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(Research Article)

A mechanism to control the orientation of vertical axis wind turbine airfoils

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Abstract

This paper proposes a new mechanism to control the orientation of airfoil panels of a specific drag-type vertical-axis wind turbine. In this type of turbine, panel-type airfoils are exposed to catch the wind during the downwind sector of their travel and must be rotated for minimal resistance during their upwind travel. A mechanism is presented in this paper to control the orientation of the airfoil panels to achieve the desired sequence of changes of the orientations. Alternatives for the configuration of the panels are also discussed; although the mechanism works with single or sectioned airfoils, analysis is provided which indicates that sectioned airfoils have advantages for this type of turbine.

Keywords: Wind; energy; Vertical axis wind turbine; VAWT; Savonius turbine

1. Introduction

This work concerns power generation with a Savonius-type of Vertical Axis Wind Turbine (VAWT). Previous COMSOL simulations [1] have shown that the concept of dragged vertical panels is promising, but there are some additional significant design issues to be addressed. Specifically, the type of machine which we consider requires a periodic change of the orientation of a (wind-dragged) panel from horizontal to vertical orientation. In this work we explore the issues associated with this requirement and propose a design solution.

First, it should be clarified that many Vertical Axis Wind Turbine (VAWT) models which have been proposed are generally operating with either of two main principles. One class of VAWTs known as the Darrieus type [2, 3, 4], operates using airfoils powered by lift forces similarly to the lift which supports an airplane during flight. The typical example geometry is shown in Figure 1a where different air speeds above and below the airfoil create a pressure differential according to the Bernoulli effect and thus create lift forces from the higher pressure side to the lower pressure side.

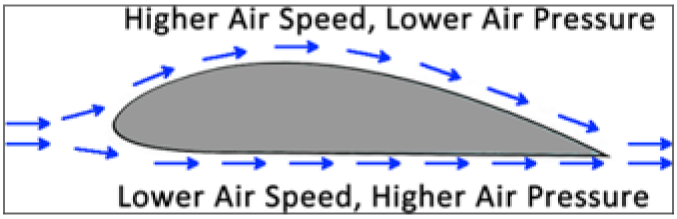

Figure 1 a Lift-based airfoil.

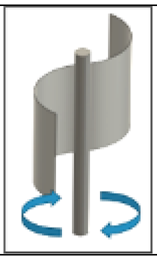

Figure 1 b Drag-based airfoil

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The second class of VAWTs known as the Savonius type[5, 6, 7], operates by using airfoils which deflect the flow of air and thus are powered by air drag forces. Various configurations have been proposed to create asymmetric drag forces on opposite sides of the vertical shaft. Some, like the ones shown in Figure 1b, use static designs which have different drag properties based on their rotational position, and some are based on actively changing the orientation of the airfoil during the rotation. An example of the latter design is shown in Figure 2 where the airfoils consist of simple flat panels.

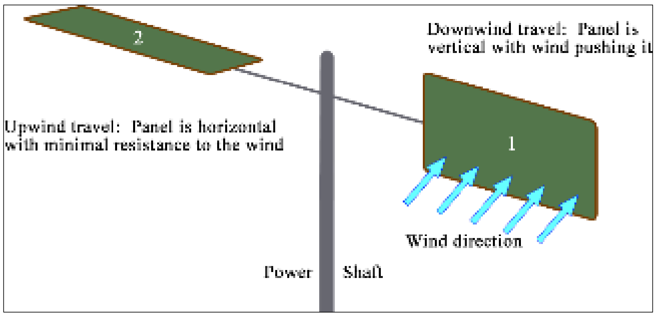

Figure 2 Design concept of a wind drag powered turbine.

In this configuration, the panel 1 -standing vertically- is deflecting the wind so drag is induced on it, whereas panel 2 is horizontal so the drag on it is minimal. The asymmetric drag causes the power shaft to rotate. In order to sustain the rotation the panels must flip orientations once panel 1 reaches the farthest downwind position where it is aligned to the wind direction. At that position, panel 2 starts its downwind travel and thus the wind needs to push it, so it has to flip up.

