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OPTIMIZATION OF DESIGN OF VANE TYPE WIND TURBINE

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ABSTRACT

Today wind energy produces less than 1.0% of total energy used world-wide mainly by propeller type wind turbines. Practically a standard three-blade propellers efficiency of use of the wind energy is around 20% due to design and shape, one that uses the wind lift force and rotate turbine. Also these turbines are quite expensive due to complex aerodynamically shape of propellers that made from composite materials. The new world boom for wind turbines obliged inventors to create new wind turbine design that have high efficiency and better than known designs. The vane wind turbine designed increases the output of a wind turbine by using kinetic energy of the wind. It can be used world-wide due to its high efficiency, simple construction and simple technology and can be made from cheap materials. Vanes located on vertical bars that installed in hinges of the frames. Such design enable to rotate bares with frames under action of wind force simultaneously at one direction and independently at other direction. New design of the wind turbine has quite small sizes if compare with propeller type, one with same output power.

Keywords: wind turbine, vane, propeller.

1. INTRODUCTION

Wind energy is one of the cheapest and cleanest of the renewable energy technologies than all other known ones. The potential energy created by wind power is plentiful, and reduces greenhouse gas emissions when it displaces fossil-fuel-derived electricity. Wind turbine technology has steadily improved. Typical capacity for a single unit is now 250-500 KW. The competitiveness and environmental advantages of wind energy are obvious [1].

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 three basic types of wind turbine which are commonly used today. There are the horizontal axial propeller 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 (Figure-1). The propeller type 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. However, simple analysis of these wind turbine designs shows that these designs are not perfect and the wind force does not use in full scale due to many engineering reasons.

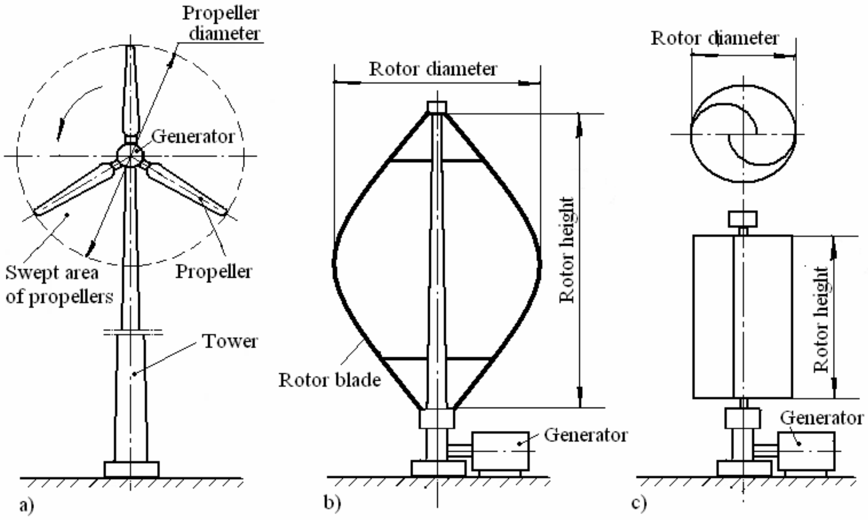

Figure-1. Wind turbine configurations: (a) propeller type; (b) Darrieus; (c) Savonius.

2. BREIF DESCRIPTIONS OF THE WIND TURBINE CONFIGURATIONS

2.1 Propeller type wind turbines

Modern propeller type wind turbines use the wind lift force as an aircraft wing due to the shape and geometry of the blades, and are neither built with many rotor blades nor with very wide blades. The number of the blades of a turbine has great impact on its performance. Large number of rotor blades decreases the stability of the turbine. Experiments show that two wind turbines with the same diameters, the one has 3 blades generated even more power than the one with 12 blades due to fact that the aerodynamic loss from the many-bladed turbines is huge. The long size of the blade creates technical problem for lifting of the propeller on the top of the pole and assembling process. Spin of the propeller around vertical axis of the pole results in a gyroscopic effect on the body, and increases the gyroscopic fatigue [2]. Turbine propeller blades are designed from composite materials with very complex optimality criteria involving more than aerodynamic efficiency. Computational cost of the propeller blade is too high to estimate many design variables.

