]. The situation for domestic consumers is much worse. Although there are domestic manufacturers of wind turbines, which have built their own business in the market and have proven themselves from the best side: “Vetro-Svet”; “Rkraft”; “SKB Iskra”; “Sapsan-Energiya”; “Vetroenergetika”. These organizations not only manufacture products to individual orders, but also provide services for calculation and design of wind power plants, allow their customer to choose the most suitable equipment based on individual measurements, calculations and indicators of the desired power. Models of the following international manufacturers are particularly popular: Ming Yang, Sinovel, Goldwind (China); Vestas (Denmark); Gamesa (Spain); Suzion (India); GE Energy (USA); Siemens, Enercon (Germany). Foreign wind power plants are distinguished by a higher level of quality, which is achieved through high-tech equipment. However, the installation of such power plants involves costly repairs and the lack of necessary spare parts for sale. Wind turbines offered to the public do not fully meet the requirements for domestic wind turbines [5]. They are characterized by high cost; large weight and dimensions; installation complexity; impossibility of installation in cramped conditions; high noise and vibration.
2. Problem statement
The authors had a task to develop a physical model of a household compact wind generator with a wind guide device for power supply of household consumers and small businesses.

The main argument for the purchase of a wind generator is the possibility of saving electricity generated from a centralized power supply system [6]. The efficiency of using wind turbines to power household consumers is explained by the fact that the average annual wind speed in most regions of the country is in the range of 4.0–4.5 m/s, this indicator is sufficient for a home wind power station to be advantageous to use. But from the point of view of ensuring acceptable noise characteristics, the installation of wind turbines in the cramped conditions of human settlements is rather problematic [7, 8]. The wind turbine should be well balanced and completely closed by nosing, which pre-vents the penetration of foreign objects and does not violate the landscape at the installation site of the wind turbine [9].

When developing a domestic wind generator, it is necessary to consider the following requirements:
1. The payback period should not exceed 5 years.
2. There should be a possibility of its transportation by car.
3. Installation at the installation site should be carried out by one worker.
4. The design should be compact for installation in cramped conditions.
5. The device must comply with sanitary standards for noise and vibration levels established for residential areas of cities and towns.

Wind generators differ from each other by axis orientation. Wind generators are divided into that with a horizontal axis oriented perpendicular to the air flow and that with a vertical axis. The horizontal axis wind generator has an increased efficiency. Vertical axis wind generators are more compact, but more expensive. Their design features do not depend on the direction of the wind, so blades are constructed in the form of turbines. This reduces the load on axis and efficiency [10, 11]. Many developers follow the path of creating hybrid systems based on solar, wind energy and diesel generators [12].

The authors of the article proposed the design of a compact domestic wind generator with a wind guide devices, which combines advantages of both types of wind generators (Figure 1). Also this design meets the above listed requirements.

3. Operation principle
The aerodynamics of the considered wind turbine is based on the impact of the wind-guide devices on the incident wind flow, which provide the initial compression of the wind flow with its subsequent expansion. As it seen from Figure 2, the flow part of the wind turbine is a channel narrowed in the

Figure 1. External view of a compact household wind generator.
middle. This design is a characteristic of a Laval nozzle operating in the field of subsonic airflow velocities.

The basic equation relating the gradient of the sectional area, the velocity gradient and the Mach number for the Laval nozzle, has the form:

\[
(M^2 - 1) \frac{\partial v}{\partial x} = \frac{v}{s} \frac{\partial s}{\partial x}
\]

where \( S \) is the nozzle section area, \( m^2 \); \( v \) is gas velocity, \( m/s \); \( M \) is the Mach number (the ratio of gas velocity at any point in the stream and the speed of sound at the same point).

From equation (1) it follows that when \( M < 1 \), the gas flow at the nozzle inlet is subsonic [13].

a) The flow in the narrowing channel is accelerated if \( \partial S/\partial x < 0 \), \( a > 0 \).

b) The flow in the expanding channel is decelerated if \( \partial S/\partial x > 0 \), and \( \partial v/\partial x < 0 \).

![Figure 2](image)

**Figure 2.** Aerodynamic scheme of a compact domestic wind generator: 1-confuser, 2-wind turbine, 3-working chamber, 4-electric generator, 5-diffuser.

The incident wind flow enters the confuser 1, compresses and forms an elevated pressure zone in front of the wind turbine 2. Compressed wind flow, acting on the blades of a wind turbine, gives it some part of its energy, and rotates a wind turbine mounted on the shaft of the electric generator 4. When rotating, the electric generator generates electricity directed to consumer or to the energy storage system. In turn, the outer layers of the wind flow “a-a”, flowing around the expanding diffuser 5, create a discharge zone at its rear section, thereby reducing the air pressure behind the wind turbine.

To determine the increase in wind speed, and relative increase in the efficiency of wind energy conversion in a wind generator, the stationary gas outflow from a large vessel through a tube of variable cross section (nozzle) is considered. If we assume that the gas movement in each place of the pipe is uniform over its cross section, and the speed is directed almost along the pipe axis, then the amount (flow rate) of gas \( Q \) passing per unit time through the cross section \( S \) of the pipe should remain constant along the entire pipe [14]:

\[
Q = js = \text{const}
\]

where \( j = \rho v \) is flow density, \( \rho \) is gas density, \( \text{kg/m}^3 \).
Figure 3 presents relationship between gas flow density \( j \) change along the nozzle and pressure, described by expression (3):

\[
j = \left( \frac{p}{p_0} \right)^{1/\gamma} \left\{ \frac{2\gamma}{\gamma-1} \rho_0 p_0 \left[ 1 - \left( \frac{p}{p_0} \right)^{\frac{\gamma-1}{\gamma}} \right] \right\}^{1/2}
\]

where \( \gamma \) is adiabatic index.