2. Design Issues

Consider the concept of Figure 2 as illustrated in Figure 3. In order for the concept of Figure 3 to work, the VAWT must implement some mechanism to change the orientation of the airfoil panel which is used for power generation. This panel must remain horizontal when travelling upwind. Then it should be changed to a vertical orientation right when it is at the position where it starts its downwind travel (shown as position A) and it must be turned back to horizontal when it is at the point where it starts its upwind travel (shown as position B). At position A the panel would start catching the drag and be productive, and at position B it has lost the drag and will no longer be productive as it travels upwind to position A again.

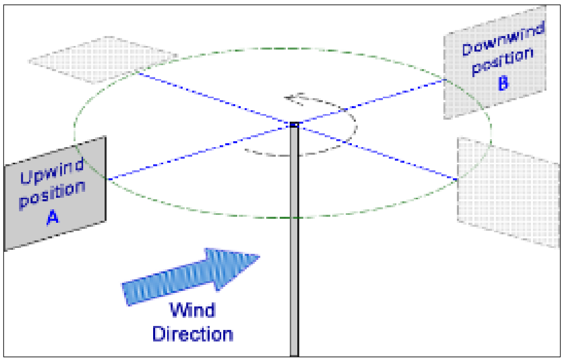

Figure 3 Reference positions for re-orienting the airfoil panels

Therefore a mechanism is needed to implement the orientation changes. There are a couple of possibilities; a passive one which initially appears attractive and an active one which appears more appropriate.

2.1. Passive Designs

It is possible to use a passive configuration where the wind itself re-orients the panels when they switch sectors between downwind and upwind. For example:

It is possible to use asymmetric support for the panels, so that the wind itself can change the orientation of a panel depending on which side the wind hits it. Along with asymmetric support, a panel may maintain an orientation that is almost horizontal but not completely horizontal, so that at the beginning of the downwind section the wind catches the edge of the panel and does the work of turning the panel vertical (hence the passive mode). Obviously, the mounts of the panel onto the horizontal axis must only allow a quarter turn of the panel, i.e. only between the horizontal and vertical orientations. Possible designs to do this are shown in Figures 4 and 5 but the key drawback is exactly that the wind is expected to do the re-orientation work. This would require either very lightweight panels or substantial wind intensity and would not work well with light winds.

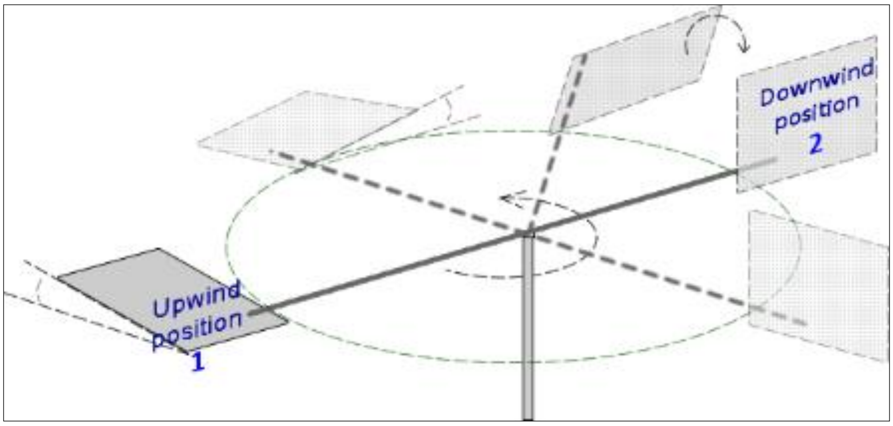

Figure 4 The horizontal shafts support the panels off-center so that the panel's orientation can be turned by the wind itself. On the downwind travel the panel exposes a side which the wind can catch and turn it

