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EFFECT OF NUMBERS OF BLADE AND BLADE ANGLE OF A SAVONIUS TYPE VERTICAL AXIS WIND TURBINE

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Abstract*- The primary objective of this paper is to investigate a cyclonic domestic scale vertical axis wind turbine with semicircular shaped blades under a range of wind speeds. A 16-bladed rotor was initially designed and its torques and angular speeds were measured over a range of wind speeds using a wind tunnel. Another 8-bladed rotor was also manufactured to investigate the effect of blade number on the maximum power generation by the turbine. Maximum power curves as a function of wind speeds were established for each configuration. The results show that with the use 10° blade angle, the average rotor speed increased by about 60% for the 8-bladed rotor compared to 0° blade angle. A significant increase (aver 350%) of power output was also found for the 8-bladed rotor with 10° blade angle at 35 km/h wind speed. The results indicated that 10° blade angle can increase the power output of this domestic scale vertical axis wind turbine especially with a reduce number of blades.*

Keywords: Vertical axis wind turbine, Wind tunnel, Power, Torque, Rotor, Numbers of blade, Blade angle.

1. INTRODUCTION

Australia is one of the best wind resourceful countries in the world. Almost all of the major cities are situated along the coastal belt with average wind speeds of more than 8 m/s. With Australia's commitment to the Kyoto Protocol, which promised a target of 20% renewable power by 2020, it is wise to utilize the huge untapped potential of urban wind power generation [1-3]. However, one of the main disadvantages is that the atmospheric wind becomes highly turbulent and exhibits significant fluctuations of gust speed and high variability of wind direction caused by the urban structures and buildings. Under such conditions, existing Horizontal Axis Wind Turbines (HAWTs) are not very effective for power generation.

The effect of solidity and blade angle has great impacts on aerodynamic performance of a Vertical Axis Wind Turbine (VAWT). It is crucial to understand the aerodynamic performance of a VAWT in urban and built up area where the atmospheric wind is at low speeds. The wind speed has a cubic effect on the power generated. Researchers like Zhang et al. [4] studied the effect of solidity and concluded that, by increasing the number of blades, the self-starting performance at low tip speed ratio was improved but the power coefficient reduced. Izadi et al. [5] have also studied the effect of number of blades on the aerodynamic performance of a venturi effect fluid turbine (VEFT) by numerical simulation. The results show that increasing the number of blades increases the magnitude of the torque generated by VAWT and, therefore, increases the efficiency of the wind turbine. However, a VAWT with a higher number of blades is more expensive due to higher design and manufacturing costs. Accordingly, there is an optimum design with respect to efficiency and capital investment. Li et al. [6] explored the effect of blade number on the starting performance of straight-blade vertical-axis wind turbine. They constructed a model which can change the number of blades from one to five. The starting torques at different azimuth angles were obtained by wind tunnel test and the results were compared with the simulation results by the starting torque of the model with one blade. They concluded that the starting performance was averagely improved with the increasing of blade number. These studies prove that we can increase the efficiency of Vertical Axis Wind Turbines by changing the number of blades.

Alam et al. [7] reported a Savonius type VAWT for domestic scale wind generation. Their study was based on a preliminary design and testing of a card board model of a VAWT. The turbine was tested with two configurations over a range of wind speeds (5 to 30 km/h). The first configuration was the bare rotor without a cowling and the other configuration was the bare rotor shrouded with a cowling. Only the speeds of the rotor with these two configurations were tested and their study indicated an increase of rotor speed over 130% with the cowling. However, the study neither considered the effect of the number of blades nor measured the rotor torque and angular velocity which is an important parameter to determine the possible power generation by a wind turbine. Therefore, the main purpose of this study is to measure the power output of an improved model of VAWT for four different configurations using better construction material (e.g., fiber glass) and considering the effect of number of blades and blade angle.

2. METHODOLOGY

In this study, classic Savonius type VAWT rotors with semicircle shaped blades were modelled with variation of blade number and angle of the blade with respect to wind direction. Fiber glass material with 2 mm thickness was used to manufacture the blade and rotor parts. Detailed dimensions of an individual blade are shown in Fig. 1.

