# Calculation of the vertical axis wind turbine rotor and its moment of inertia

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**Abstract.** In the article, the problem of determining and calculating the equation of force and moments of inertia arising in the rotor under the influence of wind pressure was set and a solution was found. The final conclusions are given on determining the value of the energy absorbed by the rotor, which is generated in the reciprocal ratio of wind speed, rotor radius and resistance moment.

## INTRODUCTION

The use of such technology to provide a specific area with electricity is very important, especially for remote and inaccessible areas where the construction of power lines is not economically feasible. According to data, today millions of tons of oil, gas, uranium and other natural sources of energy are being extracted in the world every day. If we take into account that it takes 100 million years for the formation of just one "black gold", then the probability that the existing resources will run out in the 22nd century is very high. However, it should not be forgotten that more than 80 percent of air pollution is caused by this energy sector. Therefore, the amount of damage caused to the environment is very large. Therefore, the world community is now looking to renewable energy sources as a salvation [1].

The history of wind energy dates back hundreds of years to when people used windmills to pump water to irrigate crops and grind grain into flour [2]. This research and development program developed many of the megawatt wind turbine technologies used today, including steel tube towers, variable speed generators, composite blade materials, as well as aerodynamic, structural, and acoustic engineering designs [1-2]. The capabilities of the large wind turbines developed under this effort have set several world records for diameter and power.

## RESEARCH METHOD

Nowadays, we can see wind turbines in many places, coastal areas are ideal for such installations, and even offshore areas are good places to use wind power. Wind turbines have evolved a lot in the last 35 years. They are more reliable, more economical and quieter. However, it is not possible to conclude that the period of evolution is over. In places where wind speeds are low, energy costs could be reduced[3]. Turbines are still commercially viable for long-term use. The use of wind energy offers great opportunities in the world. In order to increase the economic efficiency of turbines, designers need to be constantly searching. Improved engineering methods for analysis, design and mass production are required. There is also scope for developing new ones. More attention should be paid to materials to increase the life of wind turbines. In all cases, the development of the wind industry represents an opportunity and a challenge for a wide range of disciplines, in particular mechanical, electrical, materials, ocean and civil engineering, and computer science, which also play an important role [4].

In recent years, the use of wind energy has become one of the most important priorities. In particular, during the first stage of wind energy development, wind energy began to develop rapidly in 14 countries where the electricity sector had reached high levels. At the end of the stage, the leadership in the introduction of new capacities belonged to the USA (1525 MW), followed by Denmark (310 MW) and Germany (60 MW) [4-5].

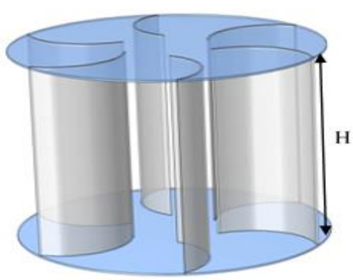
## PROBLEM FORMULATION

In the second phase of wind energy development, the number of countries using wind energy reached at least 35. Germany (6113 MW in 2000) took the first place and held the first place until 2008, the USA (2578 MW) could not maintain its leadership and fell to second place. The third and subsequent places were distributed as follows: Denmark (2301 MW), Spain (2235 MW), India (1214 MW), the Netherlands (446 MW), Italy (427 MW), Great Britain (406 MW), China (316 MW), Sweden (231 MW), Greece (189 MW), Denmark), South Korea and Mexico (8 MW), Russia (7 MW), Poland (5 MW) and other countries (125 MW) [5].

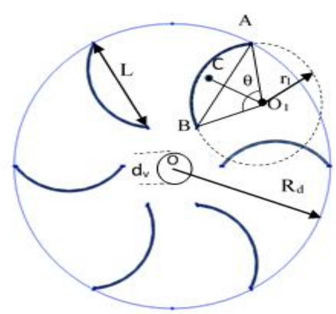
The number of countries in the third stage has reached 76, by the end of 2008, the total installed capacity in 12 countries exceeded 1500 MW, and in about six more countries the installed capacity exceeded 1000 MW in 2009. In 2008, the United States again took first place in terms of installed capacity of SHPPs. In 2006 and 2007, the electricity generated by SHPPs accounted for a share of all electricity generated in: Denmark (21.4% and 21.22%), Spain (8.8% and 11.76%), Portugal (7.0% and 9.26%), Germany (7.0% and 7.0%) and 1% worldwide [5-6].

