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Increase power coefficient for impeller type vertical axis wind turbine

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ABSTRACT

In this paper design special frame vertical axis wind turbine and test in the wind tunnel. This design is presented as vertical locations of the three movable vanes that create scoop shape when closed. Scoop shape of frame increases the drag factor and increase the torque, in the other side of impeller movable vanes are opened under action of wind and the air pass freely to reduce the negative torque. Fabricate two models of impeller with movable vanes and with fixed vanes model and test it in wind tunnel. The maximum power coefficient for three frames movable vanes is 0.32 and higher than the same dimensions of model with fixed vanes about 11%.

Introduction

Wind power is the conversion of wind kinetic energy into a useful form, such as mechanical or electrical energy that can be harnessed for practical use by using wind turbines [1, 2]. Designing a wind turbine system that can generate power with high efficiency requires a thorough understanding of the principles of aerodynamics and structural dynamics of the rotor system. Various wind turbine mechanisms are proposed and built for capturing and converting the kinetic energy of winds.

In area of the wind energy there are two main type of wind turbine , the horizontal axial and the vertical axial (Darrieus and Savonius turbines), and there are many variants of each design as well, as a number of other similar devices under development. The wind screw turbine is most commonly used in large-scale applications constituting nearly all of the turbines in the global market, while the vertical axis turbines are more commonly implemented in medium and small-scale installations. The technical characteristics of wind turbines are to be found elsewhere [3-5].

However, simple analysis of these wind turbine designs show that these designs are not perfect and the wind force does not use in full-scale wind energy due to geometrical and technical problems.

Researchers state that wind turbines of lift force design theoretically have higher power efficiencies than turbines of drag force design. Other research states that at conditions of turbulent with rapid changes in wind direction practically more power will be generated by turbines of drag force design, despite its lower efficiency [2]. However, there is the following vital information: the power output of a wind 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 as main factors of the output power to design new type of wind turbines.

Hence, capturing and converting the kinetic energy of winds depends on the active area of the blades, vanes or other elements of the wind turbines and on the wind speed, which increases with altitude of the turbine location regarding the earth level.

The technical characteristics of known designs of wind turbines show that there is necessity to design new type of the wind turbines without mentioned above lacks and with ability of use in wide area of application. First, new design should use the wind kinetic energy by maximum of the Betz limit [1]. The theoretical maximum power efficiency of wind turbine operates in opened atmosphere is Cp = 0.59 - the Betz Limit [2]. No more than 59.3% of the available power in the wind can be extracted. No turbine to date has exceeded this limit [4]. In the world the real limit is well below the Betz Limit with values of 0.35-0.45 in the best designed wind turbines. 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 [6]. The active area of blades, vanes or other elements of the new wind turbines should give less geometrical sizes one. Presented problem can be solved by new design of the vertical axis vane type wind turbine that has simple construction, technologically simple in production, uses the drag force by active area of the working elements.

The vanes of impeller type turbine are design with high drag factor to increase the efficiency and solve problems of reliable work turbine.

A determination of the *C* drag factor is the most difficult part of this procedure. It is highly variable, and many parameters can affect on the final *Cd*. Shape, altitude, inclination to the wind direction, surface roughness, spin, and nose bluntness are just a few factors that can influence *Cd*, which can range from 0.18 up to 1.8. Tests with a cylindrical body (Flettner rotor) showed that the drag coefficient can be improved by adding disks at the top and bottom of the body; this increased the drag coefficient by 60-90%. The disks effectively change the finite cylinder into an infinite one (minus viscous losses near the disks) by ensuring 2D flow patterns. In the context of the proposed wind energy converter, it can be

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expected that by closing the rotor off at the top and the bottom by a disk which protrudes over the outer rim of the rotor, the drag coefficient can be increased from 1.2 to 2.0 [7].

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 [8].

From the three methods used in calculating *Cd* (experimental; theoretical –simplified and numerical CFD), the most realistic and straightforward method is the wind tunnel. This involves solving Eq. for *Cd*, and then placing a model in a wind tunnel, with already known ρ, A, and V. The test results are used to measure the force acting on the device that holds the model and calculates $Cd = F / A$.

These new invention based on the impeller type turbine, which designed with special frames that have cavities shape created by vanes. Cavities of the frames enables to increase the drag factor hence increase the efficiency of turbine.

