Aerodynamic study of a Savonius type vertical axis wind turbine for different axial positions between the blades

Habib Merouane [a]*, Mohammed Senouci [b], Ismail Drai [a,] Rachid Sahnoun [a]

[a] *Department of Mechanical Engineering, University of Mascara,* Algeria

[b] *Preparatory School in science and technology, Oran, Algeria*

* Corresponding author, E-mail address: merhabib@gmail.com

Abstract

In this work we present a numerical study on the aerodynamic behavior of a vertical axis wind turbine of the Savonius type for different axial positions between the blades (overlap rates a/D). The study focuses on predicting the effect of the axial position of the blades to the torque coefficient and also to determine the dynamic field of the flow around the wind turbine for three cases overlap rates (a/D=0, a/D=0.16 and a/D=0.32). The study of the numerical simulation is carried out using a CFD calculation code with use of the finite volume method for the discretization of the differential equations. The equations governing the flow are solved by the SIMPLE algorithm using the K-epsilon model as the closure model.

Keywords: Savonius turbine, Wind turbine, vertical axis wind

1. Introduction

The Savonius rotor is one of the simplest devices to generate energy by converting the wind energy into electrical energy in a more economical way and without any pollution. The construction and the aerodynamic profiles of the blades rotor having a significant effect on the efficiency and power of the wind turbines. Several research and works have been carried out in recent years which have led to very useful and important developments to improve the efficiency of vertical axis wind turbines despite the Betz limit [1-5]. Ebrahimpour et al [6] investigated the effect of the central axial and radial position of the blades to the performance of the vertical axis wind turbine by the numerical study by using a realizable K-ε model. They found that the rotor with central axial position e1/R = 0, 15 and central radial position e2/R = 0, 1 illustrate good performances to other Savonius wind turbine. And they found also that the

coefficient torque Cm is performed about 16 % and the power coefficient Cp is performed about 7.5 % compared to the Savonius wind turbine with a zero central axial and radial position.

K.R.Abdelaziz et al [7] studied by the numerical simulation the performance of the standard vertical axis turbine for three different blades configurations. They use the URANS approach and the Shear Stress Transport model to predict the flow around the wind turbine. They found that the power coefficient of the vertical axis turbine increase for the case of the wind turbines that have blades with auxiliary and straight curves.

Nur Alom et al [8] investigated the effect of blade profiles of the Savonius wind turbine on the performance of the coefficient torque and power coefficient by the numerical simulation and experimental study. A modified Bach, semicircular, and elliptical profiles are tested. The k-ω model is employed for the numerical simulation. They found that the power coefficient Cp of the elliptical bladed wind turbine is performed by 20.25% then the semicircular, 19.49% then the Benesh and 17.28% then the modified Bach rotors.

Dominicus et al [9] investigated by the experimental study the influence of the wind velocity to the torque and power coefficients of the Savonius rotor with slotted blades. In his experimental study they used two different blades with different overlap ratio. The wind velocity adopted in the experimental test is 5, 94 m/s. They found that the addition of slotted blades can gives good efficiency of the Savonius rotor and they prove that the Savonius rotor with 10 % overlap ratio gives the best performance.

Alom and Saha [10] studied the influence of the central axial positions between the blades on an elliptical profile by numerical simulation by varying the overlap ratio from zero to 0.3. They found that the wind turbine with overlap ratio 0.15 gives good performance compared to the wind turbine with overlap ratio 0.2.