Propeller type turbines built on the tower and cannot use guy wires to support one, because the propeller spins both above and below the top of the tower. These turbines require a strong tower that grows dramatically with the size of the propeller. Other disadvantage of the propeller type wind turbine is most of the wind passing through the space between blades and misses them completely and so this wind kinetic energy does not use by blades. Actual efficiency of the propeller type turbines is 20% [3].

2.2. The darrieus wind turbine

This type of vertical axis wind turbine consists of a number of airfoils usually vertically mounted on a rotating shaft or framework. Vertical turbine is equally effective no matter which direction the wind is blowing. Darrieus wind turbines use only the wind lift force as result of acting the wind speed on the airfoil, and its efficiency is rarely realized due to the physical stresses and limitations imposed by a practical design and wind speed variation. Darrieus wind turbines can rotate with high speed with low torque and can be useful for small pumps and small electrical generators. Efficiency of the Darrieus type turbines is less than 10% [4]. There are also major difficulties in protecting the Darrieus turbine from extreme wind conditions and in making it self-starting.

The Darrieus turbine blade generates maximum torque at two points on its cycle. This leads to a sinusoidal power cycle that creates resonant modes that can cause blades to break. Some design of the blades canted into a helix that spreads the torque evenly over the entire revolution, thus preventing destructive pulsations. Another problem of the mass of the rotating mechanism is at the periphery that leads to very high centrifugal stresses on the blades, which must be stronger and heavier than otherwise to withstand them. This design uses much more expensive material in blades while most of the blade is too near of ground to give any real power [5].

Modifications of the Darrieus turbine are the Giromill and Cycloturbines [6]. The main advantage to these designs are that the torque generated remains almost constant over a fairly wide angle, have the advantage of being able to self start, by pitching the "downwind moving" blade flat to the wind to generate drag and start the turbine spinning at a low speed. On the downside, the blade pitching mechanism is complex and generally heavy, and the wind-direction sensor needs to be added in order to pitch the blades properly.

2.3. Savonius wind turbines

These turbines are one of the simplest self-starting vertical-axis turbines. Aerodynamically, they are drag-type devices, consisting of two or three scoops. Turbines use the cavity shape of the blades that allow the pressure wind rotates turbine with low speed and creates high bending moment on the shaft of the turbine due to big area of the curved elements. Savonius wind turbines is useful in medium and small-scale installations. Efficiency of the Savonius type turbines is around 15% [7]. The two-scoop rotor looks like an "S" shape in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. Some designs have long helical scoops, to give smooth torque. Much of the swept area of a Savonius rotor is near the ground, making the overall energy extraction less effective due to lower wind speed at lower heights. The most ubiquitous application of the Savonius wind turbine is the ventilator which is commonly seen on the roofs of vans and buses and is used as a cooling device.

3. BRIEF DESCRIPTION OF THE DESIGN AND WORK OF THE VANE TYPE WIND TURBINE

Proposed new the vane type vertical wind turbine can be designed by two types of construction (Figure-2) [8]. The first is four frames with angles of 90^0 between one and horizontally constructed bars with vanes that have ability to twist on 90^o. The second is three frames with angles of 120^0 between one. Frames elements should be designed of aerodynamically form to reduce drug force on the wind action for 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. Vane bars can be designed vertically, but in such case frames will have vanes flipping effect that can decrease reliability of a turbine and create noise. The frame vertical components can be designed as Darrieus type to increase the output of the wind turbine. Also to increase the turbine efficiency the vanes construction can be designed with cavities that increase drug 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 open and 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. 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 bars to increase the construction stiffness (did not showed on the sketch). Other components of the wind turbine like the tower (pole) can be made from metallic frame and so forth and designed according to the area of application of the wind station.

Simple analysis of the sketch of the vane type wind turbine shows only positive technical data one and benefits only. Proposed the vane type wind turbine posses all advantages of vertical acting wind turbines, and can be concurrent solution to known constructions due to advantages that shown above.