The work design

The sketch of the proposed design in Fig.1 is presents common projection of the wind turbine. Figure is presents design of the frame with which create the cavity of acting part of turbine.

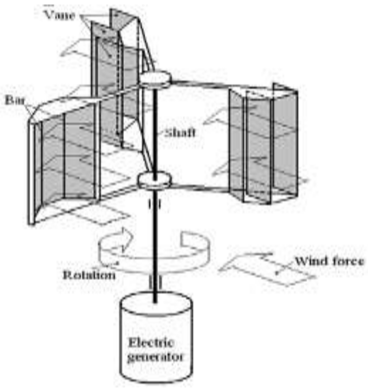

Figure 1. Sketch of the vane type wind turbine

The vertical vanes fastened on the vertical bars that located in hinges of the frame. Under action of the wind force the vanes with bars turned until stopper that locates on the neighboring bars. All vanes close the frame's hole. To increase the turbine efficiency the vanes construction designed with cavities that increase drag force dramatically, under action of the 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 turned by the wind force and frame is open. The wind force is passing through the open frame. This design enables the wind force to close left side vanes and simultaneously opens the right side vanes.

Analytical approach

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 generator is [9]:

$$P=0.5*\rho* A* V^3* \lambda \text{Watt} \quad (1)$$

Where: P - power produced by the wind turbine, W; ρ - air density, V- wind speed approaching the wind turbine, λ = wind turbine efficiency for common case; and A - projected area of the turbine perpendicular to the approaching wind. λ is wind turbine efficiency.

It is well-known that modern wind turbine is designed with very complex optimality criteria involving more than aerodynamic efficiency. The main objective is to maximize the drag factor *C*, which is function of the turbine element geometry, Reynolds number, Froude number, and Mach number.

For simplicity it is analyzed model of the cavity-vanes wind turbine. The model of the vane type turbines is three sections of vanes assembled on frames. Plan view of the impeller wind turbine presented in Fig. 2. The model has three sections of scoop-vanes, which are 120^0 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 located at one side of the output shaft. Relationship between acting physical parameters on the vane can be considered by known approaches. Acting forces, location of the vanes, wind shadow, and the wind pressure on the vanes is 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. It is necessary for analytical approach the ultimate simplification of considering the force acting on stationary vanes [6, 10].

Force component F acting on stationary vertical vanes of left side frame is expressed by the following formula [1-3]

$$F = (1/2)C_d \rho A V^2 \cos\alpha \quad (2)$$

where all parameters specified in Figure 2 below.

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

$$T = (1/2)AC_d \rho V^2 R \sin\alpha \quad (3)$$

Where R is distance from the shaft center line to the center of pressure of the vane surface,

R= b+(c/2)

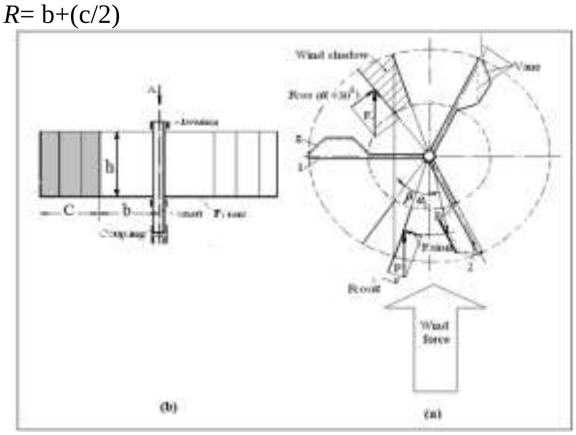

Fig. 2.Vane type wind turbine (a) three frame (b) front view frames

The output power is calculated by the following equation

$$P = T\omega = (1/2)\, AC_d \rho V^2 R\cos\alpha * V/R$$
$$= (1/2)\, AC_d \rho V^3 \cos\alpha \text{ (Watt)} \quad (4)$$

Where ω is the angular velocity of turbine rotating, other parameters specified above.

Next step is to develop the mathematical model of the resultant force acting on moving vanes. This entails determining

a) The velocity of oncoming air relative to the front surface of the first frame vanes and

b) The affect of the wind on the surface of the second frame vanes.

In rotation of the frames with vanes, pressure builds up along the surface of an object. A surface more perpendicular to the stream line of wind tends to have a higher pressure. The resultant force acts in the center of pressure that is found by calculating the pressure distribution across of the variable vanes location, then integrating it. The forces acting on the sides of the frames can be neglected due to face sided small areas.