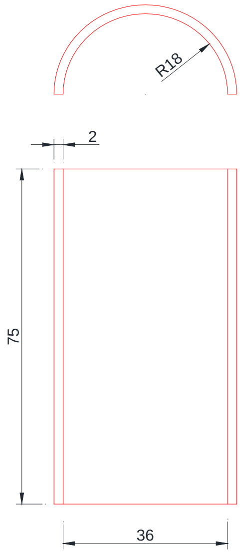

Fig.1: Dimensions (mm) of the semicircle shaped wind turbine blade

The blades were mounted in between two circular discs by providing equal space. The rotor radius was 150 mm. Two rotors: one with 16 blades and another with 8 blades were constructed. The schematic of the 16-bladed rotor is shown in Fig. 2. Blade angle with respect to the wind direction is shown in Fig.3. In order to investigate the effect of blade angle on the wind turbine performance the blades can be adjusted at two different angles (at 0 and 10) between the two discs. Additionally, to investigate the effect of numbers of blade, the rotor can be configured with either 16 or 8 blades. Fig. 4 shows the 3D model of the assembly for the 16-bladed turbine rotor.

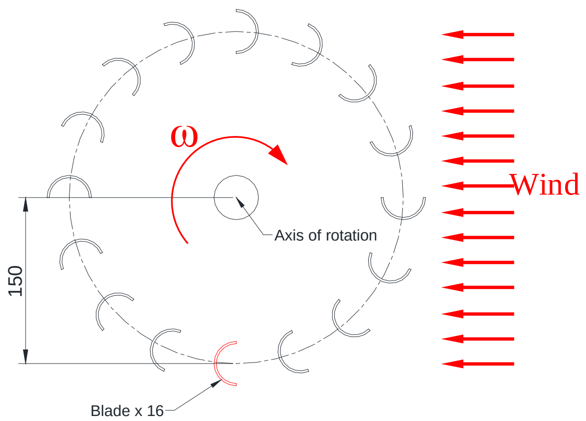

Fig.2: Schematic of the 16-bladed rotor (top view)

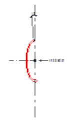

Fig.3: Schematic of blade angle

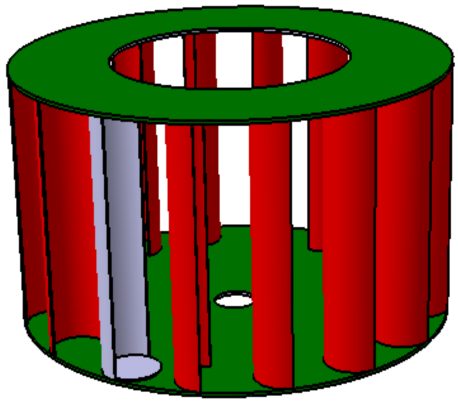

Fig.4: 3D model of the 16-bladed turbine rotor

The RMIT Industrial Wind Tunnel was used to measure the torque and rpm of the wind turbine. The tunnel is a closed return circuit wind tunnel. The maximum speed of the tunnel is approximately 145 km/h. The rectangular test section dimensions are 3 meters wide, 2 meters high and 9 meters long, and the tunnel's cross sectional area is 6 square meters. A plan view of the tunnel is shown in Fig. 5. The tunnel was calibrated prior conducting the experiments and air speeds inside the wind tunnel were measured with a modified National Physical Laboratory (NPL) ellipsoidal head pitot-static tube (located at the entry of the test section) which was connected through flexible tubing with the Baratron® pressure sensor made by MKS Instruments, USA.

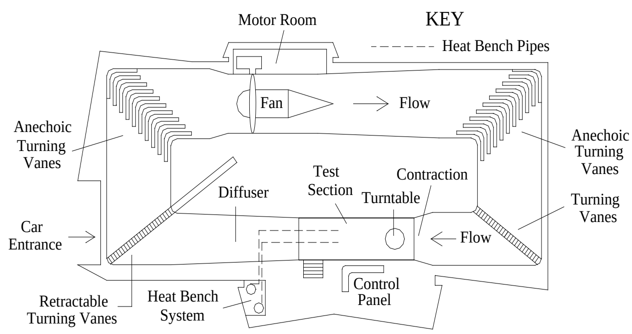

Fig.5: A plan view of RMIT Industrial Wind Tunnel

The experimental turbine model was connected through a mounting sting with the torque transducer (model: T20WN, manufactured by HBM GmbH, Germany) and a mechanical breaking system through a circular rod and bearing supports. Fig. 6 shows the schematic of the experimental setup.