In this work we present a numerical simulation study on the aerodynamic behavior of the Savonius wind turbine for different axial positions between the blades (overlap ration a/D). The study focuses on predicting the effect of the axial position of the blades to the torque coefficient and also to calculate the dynamic flow field around the Savonius wind turbine for three cases overlap ratio (a/D=0, a/D=0.16 and a/D=0.32). Our study focuses on a vertical axis wind turbine of Savonius type shown in Figure 1. The Savonius rotor is composed of two shaped blades of height H = 1.6D offset from each other by a distance e=0.16D and different overlap rates (a/D=0, a/D=0.16 and a/D=0.32).
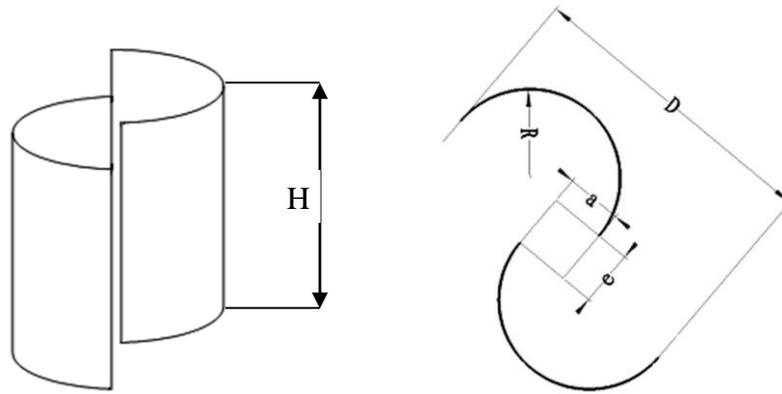
Fig.1 Savonius rotor

2 Mathematical modelling

2.1 The model of turbulence k-ε

The model of turbulence k-ε is the most used for the prediction of turbulent flows. This model is based on the Boussinesq approximation by modelling the Reynolds stresses

$$-\rho \overline{u_i' u_j'} = \mu_t \left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i} \right) - \frac{2}{3} \rho k \delta_{ij} \tag{1}$$

With k present the kinetic energy of turbulence defined by:

$$k = \frac{1}{2} \overline{u_i' u_i'} \tag{2}$$

The viscosity of turbulence μ_t is modeled as follows:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{3}$$

With ε is the dissipation rate given by:

$$\varepsilon = \frac{\mu_t}{\rho} \left(\frac{\overline{\partial u_i}}{\partial u_j} \frac{\partial u_i}{\partial u_j} \right) \tag{4}$$

For the k-epsilon model the two additional equations are given by:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k \overline{u}_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_M + S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_i}(\rho \varepsilon \overline{u}_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{\varepsilon 1} \frac{\varepsilon}{k}(G_k + C_{\varepsilon 3} G_b) - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k} + S_\varepsilon \tag{6}$$

Were G_k and G_b are the kinetic energy of turbulence due to mean speed gradients and buoyancy, respectively.

$C_{\varepsilon 1}$, $C_{\varepsilon 2}$, and $C_{\varepsilon 3}$ are the constants given in table 1.

σ_k and σ_ε are the turbulent Prandtl numbers for k and respectively given in Table 1.

S_k et S_ε are the source terms for k and ε respectively.

The coefficients of the model are given in Table 1:

Table 1. Constants of the standard k − ε model

C_μ	$C_{\varepsilon 1}$	$C_{\varepsilon 2}$	$C_{\varepsilon 3}$	σ_k	σ_ε
0, 09	1, 44	1, 92	0.5	1, 0	1, 3

The power coefficient of a wind turbine is defined as:

$$C_p = \frac{P}{\frac{1}{2}\rho V^2 SR} \tag{7}$$

Where P is the maximum power obtained from the wind, ρ is the density of air, V is the wind speed; S is the area of the turbine, R is the radius of rotation of the turbine

The torque coefficient of the wind turbine is defined as:

$$C_m = \frac{C}{\frac{1}{2}\rho V^2 SR} \tag{8}$$

With

C: represents the actual torque produced by the rotor.

