On Control of Phase Transitions in Airborne Wind Energy Systems

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To operate efficiently and reliably, AWES are supported by active control systems in all phases, such as take-off, landing and power generation, possibly composed of further sub-phases [1,2,3]. Employing modern control theory, state-of-the-art controllers are able to obtain rather repetitive operation in each phase.

In non-repetitive phases like vertical take-off and landing (VTOL) pumping systems the aircraft is lifted with an hovering controller, then its forward speed and pitch angle are increased until switching to an “airplane” controller when the airspeed is large enough, and possibly to a “tethered airplane” controller to enter crosswind mode, when its attitude lies in a chosen set. These solutions have the advantage of being simple to conceive and implement, however they may yield virtually no guarantee of robustness against wind uncertainty, which is indeed an important performance metric in AWES operation and the jumps in the control signal are undesirable.

On the other hand, novel control strategies for ride-through between operational phases promise rigorous theoretical guarantees as well as increased efficiency for phase transitions[4]. Moreover, these tools can also be useful to analyze the robustness properties of existing solutions. The aim of this research is to provide a two degree of freedom controller synthesis method for provably robust transitions between modes of operation, with application to AWES. We adopt a sequence of switching linear state-feedback controllers designed by linearization at chosen points along the trajectory. Robustness is guaranteed by formulating a bound on the maximum deviation from the reference trajectory and applying a simultaneous Lyapunov stability result on the set of possible linearized models under feedback control. The computed piece-wise affine control law can be stored with little memory and thus implemented in embedded systems with a high sampling rate. Furthermore, we allow a smooth transition to given control laws from the beginning and to the end. Thus, the approach can be easily integrated with existing control strategies employed in the starting and ending phases.

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