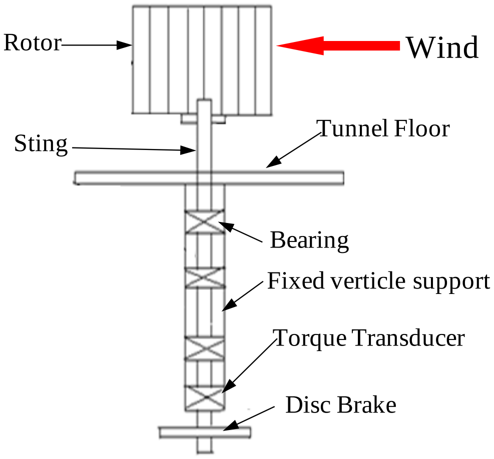

Fig.6: Schematic of the experimental setup

The setup was positioned at the middle of the wind tunnel test section and fixed properly on top of the wind tunnel floor to minimize vibration which may cause measurement errors. The setup was positioned 150 mm above the tunnel floor to minimize boundary layer effect. Fig. 7 shows the experimental setup inside the RMIT Industrial Wind Tunnel.

Fig.7: Experimental setup inside the RMIT Industrial Wind Tunnel

Tests were conducted at a range of wind speeds (20 to 45 km/h with an increment of 5 km/h). The torque transducer has the maximum capacity of 5 kN with 0.01% accuracy. Data logging software supplied by the torque transducer manufacturer was used to log the data (i.e., speed and torque). Each measurement was taken three times for each configuration and the wind speed tested. The average values were presented in this study. The minimum wind speed was constrained by the ability of the turbine to overcome bearing friction and inertia. The upper limit of wind speed was limited by safety consideration due to structural resonant vibrations. Maximum torque at each speed tested was analyzed to calculate the maximum power using the following formula:

$$P = T\omega \tag{1}$$

3. RESULTS AND DISCUSSION

Fig. 8 shows the variation of torque with rotor speeds at 20, 30 and 40 km/h wind speeds for the 16-blade rotor. It can be observed that the torque value increases with the increase of wind speed. Fig. 9 shows the variation of maximum rotor speeds with wind speeds for each configuration tested. Linear relationships can be found with the rotor speed and the wind speed for all 4 configurations. Fig. 10 represents the maximum power curves for 4 configurations of turbine tested. It is found that 16-blade rotor with 10° blade angle is more efficient (generates more power) at wind speeds below 45 km/h.

Results indicated an increase of rotor speed with the increase wind speed for the baseline configuration: 16-blade rotor at 0° blade angle (α). The data from this study for this baseline configuration compares well with the investigation by Alam et al. [7]. The results also show the similar trend for the other three configurations. However, the rate of change of rotor rpm over the wind speeds is different for each configuration. The average rotor speed increased by 12% with the use of double the number of blades. However, the rotor speed increased significantly by changing the blade angle by 10°. It was found that rotor speed increased by about 60% for the 16-bladed rotor compared to the baseline configuration. A significant increase (about 14%) of rotor speed was also found for the 8-bladed rotor with 10° blade angle. It is clear from the experimental data that for both rotors (8 and 16 bladed) have positive effect for blade angle. Therefore, it is possible to produce more power can by changing the blade angle to 10°.

The effectiveness of a domestic scale vertical axis wind turbine mainly depends on its power generation capability. Therefore, it is important to analyze the power output over a range of wind speeds. The result shows that the 16-bladed rotor with 10° blade angle indicated better power output capability than other three configurations up to 45 km/h wind speed.

Fig. 11 shows percent increase of power output at different wind speeds for two rotors tested with respect to blade angles. The result indicated that blade angle affect the power output differently based on their blade numbers. 8-bladed rotor shows more increase than that of the 16-bladed rotor and the maximum increase observed at 35 km/h wind speed. Therefore, it is clear that the blade angle can increase the power out of this domestic scale vertical axis wind turbine especially with a reduce number of blades.

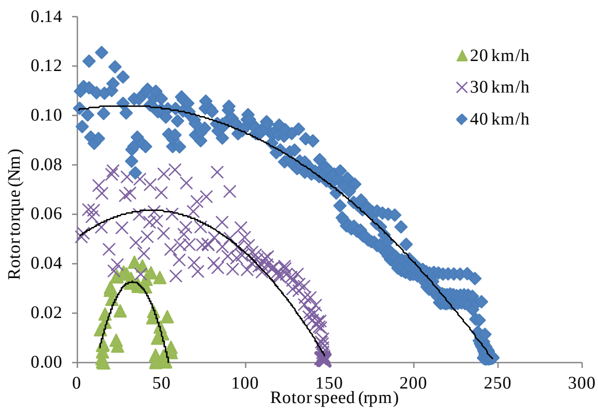

Fig.8: rotor speed as a function of torque for the 16-blade rotor without a cowling.