$$C_p = \lambda\, C_m \tag{9}$$

λ is the Tip speed ratio between tangential speed from the rotor tip and the free-flow speed of the wind

$$\lambda = \frac{\omega R}{V} \tag{10}$$

Were

ω : is the angular velocity of rotor and R is the radius of the rotor

3. Computational domain and mesh generation

The mesh is generated by using the CFD code with triangular cells (figure 3); the area modeled has dimensioned 8.9D in height and 14.2D in length. The domain of the mesh is divided in two regions; the first for stationary mesh and the second for the mobile mesh.
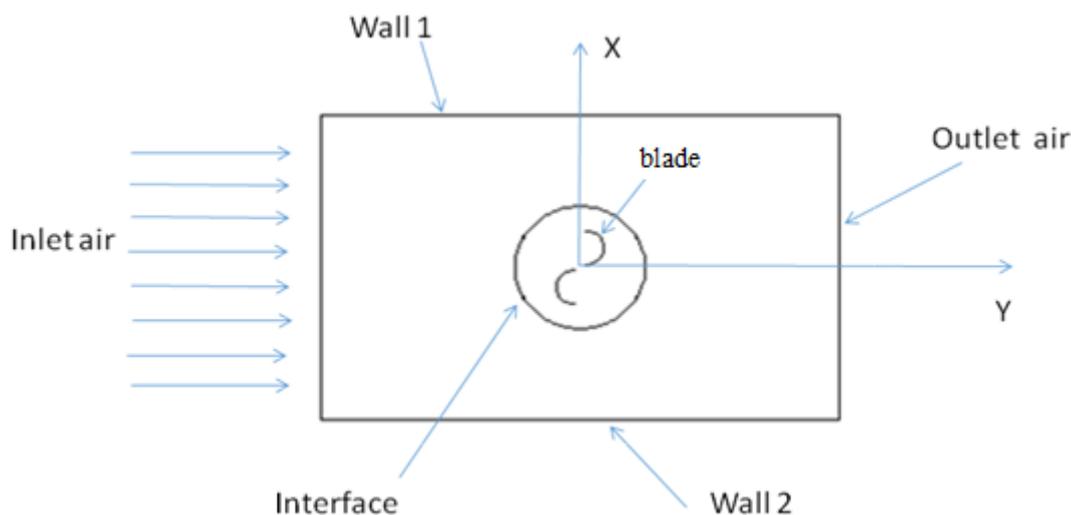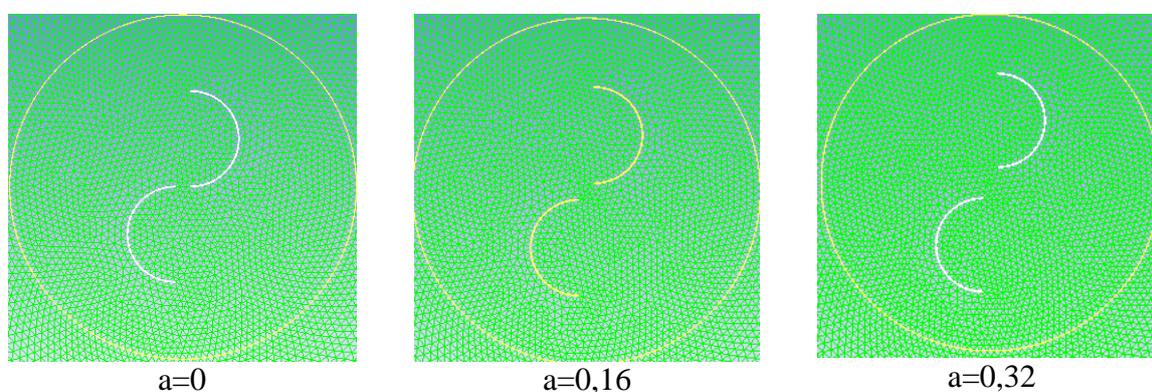
Fig.2 Computational domain

| a=0 | a=0,16 | a=0,32 |

Fig.3 mesh generation

4. Boundary conditions

The boundary conditions were chosen for four borders: at the inlet of the flow the speed is imposed (12 m/s), at the outlet of the flow atmospheric pressure is imposed. The wind turbine is limited by its two sides with two walls (Wall conditions).