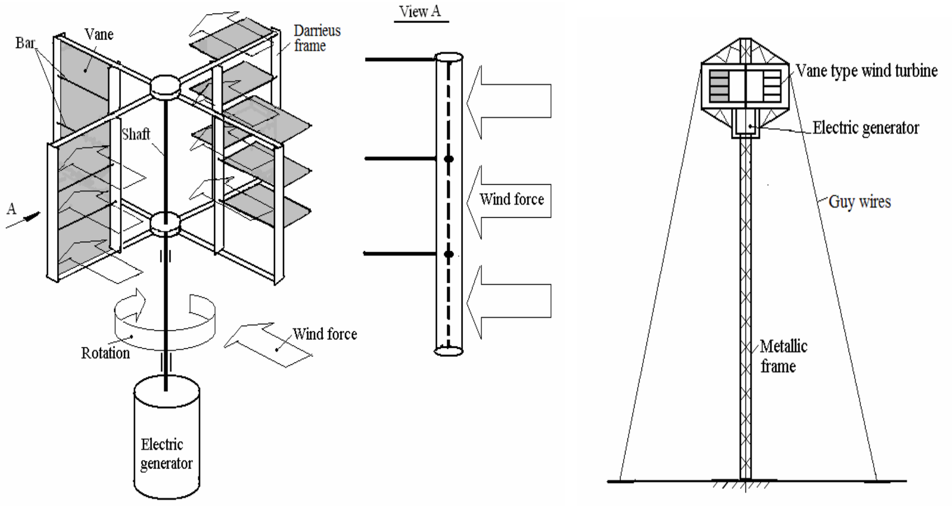

Figure-2. (a) Sketch of the vane type wind turbine, (b) general view of the wind station.

4. ANALYTICAL APPROACH

The wind turbine generators use mainly aerodynamic lift force and drug 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 one (drug force design). However, other researches 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 [9]. Other side practice shows the propeller type hydraulic turbines are not used due to its low efficiency and used the design of blades that work by drug force to generate power. However, there is the following vital information: the power output of a wind generator is proportional to the area swept by the rotor 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 do design new type wind turbines.

For calculation of the power of wind turbines many complicated equations are used. 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]:

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

Where

P = power produced by the wind turbine, W
ρ = air density
V = wind speed approaching the wind turbine
λ = wind turbine efficiency
A = projected area of the turbine perpendicular to the approaching wind, m^2
λ = wind turbine efficiency that consists following factors and calculated by following formula:

$$\lambda = C_pC*N_g*N_b$$

Where

C_p = coefficient of performance (C = 0.35 for a good design)
C = C_l or C_d (or resulting of them) - are lift and drag factors respectively and depend on the shape and form of the blades or vanes and on the orientation of the wind flow with respect to the object
N_g = generator efficiency (80% or possibly more for a permanent magnet generator or grid-connected induction generator)
N_b = gearbox/bearings efficiency (95% for a good design)

Mathematical modeling of the wind turbines power is a very difficult problem and generally should be solved by numerical methods of Computational Fluid Dynamics. Finally results of mathematical modeling should proof and confirm practical tests in the aerodynamic wind tunnel. For this contribution range simple mathematical descriptions of the wind turbine design and its work can give initial information and ability to evaluate all benefits of proposed construction.

For simplicity two models of the flat-vanes wind turbine were analyzed. Plan view of the vane type wind turbine presented in Figure-3. The first model of the vane type turbines is four sections of vanes assembled on frames, which is perpendicular to each other and joined with the main output shaft. The second one is three sections of vanes, which is 120^0 to each other and joined with the main output shaft.

Power output depends on a wind force, 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 approach briefly described here follows from the analogy of a water jet being directed on to a flat sheet of metal. The first things to calculate is 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. This simplification leads to different results depending on the assumptions made. The important assumptions made in the following are as follows:

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 drug force acting on the left and right frame components is equal.

Force component *F* acting on stationary vertical vanes of left side frame is expressed by the following formula [7]:

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

where all parameters specified in Figure-3 and above.

