**Design of Vertical Axis Wind Turbine with Movable Vanes**

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**Abstract:** This paper designs the rotor wind turbine, which uses more effectively the wind energy and depends only on the acting area of the vanes. The vane wind turbine is designed to reduce negative torque in the framework at the opposite direction of wind, by uses movable vane's horizontal locations to the wind turbine, which uses kinetic energy of the wind. It can be used worldwide due to its high efficiency, simple construction, and simple technology. Fabricate a model of design and test it in the wind tunnel.

**Key words:** wind turbine, vane, design, energy.

**INTRODUCTION**

The power from the wind will never cease while the sun is still rising, and the earth is revolving. Wind exists everywhere on the earth, and in some places with considerable energy density. This thesis aims to study this renewable energy, which will remain a useful power source until the end of this world. Wind has been used in the past to generate mechanical power. Nowadays, wind power has become a promising source to generate electricity because wind power is clean, quiet and efficient. It reduces acid rain, smog and pollutants to the atmosphere.

The theoretical maximum power efficiency of any design of wind turbine operate in open atmosphere is \( C_e = 0.59 \) - the Betz Limit (Manwell, J.F., 2002; Mathew, S., 2006). The real-world limit is well below the Betz Limit with values of 0.35 - 0.45 common even in the best design wind turbines. Except this one there are other energy losses in a complete wind turbine system (the generator, bearings, power transmission, etc.) and only 10% - 30% of the power of the wind is ever actually converted into usable electricity.

The wind turbine generators use mainly aerodynamic lift force and drag forces acting on the surfaces of blades or vanes. Today researches are stating that horizontal axis wind turbines (lift force design) theoretically have higher power efficiencies than vertical axis wind turbines (drag force design). However, other research state that at conditions of turbulent with rapid changes in wind direction practically more electricity will be generated by vertical turbines, despite its lower efficiency. However, there is the following vital information: the power output of a wind turbine generator is proportional to the acting area of wind turbines and the power output of a wind generator is proportional to the cube of the wind speed. These peculiarities should be considered main factors of the output power to design new type of wind turbines.

For calculation of the power of wind turbines are used many complicated equations. The fluid dynamics theory gives one formula with minor variations for calculation of the power for the different wind turbine designs. The fundamental equation that governs the power output of a wind turbine is (Munson, B.R., 2002):

\[
P = 0.5 \rho A V^2 \lambda , \text{ Watt} \tag{1}
\]

where: \( P \) - power produced by the wind turbine, \( W \); \( \rho \) - air density, \( V \)- wind speed approaching the wind turbine, \( \lambda \) = wind turbine efficiency for common case; and \( A \) - projected area of the turbine perpendicular to the approaching wind.

For a propeller wind turbine \( A \) is swept area of rotating blades, but actual area of blades 4-5 times less of the swept area. The wind between propellers passes freely and does not affect on the blades. The real output the power of the propeller wind turbine is 4-5 times less than theoretical power of the turbine. The maximum efficiency for a flat plate rotor (excluding the potential effect of wind pressure acting on more than one rotor blade) therefore only reaches 18% for plate aspect ratios of less than 5:1. This rather low efficiency is usually the reason to dismiss the vertical axis resistance converter as an inefficient concept.

**Turbine Designe:**

The proposed vane type vertical wind turbine can be designed by two types of construction (Fig. 2). The first is four frames with angles of 90° to each other and horizontally constructed bars with vanes that have ability to twist on 90°. The second is three frames with angles of 120° between each other. Increase the number of frames will not increase efficiency of the wind turbine because increases the vane inter-frame wind shadow area and increase the weight of turbine.
Frame’s elements should be designed of aerodynamic form to reduce the drag force of the wind action on not working elements of a turbine. The frames connected with the shaft and the shaft with the electrical generator. The vanes fastened on the bars that located on sides of the frame. The frame vertical components can be designed as Darrieus type to increase the output of the wind turbine. Under action of a wind force, vanes on left side of the frame are closed and bear the wind force in full-scale. The vanes on the right side of frame are open and a wind force is passing through the open frame. Left side vanes should be cinematically connected with right side vanes, so vanes can be double acting. This design enables the wind force to close left side vanes and simultaneously opens the right side vanes. The torque created by the wind force rotates frames with the output shaft, which transfers the torque via gearing to the electrical generator. Vertical frames should be connected by stringers to increase the construction stiffness. Other components of the wind turbine like the tower (pole) can be made from the metallic frame and designed according to the area of application of the wind station. The sketch of the vane type wind turbine is presented in Fig. 1.

![Fig. 1: (a) Sketch of the vane type wind turbine, (b) general view of wind station.](image)

Simple analysis of the sketch of the vane type wind turbine shows many positive technical data and benefits. This vane type wind turbine possesses all advantages of vertical and horizontal acting wind turbines, and can be concurrent solution for known constructions (R. Usubamatov, 2010).

For simplicity two models of the flat-vane wind turbines are analysed. A plan view of the vane-type wind turbine is presented in Fig. 2. The first model of the vane-type turbines is four sections of vanes assembled on frames, which are perpendicular to each other and joined with the main output shaft. The second one is three sections of vanes, which are 120° to each other and joined with the main output shaft.

