Open Invited Track at the 2020 IFAC World Congress on

Control of Tethered Airborne Wind and Marine Hydrokinetic Energy Systems

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Abstract

Tethered airborne and marine hydrokinetic energy systems represent revolutionary energy harvesting technologies that provides access to high-altitude wind resources and deep-water tidal and ocean resources that are unreachable with towered systems. Today, a thriving worldwide, multi-disciplinary community of researchers and technologists has been established in this field. The delivered research results are gradually assessing and eliminating feasibility risks and improving our understanding of tethered energy systems, ultimately bringing these concepts closer and closer to commercialization. The demonstrated and projected advantages of these systems include lower installation costs, higher capacity factors, higher density of generated power per unit area of occupied space, and higher flexibility with respect to the current established renewable technologies, up to a level that will at maturity be competitive with fossil fuels without the need for political and economic incentives. While tethered airborne and marine hydrokinetic system concepts differ widely in their designs, they all share a common theme - replacement of conventional towers with tethers. This unifying theme, and the additional degrees of freedom that exist with tethered systems, makes control a central theme in the effective operation of these systems. The goal of this Open Invited Track at the 2020 IFAC World Congress is to bring together researchers from industry and academia to present and share their latest advancements and discuss the current and future research and development needs in this timely and thriving field.

Background and Motivation

Tethered airborne wind energy (AWE) and marine hydrokinetic (MHK) energy systems generate renewable energy from wind and currents through the control of tethered *lifting bodies* (e.g., rigid wings, fabric kites, and/or aerostats), whose motion is stabilized by active control systems [1], [2]. The claimed advantages of this concept over established technologies like wind turbines are the lower construction and installation costs and the possibility to reach stronger resources at high altitudes and in deep waters. The main challenge lies in the higher complexity of these systems, which calls for significant research and development efforts in the areas of aerodynamics, controls, materials, mechanics and power electronics. While the first ideas and conceptual studies concerning tethered energy systems appeared in the late 1970s [3], [4], it is only in the last 15 years that a significant and growing research and development effort has been undertaken by academia and industry, with the aim of transforming those concepts into products. Such an effort has been favored by improvements in sensor, computation, material, aerodynamics and power electronics technologies, which make it feasible for modern AWE and tethered MHK systems to cope with stringent requirements in terms of reliability and optimality of operation. Today, an ever-growing community of scientists and technologists from different disciplines is working worldwide to develop tethered energy systems. Recent highlights are the flight tests of Makani power 600-kW prorotype offshore of Norway [5], Minesto's Memorandum of Understanding (MOU) with the government of Antigua and Barbuda [6], and the foundation of Airborne Wind Europe [7], the European association of AWE stakeholders, part of WindEurope.

Fig. 1. Examples of tethered energy systems. From left: a ground-based generator with soft kite from TU Delft [8], a buoyant system from Altaeros Energies [9], two rigid wings for ground-based generation by Ampyx Power [10], a 600-kW system with onboard generation from Makani Power-GoogleX [11], and a tethered hydrokinetic marine system concept from Minesto [6].

Tethered energy systems can be classified by the way the lift force that keeps the lifting body aloft is generated - either aerodynamic (or hydrodynamic) lift, like the one produced by standard airplane wings or kites immersed in a wind flow [13], [14], [8], [12], [10], [11], or aerostatic (or hydrostatic) lift, like the one obtained by using lighter-than-air structures [9] - and by the placement of the electrical generators - either on-board the lifting body [11], [9] or on the ground [13], [14],

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[12], [8], [10]. Among the systems that exploit aerodynamic lift and ground-level generators, a further distinction can be made between concepts that rely on rigid wings [10], similar to gliders, and concepts that employ flexible wings like power kites [13], [14], [8], [12]. Small-scale prototypes (10-50 kW of rated power) of the mentioned concepts have been realized and successfully tested to demonstrate their power generation functionalities. Moreover, scientific contributions concerned with aspects like aerodynamics [15], [16], [17], [18], [19], controls [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], resource assessment [32], [33], economics [34], [35], prototype design [36], and power conversion [37], have recently appeared, gradually improving and expanding our understanding of such systems.

Notwithstanding the continuous development of the field, several relevant aspects still need to be addressed in order to ultimately prove the commercial feasibility of the idea. Many of such challenges involve deeply control, modeling, identification, estimation and optimization aspects. Each one of the mentioned technologies has specific features that imply different problems and require ad-hoc control approaches, and all of them will have to reliably operate in changing environmental conditions, adapting their configuration in order to extract the maximal possible energy while keeping stability and avoiding failures. The involved control problems are nonlinear, multi-variable, with uncertain and relatively fast dynamics, multiple competing objectives, operational constraints, and subject to unmeasured disturbances, hence presenting important challenges to the controls community. The multi-disciplinary nature of tethered energy systems and their relatively early development, hence the little availability of established design guidelines, confer to control and optimization an even higher importance, since all of the system components have to be designed and integrated by taking explicitly into account aspects like system controllability, observability, and robustness.

"Control of Tethered Airborne Wind and Marine Hydrokinetic Energy Systems" is an open invited track at the 2020 IFAC World Congress dedicated to this timely, thriving and exciting research field. The session aims to bring together researchers working on various control-related challenges pertinent to AWE and tethered MHK systems to present and share their results, to establish connections and to discuss on the current and future research needs in the field.

SESSION TOPICS

The topics of relevance for this invited session include, but are not limited to, the following:

- Control strategies for tethered energy systems
- Modeling of tethered energy systems
- Optimization of power generation cycles
- Combined control design/system design studies and optimization
- Autonomous take-off and landing of AWE systems
- State and parameter estimation for tethered energy systems
- Fault diagnosis and fault tolerant control of tethered energy systems
- Experimental results of implemented concepts

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