## RESULTS AND DISCUSSION

In recent years, wind turbines have played an important role in the efficient use of wind energy. Leading countries have developed various designs in this regard, and the use of this type of wind generator is widespread. However, the creation of wind turbines requires separate calculations for the use of small amounts of wind. In particular, the rotor and geometric dimensions of the wind turbine. The rotor of a wind turbine consists of blades connected to the upper and lower disks, and a rotor shaft (Figure 1). The moment of inertia varies depending on the geometric dimensions of the rotor and the type of materials used for it[6-7]. As mentioned in the previous topics, increasing the surface area of the blade in contact with the wind by increasing the rotor diameter leads to a decrease in the moment of inertia, which leads to a decrease in the rotor rotation frequency. This drawback can be avoided by using materials with a low density for the rotor disk and blades, but this drawback cannot be completely eliminated by increasing the torque shoulder generated by the blades. By increasing the height of the blades, it is possible to increase the surface area of interaction with the wind, but even in this case, the deformation of the rotor shaft and bearings increases, with an increase in vibrations compared to the static equilibrium state. As a result, excessive energy loss is observed. Therefore, it is important to determine the optimal values for the rotor radius $R_r$, height H, geometric shape and width L of the blades, and the number [7].




a)




b)

**Figure 1.** Wind turbine rotor. a) General view of the turbine rotor; b) Calculation diagram of the turbine rotor seen from above.

The rotor blade is shown in Figure 1. It has the shape of an arc subtended by a central angle θ of a circle of radius r. Let the segment AB connecting the ends of this arc have the length L. From the triangle $AO_1B$:

$$\frac{L}{2} = r\sin\frac{\theta}{2}$$

$$L = 2r\sin\frac{\theta}{2} \tag{1}$$

The distance between the axis parallel to the axis of rotation passing through the center of gravity S of the wing:

$$d = R_d - \frac{L}{2} \tag{1,a}$$

Increasing the number of blades leads to a decrease in the central angle between the two blades. As a result, the leading blade blocks a certain part of the following blade. In this case, the parts of the blade that are not exposed to the wind cause an excess moment of inertia. In this case, it is advisable to reduce L in accordance with the number of blades. When the number of blades decreases, the value of L must increase to effectively use the wind flow. Therefore, we obtain the following relationship between L and Rd:

$$L = k_b R_d \tag{2}$$

where $k_b$ is the proportionality factor.

One of the main tasks in determining the moment of inertia of the turbine rotor relative to the axis of rotation is wind turbines [8]. The rotor of a wind turbine consists of two disks and n blades connected between them, and a rotating shaft. As is known from mechanics courses, the moment of inertia of two disks with a thickness of bd about an axis passing through their centers is determined by the sum of the moments of inertia of each disk as follows:

$$I_d = 2 \cdot \frac{1}{2} m_d R_d^2 = m_d R_d^2 = \pi \rho_d b_d R_d^4; \quad m_d = 2\pi \rho_d b_d R_d^2 \tag{3}$$

In cases where the size of the turbine shaft is important, its moment of inertia about an axis passing through its center must also be taken into account:

$$I_v = \frac{1}{2} m_v R_v^2 = \frac{1}{2} \pi \rho_v H R_v^2; \qquad m_v = \pi \rho_v b_v R_v^2 \tag{4}$$

The blades are prepared by cutting an arc AB from a cylindrical tube with an inner radius $r_1$ as shown in Figure 1.b. From Figure 1.b, the inner radius of the arc is determined as follows:

$$r_1 = r - b_p \tag{5}$$

where $b_p$ is the thickness of the sheet wall.