Power output depends on a wind force and speed and the acting surface area $A$ of vanes that are located at one side of the output shaft. The relationship between physical parameters acting on the vane can be considered by known approaches. Acting forces, location of the vanes, wind shadow, and the wind pressure on the vanes are proportional to some power of the wind speed. The first thing is to calculate the force acting on the vanes due to the momentum change of the air impinging upon them. The ultimate simplification is necessary for an analytical approach of considering the force acting on stationary vanes.

This simplification leads to different results depending on the assumptions made. The important assumptions made are the following:

a) The wind turbine vanes are smooth.

b) The air hitting the vanes has no viscosity. It is further assumed that air, having struck on the vanes, moves off along the surface without causing a tangential frictional force.

c) The drag forces acting on the left and right frame components are equal.

The flat vane, with its plane normal to the air stream, represents a common situation for wind force loads on the vane. For a flat vane with its plane normal to the wind flow, the only aerodynamic force will be one parallel to the wind flow, i.e. a wind force.
Fig. 2: Vane-type wind turbine (b) of four Frame (c) three frames.

Practice shows the value of the drag factor $C_D$ is variable and depends on many factors like vane configuration, wind speed, the wind angle of attack of vanes, etc. There is also a tangential component or ‘skin friction’ force (Burton, T., 2000).

3. Theoretical Analysis:

The force component $F$ acting on stationary vertical vanes of the left side frame is expressed by the following formula (Manwell, J.F., 2002; Mathew, S., 2006; Ackermann, T., 2005).

$$F = (1/2) C_D \rho A V^2 \sin \alpha$$  \hspace{1cm} (2)

where $C_D$ is drag coefficient, and to determine the starting torque $T$ on wind turbine vanes, it is necessary to define the whole vane area, and distance from the centre of the output shaft to the centre of wind pressure, then the formula has the following expression

$$T = (1/2) A C_D \rho V^2 R \sin \alpha$$  \hspace{1cm} (3)

where $R$ is the distance from the shaft centre line to the centre of pressure of the vane surface, The output power is calculated by the following equation

$$P = T \omega = (1/2) \rho A C_D V^2 \sin \alpha \text{ (Watt)}$$  \hspace{1cm} (4)

where $\omega$ is the angular velocity of the rotating turbine, $\rho$ is air density, $R$ is impeller turbine radius.

The torque created by the first and second frames with group of vanes calculated by the following equations:

1. The torque created by the first frame and second frame at the angle of rotation without wind shadow

$$T_1 = C_{D1} \rho [hc(b + c / 2)] \sin \alpha$$  \hspace{1cm} (5)

where $C_{D1}$ is drag factor, $\rho$ is wind pressure

2. The torque created by the first vanes at the angle of rotation from $\alpha_1$ to $\alpha_1 + \beta / 2$ when of the second vanes begins create wind shadow

$$T_2 = C_{D1} \rho [hc(c - k\Delta \alpha)] [(b + k\Delta \alpha) + (c - k\Delta \alpha) / 2] \sin \alpha + C_{D2} \rho [hk\Delta \alpha] (b + k\Delta \alpha / 2) \sin \alpha \left[\frac{\beta / 2}{\alpha_1}\right]$$  \hspace{1cm} (6)

where $C_{D2}$ is drag factor for vanes at zone of wind shadow

3. The torque created by the first vanes at the angle of rotation from $\alpha_1 + \beta / 2$ to $\alpha_1 + \beta$ when of the second vanes ending wind shadow
where $C_f$ is skin friction coefficient

4. **Experimental Setup in the Wind Tunnel:**

The object of the wind turbine test is verifying the ability of performance design, to get real data, compare with theoretical results and analysis efficiency of product testing. The wind turbine testing used the two model fabricated with dimensions presented in Fig. 2, [for 4 frame $c = 0.048$ m, $h = 0.06$ m and $b = 0.052$ m], and [for 3 frame $c = 0.044$ m, $h = 0.07$ m and $b = 0.066$ m]. The analyses considered power output test, and number of revolutions per second of the rotating shaft. The typical wind tunnel used stationary turbofan engines that sucked air through a duct equipped with a viewing port and instrumentation where models on the ball bearings shaft are mounted in order to study. The testing area of the wind tunnel length is the cube with dimensions 300x300x300 mm$^3$. The model of the vane-type wind turbine is located in the middle of the wind tunnel testing area and attached on the bicycle dynamo Model Golden Cat 8P-5, 6V and 5W. The range of the wind speed used is between 5 m/s and 18 m/s. The digital anemometer model HV935 TF Instrument INC was used to measure the wind speed. The tachometer model Compact Instrument Advent Tachopole was used to measure the rotation speed of the wind turbine shaft with the piece of white paper attached, which reflects light. In the analysis data experiments showed the four vanes is a higher speed compared to the three vanes. The situation occurs in both testing cases when the dynamo is attached on the wind turbine and without the dynamo. Obtained results proved the theoretical approach that four-frame wind turbine has a higher efficiency than the three-frame turbine (Fig. 3). The speed of revolution per second of two types of turbines experiences a decrease on 0.6-0.7 rev/s when the dynamo is connected on the turbine shaft. The dynamo was used when the wind speed exceeded 12 m/s, because the acting area of the turbine vanes did not support stable rotation for the turbine with the dynamo, which did not generate stable power. The high speed of wind is not a statistically average condition for the wind turbine and this is the reason that power was not measured by the multimeter.

