Advances in Dynamic Simulation Techniques for AWE Systems

Evaluating the role of kite inertia in a soft kite, pumping cycle system.

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Abstract:

Airborne Wind Energy (AWE) systems harness wind power through devices that fly in controlled patterns. Two main concepts exist: the 'drag mode' concept, where power is generated onboard, and the 'pumping cycle' concept, where power is generated on the ground. Quasi-Steady State Modeling (QSM) is a robust technique for simulating the behavior of a soft kite in a pumping cycle AWE system due to its ease of use—requiring minimal tuning of modeling coefficients—and its ability to rapidly deliver results with reasonable accuracy. QSM effectively predicts parameters like tether force and kite velocity for smaller AWE systems. However, its limitations become apparent with increasing kite mass, where the neglect of inertial forces leads to notable inaccuracies in tether tension and unresolved phase differences between acceleration and velocity. The threshold kite mass-to-surface ratio at which these errors become significant remains undefined. This research aims to quantify the importance of accounting for kite inertia by assessing the relationship between kite mass-to-surface ratio and modeling errors. Dynamic equations of motion tailored to AWE applications are introduced, and the flight path is parameterized to obtain the tether tension resulting from a predetermined flight path. Three modeling approaches—steady state, quasi-steady state, and fully dynamic—are compared to assess the significance of different components of inertial forces, such as those caused by Coriolis, centrifugal, or relative accelerations. The limitations of this analysis stem from the use of a steady aerodynamic model with constant lift and drag coefficients, and the assumption of a rigid, straight, steady tether. Consequently, the presented model still leaves various unsteady real-world effects unresolved, thereby introducing potential sources of error. This research seeks to guide the development of more accurate dynamic models, enhancing the predictability and operational efficiency of AWE systems.