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Aerodynamic Behaviour of Small Savonius Turbine with 3 Different Configurations

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Abstract

The primary objective of this paper is to study the effect of different configuration of Savonius type domestic scale vertical axis wind turbine with semicircular shaped blades. 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. The second prototype was designed in such a way that the blades were slightly twisted with the base plate diameter larger than the top plate diameter to enhance the turbine efficiency by directing the air flow to the tip of the base plate to increase the tip speed. The third prototype was designed with the top plate larger than the base plate to enhance the turbine efficiency by directing the air flow to the tip of the top plate. Maximum power curves as a function of wind speeds were established for each configuration. The results show that the rotor design with inverted-pyramid configuration extracted more energy from the wind compared to the straight configuration by around 27.1 % and pyramid configuration by around 48.9 %.

Introduction

The increasing awareness of global warming and climate change, diminishing fossil fuel energy sources, and tightening carbon emission target require the development of renewable energy resources to generate power [1-4]. Over decades, many research works have been carried out to investigate and enhance the power generation performance of various wind turbine configurations. Most of these research studies have been focused on large scale horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) installations in open areas or fields with a constant undisturbed wind source. However, limited research has been focusing on wind power generation in built up areas [5-6]. In urban and built-up area, 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 HAWTs are not effective power generators. On the other hand, despite having some advantages (fewer moving parts, lower tip speed ratio, quieter, lower cost, & insensitive to wind direction) over HAWT, VAWTs currently used in urban applications do not produce much more appreciable power [7]. One of the major limitations of current Savonius VAWTs is its low tip speed ratio. This restricts the rotor from accelerating to higher torque producing speeds. This can be overcome by designing a Savonius rotor in such a way that the blades were slightly twisted with the top plate diameter larger than the base plate diameter to enhance the turbine efficiency by directing the air flow to the tip of the top plate to increase the tip speed. Over the years, researches have tried to improve the performance of VAWT. Ogawa et al. [8] examined the effect of flow deflector plate and found that the rotor power increases nearly 30 percent. Irabu and Roy [9] studied the effect of surrounding the turbine with a guide box and found increases about 1.5 times with three blades and 1.23 times with two blades greater than that without guide-box tunnel, respectively. Altan et al. [10] found that the maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. These studies prove that we can increase the efficiency of a Savonius rotor by using enhancements. Therefore, the main purpose of this study is to measure the power output of a small savonius turbine with 3 different Configuration.

Design of Turbines Rotors

In this study, three 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. Figure 1 shows three configurations of turbine. Figure 2 shows the angle of attack orientation and the plan view of the rotor is shown in Figure 3.

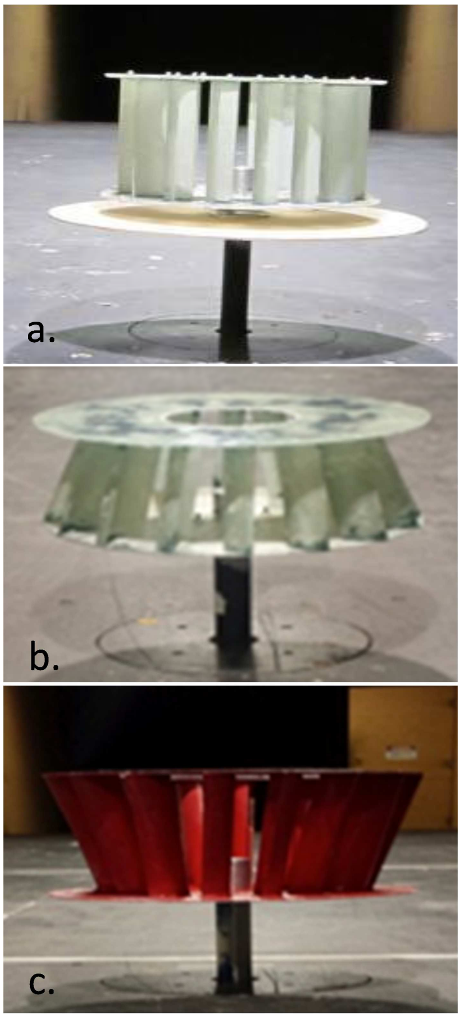

Figure 1. Three configurations of a classic Savonius type VAWT rotor: (a) Straight, (b) Pyramid and (c) Inverted pyramid.

