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Investigation of the effect of free-wind velocity on the performance of small-scale vertical axis wind turbine

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ABSTRACT: In the present research, the effects of various parameters in simulating wind flow around an H-type vertical axis wind turbine with NACA0018 airfoils are studied. All computations are carried out using the computational fluid dynamics method and finite volume approach. Free-wind velocities of 5, 10, and 15 m/s, and tip speed ratios of 3 and 5 are considered. Grid size, time-step size, rotating zone diameter, and domain size independence studies are investigated. All obtained results are compared with experimental data and show good agreement. Examination of obtained results reveals that by increasing Free-wind velocity, maximum momentum coefficient occurs at higher azimuthal angles. Also, by decreasing tip speed ratio, more volume of air penetrates the rotor and therefore, fluctuations of wind turbine increase and, lifecycle and performance of wind turbine decrease. Furthermore, the effect of tip speed ratio on the performance of wind turbine is more significant than Free-wind velocity so that by increasing tip speed ratio from 3 to 5 at a constant Free-wind velocity of 10 m/s, the power coefficient increases by 81.87% and by increasing Free-wind velocity from 5 to 10 m/s at a constant tip speed ratio of 3, power coefficient increases by 58.2%.

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1- Introduction

By increasing the global population, demand to use energy sources increases. Among these energy sources, fossil fuels are used in most countries because of their benefits to the traders and their compatibility with machines and devices. Using fossil fuels as providing energy sources has disadvantages such as increasing greenhouse gases, global warming, pollution, acidic rain, polar ice caps melting, draining water resources, etc. The best solution to prevent the mentioned results of using fossil fuels are renewable energy resources such as wind, solar, ocean waves, hydroelectric and geothermal. Among these energy resources, wind energy is one of the most available energy resources. Wind Energy can be harnessed in residential and nonresidential places, coastlines, offshore, during the day and night, and in many climate conditions if the wind velocity is within the proper limit for harnessing energy by wind turbines. Wind turbines are used to capture wind energy source. Wind turbines are manufactured in two types of Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT). HAWTs are more efficient than VAWTs but have more installation and maintenance costs. Also, HAWTs need more space for installation and are sensitive to wind flow direction but VAWTs need a small space of installation and are not sensitive to the wind flow direction. In the following, some published papers about VAWTs are reviewed.

Li et al. [1-3] studied the effects of aerodynamic forces, the number of blades, and pitch angles of blades. They showed that by increasing the number of blades, power coefficient of the wind turbine decrease, and maximum power coefficient occurs at a pitch angle of 6 deg. Howell et al. [4] showed that by increasing surface smoothness of blades, power coefficient of wind turbine decrease at low Reynolds numbers (Re<30000). Rezaeiha et al. [5, 6] studied the minimum requirements for wind turbine simulation and concluded that by reducing time-step size smaller than 0.5 degree of revolution of wind turbine, numerical results do not change significantly. Mohamed [7] investigated noise emission of a double-airfoil VAWT and revealed that 60% spacing between two airfoils is the best configuration to reduce noise emission.

In the present study, the effects of several parameters to simulate flow field around a VAWT accurately, are investigated. Also, performance of a two-bladed H-type Darrieus VAWT under several free-wind velocities and tip speed ratios are studied.

2- Computational Domain

A two-bladed H-type Darrieus VAWT with NACA0018 airfoils is simulated numerically to study the performance of wind turbine under different conditions. Two-dimensional computational domain is shown in Fig. 1. In Table 1, geometric specifications of the computational domain are shown.

