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INCIDENCE ANGLE EFFECT ON THE TURBULENT FLOW AROUND A SAVONIUS WIND ROTOR

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Abstract

This study aims to investigate the effect of the incidence angle on the aerodynamic characteristics of the flow around a Savonius wind rotor. Six configurations with different incidence angles equal to θ=0°, θ=30°, θ=60°, θ=90°, θ=120° and θ=150° were studied. For this, we have developed a numerical simulation using the Computational Fluid Dynamic (CFD) code Fluent. The considered numerical model is based on the resolution of the Navier-Stokes equations in conjunction with the k-ε turbulence model. These equations are solved by a finite volume discretization method. Particularly, we are interested in visualizing the velocity field, the mean velocity, the static pressure, the dynamic pressure, the turbulent kinetic energy, the dissipation rate of the turbulent kinetic energy and the turbulent viscosity. Results confirm that the variation of the incidence angle has an effect on the local characteristics. Our numerical results were compared with those obtained by anterior results. The comparison shows a good agreement and confirms the numerical method.

Keywords: wind, energy, earth, source, power.

Introduction

In recent years, an interest in wind energy has been growing and wind turbines are developed to generate electricity from the kinetic power of the wind. Wind turbines can rotate about either a horizontal or a vertical axis. Savonius wind rotors are a type of vertical-axis wind turbine. The Savonius wind rotor has the advantage of being compact, economical and aesthetic. In addition, they have good starting characteristics, operate at relatively low operating speeds and have the ability to accept the wind from any direction. For several years, many studies have significantly improved the performance of Savonius rotors. For example Kamoji et al. [1] investigated the performance of modified forms of conventional rotors with and without central shaft between the end plates.

Research results

Menet and Bourabaa [2] tested different configuration of the Savonius rotor and found that the best value of the static torque coefficient is obtained for an incidence angle equal to θ=45° and a relative overlap equal to e/d=0.24. They compared their numerical results with those obtained by Blachwell et al. [3] and a good agreement was obtained. Aldos [4] studied the power augmentation of the Savonius rotor by allowing the rotor blades to swing back when on the upwind side. He reported a power augmentation of the order of 11.25% with the increase in Cp from 0.015 to 0.17. Ushiyama and Nagai [5] tested several parameters of the Savonius rotor including gap ratio, aspect ratio, the number of cylindrical buckets, the number of stages, endplate effects, overlap ratio, and bucket design. The highest efficiency of all configurations tested was 24% for a two-stage, two-bucket rotor. Grinspan et al. [6] [developed a new blade shape with a twist for the Savonius rotor. They obtained a maximum power coefficient of 0.5 with this model. Saha and Rajkumar [7] compared the performance of a bladed metallic Savonius rotor to a conventional semi-circular blade having no twist. The twist produced good starting torque and larger rotational speeds and gives an efficiency of 0.14. The best torque was obtained with blades twisted by an angle α=12.5°. Akwa et al. [8] studied the influence of the buckets overlap ratio of a Savonius wind rotor on the averaged torque and power coefficients by changing the geometry of the rotor. They noticed that the maximum device performance occurs for buckets overlap ratios with values close to 0.15. Khan et al. [9] tested different blade profiles of a Savonius rotor both in tunnel and natural wind conditions and they varied the overlap. The highest Cp of 0.375 was obtained for blade profile of S-section Savonius rotor at an optimum overlap ratio of 30%. Rogowski and Maroński [10] studied the aerodynamic efficiency of the Savonius rotor using computational methods of fluid dynamics. The obtained CFD results are compared with the experiment. The study has demonstrated that the CFD methods confirm the experimental results and can be used to optimize the shape of buckets of the Savonius rotor. Mohamed et al. [11] considered an improved design in order to increase the output power of a Savonius turbine with either two or three blades. Choudhury et al. [12] analyzed flow characteristics of two bladed Savonius rotor with 2D and 3D analyses using CFD ANSYS Fluent software. They also studied the static pressure, the velocity, the vorticity and the turbulent kinetic energy. According to their results, the drag and the torque coefficient are maximum respectively at 0 and 30° rotor blade angles, the vorticity and the turbulent kinetic energy show the maximum value at 30° rotor blade angle. Driss et al. [13] conducted a computational fluid dynamic study to present the local characteristics of the turbulent flow around a Savonius wind rotor. They compared their numerical results with experimental results and a good agreement was obtained. Driss et al. [14] made a numerical simulation of the turbulent flow around a small incurved Savonius rotor and compared the results with experimental results conducted in an open wind tunnel. In comparison with a circular Savonius rotor, the flow circulation of this rotor is enhanced. Driss et al. [15] compared different design of rotors characterized by the bucket angles equal to ψ=60°, ψ=75°, ψ=90° and ψ=130°. It has been noted that the depression zones increase with the increase of the bucket arc angle. The acceleration zone, where the maximum velocity values are recorded, is formed in the convex surface of the rotor bucket and gets greater as the bucket arc. The wakes characteristics of the maximum turbulent values are more developed with the increase of the bucket arc angle. Matrawy et al. [16] considered main design and performance parameters of a small scale vertical axis wind turbine. They designed two models (Two and Four cambered blades) and tested in an open wind tunnel. They studied parameters including the variation of the rotational speed at different blade angles as well as the variation of torque and power coefficients at different tip-speed ratios. They also carried out to the investigation on the performance of the turbine with and without leading edge flap blades. The experimental results showed that the blade angle of 45° increases the performance of the vertical axis turbine comparing to the other ones for both two and four-bladed rotors. Using of flap blade showed increase of the power coefficient by 2.4% compared with the same model without flap blade. Ahmed et al. [17] designed vertical axis wind turbine model having three frames with cavity vanes, fabricated and tested in a low-speed wind tunnel. This type of model has a high drag coefficient when the vanes close the frame on one side while rotating with wind direction and capture the wind efficiently. On the other side, the frame rotates in the opposite direction of the wind which opens the frame causing the wind to pass through the frame with low resistance. The model is tested in a wind tunnel with different wind speeds. This new model gives the maximum power coefficient of 0.32 at a wind speed of 8.2 m/s and tip speed ratio of 0.31. Other works [18-21] [18] performed unsteady simulation and compared improved version of Savonius rotor to contribute on the improvement of Savonius rotor. Roy et al. [19] reviewed the numerical works. They have shown that with the selection of a proper computational methodology, the design, performance, and efficiency of a Savonius rotor can be enhanced significantly.

In this context, we are interested in studying the effect of the incidence angle on the aerodynamic characteristics of the flow around a Savonius wind rotor. For thus, we develop numerical simulations of the turbulent flow using a CFD code.

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Conclusions

Numerical simulation of the turbulent flow around a Savonius wind rotor was investigated for different incidence angles. According to the obtained results, the incidence angle of the Savonius wind rotor has a direct effect on the turbulent flow. Local characteristics such as velocity field, mean velocity, static pressure, dynamic pressure, turbulent kinetic energy, dissipation rate of the turbulent kinetic energy and turbulent viscosity are different from one configuration to another. The variation of the coefficient of the static torque C_{Ms} of the Savonius rotor was also studied and numerical results were compared with those obtained by anterior results. A good agreement was obtained and confirmed the numerical method. In the future, we propose to study the effect of the overlap of the buckets on the turbulent flow around the Savonius wind rotor.

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