The moment of inertia of the plane of the beam relative to point $O_1$ (Fig. 1.b):

$$J_u = \frac{r^4 - r_1^4}{8} \left( \frac{\pi\theta}{180^0} + \sin\theta \right); \tag{6}$$

The moment of inertia of the wing relative to the coordinate axes at the center of gravity located at point C in the transverse plane of the wing is:

$$J_x = J_u - F v_0^2;$$
$$J_y = \frac{r^4 - r_1^4}{8} \left( \frac{\pi\theta}{180^0} - \sin\theta \right); \tag{7}$$

In this case, the volumetric moment of inertia about the axis parallel to the axis of rotation passing through the point S:

$$I_p = \frac{1}{2} (J_x + J_y) \cdot \rho H; \tag{8}$$

(2.3.6)-(2.3.8) moment of inertia relative to the center of gravity for one wing using formulas

$$I_p = \frac{1}{2} \left[ \frac{r^4 - r_1^4}{8} \left( \frac{\pi\theta}{180^0} - \sin\theta \right) - \theta r b_p \left( \frac{4}{3} \frac{r^3 - r_1^3}{r^2 - r_1^2} \cdot \frac{180^0}{\pi\theta} \sin\frac{\theta}{2} \right) \right] = \tag{9}$$
$$= \frac{1}{2} \left[ \frac{r^4 - r_1^4}{4} \frac{\pi\theta}{180^0} - \frac{240 r b_p}{\pi} \frac{r^3 - r_1^3}{r^2 - r_1^2} \sin\frac{\theta}{2} \right] \rho_p H$$

The moment of inertia of one blade relative to the rotation shaft of the rotor is determined according to the Huygens-Stern theorem:

$$I_{0p} = I_p + m_p \left( R_d - \frac{L}{2} \right)^2; \tag{10}$$

$$m_p = \rho_p \theta r b_p H; \tag{11}$$

Thin cross-sectional area:

$$S = \theta r b_p \tag{12}$$

The distance between points C and $O_1$ is:

$$l_0 = \frac{4}{3} \frac{r^3 - r_1^3}{r^2 - r_1^2} \cdot \frac{180}{\pi\theta} \sin\frac{\theta}{2}; \tag{13}$$

The full moment of inertia of the rotor relative to the rotating shaft is determined by the algebraic sum of the moments of inertia of the shaft, disc and blades:

$$I_{tot} = I_d + I_v + nI_{0d} \quad (14)$$

From the equation given above, the total moment of inertia about the rotating shaft means the algebraic sum of the moments of inertia of the shaft, disc and blades. In this way, wind turbines capture and capture even small-flow winds and increase the efficiency of rotation and power generation[9].

In recent years, the true nature of renewable energy in the form of wind resources has been explored through scientific research and practical experiments to solve energy problems. However, due to the unevenness of global winds, pressure differences occur along the Earth's surface, and solar radiation and heating of the Earth also play a particularly important role. For example, the amount of solar radiation absorbed by the Earth's surface is greater at the equator than at the poles. The change in incoming energy is set by convective cells in the lower layers of the atmosphere, in a simple flow model, air rises at the equator and sinks at the poles. As a result, the uneven heating of the atmosphere is greatly affected by the effect of the Earth's rotation. At the equator, the speed of the wind is 1670 kilometers per hour, and at the poles it decreases to zero). In addition, changes in the seasonal distribution of solar energy cause changes in the circulation. Since wind power is proportional to the cubic wind speed, it is very important to have detailed information about the characteristics of the wind specific to the object. Even small errors in wind speed estimation can have a large impact on energy yield, but they can lead to poor turbine and site selection. Average wind speed is not enough. Wind characteristics specific to wind turbines include: average wind speed: Interesting as a title, but it does not tell you how fast the wind speed is occurring. wind speed distribution: daily, seasonal, annual patterns turbulence short-term fluctuations long-term fluctuations wind direction distribution wind shear However, due to sensitivity, no calculation can replace the components of on-site wind measurements[10].

Spatial variations in the transfer of heat to the Earth's atmosphere cause changes in the atmospheric pressure field, which causes air to move from high pressure to low pressure. There is a pressure gradient force in the vertical direction, but this is usually canceled out by the downward force of gravity. Thus, winds blow mainly in a horizontal plane, and pressure gradients respond to the horizontal. At the same time, there are forces that tend to mix different temperatures and pressure air masses that are distributed over the Earth's surface. In addition to the pressure gradient and the forces of gravity, air inertia, the Earth's rotation, and friction with the Earth's surface (resulting in turbulence), atmospheric winds are affected[11]. The effect of each of these forces varies depending on the scale of motion of the atmospheric wind systems considered. Today's global wind circulation involves large-scale wind patterns that span the entire planet[12]. They affect the winds that prevail near the surface winds. It should be noted that this model is oversimplified, as it does not reflect the effects of land masses on the wind distribution.