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 formula has the following expression:

$$T = (1/2)\, A C_d \rho V^2 R \cos\alpha \qquad (3)$$

where *R*- distance from the shaft center line to the center of pressure of the vane surface, other parameters are specified above.

The output power is calculated by the following equation:

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

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

Next step is to develop the mathematical model further by considering moving vanes. This entails determining:

a) the velocity of oncoming air relative to the front surface of the first frame vanes; and
b) the effect of the air 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 is the center of pressure that is found by calculating the pressure distribution across of the variable vanes location, then integrating it. There forces acting on the sides of the frames can be neglected due to face sided small areas.

A good vane design will combine the aerodynamics, the mass properties, and the spin of the vane to permit the projectile to be pointy end forward for the entire air stream line. However, the very location of the frames with vanes contributes to instability of the forces acting on the vanes and instability of the output shaft rotation.

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 its plane normal to the wind flow, the only aerodynamic force will be one parallel to the wind flow, i.e., a wind force.

Practice shows, the mean drag factor C_d for various vanes configurations is different. In the case with the wind at an oblique angle of attack, α, a drug factor also very. There is also a tangential component or ‘skin friction’ force [2].

A formula for the drag factor on plates of height/breadth (h/c) ratio in the range 1/30 - *h*/*c* - 30, in smooth uniform flow normal to the plate, is reproduced in equation (4).

$$C_d = 1.10 + 0.02[(h/c) + (c/h)] \qquad (5)$$

4.1 Vane type wind turbine with four frames

The vane type wind turbine of four frames works with two frames that located at one side from its vertical shaft. The vanes from other two frames are open and wind force does not act on their surfaces (Figure-3) [8]. The frames with vanes located perpendicular to each other due to design of the wind turbine. Location of the acting vanes is variable due to rotary motion of the turbine, so the torque created by the wind force also variable. It is very important to know the variation of the torque applied on the shaft to calculate the output power. Figure-3 presents the sketch of the calculation the forces acting on the vanes that enable to calculate the torque applied to the wind turbine shaft.

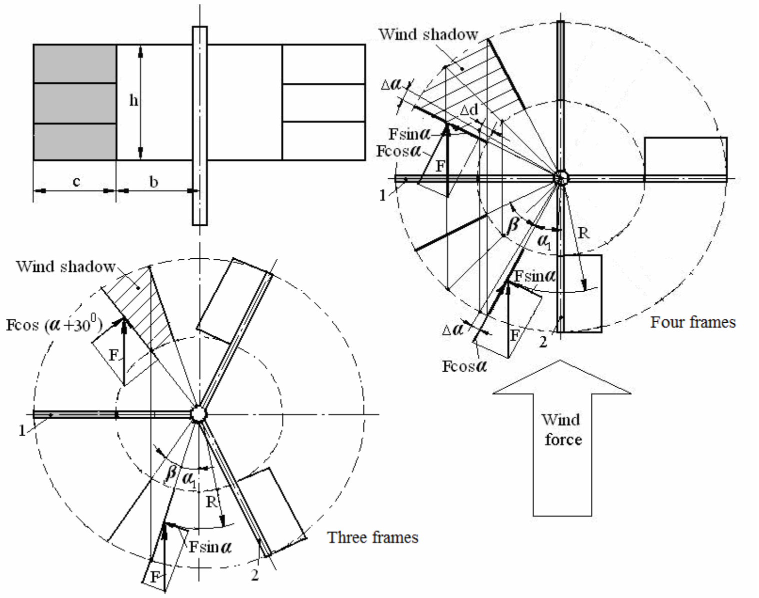

Figure-3. Vane type wind turbine of four and three frames.

The left side of the vane turbine has two action frames that create the torque due to action of the wind force. 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. The second frame vanes work without wind shadow (Figure-3, four frames).

