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Effect of number of blades on aerodynamic forces on a straight-bladed Vertical Axis Wind Turbine

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ABSTRACT

Small wind turbine performance and safety standard for straight-bladed Vertical Axis Wind Turbine (VAWT) have not been developed in the world because of the lack of fundament experimental data. This paper focuses on the evaluation of aerodynamic forces depending on several numbers of blades in wind tunnel experiment. In the present study, the test airfoil of blade is symmetry airfoil of NACA 0021 and the number of blades is from two to five. Pressure acting on the surface of rotor blade is measured during rotation by multiport pressure devices and transmitted to a stationary system through wireless LAN. And then, the aerodynamic forces (tangential force, normal force et al.) are discussed as a function of azimuth angle, achieving a quantitative analysis of the effect of numbers of blades. Finally, the loads are compared with the experimental data of six-component balance. As a result, it is clarified that the power coefficient decreases with the increase of numbers of blades. Furthermore, the power which is absorbed from wind by wind turbine mainly depends on upstream region of azimuth angle of $\theta = 0°\sim180°$. In this way, these results are very important for developing the simple design equations and applications for straight-bladed VAWT.

1. Introduction

The wind energy has been one of the veritable alternative resources for power production in recent years because of the potential that they offer for carbon free power generation [1,2,33]. Wind energy technology development is mainly attributing of HAWTs (Horizontal Axis Wind Turbines) which have major recognized implementation, such as large scale windfarms on flat land, offshore and mountainous terrain [4]. For VAWTs (Vertical Axis Wind Turbines), the generator can be placed near the ground, so the tower does not need to support it, also makes maintenance easier wind and always be used in urban areas, as shown in Fig. 1. This type VAWT can reduce the transmission losses due to proximity to the demand center. Moreover, VAWT can be applied in the remote areas, street lights and general families, etc, because of its independent power generation system. It also can provide power for portable device, crisis evacuation indicator in disaster events, etc. Therefore, there has been an increasing interest in the deploying VAWTs in urban areas [5]. However, compared with the HAWT, very few VAWTs are available commercially [3].

According to IEC (International Electrotechnical Commission), AWEA (American Wind Energy Association) and BWEA (British Wind Energy Association), small wind turbine performance and safety standard have been developed for HAWTs [6]. For example, IEC 61400-2 and JISCI1400-2 have a very good expression of simple design equations and design standards. However, R & D of the performance and safety standard for small VAWT have not been developed in the world because of the lack of fundament experimental data [7].

VAWTs are classified into Darrieus type wind turbine (Egg-beater type wind turbine, Straight-bladed type wind turbine, Crossflex wind turbine and so on), Savonius rotor, Combined Savonius and Darrieus rotor, Sistan type wind turbine and so on [8]. In this study, small straight-bladed VAWT which is the most popular in domestic and foreign is studied as the research object. Blades of VAWT are made of uniform section and non-twisted, making them relatively easy to fabricate and extrude.

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Nomenclature

A	swept area of wind turbine [m^2]
c	airfoil chord length (=0.265) [m]
C_D	drag coefficient ($=F_D/(0.5\rho cU_0^2)$)
C_L	lift coefficient ($=F_L/(0.5\rho\ cU_0^2)$)
C_p	pressure coefficient ($=P/(0.5\rho U_0^2)$)
C_{power}	power coefficient ($=Q\omega/(0.5\rho DHU_0^3)$)
C_Q	torque coefficient ($=Q/(0.5\rho DHRU_0^2)$)
C_N	normal force coefficient ($=F_N/(0.5\rho cU_0^2)$)
C_{thrust}	thrust coefficient ($=F_x/(0.5\rho DHU_0^2)$)
C_T	tangential force coefficient ($=F_T/(0.5\rho cU_0^2)$)
D	rotor diameter (=2.0) [m]
F_D	drag force per unit length [N/m]
F_L	lift force per unit length [N/m]
F_N	normal force per unit length [N/m]
F_T	tangential force per unit length [N/m]
F_x	thrust force per unit length [N/m]
H	height of rotor blade (=1.2) [m]
N	number of blades (2~5)
P	pressure on the surface of blade [Pa]
P_{ower}	power putout [W]
Q	rotor torque [N m]
R	rotor radius (=1.0) [m]
Re	local Reynolds number ($=Wc/\nu$)
U_0	mainstream wind velocity [m/s]
V	tip speed of blade ($=R\omega$) [m/s]
W	resultant flow velocity [m/s]
α	angle of attack [deg]
β	blade pitch angle [deg]
θ	azimuth angle [deg]
λ	tip speed ratio ($=R\omega/U_0$)
ν	kinematic viscosity [m^2/s]
ρ	air density [kg/m^3]
ω	angular velocity of rotor [rad/s]