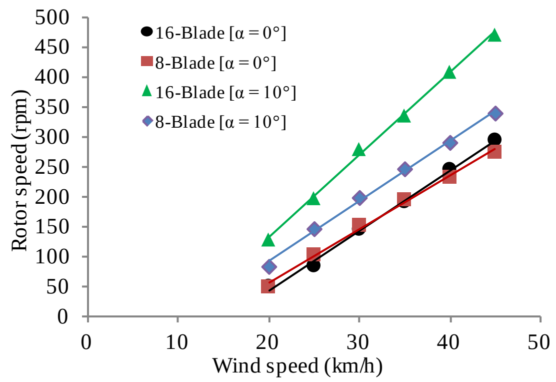

Fig.9: Maximum rotor speed vs. wind speeds

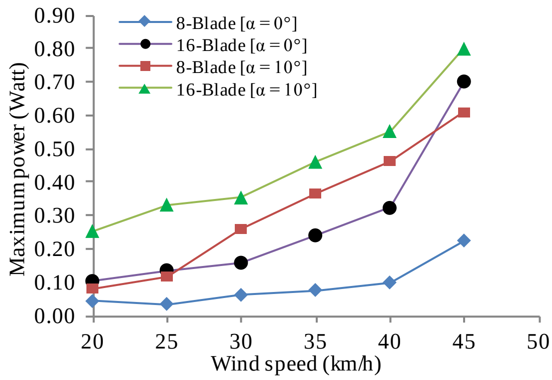

Fig.10: Maximum power as a function of wind speeds

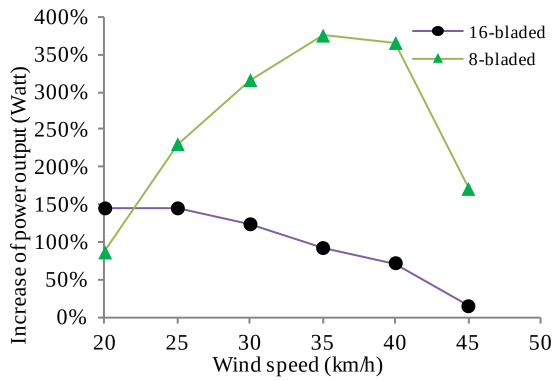

Fig.11: Increase of power output vs. wind speeds

4. CONCLUSIONS

The results show that the blade angle has positive effect to increase the rotor speed to a significant amount. With the use 10° blade angle, the average rotor speed increased by about 60% for the 8-bladed rotor compared to 0° blade angle. A significant increase (aver 350%) of power output was also found for the 8-bladed rotor with 10° blade angle at 35 km/h wind speed. The results indicated that 10° blade angle can increase the power output of this domestic scale vertical axis wind turbine especially with a reduce number of blades.

5. REFERENCES

[1] A. C. Hansen and C. P. Butterfield, "Aerodynamics of Horizontal Axis Wind Turbines", *Annual Review of Fluid Mechanics*, vol. 25, pp. 115-149, 1993.

[2] H. Hirahara, M. Z. Hossain, M. Kawahashi and Y. Nonomura, "Testing basic performance of a very small wind turbine designed for multi-purposes", *Renewable Energy*, vol. 30, pp. 1279-1297, 2005.

[3] R. Howell, N. Qin, J. Edwards and N. Durrani, "Wind tunnel and numerical study of a small vertical axis wind turbine", *Renewable Energy*, vol. 35, pp. 412-422, 2010.

[4] A. Zhang, L. Liang, Y. Li, E. Wei, Y. Yang and Y. Guo, "Effects analysis of solidity on aerodynamic performance of straight-bladed vertical axis wind turbine", *Transactions of the Chinese Society for Agricultural Machinery*, vol. 44, no. 5, pp. 169-174, 2013.

[5] M. Izadi, A. Bahrami, D. K. Aidun, P. Marzocca, B. Ghebreselassie and M. Williams, "Studying the effect of number of blades on the aerodynamic performance of a venturi effect fluid turbine (VEFT) by numerical simulation", in *International Mechanical Engineering Congress and Exposition, (IMECE 2011)*, pp. 1253-1262, 2011.

[6] Y. Li, T. Kotaro and F. Feng, "An experimental study on the starting performance of straight-bladed vertical axis wind turbine", *Taiyangneng Xuebao/Acta Energiae Solaris Sinica*, vol. 32, no. 6, pp. 885-890, 2011.

[7] F. Alam and S. Golde, "An Aerodynamic Study of a Micro Scale Vertical Axis Wind Turbine", *Procedia Engineering*, vol. 56, pp. 568-572, 2013.

6. NOMENCLATURE

Symbol	Meaning	Unit
N	Rotor speed	(rpm)
α	Blade angle	(degree)
ω	Angular velocity	(rad/s)
P	Power	(W)
T	Torque	(Nm)