The impeller type wind turbine of three frames works with two frames that located at left side from its vertical shaft (Fig.2). The magnitude of the torque is variable due to rotation of the frames with vanes. The vanes of two frames work at different conditions. The first frame vanes work with wind shadow at some angles of rotation. The second frame vanes work without wind shadow and acts after rotation of the first frame vanes on 30^0. The total torque created by two frames vanes of three frames wind turbine is calculated by different angular coordinates of vanes rotations and wind shadow. The equation of the torque average created by impeller type turbine has the following expression [13, 15].

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 vanes at the angle of rotation from 90^0 to α_1 without wind shadow

$$T_1 = C_d\, p[hc(b + c/2)]\sin\alpha \,\Big|_{90}^{\alpha_1} \qquad (5)$$

where C_d is drag factor, p is wind pressure

2. The torque created by the first vanes at the angle of rotation from α_1 to $\alpha_1 + \beta/2$ when of the second vanes begins create wind shadow

$$T_2 = C_{d1} ph(c - k\Delta\alpha)[(b + k\Delta\alpha) + (c - k\Delta\alpha)/2]\sin\alpha + C_{d2}\, p[hk\Delta\alpha)(b + k\Delta\alpha/2]\sin\alpha \,\Big|_{\alpha_1}^{\beta/2} \qquad (6)$$

where C_{d2} is drug 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

$$T_3 = C_{d2} ph(c - \Delta d)[(b + \Delta d) + (c - \Delta d)/2]\sin\alpha + C_{d1}\, p[h\Delta d)(b + \Delta d/2]\sin\alpha \,\Big|_{\beta/2}^{\beta} \qquad (7)$$

4. The torque created by the first vanes at the angle of rotation from $\alpha_1+\beta$ to 180^0 without wind shadow

$$T_4 = C_{d1}\, p[hc(b + c/2)]\sin\alpha \,\Big|_{\alpha_1+\beta}^{180^0} \qquad (8)$$

5. The torque created by the second frame vanes at the angle $(\alpha+30)$ of rotation from 0^0 to 120^0 without wind shadow

$$T_5 = C_{d1}\, p[hc(b + c/2)]\sin(\alpha + 30) \,\Big|_{0^0}^{120^0} \qquad (9)$$

6. Negative torque

$$F = [\textstyle\sum 0.5\, Cd\, \rho\, ArodV^2 + 6 * (Cf\, 0.5\rho Avane\, V^2)]\sin\alpha \,\Big|_{180}^{0} \qquad (10)$$

$T = F(b+c/2)$

Where Cf is skin friction coefficient.

Experimental of the vane-type turbines in the wind tunnel

The object of the wind turbine test is verifying the ability of performance design, to get real data, and analysis efficiency of product testing. The wind turbine testing used the model fabricated by hard plastic with dimensions presented in (Fig. 2), [c = 0.03 m, h = 0.116 m and b = 0.07 m], the model has three frames movable vane and three fame fixed vane.

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 connected with generator Fig.3. The range of the wind speed used is between 5 m/s and 17 m/s. The wind speed measure by recorded pressure drop from a pitot tube (Δp) and use Bernoulli equation to get wind velocity.

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.

Figure 3 three frames movable vanes wind turbine in wind tunnel

Results and discussion

The starting wind speed for three frame fixed vanes model test in wind tunnel is 5.93 m/s. The results in figure 4 show that the three frames movable vanes wind turbine has high angular revolution (rpm) than three frames fixed vanes.

