Investigation of the Parameters Effect on the Rotor Wind Turbine

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INTRODUCTION

Wind turbine generators use mainly aerodynamic lift force and drag forces acting on their surfaces of blades or vanes. Today many researchers say that horizontal axis wind turbines (lift force design) theoretically have higher power efficiencies than vertical axis one (drag force design) (Nobile et al. 2011). There are also researchers who state that under turbulent conditions with rapid changes in wind direction practically more electricity will be generated by vertical turbines, despite their lower efficiency.

The theoretical maximum power efficiency of any design of wind turbine operating in open atmosphere is lower than 59.3 % efficiency (Mathew, S.2006). This is known as the Betz Limit. It is reached by setting up the ratio between the maximum powers extractable and the energy in the wind as it passes the actuator disc. Yan1 et al. (2008) studied the effect of the weight of frame (when attached to blade surface) on the power coefficient in a wind tunnel test. According to the test results, the rotational performance and power performance were reduced with the existence of attachments.

Holmes, (2001) studied the case of two thin normal plates in series, normal to the flow. At zero spacing, the two plates act like a single plate with a combined drag coefficient (based on the frontal area of one plate) of about 1.1, for a square plate. For spacing in the range of 0 to about 2b, (where b is the length of the plate), the combined drag coefficient is actually lower than that for a single plate, reaching a value of about 0.8 at a spacing of about 1.5b, for two square plates. As the spacing increases, the combined drag coefficient then increases, so that, for very high spacing, the plates act like individual plates with no interference with each other, and a combined drag coefficient of about 2.2.

Saha and Rajkumar investigated the feasibility of twisted blade Savonious rotor for power generation by conducting experiments on a three-bladed rotor system having twisted blade in a low speed wind tunnel. Its performance was compared with that of a rotor system of conventional semicircular blades (with twist angle of 0°). Performance analysis was made on the basis of starting characteristics, static torque and rotational speed. Their experimental evidence shows the potential of the twisted bladed rotor in terms of smooth running, higher efficiency and self-starting capability as compared to that of the conventional bladed rotor.

Mohamed et al. have considered a considerably improved design in order to increase the output power of a Savonius turbine with two or three blades. Their improved design leads to a better self-starting capability. They carried out the automatic optimization by coupling an in-house optimization library (OPAL) with an industrial flow simulation code (ANSYS- Fluent). They proved that the optimized configuration involving a two-blade rotor is better than the three-blade design.

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1. **Theoretical Approach:**

The shaft power output normally not used directly, but is usually coupled to a load through a transmission or gear box. The load may be a pump, compressor, grinder, electrical generator, and so on. For the purpose of illustration, an electrical generator will be considered as a load. The basic system is then shown in Figure (1).

Starting with the power of the wind, \( W_{\text{wind}} \) which is an input to the wind turbine, a mechanical power \( W_m \) is obtained at the turbine angular velocity \( \omega_m \) which is then supplied to the transmission device. The transmission output power \( W_t \) is converted to electric power by the generator coupled to the transmission device. The mechanical power and the transmission output power are given by:

\[
W_m = C_p \times W_{\text{wind}} \quad (1)
\]
\[
W_t = N_m \times W_m \quad (2)
\]

**Fig. 1:** Wind electric systems.

Similarly, the generator output power \( W_e \) is given by the product of the transmission output power and the generator efficiency \( N_g \):

\[
W_e = N_g \times W_t
\]

The relationship between the electrical power outputs to wind power input is then given by:

\[
W_e = C_p \times N_m \times N_g \times W_w \quad (3)
\]

Figure 2 shows the block diagram of the experimental setup for the present investigation. It can be seen that \( W_{\text{wind}} \) is the input to the rotor of the wind turbine. The moving blades of the rotor of the wind turbine convert part of the wind power as calculated by Eq. 1. The other outputs of the devices are marked in the figure. The required relations between different outputs of the devices are also shown in Figure 2.

**Fig. 2:** Block diagram for input and output parameters.
The theoretical power output of a wind turbine generator is proportional to the acting area of wind turbine and to the cube of the wind speed. These should be considered as main factors for the power output while designing new type of wind turbines.

For calculation of the power of wind turbines, the fluid dynamics theory is applied. It is known that wind has pressure due to its velocity. This wind pressure is calculated from:

\[ P = \frac{1}{2} \rho \times V^2 \]  

(4)

The wind force component \( F \) acting on stationary vertical vanes of the left side frame is expressed by:

\[ F = P \times A = \frac{1}{2} (\rho \times A \times V^2 \times C_D) \times \sin \gamma \]  

(5)

where, \( A \) is acting surface area of vanes, \( P \) is the wind pressure, and \( C_D \) is dragging factor depending on the shape of the vane, \( \gamma \) is the angle of frame.

