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Numerical Investigation of Dynamics Stall on Vertical Axis Wind Turbine

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Abstract. Dynamic stall poses a significant aerodynamic challenge for vertical axis wind turbines (VAWTs) and serves as a key impediment to enhancing their overall efficiency. Consequently, to elucidate the underlying mechanism of dynamic stall and facilitate a clearer understanding of the entire dynamic stall process, a numerical investigation is conducted over the blades of a VAWT system. A two-dimensional numerical simulation is conducted by employing unsteady Reynolds-averaged Navier-Stokes (RANS) calculations with a Reynolds stress turbulence model. Four real-time key indicators are generalized to quantitatively characterize dynamic stall over the VAWTs. These indicators have been demonstrated to accurately predict the initiation and detachment times of the dynamic stall vortex (DSV), providing deeper insights into the underlying mechanism of DSV development. Additionally, this study explores the impact of blade thickness on the dynamic stall of VAWTs. Three airfoils from the NACA 4-digit series, each featuring distinct ratios of thickness to chord length, are examined. As the blade cross-section transitions from NACA 0012 to NACA 0015 and NACA 0018, heightened blade thickness results in a delayed onset of dynamic stall, shifting from leading edge stall to trailing edge stall. Moreover, the blade thickness significantly influences the efficiency of VAWT system, with increased airfoil thickness contributing to an improved utilization of wind energy.

AMS subject classifications: 76G25

Key words: Dynamics stall vortex, vertical axis wind turbines, blade thickness, leading-edge stall, trailing-edge stall.

1 Introduction

In recent years, due to environmental pollution, global warming and shortage of tradit-

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ional fossil energy, renewable energy such as solar energy, geothermal energy, biomass energy, wind energy, wave energy has been significantly developed. Among them, wind energy is one of the most promising energy sources in the renewable energy industry [1]. Wind power generation is currently the main form of utilizing wind energy. A wind turbine is a device that converts wind energy into mechanical work and then into electrical energy. Wind turbines typically consist of a tower, rotor, nacelle, and control systems. Wind turbines can be classified into two main types: horizontal axis wind turbines and vertical axis wind turbines. In a horizontal axis wind turbine (HAWT), the rotor rotates around a horizontal axis parallel to the ground. In contrast, a vertical axis wind turbine (VAWT) has a rotor that rotates around a vertical axis perpendicular to the ground. Each category of wind turbines possesses distinct advantages and is well-suited for specific applications [2].

Compared to HAWT, VAWT offers several advantages. Firstly, VAWT outperforms in low wind speed conditions owing to its lower cut-in wind speed, enabling it to commence operations at lower wind speeds. This makes VAWT more efficient in areas with lower average wind speeds. Secondly, VAWT's compact design allows for installation on rooftops or in other limited spaces, making it a preferred choice in urban and densely populated areas where HAWT installations are not suitable [3, 4]. Simultaneously, VAWT's vertical axis allows it to capture wind from any direction, making it well-suited for urban environments with irregular wind patterns [5]. Furthermore, VAWT can operate effectively in harsh conditions and is relatively easier to maintain compared to HAWT. In addition, VAWT can be integrated into hybrid renewable energy systems, working in conjunction with other energy sources such as solar panels or diesel generators, providing a more stable and reliable energy supply.

The efficiency of VAWT is directly impacted by its aerodynamic performance, which, in turn, is characterized by a rather complex set of aerodynamic features. As the blades of a VAWT rotate, they experience different wind speeds and angles of attack during each rotation. As shown in Fig. 1, the relative wind velocity W, which is the combination of the rotational velocity ωR and the freestream wind speed U_∞, undergoes changes in magnitude and direction with the azimuth angle θ. Consequently, the effective angle of attack (AoA) of the blades varies accordingly. Figs. 2(a) and (b) show the changes of effective AoA and relative wind velocity with azimuth angle for a blade-tip speed ratio (TSR) of 2. During blade rotation, the angle of attack exceeds the static stall angle of the airfoil within a specific azimuth angle range, causing the separation of airflow over the blades. Consequently, the flow over the blades alternates between an attached flow state and a stalled flow state throughout a rotation cycle, leading to dynamic stall [6]. Blade dynamic stall is a primary aerodynamic challenge faced by VAWT and constitutes a major obstacle to achieving higher efficiency in VAWT. More specifically, when the angle of attack of the airfoil changes rapidly, a shear layer near the leading edge (LE) of the airfoil rolls up and forms a leading-edge vortex (LEV), causing the airfoil suction surface to gain additional suction. As a result, airfoil's lift increases dramatically and stall is delayed. However, the leading-edge vortex quickly becomes unstable and detaches from