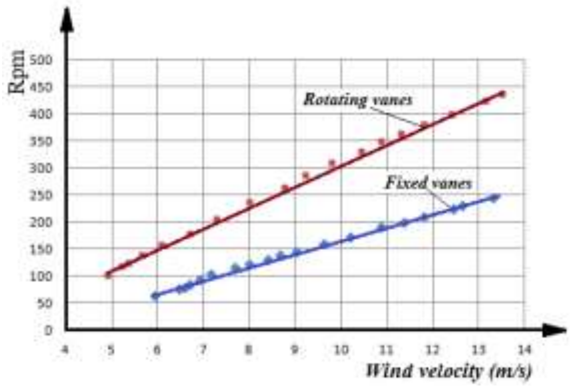

Figure 5 rpm of three frames impeller fixed and movable vanes versus wind speed

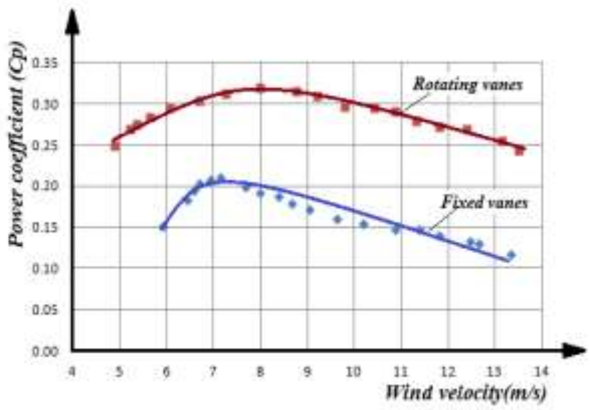

Figure 6 power coefficients for three frames fixed &movable vanes versus wind speed

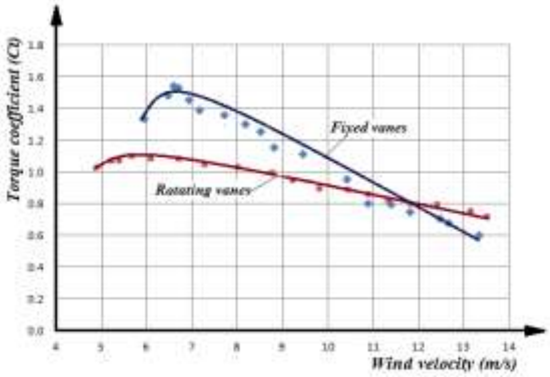

Figure 7 Torque coefficients for three frames (fixed &movable vanes) versus wind speed

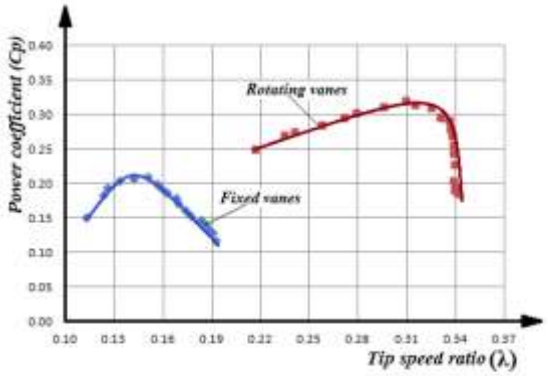

Figure 8 power coefficients for three frames (fixed &movable vanes) versus tip speed ratio

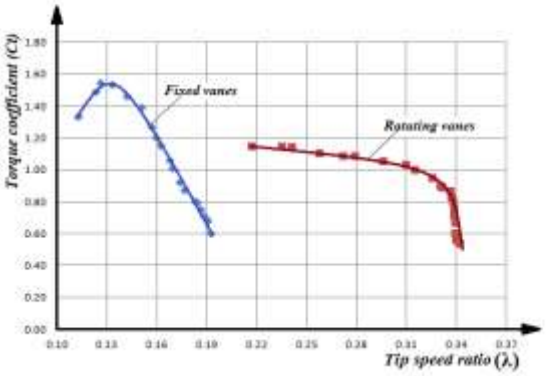

Figure 9 Torque coefficients for three frames (fixed &movable vanes) versus tip speed ratio

Figures 6, 7, 8 and 9, show that the three-frame turbine model has a higher power coefficient and torque coefficient than the three frames fixed vanes turbine model.

Obtained results by tests show that the maximum power coefficient for three frames fixed vane is (0.21) at wind velocity 7 m/s.

Conclusions

Results shows that new type wind turbines posses better technical properties than other type turbines and can be used for generating a power. The impeller scoop-frame type movable vanes wind turbine has high efficiency; the power coefficient is about 0.32 compares with scoop vane wind turbine fixed vanes model power coefficient about 0.21. The wind turbine has high drag factor enables to capture wind energy. And the impeller scoop-frame type with movable vanes wind turbine has more high. This is caused the wind turbine has very low negative torque. This type wind turbine has good technical properties and can be used for generating a power more efficiently for the low speed of the wind.

New impeller wind turbine with movable vanes possesses all advantages of vertical and horizontal types of turbines and can be concurrent for known wind turbine designs. The new turbine presents simple construction and for manufacturing can use simple technology and produce from cheap materials.

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