The toque created by the first vane has some drop due to wind shadow at some angle of the frame rotation. The angle of shadow begins from the angle α_1 until the angle (α_1 + β). The presented angles calculated from geometry of vanes location by formula:

$$(c+b)\sin\alpha_1 = b\cos\alpha_1,\ \beta = 90^0 - 2\alpha_1$$

After transformations and substituting:

$$\alpha_1 = \arctan\frac{b}{c+b},$$

The radius of the wind force applied is $R = b + c/2$, in case of wind shadow the radius R is variable $R = (b + \Delta d) + (c - \Delta d)/2$. The incremental magnitude Δd is changeable with incremental angle $\Delta\alpha$ of the vane turn in zone of wind shadow. The dependency of Δd and $\Delta\alpha$ has expression $\Delta d = k\,\Delta\alpha$, where $k = b/(\beta/2)$.

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

a) The torque created by the first vanes at the angle of rotation from 0^0 to α_1 without wind shadow:

$$T_1 = C_1 F[hc(b+c/2)]\cos\alpha\ \Big|_0^{\alpha_1} \tag{6}$$

where C_1 is drug factor (Equation (5)).

b) 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:

$$T_2 = C_1 F[h(c-\Delta d)(b+\Delta d) + (c-\Delta d)/2]\cos\alpha + C_2 F[h\Delta d)(b+\Delta d/2]\cos\alpha\ \Big|_{\alpha_1}^{\beta/2},$$

$$\text{or } T_2 = C_1 F[h(c-k\Delta\alpha)(b+k\Delta\alpha) + (c-k\Delta\alpha)/2]\cos\alpha + C_2 F[hk\Delta\alpha)(b+k\Delta\alpha/2]\cos\alpha\ \Big|_{\alpha_1}^{\beta/2} \tag{7}$$

where C_2 is drug factor for vanes at zone of wind shadow.

c) 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:

$$T_3 = C_2 F[h(c-\Delta d)(b+\Delta d) + (c-\Delta d)/2]\cos\alpha + C_1 F[h\Delta d)(b+\Delta d/2]\cos\alpha\ \Big|_{\beta/2}^{\beta} \tag{8}$$

d) The torque created by the first vanes at the angle of rotation from $\alpha_1+\beta$ to 90^0 without wind shadow:

$$T_4 = C_1F[hc(b+c/2)]\cos\alpha \Big|_{\alpha_1+\beta}^{90^0} \qquad (9)$$

e) The torque created by the second frame vanes at the angle α of rotation from 00 to 90^0 without wind shadow:

$$T_5 = C_1F[hc(b+c/2)]\sin\alpha \Big|_{0^0}^{90^0} \qquad (10)$$

The total torque created by two frames vanes of four frames wind turbine is calculated by the following equation:

$$T = \sum_{i=1}^{5} T_i = C_1F[hc(b+c/2)]\cos\alpha \Big|_{0}^{\alpha_1} +$$

$$C_1F[h(c-\Delta d)(b+\Delta d)+(c-\Delta d)/2]\cos\alpha + C_2F[h\Delta d)(b+\Delta d/2]\cos\alpha \Big|_{\alpha_1}^{\beta/2} +$$

$$C_2F[h(c-\Delta d)(b+\Delta d)+(c-\Delta d)/2]\cos\alpha + C_1F[h\Delta d)(b+\Delta d/2]\cos\alpha \Big|_{\beta/2}^{\beta} +$$

$$C_1F[hc(b+c/2)]\cos\alpha \Big|_{\alpha_1+\beta}^{90^0} +$$

$$C_1F[hc(b+c/2)]\sin\alpha \Big|_{0^0}^{90^0} \qquad (11)$$

4.2 Vane type wind turbine with three frames

The vane type wind turbine of three frames works also with two frames is located at left side from its vertical shaft. The vanes of from right side frames are open and wind force does not act on their surfaces (Figure-3, tree frames). The formula of the torque created by the first and second frames vanes is same as for the wind turbine with four frames. However the only one difference is that the second frame vanes acts after rotation of the first frame vanes on 30^0. The wind shadow zone is also different. The total torque created by two frames vanes of three frames wind turbine is calculated by Equation (11) with different angular coordinates of vanes rotations and wind shadow.

