Preliminary design and testing of VAWT blade for low wind speed using CFD

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Abstract. This research aims to study and design vertical-axis wind turbine (VAWT) for low wind speed using computational fluid dynamics (CFD) program called ANSYS® Academic Student Release 19.2. The wind turbine type used is of Savonius type with some parts being modified in order to optimize its rotation in the simulation. The simulation setup is to place the turbine in the middle of the wind tunnel, using initial wind speed of 5 m/s. The turbine itself has dimension of 20 cm of height, 10 cm of radius and 0.15 cm of thickness. These simulation data are used to analyses wind flow dynamics, rotational speed of the turbine, tip speed ratio and Reynolds number of this design. It found that the angular velocity is 200 rpm or 20.94 rad/s, tip speed ratio is 0.41 while Reynolds number is in turbulent flow of 6,798,002.

1. Introduction

Wind energy is one of the important renewable energy in the world. Wind turbine is one of the most common way to capture wind energy for producing power. Generally, there are two types of wind turbine, vertical and horizontal axis turbines, which used to convert kinetic energy to mechanical energy of wind turbine. The type of wind turbine used for this work is vertical wind axis turbine (VAWT) due to omnidirectional capability at low wind speeds [1]. VAWT that considered in this work is Savonius wind turbine. Savonius wind turbine is a drag driven wind turbine. While operating, in certain angular position of the rotor, and while the tip speed ratio is greater than one, the lift force acts on blades [2].

In this work, computational fluid dynamics (CFD) is use for the simulations to study aerodynamic characteristics and the performance of wind turbine design. The turbine used for simulation is a two-stack Savonius wind turbine as shown in figure 1. Physical properties of the turbine is show in table 1. The setup condition to be use in CFD simulation is to place wind turbine in the middle of wind tunnel with dimension of 30x30 cm² and 2 m long using wind speed of 5 m/s injected from the inlet of wind tunnel. The data collected form the simulation is rotational speed of wind turbine, collected by placing a measurement point between the blades. This measurement point will record wind velocity as a function of time. Its time evolution graph can be used to calculate the rotational speed as the velocity normally drops when one of the blades is passing through the point. Other physical values such as angular velocity, torque, Reynolds number etc. can then be calculated from the measured rotational speed [3].
Table 1. Illustration of Savonius wind turbine.

| Properties of the wind turbine | Detail |
|--------------------------------|--------|
| Number of blade                | 2x2 (stack) |
| Height                         | 20 cm  |
| Radius                         | 10 cm  |
| Blade thickness                | 0.15 cm |
| Plate thickness                | 0.1 cm  |
| Gap between two blades         | 2 cm    |
| Material                       | Acrylic |
| Mass                           | 217.0957 |
| Moment of inertia              | 0.00092 kg.m² |

Figure 1. Two-stack Savonius wind turbine (a) Image in simulation (b) Image of geography (Images used courtesy of ANSYS, Inc.).

2. Method

2.1. Methods

2.1.1. Wind power. Wind power is a kinetic power that flows into wind turbine [4]. It can be calculated as follows:

\[ P_{\text{wind}} = \frac{1}{2} \rho A v^3 \]  

(1)

where \( \rho \) is air density (kg/m³), \( A \) is rotational area and \( v \) is wind speed (m/s)

2.1.2. Angular velocity. Angular velocity refers to how fast an object rotates or revolves relative to a reference point [5]. In general, angular velocity is measure in angle per unit time, which is radians per second in SI units. The unit can be change to rpm (round per minute) as shown:

\[ 1 \text{ rad/s} = \frac{1}{2} \text{ Hz} = \frac{60}{\pi} \text{ rpm} \]  

(2)

2.1.3. Tip speed ratio. The tip speed ratio is defined as the ratio of the blade tip speed and the wind speed at which the blade tip moves with rotation [3], calculated as:

\[ \lambda = \frac{\omega r}{v} \]  

(3)
where \( \lambda \) is tip speed ratio, \( \omega \) is the angular velocity of wind turbine (rad/s), and \( r \) is the radius of wind turbine (m).

2.1.4. Reynolds number. The Reynolds number is a dimensionless value that measures the ratio of inertial forces to viscous forces and describes the degree of laminar or turbulent flow [6] as shown:

\[
Re = \frac{\rho v}{\mu} \frac{vL}{k}
\]

(4)

where \( Re \) is Reynolds number, \( \mu \) is dynamic viscosity (Ns/m\(^2\)), \( L \) is the blade chord length (m) and \( k \) the kinematic air viscosity (m\(^2\)/s).

2.2. CFD simulation parameters. The simulation program used for study is ANSYS® Academic Student Release 19.2, the parameters for simulations are shown in table 2.

| Parameter          | Values          |
|--------------------|-----------------|
| Wind speed         | 5 m/s           |
| Viscous model      | k-epsilon       |
| Air density        | 1.225 kg/m\(^3\) |
| Air viscosity      | 1.7894e-05 kg/m\(^2\)/s |

3. Result and discussion

Figure 2 shows the effect of wind speed on wind turbine blades, presented using contour plot. Note that the contour line on upper blade and lower blade are the same. It can be seen that the wind speed close to the blades ranges from close to 0 (in front of the blade) to around 13.37 m/s (at the back of the blade).

![Figure 2. Contour line illustrating the effect of wind speed on wind turbine blades at different time (Images used courtesy of ANSYS, Inc.)](image)

Figure 3 demonstrates a time evolution of wind velocity of a single point inside the rotation region, used for measurement, in the simulation grid as marked in figure 2. It can be seen that the wind velocity varies up and down as the blades spin around. The dropped values correspond to the moment where one of the blades coincide with the measuring point. Hence, the frequency of the dropped wind velocity can be used to estimate the rotational speed for the wind turbine. As a result, for a wind speed of 5 m/s, the rotational speed is equal to 200 rpm. Consequently, other parameters can be calculated i.e.
the angular velocity is 20.94 rad/s. The tip speed ratio is 0.41 which is normally too low for tip speed ratio standard for 2 blade type turbine [7]. Reynolds number equals to 6798002 which means that the flow around the blade is categorized as turbulence [8].

4. Conclusion
In this study using computational fluid dynamic, the results show that dynamic mesh method can be used to study the performance of wind turbine in pre-defined condition. The preliminary result show that the turbine has rotational speed of 20.94 rad/s at incoming wind speed of 5 m/s. Tip speed ratio and Reynolds number show that this wind turbine has a low efficiency but can perform at the low wind speed.

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