5. Results and discussion

Figure 4 shows the rosette of the torque coefficient obtained by the numerical simulation for different axial positions between the blades (center distance) a/D=0, a/D=0.16 and a/D= 0.32. The results indicate that the torque coefficient is maximum when the Savonius is facing the direction of the wind for the 0° and 180° angles. The torque coefficient remains positive when the wind turbine is oriented for the angle intervals between 0° to 36°, from 160° to 230° and from 336 ° to 360°. The torque coefficient is negative for the angles between 36° to 140°, 230° to 336 one also notices that the torque coefficient increases appreciably when one shifts the position of the blades of the axis of the wind turbine.

The figure 5 shows the dynamic fields of the mean axial velocity for different axial positions between the blades (a/D=0, a/D=0.16 and a/D=0.32) for an angle close to 360°. There is a significant depression created behind the blades with a distant center distance. This depression generates a negative or almost zero dynamic fields behind the wind turbine.
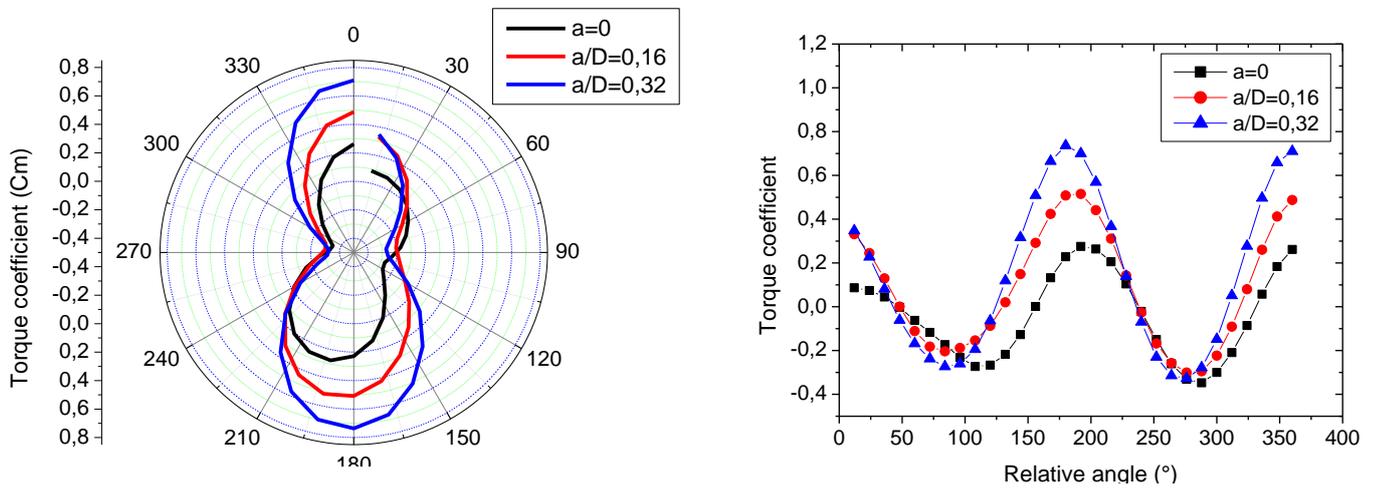

