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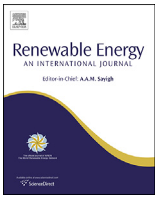

Innovative improvement of a drag wind turbine performance

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ABSTRACT

Drag type wind turbines have strong potential in small and medium power applications due to their simple design. However, a major disadvantage of this design is the noticeable low conversion efficiency. Therefore, more research is required to improve the efficiency of this design. The present work introduces a novel design of a three-rotor Savonius turbine with rotors arranged in a triangular pattern. The performance of the new design is assessed by computational modeling of the flow around the three rotors. The 2D computational model is firstly applied to investigate the performance of a single rotor design to validate the model by comparison with experimental measurements. The model introduced an acceptable accuracy compared to the experimental measurements. The performance of the new design is then investigated using the same model. The results indicated that the new design performance has higher power coefficient compared with single rotor design. The peak power coefficient of the three rotor turbine is 44% higher than that of the single rotor design (relative increase). The improved performance is attributed to the favorable interaction between the rotors which accelerates the flow approaching the downstream rotors and generates higher turning moment in the direction of rotation of each rotor.

1. Introduction

Wind energy conversion systems became widely spread as a clean and environmentally friendly means of electric or mechanical power generation. Wind turbines are used to convert the mechanical energy of the wind into mechanical shaft power needed to directly drive machinery or electric generators to generate electricity. Large capacity wind farms now represent a reliable means of electricity supply in many regions.

Wind turbines are classified into two categories according to the orientation of the turbine rotating shaft; horizontal axis type (HAWT) and vertical axis type (VAWT). The modern design of HAWT utilizes high lift devices, airfoils, to generate driving forces by the action of wind. Such design normally uses three blades of diameters up to 120 m to generate power up to 5 MW or more. The energy conversion efficiency of these turbines may reach 47% [1,2]. VAWT, on the other hand, have been limited in use, compared to HAWT because their conventional designs have relatively lower efficiency. These turbines have two types; lift driven types which use airfoil blades arranged in a vertical orientation on the periphery of a circle and driving a vertical shaft located at the center of this circle. The former turbine type is called Darrieus wind turbine, after the French inventor, Georges Darrieus in 1931. In our group, the performance of the Darrieus turbine has been investigated and improved [3–5]. Moreover, drag driven type using semicircular buckets also arranged vertically with the Darrieus turbine to drive the turbine shaft. The turbine is called Savonius wind turbine, after the Finish engineer Sigurd Savonius in 1929.

Research in the field of Savonius wind turbines has received considerable attention in the recent years due to the following advantages (see Akwa et al. [6] for a comprehensive review):

1. Simple construction.
2. The location of the mechanical systems can be installed near ground level.
3. Self-starting at low wind speed.
4. Performance is independent on wind direction.
5. Limited wake effect.

Recent research work has been directed towards enhancing the performance of this turbine type to allow economical application for small/medium stand-alone systems. Further, Dabiri [7] showed

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that wind farms utilizing VAWT have higher power density by using Darrieus turbines, compared to the power density of HAWT. Therefore, VAWT can be extended in use to wind farms too. Due to their limited wake effects, VAWT new designs are sought to increase their energy conversion efficiency to enhance their capabilities in this field.

The basic shape of Savonius wind turbine is shown in Fig. 1. It consists of two buckets, usually of semicircular shape, which are positioned in opposite orientation to wind direction. In the static condition, the concave bucket facing the wind is subjected to high drag force due to wind action while convex bucket is experiencing lower drag force. This difference in drag forces allows the turbine to start rotation under the action of the wind. Following startup, the wind forces on the buckets continue to generate the required torque to drive the turbine and useful power can be extracted from the turbine.

The performance of the Savonius turbine is affected by many geometric parameters. These include bucket shape, spacing and overlap ratio between the buckets, number of buckets and number of turbine stages. The aspect ratio be-tween turbine height and diameter also affects the performance of the turbine. A review of research work on these effects is also reported by Akwa et al. [6]. Fig. 2 shows a comparison of the power coefficient Cp between. different types of wind turbines, including the Savonius turbine [2]. The power coefficient is the ratio between the power output of a wind turbine and the available power in wind and it is defined as:

$$C_p = \frac{M\omega}{\frac{1}{2}\rho U_w^3 A} \qquad (1)$$

where M is the average aerodynamic moment acting on the rotor shaft, is the angular speed of the rotor, A is the frontal area of the turbine, is the air density and U_W is the approaching wind speed. The moment coefficient of the turbine Cm is defined as:

$$C_m = \frac{M}{\frac{1}{2}\rho U_w^2 AR} \qquad (2)$$

where R is the rotor radius. The tip speed ratio of the turbine is defined as:

$$\lambda = \frac{\omega R}{U_w} \qquad (3)$$

Using (3) the relationship between turbine power coefficient and moment coefficient is written:

$$C_p = \lambda C_m \qquad (4)$$

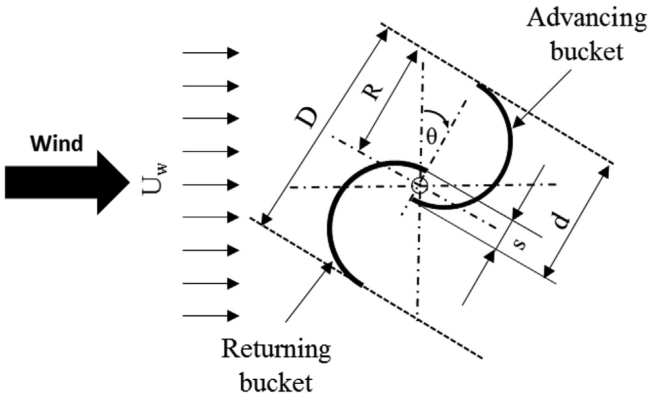

Fig. 1. Basic geometry of Savonius Turbine.

As can be seen in Fig. 2, the power coefficient of the HAWT reaches nearly 50% at λ > 6. On the other hand, Darrieus type VAWT has a maximum power coefficient of 40% at λ = 5 for darrieus turbine [6]. The Savonius turbine has the least value of the power coefficient of 18% at λ ~1. Many modifications to enhance the performance of the Savonius turbine using geometric optimization resulted in increasing the power coefficient of the turbine to 25% at λ.

~0.8 [8–12]. Other efforts were directed to using frontal guiding plates to shield the returning bucket from the unfavorable drag effects and resulted in good improvement of the pressure coefficient. Using flat plate deflectors, some researchers reported a peak power coefficient of 40% [8,13].

Computational fluid dynamics (CFD) has been applied extensively in wind turbine flow analysis and turbine performance evaluation. In this technique the governing flow equations are discretized by integrating them over finite volumes which are constructed to cover the flow domain of interest and applying the appropriate boundary conditions. The discretized set of algebraic equations is solved using numerical techniques for simultaneous algebraic equations to obtain the distribution of flow variables such as velocity, pressure and turbulence quantities. These variables are further employed to obtain the interacting forces between fluid and turbine elements. The CFD technique provides effective means of investigating the fluid–turbine interaction parameters by providing detailed view of flow behavior in the domain of interest. The information obtained may sometimes be impossible to obtain using experimental techniques due the complex nature of flow interactions and the rotation of the turbine rotor which does not allow fixing instrumentation to the rotor.

Many authors have reported CFD application for the analysis of wind turbine flow with high accuracy including (Mohamed et al. [8,9], Altan and Atılgan [13], Akwa et al. [15], D'Alessandro et al. [16]). The solution accuracy obtained using CFD is judged by comparison between the simulation results and available experimental results. Dobrev and Massouh [17] reported a comparison between CFD simulations with k- SST model and PIV (Particle Imaging Velocimetry) measurements for the flow around Savonius wind turbine. Reynolds number calculated with rotor diameter and rotor peripheral velocities during the tests varies between 140,000 and 170,000. They concluded that the CFD results can be reliably used for overall assessment of flow–turbine interactions. [Mohamed et al. [8] [9], Altan and Atılgan [13]] also reported CFD results for guide plate effect on the performance of Savonius turbine performance. Akwa et al. [15] examined the effect of overlap ratio between buckets of a Savonius turbine using CFD.

Very few studies have been reported on the analysis of multi-rotor Savonius wind turbine [18,19]. This arrangement involves interaction between the rotors and was found to produce favorable effects and to enhance the performance of the turbine. Sun et al. [18] studied the aerodynamic coupling effect between multiple Savonius turbines using numerical simulations. They investigated different rotor arrangements including two and three parallel and rotors in triangular arrangement. They reported enhanced average performance for the three rotors in triangular arrangement compared with single rotor. The optimized spacing and phase shift arrangement between rotors resulted in a power coefficient of 30% at $\lambda = 1$. Shigetomi et al. [19] also reported numerical study on the interactive flow field around two Savonius turbines. They showed some interesting interaction effects on the performance of twin rotor Savonius turbines which depend on the spacing between the turbines.

The idea of using multi rotor turbine was envisaged in the model proposed by horizontal axis three-bladed turbine. The purpose is to minimize the wake effect of the turbine to enable shorter