**RESULTS AND DISCUSSION**

Fig. 3 enables the calculation of the coefficient of power and coefficient of torque, the drag factor and the efficiency of the vane-type wind turbines.  

![](image)

**Fig. 3:** Number of revolutions of the wind turbine shaft versus the wind speed.

Test of flat vane in wind tunnel are presented results of the drag factor $C_D$ of the flat vane type with wind speed, Fig. 4. This diagram shows that drag factor are decreases with increase of the wind speed.

$$P_{ac} = T \omega = C_{D1} * 0.5 * \rho * r * A * V^2 \ * (b + c / 2) * 2 \pi n / 60$$

(9)
Figures (5, 6) show results of power coefficient, and torque coefficient with tip speed ratio for 3 frame wind turbine, we can see that maximum power coefficient is (0.18) at tip speed ratio (0.12), and maximum torque coefficient (1.46) at the same tip speed ratio.

Fig. 4: The drag coefficient of the vane type with wind turbine versus the wind speed. Actual power is calculated on the basis of Figs 3, 4, and uses Eqs (4).

Fig. 5: Power coefficient various tip speed ratio for 3 frame wind turbine.

Fig. 6: Torque coefficient various tip speed ratio for 3 frame wind turbine.

Figures (7, 8) show results of power coefficient, and torque coefficient with tip speed ratio for 4 frame wind turbine, we can see that maximum power coefficient is (0.21) at tip speed ratio (0.113) and maximum torque coefficient (1.93) at the tip speed ratio (0.108).
Fig. 7: power coefficient various tip speed ratio for 4 frame wind turbine.

Fig. 8: Torque coefficient various tip speed ratio for 4 frame wind turbine.

Figures 9 show results of power coefficient with wind velocity for 3 & 4 frame wind turbine, we can see for 3 frame that maximum power coefficient is (0.18) at wind speed (9 m/s). And the maximum power coefficient for 4 frame is (0.21) at the same velocity of wind.

Fig. 9: power coefficient various wind velocity for 3&4 frame wind turbine

For 4 frame that maximum power coefficient is (0.21) at wind speed (9 m/s), and maximum torque coefficient (1.93) at the same wind speed. And for 3 frame that maximum power coefficient is (0.18) at wind speed (15 m/s), and maximum torque coefficient (1.46) at the same wind speed.

The tested model of the vane-type turbines was designed with flat vanes.
Based on the results of experiments, the results satisfy the theoretical approach (Eqs. 5 - 8). The four-frame wind turbines have a higher efficiency compared to the three-frame turbine. This is because the four-frame wind turbines have more area to capture wind energy. Both test models had exposure in the same condition of wind speed by wind tunnel. Results show that the coefficient of performance and hence the efficiency of the vane-type wind turbine in the wind tunnel are decreasing with an increase in wind speed over 9 m/s. The vane-type turbines show the higher efficiency at the wind speed 9 m/s in the wind tunnel. This type of wind turbine has good technical properties and can be used for generating a power more efficiently for the low speed of the wind.

Efficiency of the vane-type turbines can be significantly increased by change of the shape of the frames, or use nozzle to construct wind to the impeller. The tests of the vane-type turbine in the wind tunnel gave new data regarding coefficient of performance and the drag factor and can be used for theoretical calculations. Proposed vane turbines can be designed from cheap material that is highly economical. The work of the vane turbine does not have restrictions. At strong wind conditions, it is possible to design the vane turbine with decreased acting numbers of vanes. The possible flipping of the vanes under action of the wind force can be avoided by simple constructive solutions.

**Conclusions:**

New vane-type wind turbines possess many positive properties and can solve the problem of increased wind energy use. The vane-type wind turbine can be high efficiency and enables an increase in the surfaces acting area and drag factor that can increase the output power. New vane-type wind turbines possess all advantages of vertical type of turbines and can be concurrent for known wind turbine designs especially for the low speed of the wind. The new turbine presents simple construction and for manufacturing can use simple technology and be produced from cheap materials.

It is possible to design new turbines that can operate at any conditions of the wind force change. For future research, mathematical modelling of the wind turbine work should be conducted on a basis of computational fluid dynamics and proofed by practical investigations in the wind tunnel. Also, it is necessary to conduct investigations on the optimal design of new turbines (power as function of the vanes geometry, weight of turbine, aerodynamic shape, wind speed, etc.). Tests of the vane-type wind turbine in the wind tunnel and correction of the mathematical model can give reliable data in order to design the vane-type wind turbine.

**REFERENCES**


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