Fig. 4 Variation of the torque coefficient with the relative angle turbine angle

a/D=0

a/D=0,16

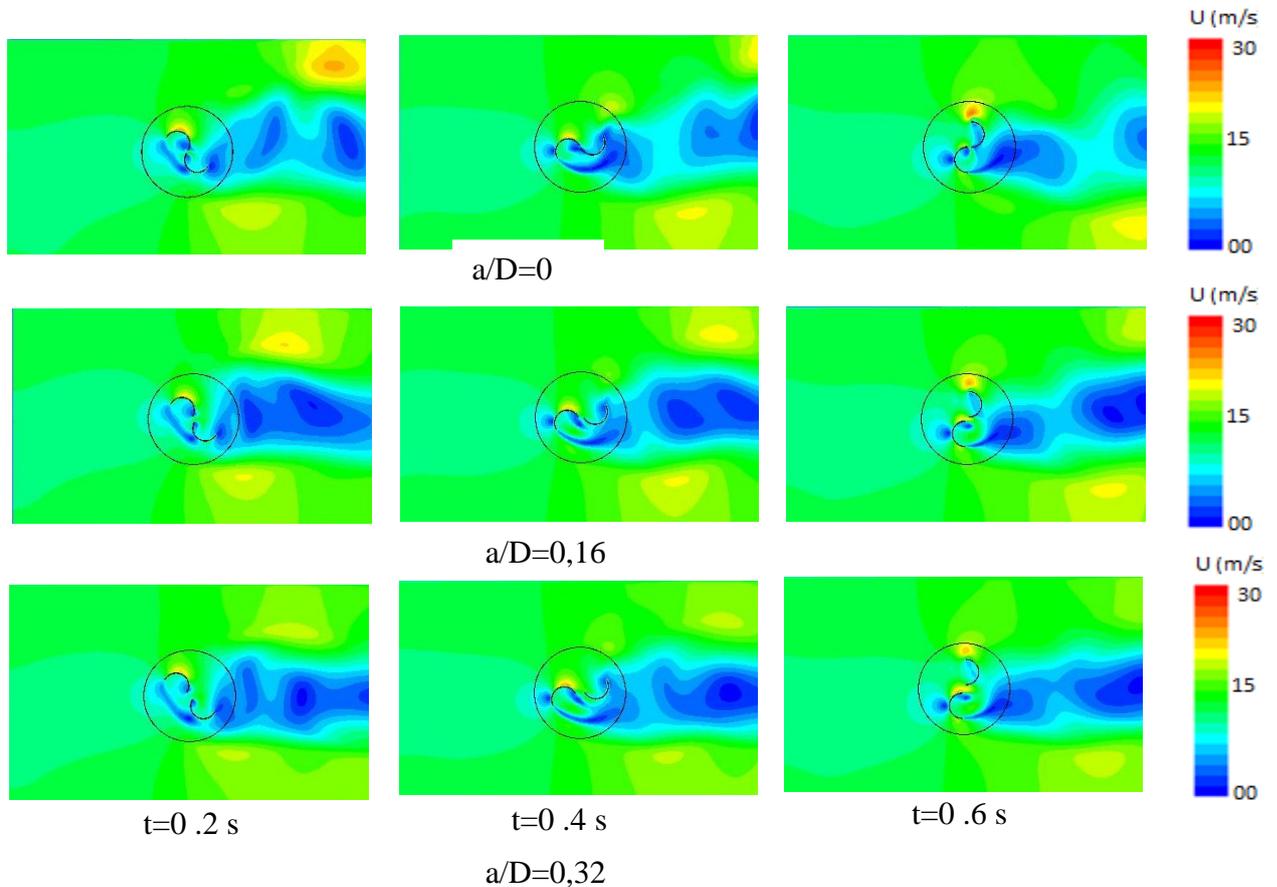t=0 .2 s   t=0 .4 s   t=0 .6 s

a/D=0,32

Fig. 5 Dynamic fields of the mean axial velocity

6. Conclusion

In this study, an unsteady numerical simulation was carried out with the CFD code to understand better the aerodynamic flow field behavior of a vertical axis wind turbine of the Savonius type for different overlap ratio

The results indicate that the torque coefficient is maximum when the wind turbine is facing the direction of the wind for the 0° and 180° angles. The torque coefficient remains positive when the wind turbine is oriented for angular intervals between 0° to 36°, 160° to 230° and 336° to 360° and is negative for angles between 36° to 140°, 230° to 336. It is also noted that the torque coefficient increases appreciably when the position of the blades of the axis of the wind turbine is shifted.

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