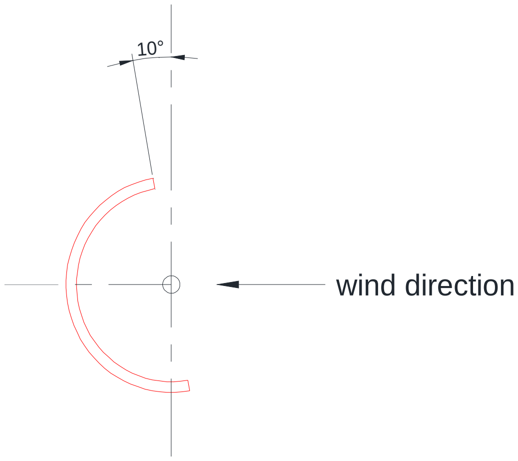

Figure 2. Angle of orientation.

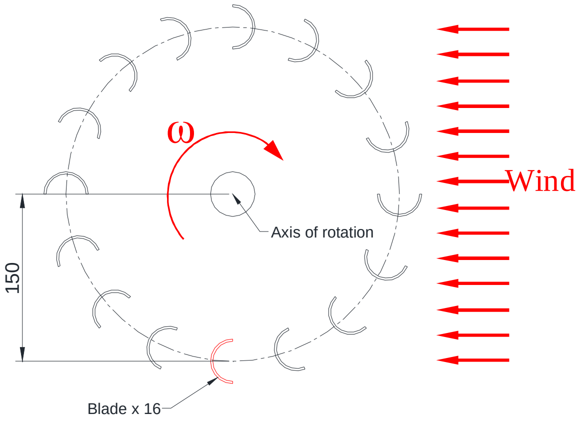

Figure 3. Schematic of the 16-bladed rotor (top view).

Wind Tunnel Testing

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 Figure 4. 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.

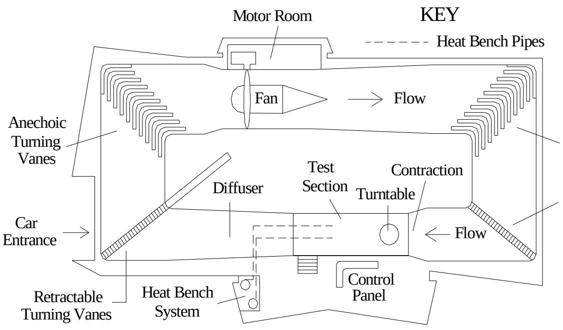

Figure 4. A plan view of RMIT Industrial Wind Tunnel.

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. Figure 5 shows the schematic of the experimental setup.

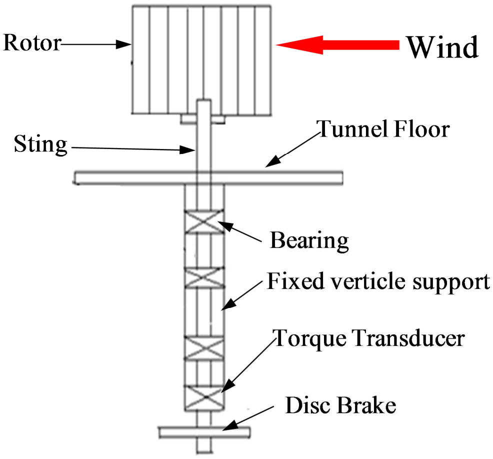

Figure 5. Schematic of the experimental setup.

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. Figure 6 shows the experimental setup for the straight blade configuration inside the RMIT Industrial Wind Tunnel.

Figure 6. 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 analysed to calculate the maximum power using the following formula:

Results and Discussion

Figures 7, 8 and 9 show the variation of torque with rotor speeds at 20, 30 and 40 km/h wind speeds for the 16-blade rotor with straight configuration, pyramid and inverted-pyramid configuration respectively. It can be observed that the torque value increases with the increase of wind speed.

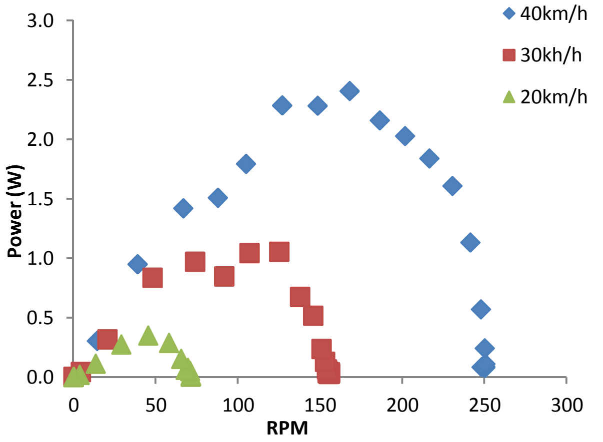

Figure 7. Rotor speed as a function of power for the straight configuration.

