Flutter analysis of vertical-axis wind turbine blades using a simplified aeroelastic model

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ABSTRACT

This study investigates the aeroelastic flutter of a vertical-axis wind turbine (VAWT) blade using a two-degree-of-freedom typical section model and the unsteady aerodynamic theory. The long-term goal of this study is to develop fast, reliable analytical models for use in aeroelastic design optimization of large-scale floating offshore VAWTs. There has been renewed interest in VAWTs in recent decades since they are considered as a viable option for offshore wind power generation. Like other lifting surfaces, the blades of a VAWT are prone to aeroelastic flutter. Few analytical models were previously developed for the aeroelastic stability analysis of VAWTs, but virtually all used a quasi-steady aerodynamic theory in their numerical analysis. Studies on the aeroelasticity of aircraft wings have proven the inadequacy of the quasi-steady aerodynamic theory. Also, to the best of the authors’ knowledge, no comprehensive parametric studies (including the effects of mass ratio, frequency ratio, and the offset between the center of mass and the elastic axis) have been made on the aeroelastic flutter of VAWTs blades. The need for such studies is felt even more now as VAWTs with lighter and longer composite blades are being considered for large-scale power generation.

In this study, a simplified aeroelastic model is developed following the classical aeroelasticity. The structural dynamics of the three-dimensional (3-D) blade is reduced to that of a 2-D typical section model with heave (in the radial direction) and pitch (in the tangential direction) degrees-of-freedom. The uncoupled natural frequencies of heaving and pitching are approximated by the natural frequencies of the first bending and torsional modes of a straight blade, respectively. Theodorsen’s unsteady aerodynamic theory is used to obtain the lift and pitching moment. Aeroelastic stability analysis is performed via the k (or U-g) and p-k methods. Numerical results from the present analytical model were validated against publicly available experimental results for a 2-m VAWT. The experiments were performed circa 1976 in the NRC 6×9 ft low speed wind tunnel with steel/aluminum blades with flat plate/airfoil cross-sections. The theoretical and experimental flutter speeds were found to be within 15% of difference for mass ratios below 85 while the difference increased at higher mass ratios. The effects of some parameters including mass ratio, frequency ratio, and cross-sectional characteristics on the flutter speed and frequency are investigated. The results show that the flutter speed is highly dependent on the mass ratio while it is weakly sensitive to the frequency ratio.