5. WORKING EXAMPLE

The vane type turbine without the Darrieus frames has following dimensions: c = 1.0 m - vane width, b = 1.0 m - length of open frame part, h = 2.0 m - height of frame, C_d = 1.0 - drug factor accepted for vanes rotated. C_d = 0.5 - drug factor at wind shadow. The force acting on the vane: F = 100N - wind force at condition of the wind speed V = 10 m/s. The air density ρ = 1.25 kg/m^3.

The maximum tougue created by one frame is:

Is $T_1 = C_1F[hc(b+c/2)] = 1.0*100[2*1(1+1/2)] = 300Nm$,

The maximum torque created by two frames is calculated by Equation (11).

The power generated by the vane type wind turbine by Equation (1) is:

P= 0.5*ρ*V^{3*}A* λ, Watt = 0.5*1.25 kg/m^3*10^3 m/s*4*1.0 =2500 W = 2.5 kW.

5.1 Four frames the vane wind turbine

Formula for α_1 - beginning of wind shadow

$$\alpha_1 = \arctan\frac{b}{b+c} = \arctan\frac{1}{1+1} = 26.56^0,$$

Formula for β- the angle of wind shadow β = 900 - 2*26.560 = 36.880

The angle of the end of wind shadow is α1 + β = 26.560 + 36.880 = 63.440

If take coefficient of wind shadow C2 = 0.5, then torque of the first vane for wind shadow at α1 + β/2 = 26.560 + 36.880/2 = 450

$$T_1 = C_2F[hc(b+c/2)]\cos 45^0 = 0.5*100\cos 45^0 *[2*1(1+1/2)] = 106.1Nm$$

The torque of the second vane at 45^0 is

$$T_2 = C_1F[hc(b+c/2)]\cos 45^0 = 1.0*100[2*1(1+1/2)]\cos 45^0 = 212.1Nm$$

Total torque with the wind shadow acting on two vanes is calculated by Equation (11):

T = T_1 + T_2 = 106.4 + 212.1 = 318.5 Nm

The torque when the first vane on half at beginning of wind shadow $\alpha = \alpha_1 + \beta/4 = 25.56^0 + 36.88^0/4 = 34.780$, $\Delta\alpha = 9.22^0$ and k = b/ (β/2 = 1/ (36.88^0/2) = 0.054 is:

$$T_2 = C_1F[h(c-k\Delta\alpha)(b+k\Delta\alpha)+(c-k\Delta\alpha)/2]\cos\alpha + C_2F[hk\Delta\alpha(b+k\Delta\alpha/2]\cos\alpha +$$
$$C_1F[hc(b+c/2)]\cos\alpha =$$
$$1*100[2(1-0.054*9.22)(1+0.054*9.22)+(1-0.054*9.22)/2]\cos 34.78^0 +$$
$$0.5*100[2*0.054*9.22(1+0.054*9.22/2)]\cos 34.78^0 + 1*100[2*1(1+1/2)]\sin 34.78^0 = 376.4Nm$$

The torque when the first vane on half at ending of wind shadow α = α_1 + 3β/4 = 25.56^0 + 3*36.88^0/4 = 53.220, Δα = 9.22^0 and k = b/ (β/2) = 1/ (36.88^0/2) = 0.054 is:

$$T_3 = C_2F[h(c-\Delta d)(b+\Delta d)+(c-\Delta d)/2]\cos\alpha + C_1F[h\Delta d)(b+\Delta d/2]\cos\alpha + C_1F[hc(b+c/2)]\cos\alpha =$$
$$0.5*100[2(1-0.5)(1+0.5)+(1-0.5)/2]\cos 53.22^0 + 1*100[2*0.5(1+0.5/2)]\cos 53.22^0 +$$
$$1*100[2*1(1+1/2)]\sin 53.22^0 = 367.4Nm$$

5.2 Three frames the vane wind turbine

Formula for α = 30^0 + α_1 - beginning of wind shadow:

$$\frac{b}{c+b} = \frac{\sin\alpha_1}{\cos(30^0+\alpha_1)}$$

$$\alpha_1 = \arctan\frac{0.866}{[(c+b)/b]+0.5} = \arctan\frac{0.866}{[(1+1)/1]+0.5} = 19.1^0$$