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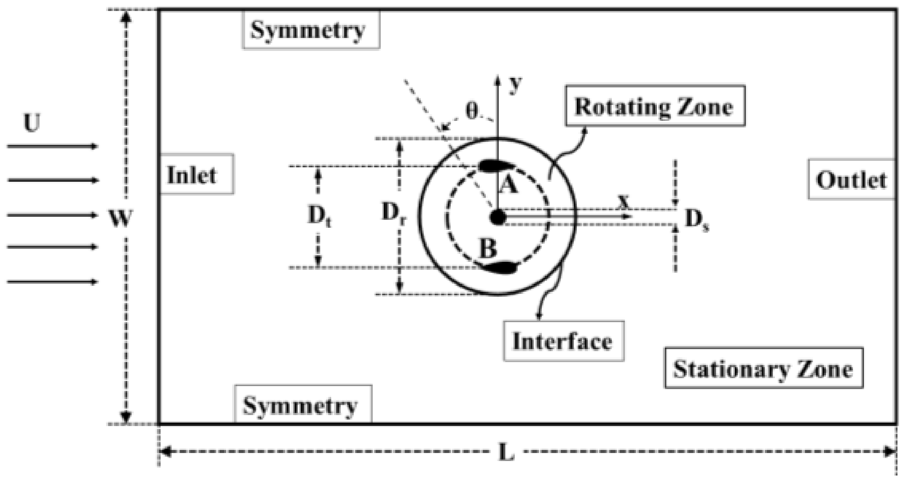

Fig. 1. Two-dimensional computational domain

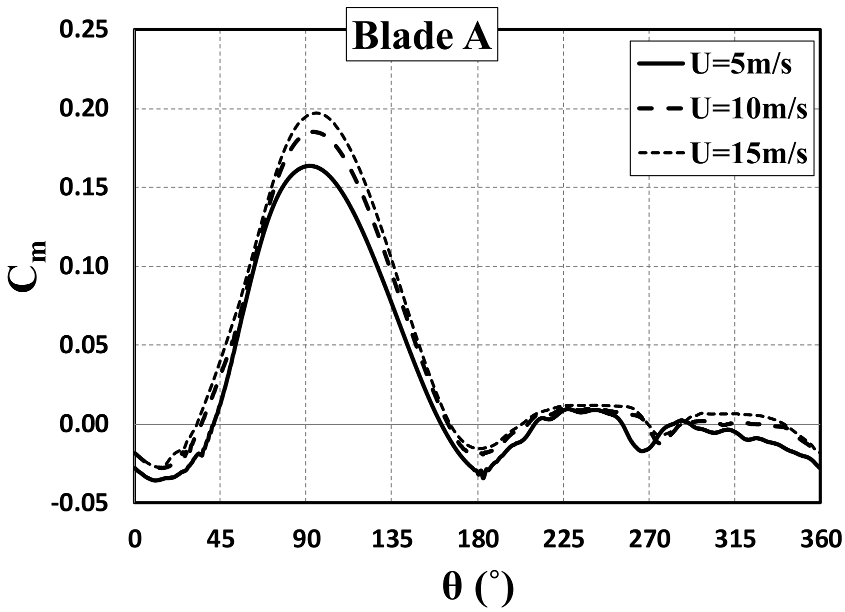

Fig. 2. Time-step size independence study for blade A

3- Governing Equations

Transition SST turbulence model is employed to evaluate turbulence effects. The governing equations for 2D, unsteady, turbulent, and incompressible flow are given as follows;

Conservation of mass:

$$\nabla.\vec{V} = 0$$

Conservation of momentum:

$$\rho \frac{D\vec{V}}{Dt} = -\nabla p + \mu \nabla^2 \vec{V}$$

The dimensionless coefficients are defined by the following equations [8]:

$$C_D = \frac{F_D}{0.5 \times \rho U^2 S}$$

$$C_L = \frac{F_L}{0.5 \times \rho U^2 S}$$

$$C_m = \frac{M}{0.5 \rho U^2 S}$$

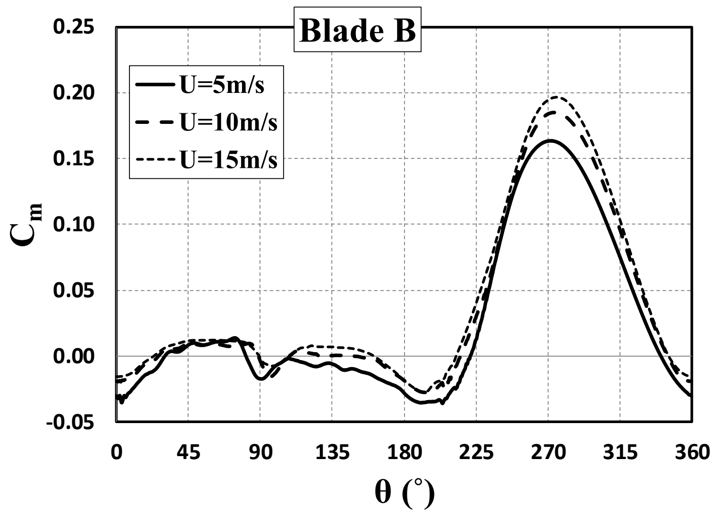

Fig. 3. Please delete the Persian sentence just under this figure!

Table 1. Geometric and functional specifications of studied wind turbine model

parameter	value
Airfoil	NACA0018
Number of blades	2
Diameter of rotor (D_t)	1 m
Chord length	60 mm
Shaft Diameter (D_s)	40 mm

4- Results and Discussion

In Fig. 2, instantaneous momentum coefficient of blades A and B for the last revolution of the rotor are shown. According to this figure, by increasing free-wind velocity, maximum momentum coefficients of blades increase and occur at higher azimuthal angles. Also, maximum momentum coefficient of blade A occurs at azimuthal angles of around 90 deg and that of blade B occurs at azimuthal angles of around 270 deg.

5- Conclusions

In this paper, numerical and geometrical parameters of an H-type VAWT have been studied in order to have an accurate simulation. Free-wind velocities of 5, 10, and 15 m/s and tip speed ratios of 3 and 5 have been investigated. By increasing free-wind velocity, maximum momentum coefficient increases. More volume of air penetrates the rotor at a tip speed ratio of 3 and therefore, by increasing fluid-solid interaction, vorticity patterns inside the rotor increase.

References

[1] Q.a. Li, T. Maeda, Y. Kamada, J. Murata, K. Furukawa, M. Yamamoto, Effect of number of blades on aerodynamic forces on a straight-bladed Vertical Axis Wind Turbine, Energy, 90, Part 1 (2015) 784-795.

[2] Q.a. Li, T. Maeda, Y. Kamada, J. Murata, T. Kawabata, K. Shimizu, T. Ogasawara, A. Nakai, T. Kasuya, Wind tunnel and numerical study of a straight-bladed vertical axis wind turbine in three-dimensional analysis (Part I: For predicting aerodynamic loads and performance), Energy, 106 (2016) 443-452.

[3] Q.a. Li, T. Maeda, Y. Kamada, J. Murata, T. Kawabata, K. Shimizu, T. Ogasawara, A. Nakai, T. Kasuya, Wind tunnel and numerical study of a straight-bladed Vertical Axis Wind Turbine in three-dimensional analysis (Part II: For predicting flow field and performance), Energy, 104 (2016) 295-307.

[4] R. Howell, N. Qin, J. Edwards, N. Durrani, Wind tunnel and numerical study of a small vertical axis wind turbine, Renewable Energy, 35(2) (2010) 412-422.

[5] A. Rezaeiha, I. Kalkman, B. Blocken, CFD simulation of a vertical axis wind turbine operating at a moderate tip speed ratio: Guidelines for minimum domain size and azimuthal increment, Renewable Energy, 107 (2017) 373-385.

[6] A. Rezaeiha, H. Montazeri, B. Blocken, Towards accurate CFD simulations of vertical axis wind turbines at different tip speed ratios and solidities: Guidelines for azimuthal increment, domain size and convergence, Energy Conversion and Management, 156 (2018) 301-316.

[7] M.H. Mohamed, Reduction of the generated aero-acoustics noise of a vertical axis wind turbine using CFD (Computational Fluid Dynamics) techniques, Energy, 96 (2016) 531-544.

[8] J.D. Anderson Jr, Fundamentals of aerodynamics, Tata McGraw-Hill Education, 2010.

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