## CONCLUSION

In recent years, one of the simplest models for wind dynamics has been able to take into account the four atmospheric forces. Seasonal climate forecasts are essential for efficient energy management, predicting the variability of wind energy resources over different time scales. Wind energy users have traditionally relied on weather forecasts with a time horizon of a few hours to a few days, because surface winds, and therefore wind energy production, are highly dependent on short-term fluctuations in wind speed. However, the wind industry is increasingly interested in long-term climate forecasts to guide investment and deployment of wind farms over the long term, over several decades. To overcome the lack of information with lead times of one month to ten years, the wind energy sector assumes that future conditions will be similar to those of the past[13]. This approach may not be able to predict events that have never occurred before. Fortunately, it is increasingly possible to use probabilistic seasonal forecasts to overcome this limitation by providing additional information for wind energy deployment. To classify the characteristics of wind energy at a given height above the ground in a given area, a wind power cascade is often created, which determines its energy significance and determines the appropriateness of the SHEQ operating modes and parameters, allowing for the provision of aerodynamic and energy characteristics of the wind.

## REFERENCES

1. Alsharif, M. H., Kim, J.,&Kim, J. H. (2018). Opportunities and challenges of solar and wind energy in South Korea:A review. Sustainability, 10(6), 1822.
2. Benbouhenni, H. (2021). A 24-sectors direct power control-feedforward neural network method of DFIGintegrated to dual-rotor wind turbine. Int J Appl Power Eng, 10(4), 291.

3. Bennouk, A., Nejmi, A.,&Ramzi, M. (2019). Performance and FMECA of a wind turbine based on SCADA andlidar data. International Journal of Applied Power Engineering (IJAPE), 8(2), 101-109.
4. Butbul, J., MacPhee, D.,&Beyene, A. (2015). The impact of inertial forces on morphing wind turbine blade invertical axis configuration. Energy onversion and management, 91, 54-62.
5. PULATOVA D.M. WIND ENERGY. Recommended as a textbook by the Council of Tashkent State Technical University. Pulatova D.M. Textbook on wind energy. Tashkent TDTU, 2023. 260 p.
6. Gafurovich, D. U., & Sotivoldievich, Z. M. (2021). The use of non-conventional power sources is a requirement of the period. Academicia Globe, 2(07), 121-126.
7. Gafurovich, D. U. (2021). Analysis of the Solution and Results of the Differential Equation of Wind Aggregate Motion. Design Engineering, 5618-5627.
8. Dabiri, J. O. (2011). Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind turbine arrays. Journal of renewable and sustainable energy, 3(4).
9. E. N. Sosnina, O. V. Masleeva, A. V. Shalukho, I. A. Lipuzhin. (2015). "Ecological impact of wind-diesel power plants on ecosystems and public health," Human Ecology 2015.12, p. 3-9.
10. Gomaa, M. R., Hammad, W., Al-Dhaifallah, M., & Rezk, H. (2020). Performance enhancement of grid-tied PVsystem through proposed design cooling techniques: An experimental study and comparative analysis.Solar Energy, 211, 1110-1127.
11. Anarboyev, I., Olimov, L., Qurbonov, N., Karimov, B., & Fozilova, M. (2025, November). Basis of development of electricity supply system based on alternative and renewable energy sources. In *American Institute of Physics Conference Series* (Vol. 3331, No. 1, p. 060016).
12. Olimov, L. O., & Anarboyev, I. I. (2022). Some electrophysical properties of polycrystalline silicon obtained in a solar oven. *Silicon*, *14*(8), 3817-3822.
13. Anarboyev, I., & Olimov, L. (2024, November). Mechanism of thermoelectric material efficiency increase. In *AIP Conference Proceedings* (Vol. 3244, No. 1, p. 060015). AIP Publishing LLC.