α = 30^0 + α_1 = 49.1^0

Formula for β – the angle of wind shadow
β = 90^0 - 30^0 -2α_1 = 60^0 - 2*19.1^0 = 21.8^0

Formula for α - the angle of ending wind shadow

α = 30^0 + α_1 + β = 30^0 +19.1^0 + 21.8^0 = 70.9^0

a) If take coefficient of wind shadow C_2 = 0.5, then torque of the first frame vane for full wind shadow at α = 30^0 + α_1 + β/2 = 30^0 + $19.1^{0\,+}$ 21.8^0/2 = 60^0

$$T_1 = C_2F[hc(b+c/2)]\cos 60^0 = 0.5*100\cos 60^0*[2*1(1+1/2)] = 75.0Nm$$

The torque of the second frame vane at 60^0 turn of first frame

$$T_2 = C_1F[hc(b+c/2)]\sin 30^0 = 1.0*100[2*1(1+1/2)]\sin 30^0 = 1500Nm$$

Total torque with the wind shadow acting on two vanes is calculated by Equation (11).

T= T_1 + T_2 = 75.0 + 150 = 225 Nm

b) The torque when the first vane on half at beginning of wind shadow α = 30^0 + α_1 + β/4 = 30^0 + 19.1^0 + 21.8^0/4 = 54.550, Δα = 5.45^0 and k = b/ (β/2) = 1/ (21.8^0/2) = 0.092 is:

$$T_1 = C_1F[h(c-k\Delta\alpha)(b+k\Delta\alpha)+(c-k\Delta\alpha)/2]\cos\alpha + C_2F[hk\Delta\alpha(b+k\Delta\alpha/2]\cos\alpha +$$
$$C_1F[hc(b+c/2)]\cos\alpha =$$
$$1*100[2(1-0.092*5.45)(1+0.092*5.45)+(1-0.092*5.45)/2]\cos 54.55^0 +$$
$$0.5*100[2*0.092*5.45(1+0.092*5.45/2)]\cos 54.55^0$$

The torque of the second frame vane at $54.55^{0\ \text{turn}}$ of first frame:

$$T_2 = 1*100[2*1(1+1/2)]\sin 24.55^0$$

c) The torque when the first vane on half at ending of wind shadow α = 30^0 + α_1 + 3β/4 = 30^0 + 19.1^0 + 3*21.8^0/4 = 65.450, Δα = 5.45^0 and k = b/ (β/2) = 1/ (21.8^0/2) = 0.092 is:

$$T_1 = C_2F[h(c-\Delta d)(b+\Delta d)+(c-\Delta d)/2]\cos\alpha + C_1F[h\Delta d)(b+\Delta d/2]\cos\alpha + C_1F[hc(b+c/2)]\cos\alpha =$$
$$0.5*100[2(1-0.5)(1+0.5)+(1-0.5)/2]\cos 65.45^0 + 1*100[2*0.5(1+0.5/2)]\cos 65.45^0 +$$
$$1*100[2*1(1+1/2)]\sin 65.45^0$$

The torque of the second frame vane at $65.45^{0\ \text{turn}}$ of first frame

$$T_2 = 1*100[2*1(1+1/2)]\sin 35.45^0$$

d) If take coefficient of wind shadow C = 0.5, then maximum moment of first vane for wind shadow at α + β/2 = 30.96^0 + 14.04^0 = 45^0

T_1 = 0.5* 141.4 Nm = 70.07Nm

Total torque with the wind shadow

T= T_1 + T_2 = 141.4 + 70.07 = 211.47 Nm

Table-1. The torque created on the output shaft of the vane type wind turbine.

