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On Airborne Wind Energy System Optimization at EnerKíte

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***Abstract*—Some aspects of the approach at EnerKíte to design an optimize future systems are discussed. A steady-state airborne wind energy system model is presented, and a path and system design optimization process is explained. The path and control optimization process looks for the best trajectory and control inputs for a given plant, while the plant optimization process seeks the smallest plant that results in our nominal total output at our desired wind-speed and operating altitude. Small plant here means a linear combination of peak motor power, wing area and maximum force, which are the main cost drivers or airborne wind energy systems.**

***Index Terms*—Airborne Wind Energy System, Optimization, Wind Energy**

I. Introduction

EnerKíte develops airborne wind energy systems (AWES) that are controlled from the ground using three tethers [3], generate electricity on the ground using the pumping-mode approach and are started and landed using a rotational arm [4], [5]. This design is due to the belief that each of these decisions leads to the most reliable system. However, the topic that is presented here is not about reliability but performance of the system at different sites and the best design for a given power class.

Power curves are a tool of classical wind turbines, describing their performance at a specific wind speed at the altitude of their rotational center and assuming that the wind shear is either small or based on a common assumption for the intended site - though only resulting in loss of efficiency estimates. Given the occurrence of wind speeds at this altitude at a site, one can estimate yield at that site over a year. For airborne wind energy systems, estimating yield is more difficult. These systems can fly at variable altitudes and could - in theory - always operate at whatever altitude results in optimal power output. Pumping-mode AWES operate by reeling-out a tether over a period of time under high tension, and reel-in all this unwound tether under low tension by reducing the aerodynamic load.

To predict the power output of an AWES at some currently occurring wind profile, one can choose a variety of methods entailing different computational cost and accuracy. The most accurate is to simulate a complete and realistic model of an AWES, together with its intended controlling software, as a regular ODE as if it was operating at the site given detailed time-based wind profile data. The resulting power is then as accurate as the model components. The drawbacks of such an approach are two-fold:

On one hand, one needs an actual controller. But for yield estimates of prospective future designs no such controller exists and would need to be designed and tuned for every system - and the result would not be the optimal power output of the system but just the state due to the tuning and approach of the controls.

On the other hand, detailed simulations need a lot of computational resources and take time.

Stating the problem as a dynamic optimal control problem removes the necessity of defining an optimal controller, and this has been used in among many [2]. However, a dynamic optimal control problem needs to resolve the trajectory in a manner fine enough to accurately solve the ODE of kite movement and hence is more expensive then a time-based simulation of the same model, since the optimal control problem needs to be solved, too. Usually the models employed for these dynamic optimal control problems are rather simple to enable optimization studies.

Assuming steady-state at given trajectory nodes simplifies the problem considerably, and enables meaningful analysis even with very few amount of discretization points. This allows for a very fast computation of the power output, but the effect of mass on the trajectory and the machine limits are modelled. In [1] the operation of a pumping-mode airborne wind energy system (AWES) is described by quasi-steady points along prescribed trajectories and solved using optimal control - and validated against measurements of the EnerKíte prototype platform [3]. This was used to derive power curves at different operating altitudes and logarithmic roughness coefficients.

The contribution here is twofold. First, some aspects of the prescribed trajectories in [1] are relaxed and added to the optimization, resulting in additional insight into the optimal trajectories and operation of AWES. Second, the resulting power output is not only used to calculate power output and resulting yields or power curve families, but an optimization process is described to find optimal plant designs. The optimization is based on the minimum of the main economic drivers behind these systems:

- Wing area, resulting in larger systems and increased cost of wing and ground station.
- Tether force, resulting not only in thicker tethers, but higher necessary torques of the motor and increased loads on all parts
- Nominal power of the motor. This is not the nominal power of the plant, which is given by the mean power output over a complete cycle and reduced by various efficiencies, but the actual peak power the motor can sustain.

The power calculation in [1] is then used as an equality constraint.

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