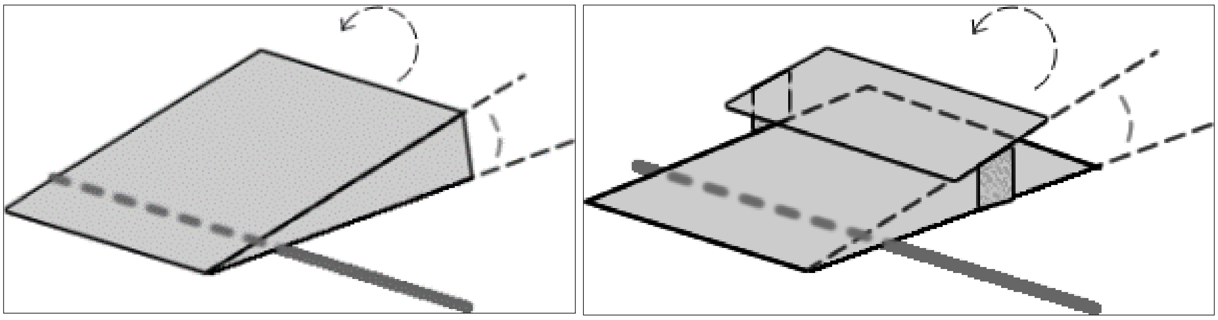

Figure 5 Different ways to expose a side which the wind can catch and flip in only one wind direction

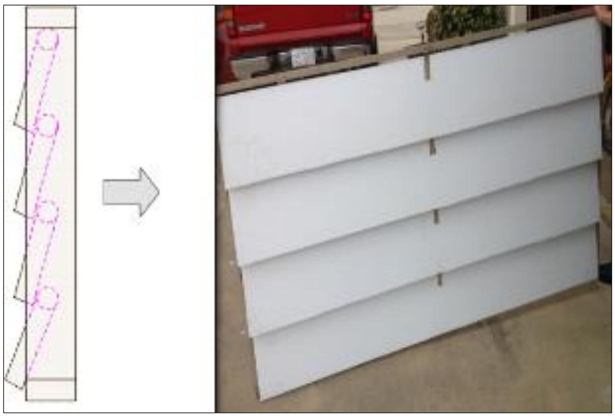

Figure 6 Louver style panels which can only open in one direction

The design of Figure 6 uses a panel which was made of louver-type of sections which can only open to a horizontal orientation when blown from one direction but they will remain vertical when blown in the opposite direction [Senior project tested by Anthony Benasco, Brody Holloway, and Hulon Reid]. The main issues with these passive designs are the following:

- First, the wind must do the work of reorienting them so a significant part of the downwind travel is not really used for the purpose of energy generation, i.e. the panel is not really pushed efficiently until the airfoil is properly reoriented.
- Second, the re-orientation of the panels (or sections thereof) is uncontrolled and thus rather abrupt resulting in excessive noise, as well as impact stresses.
- Third, while the designs are scalable, the structural stresses can be excessive with very strong winds. Specifically, large panels which would work better than small ones do not perform well with weak winds and are subject to excessive stresses with strong winds.

For such reasons, a design is sought which allows for an active and more precise control of the orientation of the panels.

2.2. Active Design

A proposed design is shown in Figure 7. The mechanism is shown with supports for 4 panels. Each supporting arm can be rotated on a horizontal axis using a control arm "C1" which is pushed up/down by a control rod "C2". Each of these control rods (C2) runs on a rail guide which is uneven and pushes the control rods up in one sector of the rotation and down in the rest of the rotation. The disk which supports the control rods C2 is fixed on the rotor so that the disk and control rods rotate all together with the rotor shaft and the panel supports. The control rail and its support base are an independent assembly with separate support so that it does not rotate with the rotor shaft.

