Special Program in Applied Mathematics and Applied Mechanics

Numerical Investigation of a Vertical-Axis Wind Turbine Using the Immersed Boundary Method

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15:00 - 18:00
308, Mathematics Research Center Building (ori. New Math. Bldg.)

This study is aimed at numerically investigating the aerodynamics and the starting of a vertical-axis wind turbine at low Reynolds number using the immersed boundary method. The influence of the Coriolis effect on dynamic stall is isolated by comparing the rotating airfoil to one undergoing an equivalent planar motion that is composed of surging and pitching motions that produce an equivalent speed and angle of attack variation over a cycle. At lower tip-speed ratios, the Coriolis force leads to the capture of a vortex pair which results in a significant decrease in lift when the angle of attack of a rotating airfoil begins to decrease in the upwind half cycle. In the absence of the wake-capturing, the equivalent planar motion is a good approximation to a rotating blade in a vertical-axis wind turbine.

Analysis on the starting torque shows that when the turbine solidity is lower than about 0.5, the starting torque distribution can be well-modeled by considering a single blade at different orientations, and starting torque distributions for multi-bladed turbines can be constructed by linearly combining the torques at the respective positions of the blades. Using this model, optimal configurations to start a multi-bladed low-solidity vertical-axis wind turbine is proposed..

A preliminary study is made to determine an optimal blade pitch for a single-bladed motor-driven turbine using optimal control theory. When the input power is minimized directly, the solution seems to converge to only a local minimum due to a lower input power reduction than that obtained by maximizing the mean tangential force. After a transient, both controls converge to time-invariant pitch angles of about the same magnitude but with opposite signs. The wake-capturing phenomenon observed in the uncontrolled case necessitates large input power. Under active control, the disappearance of wake-capturing and attendant changes in the flow field collectively result in a reduction of required input power.