In the development of the simple design equations for a HAWT, loads which are applied to blade and rotor shaft are mainly considered [9]. However, VAWT load is also applied to the support structure. To define the directions of the loads of straight-bladed VAWT, the systems of coordinate are shown in Fig. 2.

As mentioned above, the support structure coordinate system shown the different coordinate systems of blade and rotor shaft. Compared with the HAWT, the loads applied to VAWT become more and more complicated. For HAWT, centrifugal force is caused by the rotation. From this figure, it is seen clearly that blade is tensile in the radial direction [10]. Therefore, in the designing of VAWT, the tensile strength is mainly considered.

Fig. 3 illustrates blade load in the flap direction for straight-bladed VAWT. As shown in this figure, it is noted that not only the centrifugal loads are caused by the rotation, but also the bending loads are generated from fulcrum. Thence, in the designing of VAWT, the bending strength is mainly considered [11]. Furthermore, the flow field characteristics are also different between HAWT and VAWT [12]. Wind uniformly flows into the rotor surface and the torque constant for HAWT. But, for VAWT, wind velocity which flows into the rotor surface becomes disturbed flow in the downstream region [13]. Moreover, large fluctuation torque will be generated and fatigue loads of support structure become stringent.

Therefore, as described above, the simple design methods and standards of HAWT is not suitable for the load cases of VAWT. In the design process of VAWT it is crucial to maximize the aerodynamic performance ratio [14]. Therefore, industries and researchers are trying to focus aerodynamic performance for VAWTs with wind tunnel experimentally and numerically. Based on the development of the simple design equations for HAWT, it is very important to determine the parameters by experiences and theoretical [15]. The maximum power coefficient of VAWT mainly depends on rotor

Fig. 1. Small Vertical Axis Wind Turbine.

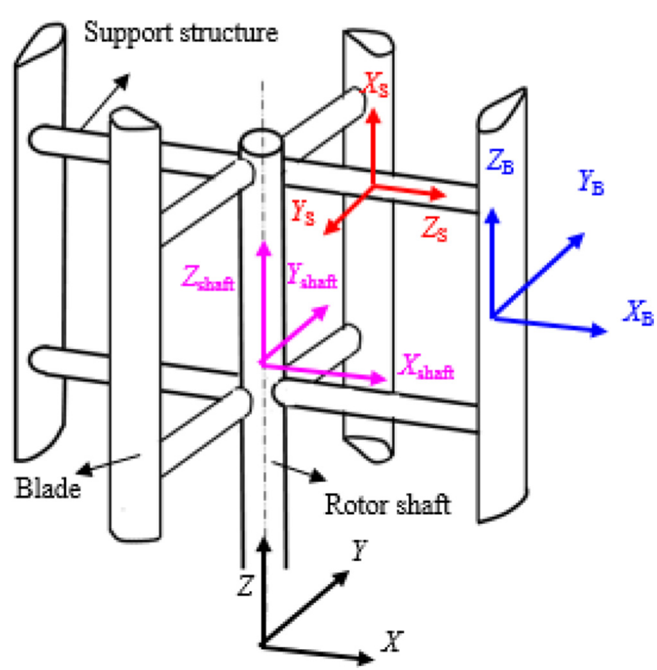

Fig. 2. Coordinate systems of Vertical Axis Wind Turbine.