The control rail (OC) must be positioned as shown in Figure 7 relative to the wind direction. Therefore, it should able to be rotated depending on the wind direction. Its positioning only depends on the wind direction and otherwise it is independent of the rest of the system. In Figure 7 a rudder-like concept is shown to orient the base relative to the wind direction, however, in reality this rudder should be a control sensor for the wind direction to provide input for a motor which rotates the support base to match the wind direction.

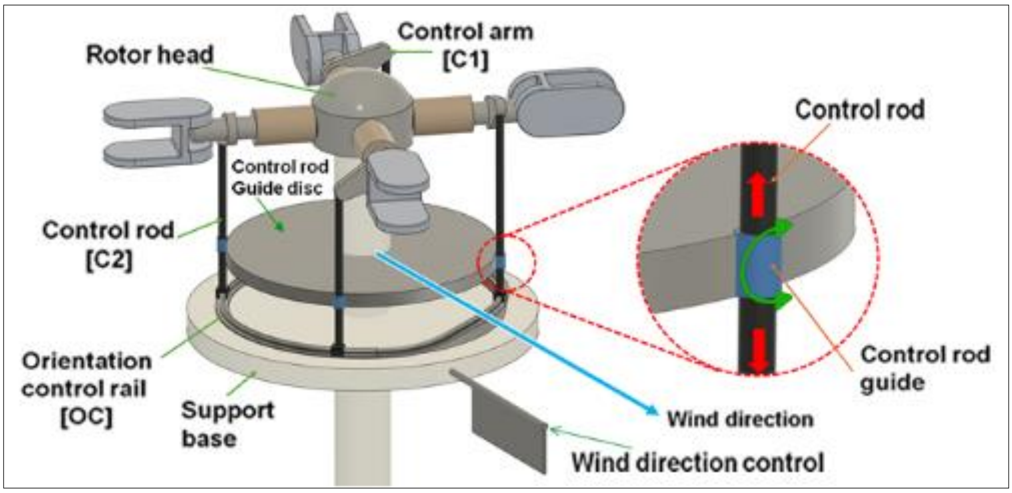

Figure 7 A proposed mechanism to control panel orientations

It should be noted that as the control rods come to the up-ramp of the rail guide, they start pushing up the control arm which in turn slightly pushes the rod away from the horizontal shaft. For this reason, the guide which holds the rod attached to the guide disk needs to have some rotational play (as shown in the detail breakout in figure 7).

3. Preferred system and airfoil

With the above considerations, the preferred system is one that uses the active design with the guide rail which controls the vertical rods, but with louver-type of panels such as in Figure 8.