Figure 3. Relationship between gas density flow change along the nozzle and pressure.

At low pressures in section \( S_{min} \), pressure \( p^* \) and speed \( v^* \) are reached. From equation (2) it follows that flow density \( j \) and air velocity \( v \) monotonously increase along the pipe, and pressure \( p \) monotonously decreases. The maximum flow density \( j^* \) is achieved in the narrowest section. In the expanding part of the nozzle, the pressure will continue to decrease and the flow density will begin to decrease in accordance with the movement along the curve of Fig. 3 from point \( b \) towards \( a \).

A pressure drop is formed on the wind turbine, which contributes to a deeper removal of wind energy, up to 35-37%.

4. Assessment of energy characteristics

To calculate the power of a compact domestic wind generator, we carried out analysis of the formula for air flow power \( P \) (W):

\[
P = \rho v^3 S / 2
\]

where \( \rho \) is air density (in normal conditions \( \rho = 1.225 \text{ kg/m}^3 \)); \( v \) is wind speed, m/s; \( S = \pi D^2/4 \) is wind flow area, m².

From the formula it follows that wind flow power is proportional to the third power of wind speed and to the second power of the turbine wheel diameter. This means that when the wind speed doubles, the flow capacity will increase by 8 times, and when blades length doubles, the power of the wind generator will increase by 4 times.

It is known that the maximum theoretical use of wind energy in ideal high-speed wing propellers is 0.593. For the best samples of high-speed wind wheels with an aerodynamic profile, this value ranges from 0.42 to 0.46. For multi-blade low-speed wind turbines, this value ranges from 0.27 to 0.35, depending on the performance quality. In our calculations, the coefficient \( k_1 = 0.35 \) is accepted. The conversion of mechanical energy into electrical energy is accompanied by losses ranging from 0.6 (for auto-tractor generators with an excitation winding) to 0.8 (for generators with excitation from permanent magnets). In formula (4), the loss accounting factor, \( k_2 = 0.8 \), is introduced. As a result, the following equation is obtained:
\[ P = k_1 k_2 \rho v^3 S / 2. \] (5)

Table 1 and Figure 4 show the relationship between wind turbine power, wind speed, and diameter of the turbine wheel.

**Table 1.** Estimated electrical power of a compact household wind generator.

| Diameter of input | Diameter of | Calculated electrical power (W) |
|------------------|-------------|---------------------------------|
| confuser cut-off (m) | wind turbine (m) | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 20 |
| 0.75              | 0.6         | 4.6 | 21.3 | 58.4 | 124.2 | 226.7 | 374.3 | 574.9 | 836.9 | 1362.8 |
| 1                | 0.8         | 8.2 | 37.9 | 103.9 | 220.8 | 403.1 | 665.3 | 1022.1 | 1487.9 | 2422.7 |
| 1.25             | 1           | 12.8 | 59.1 | 162.3 | 345.0 | 629.8 | 1039.6 | 1597.0 | 2324.8 | 3785.5 |
| 1.5              | 1.2         | 18.4 | 85.2 | 233.7 | 496.7 | 906.9 | 1497.0 | 2299.7 | 3347.7 | 5451.2 |
| 1.75             | 1.4         | 25.0 | 115.9 | 318.1 | 676.1 | 1234.4 | 2037.6 | 3130.2 | 4556.6 | 7419.6 |

**Figure 4.** Relationship between electric power of a compact domestic wind generator and wind speed and wind turbine diameter.

As it is seen from calculations, when the diameter of the confuser input cut-off is 1.5 m and wind speed is 11 m/s, the generated power is 906.9 W. For the total operation hours of wind generator equal to 3770 h/year, the output will be 3419 kWh/year, which fully covers the one apartment needs for electricity.

Wind turbines are bladed machines, because they convert mechanical energy of wind flow into electricity. For a wind turbine, the limitation is the speed of sound, which for normal conditions is 331.4 m/s. Therefore, the frequency of wind turbine rotation, depending on wind wheel diameter, should be in the range from 30 to 300 rpm. A device which increases rotation frequency of a turbine to 1500-3000 rpm is a multiplier. For a compact domestic wind generator, the use of a multiplier leads to an increase in financial and energy costs, so a quiet electric generator is needed. In industry, low-speed hydrogenerators with nominal rotor speed of about 90–150 rpm, and efficiency of 95% [15,16], are widely produced. For a domestic wind generator, the most suitable low-speed low-power generator (0.5-2 kW) is a motor-wheel motor used in electric transport [17]. At the same time, the “motor-
wheel” should have a controller to control the mode recovery - power generation. The engine of such a motor is a multi-pole three-phase machine, generating power already at 100-300 rpm.

Constructive studies have shown that total mass of the wind generator does not exceed 100 kg and, taking into account its small dimensions, it can be transported by car, and with the use of a modular tubular mast, it can be installed by one person.

5. Conclusions
A physical model of a domestic compact wind generator with a wind guide device has been developed.

Its mass, size and energy indicators were estimated. It was shown that the model meets the requirements for domestic wind generators.

The presented construction of a household compact wind turbine can be used for power supply of residential consumers, small businesses, in the field of housing and communal services and in agriculture.

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