The four frames vane wind turbine											
α^0	0	10	20	25.6	34.78	45	53.22	63.4	70	80	90
T_1	300	295.4	281.9	270.5	205.3	106.1	127.2	134.3	102.6	52.1	0
T_2	0	52.1	102.6	134.3	171.1	212.1	240.3	270.5	281.9	295.4	300
T	300	347.5	394.5	404.8	376.4	318.2	367.5	404.8	394.5	347.5	300
The three frames vane wind turbine											
α^0	0	10	20	30	40	49.1	54.55	60	65.45	80	90
T_1	300	295.4	281.9	259.8	229.8	196.4	145	75	98.6	52.1	0
T_2	0				52.1	98.1	124.6	150	174	229.8	259.8
T	300	295.4	281.9	259.8	281.9	294.5	269.6	225	272.6	281.9	259.8

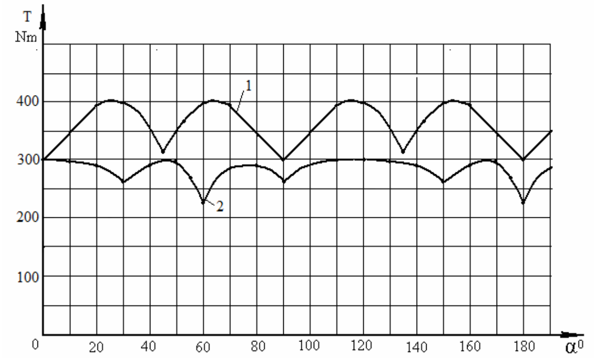

Figure-4. Torque versus the angle of output shaft rotation. 1- four frames wind turbine; 2 - three frames wind turbine.

The power generated by the four and three frames vane wind turbine is expressed by the following formula:

$P = TV/R = 360*10/1.5 = 2400$ W = 2.4 kW – four frame

where the torque T = 360 Nm is average from the diagram (Figure-4).

$P = TV/R = 260*10/1.5 = 1733.3$ W = 1.7 kW - three frame

where the torque T = 260 Nm is average from the diagram (Figure-4).

The diagram (Figure-4) and Table-1 show torque and power respectively for frames vane type wind turbine have fluctuation that numerically is expressed by the following data:

$$\delta = \frac{T_{\max} - T_{\min}}{T_{\max}} 100\%$$

The four frames turbine $\delta = \frac{T_{\max} - T_{\min}}{T_{\max}} 100\% = \frac{404.8 - 300}{404.8} 100\% = 26\%$

The three frames turbine $\delta = \frac{300 - 225}{300} 100\% = 25\%$

The torque fluctuation of both type turbines has small difference and depends on torque loss due to wind shadow of the vanes.

6. RESULTS AND DISCUSSIONS

Theoretical calculations of the torque for the vane type turbines conducted by Equations (1) and (2) shows almost same result. The difference can be explained by accepted efficiency factor λ, which can vary. Nevertheless results shows that this type wind turbines can be used for generating a power. Efficiency of the vane type turbines can be significantly increase by change of the shape frames, which can be designed with cavities. Such method can increase the drug factor. The vertical components of the frames can be designed as Darriues type wind turbine that also can add power and reduce fluctuation of the torque. The test of this turbine in the wind tunnel can give correction of the theoretical calculations.

Proposed vane turbine can be designed from cheap material that is big positive property. The work of the vane turbine does not have restrictions. At strong wind conditions, it is possible design the vane turbine with decreased acting number of vanes. At conditions of week wind non active vanes can be activated. Also it is possible to design frames with variable location of the vanes that change the radius of the torque.

7. CONCLUSIONS

Efficiency of the present vane type wind turbine can be higher than known wind turbines. Efficiency depends on the vanes acting area that can be very big. The present vane type wind turbine posses all advantages of vertical and horizontal types of turbines. This vane type wind turbine can be concurrent to known wind turbine designs. Invent design of new turbine that can operate at any type of the wind force. Mathematical modeling of the wind turbine work should be conducted on a basis of Computational Fluid Dynamics. It is necessary to conduct investigations on the optimal design of new turbine (power as function of geometry of wind turbine). Tests of the wind turbine in the wind tunnel and correction of the mathematical model can give reliable data for design of the vane type turbine.

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