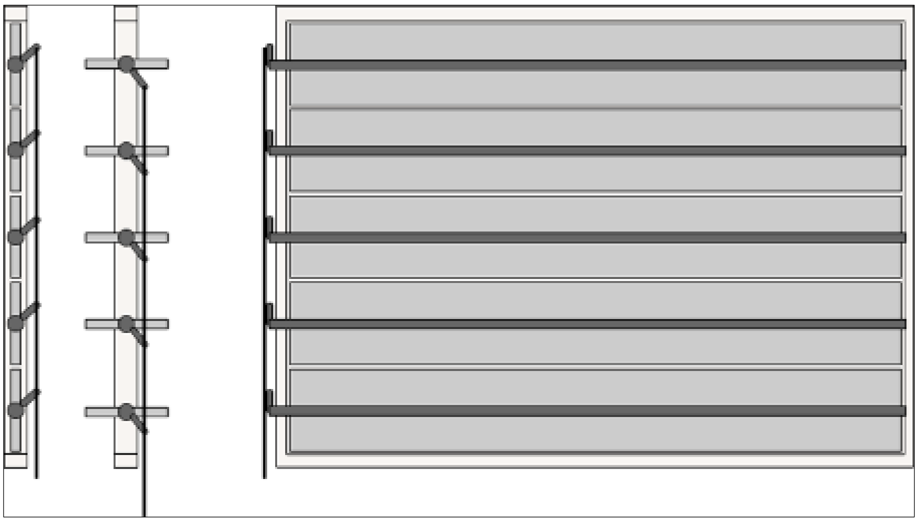

Figure 8 Louver-type sectional panels of the preferred design

Controlling a louver-type panel is preferred over rotating a large rigid panel. The motion of rotating a single-surface rigid panel for the purpose of changing its orientation, has to overcome inertia and moves air which incurs resistance to the change of orientation especially when it has to happen fairly quickly. The outer edge areas of the panel move at greater speed and so the farther away they are from the horizontal rotation axis (i.e. the larger the vertical dimension of the panel) the more the resistance to the re-orientation. Specifically, an analysis of just the inertia based on the geometry of Figure 9 is as follows:

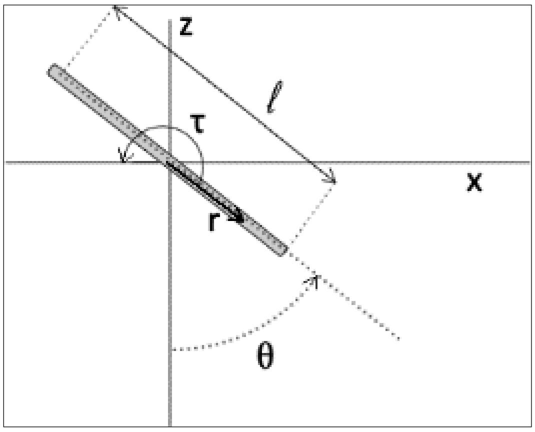

Figure 9 Inertia associated with a panel rotation

The equation of the motion of a single blade in side view is given as [8] :

$$I\ddot{\theta} = \tau,$$

where θ is the angle; τ is the torque; I is the mass moment of inertia defined as $I = \int_m r^2 \, dm$, with m and r denoting the mass of the blade and the distance measured from the rotational axis, respectively.

The mass moment of inertia can be substantially reduced by using louver-type sectional panels. If one big rectangular airfoil (panel) is used instead of multiple small panels, then referring to Fig. 9, the mass moment of inertia is computed as $I = \frac{1}{12}ml^2$, where l is the width of the panel. In this computation, the side shape of the panel is assumed to be a rectangle for simplicity. Now suppose that two identical panels, having a half width ($\frac{l}{2}$) and a half mass ($\frac{m}{2}$), are used. Then the mass moment of inertia of the two panels is computed as $I = 2\frac{1}{12}\left[\frac{m}{2}\left(\frac{l}{2}\right)^2\right] = \frac{1}{4}\frac{1}{12}ml^2$, which shows that the I of the two panels is only ¼ of the I of the single big panel.

For this reason it is advantageous for the panels to be longer in their horizontal dimension and shorter in the vertical dimension, thereby resembling orthogonal blades rather than squares. However, it is possible to take advantage of vertical space by using louver-type panels which effectively act as a collection of blades which are all controlled by the same vertical rod. When using louvers with a control rod their support should be at their center as in Figure 8 in contrast to the arrangement of Figure 6 of the passive design where the weight of each louver is supposed to aid the repositioning.

4. Conclusion

This work complements past work in which COMSOL simulations showed promise for VAWTs with vertical drag panels. A mechanism to reorient the airfoil panels was necessary for this type of VAWT design and this was the main focus of the present work.

Looking into potential extensions, it is possible to modify the design so as to variably raise the airfoil panels from the horizontal orientation, i.e. rather than raising them from horizontal to completely vertical, raise them to 75º or to 90º instead. The reason for perhaps adopting this is that we may not wish the panels fully exposed when the wind is too strong. To achieve a variable rotation of the airfoil, the control rods (C2) must be raised variably by the control rail (OC). It is possible to modify the design so that the raised part of the control rail is not static and instead it can be raised variably using actuators. To make a design like this work, the ramp parts which join the two parts of the rail can be redesigned to make them into a sleeve structure so that its length can be variable. With this, the maximum rotational speed of the turbine axis should be limited for high-speed winds.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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