To determine the mathematical torque \( T \) due to the acting force 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. The resulting torque is then given by:

\[ T = \frac{1}{2} A C_D \rho V^2 R \times \sin \gamma \]  

(6)

where, \( R \) is the distance from the shaft centre line to the centre of pressure of the vane surface.

The mathematical output power of the turbine rotor is calculated by the following equation:

\[ W_T = T \times \omega = \frac{1}{2} A C_D \rho V^3 R \times \sin \gamma \]  

(7)

where, \( \omega \) is the angular velocity of the rotating turbine.

Figure 3 shows the average torque fluctuation by radar chart versus the angle of output shaft rotation of the three frames and four frames model at wind speed 6 m/s.

Fig. 3: Radar chart for torque versus the angle of rotation for three and four frames at wind speed 6m/s.

3. Experimental Approach:

The wind tunnel used for testing the proposed model wind turbine has a test section of dimension 30x30x30 cm. This small cross section area limits the size of the model to be tested in the wind tunnel. To fabricate the model the immediate issue of solid blockage in the wind tunnel has to be addressed knowing the solid blockage fact that the high end of the acceptable blockage range is 10% (Barlow, 1999). Therefore, the model must have dimensions to leave acceptable open areas between the model and tunnel walls to allow for wind flow from all sides.

The wind tunnel has a cross-sectional area of 900 cm²; and the detailed design of the present rotor type vertical axis wind turbine can be found in Qasim et al. (2011). The model has an actual solidity of approximately 37%, so the maximum cross-sectional area of the model is:
\[900 \times 10\% = A_{\text{model}} \times 37\%\]

\[A_{\text{model}} \times \text{Max} = 243 \text{ cm}^2\]

For this project the wind tunnel is operated at free-air velocities between 5 m/s and 30 m/s. The acceptable maximum diameter of the model operating in the wind tunnel is 20 cm which will the scale ratio with prototype is one-tenth. The shaft should be in the middle of the rotor gives a space of 5cm between the frame end and the wind tunnel’s walls.

The cord length \((C)\) is 70% of the frame length.

Cord is containing three vanes [two vanes are oblique in 45˚and one vane is straight]. So the cord length is:

\[C = Z + 2Z \cos 45^\circ\]

Where, \(Z\) is the vanes width.

The frame height is calculated to be 1.618 times the cord length (nature ratio) \((\text{Livio, Mario. 2002})^9\).

The efficiency with which a rotor can extract power from the wind depends on the dynamic matching between the rotor and the wind stream. Hence, the performance of a wind turbine rotor is usually characterized by the variations in its power coefficient with the tip speed ratio. As both these parameters are dimensionless, the power coefficient represents the amount of energy that a specific turbine can absorb from the wind.

4. Test Model in Wind Tunnel:

The model was designed, fabricated, and the third step is testing in a wind tunnel. The rotor of wind-turbine models testing used movable vanes cavity shape frame made from the transparent acrylic plates with dimensions presented in Qasim et al. (2011). \([c = 0.03 \text{ m}, h = 0.116 \text{ m and } b = 0.07 \text{ m}]\) with thickness of metal for three frames \([t = 2\text{ mm}, \text{impeller weight } = 172 \text{ grams}]\), and for four frame model with thickness of metal, \([t = 2\text{ mm}, \text{impeller weight } = 236 \text{ grams}]\). The analyses considered power output test, and number of revolutions per minute of the rotating shaft.

The manometer was reset to reflect zero differential pressure to compensate for barometric changes. The tunnel air speed control was advanced slowly until the turbine model began spinning. At this point, the tunnel fan and turbine speed were allowed to stabilize momentarily. The laser tachometer was aimed at the reflective strip on the turbine model blade, and an RPM reading was taken. Tunnel differential pressure, tunnel wind speed, control setting and turbine RPM was recorded at each tunnel control setting.

The tunnel speed control rheostat was advanced in increments of 1.5, each of which resulted in a tunnel wind speed increase of 1 m/s. This process was continued up to a maximum setting of 45, which corresponded to a tunnel wind speed of around 30 m/s. This maximum was chosen based on the amount of vibrations in the stinger and turbine model. At control settings above 25 m/s, the stinger and model vibration could lead to destruction of the model. It was determined that it was more important to establish the performance characteristics of the model than to establish at what tunnel speed the model would experience catastrophic failure.

The RPM of the rotor is found with a digital tachometer. Initially, experiments have been done on the three frames movable vanes model and four frames movable vanes model. The turbine model was operated through the range of speeds 5 m/s to 17 m/s, and the range of the value of rotor speed (RPM), the standard deviation is calculated to be \(\pm 8\). The test results in wind tunnel of RPM for 3-frame and 4-frame model various wind velocities is shown in Figure (4). The results show that three frames wind turbine has high rotational speed (RPM) than four frames.