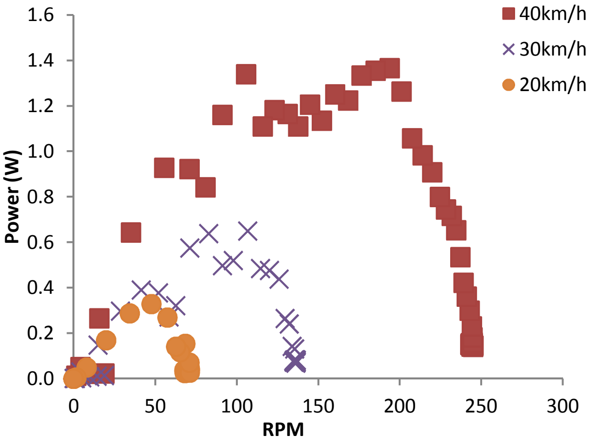

Figure 8. Rotor speed as a function of power for the pyramid configuration.

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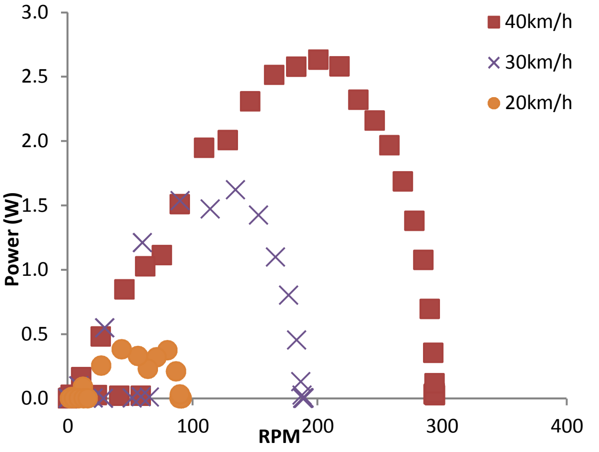

Figure 9. Rotor speed as a function of power for the inverted-pyramid configuration.

It can be seen that inverted-pyramid configuration showed higher maximum rotational speeds and power output in every wind speed compared to the first orientation and the base design. It produced an average of 27.1 % power and rotation speed compared to the pyramid configuration in every wind speed.

The effectiveness of a domestic scale vertical axis wind turbine mainly depends on its power generation capability at low wind velocity. Therefore, it is important to analyse the power output over a range of wind speeds. Figure 10 shows the variation of maximum rotor speeds with wind speeds for each configuration tested. It is found that the standard Savonius turbine (straight blade) produced the highest power, around 0.76 Watts compared to 0.74 Watts for the inverted-pyramid configuration and 0.40 Watts for the pyramid configuration at speeds below 25 km/h. However inverted-pyramid configuration was the most efficient for wind speeds above 25 km/h. inverted-pyramid configuration produced at an average of 2.5 Watts compared to 1.97 Watts for the base design. It is an increase of 27 %. Comparing the results of the straight and pyramid configuration, the straight design produced around 29.7% more power.

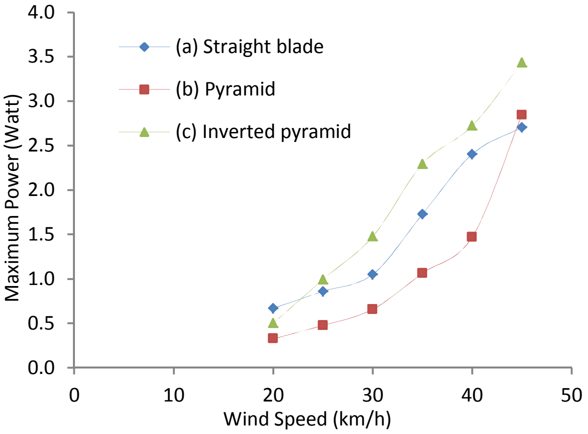

Figure 10. Power as a function of wind speed for 3 rotor configurations.

Conclusions

The results show that the conical blade angle has significant effect on the power output of a Savonius turbine. The most efficient configuration is the inverted-pyramid configuration. This configuration generated 27.1% more power the straight configuration and also increased the power output by around 48.9% from the pyramid configuration.

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