The results obtained in Figure 5, show the power coefficient of the 3-frame rotor is higher than 4-frame rotor for all wind speeds and it achieves a maximum power coefficient of 0.32 at a wind speed 8 m/sec and tip speed ratio of 0.31. For the 4-frame rotor the maximum power coefficient achieved is 0.26 at wind speed 8 m/sec and tip speed ratio 0.24.

Figure 6 show the torque coefficients for three and four frames versus tip speed ratio and wind speed. It shows the torque coefficient of the 3-frames wind turbine model is higher than the 4-frames wind turbine from beginning till wind speed 15 m/sec. After that, the torque coefficient decreases slightly for the 3-frame rotor than the 4-frame one.
From the results obtained, while testing three frames movable vanes model in the wind tunnel, the torque of the model at wind velocity 8 m/s (the maximum power coefficient from the experiment is at this wind speed) is calculated as:

\[ W_{\text{gen}} = T \cdot \omega \rightarrow T = \frac{W_{\text{gen}}}{\omega} \]  

(8)
From the practical test results we notice that the torque of the 4-frame is slightly higher than 3-frame torque. However, the rotational speed of the 3-frame turbine is found to be faster than that of the 4-frame for the wind speed of 8 m/s. This trend is noticed for other wind speed as well. The power coefficient is the product of torque of the rotor and the angular speed of the rotor. Because of the higher speed of rotation for the 3-frame turbine model, its power coefficient is found to be higher than that for the 4-frame turbine model in same wind velocity.

\[
C_p = \frac{T \cdot \omega}{\frac{1}{2} \rho A V_{wind}^3}
\]

Equation (9)

\(C_p\) for 3-Frame > \(C_p\) for 4-Frame

The slow rotational speed of 4-frame turbine model may be caused due to the following reasons:

1. Higher weight (four frame thicknesses of metal 2mm impeller weight 236 grams VS. the three-frame thicknesses of metal 2mm impeller weight 172 grams.
2. Decreasing the distance between the frames lower than the limit, has getting a lower drag force as seen in Figure 7.
3. The effect of vortex consists and still airs area behind the vane gives high resistance, in four frames more than three frames.
4. Increasing the negative torque generating by the frame rotating in the opposite direction of the wind.
5. The drop in drag force when the number of frame increases from 3-frame to 4-frame.

5. The Discussion of Number of Frame Effect:

The greater the number of frames in impeller the exposed area of the air will increase, and therefore, it is logical that increasing the amount of torque generated, but what is the maximum number of frames in impeller which gives the maximum torque. There are some reasons to decrease the torque and the power of the impeller wind turbine when increase the number of the frames:

1. It has been calculated that mathematically for dimensional of a frame previously and show that the angle of the wind shadow for three frames is 34.3° and when increasing the frames to four, the angle of the wind shadow is also increase to be 56.6°, i.e. the first frame of impeller for four frame model work under shadow in along the angle 56.6°, it is higher than the distance work of the first frame in the three frames model under shadows angle 34.3°.
2. The second frame is fair to the wind directly and works strongly complete drag force, the wind after the second frame needs a distance to return rework on the first frame in the same power of the second frame.
3. It is observed that the power coefficient of the rotor decreases when the number of blades increases from three to four. When the number of blades is increased to four, the air which strikes on one blade gets reflected back on the following blade so that the following blade rotates in a negative direction as compared to the succeeding blade Figure 7.b.

Hence, with an increase of the number of blades, the rotor performance decreases. It can be concluded from the experimental evidence that a three-frame system gives high performance.

Test of drag force for two frames with two distances between frames 8 cm and 15 cm gives the performance for 4- and 3-frames, respectively as shown in Figure 8.

It is therefore, concluded that:

1. The greater the number of frame in impeller the larger the exposed area for the air which increases the amount of torque generated. The practical test on the two models (3- and 4-frame) in wind tunnel show that the 4-frame impeller wind turbine gives slightly higher torque than 3-frame impeller wind turbine.
2. However, the rotational speed of the 3-frame wind turbine is found to be higher than that of the 4-frame wind turbine for the same wind speed, as confirmed by the experiments.
3. It is found that the power coefficient for 3-frame wind turbine model is higher than of 4-frame wind turbine model for the same wind velocity.
a) Correct distance between blades in impeller

b) Air reflected back between two blades in impeller

**Fig. 7:** Distance between Two blades a) correct distance b) small distance.

**Fig. 8:** Test double frame scoop-vanes in wind tunnel with different distance versus wind speed.

**REFERENCES**


