Electrical Energy Conversion System for an Experimental Pumping Airborne Wind Energy Set-up

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I. Introduction

Harvesting wind energy using tethered airplanes offers an alternative to traditional wind turbines by flying crosswind cycles with the tethered airplane. By reeling out under high tether tension and reeling in under low tether tension, net electrical power can be generated. This pumping cycle is illustrated by Fig. 1 [1] and explained in more detail in [2]. The tether tension is varied by controlling the flight path of the airplane. To validate and test this concept, an experimental test set-up is developed, which requires various electrical components. In the past, a scaled indoors version has been built at KU Leuven [3]. However, more extensive testing under outdoors conditions is required. The design and implementation of the entire electrical energy conversion system for this outdoors test set-up is the subject of the paper and the completed system is shown in Figure 2.

II. Approach

The paper first presents the developed test set-up, including important mechanical design features. Then the electrical energy conversion system is covered, based on this design. Next, the distributed control of the two main motors and safety features of the developed system are explained. Finally, the general underlying electrical design is presented.

III. Details

Two motors are subject of this paper: a winch motor and a carousel motor. The winch motor is used to vary the tether length and generates electricity from the pumping cycle. The carousel motor is used to drive the carousel developed in [2], [4]. This carousel is used to launch and land the kite using a rotation start. During a rotation start, the airplane is brought up to speed by rotating it around a central axis. Once the speed is sufficient, the tether is reeled out, allowing the airplane to gain altitude.

To comply to all requirements, a tailored drive system is selected consisting of motors, motor converters, an active front-end and peripherals. A complete electrical system is developed around this drive system for it to be mobile and be used on an outdoors, weather proof, set-up. Additionally, a complete safety system is designed, combining a manual remote control and automated, computerized, control system.

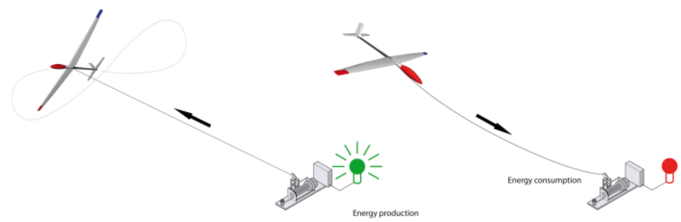

Figure 1: Example of a pumping cycle with a reel-in and reel-out phase as achieved by Ampyx Power [1].

The selection of the winch motor is a trade-off between efficiency, size, weight and cooling. For this set-up an 8 kW motor is required. This motor and its power electronics have a direct effect on the optimal cycles, so correct dimensioning and high efficiency is crucial [5]. Furthermore, the motor is mounted in the rotating part of the carousel, hence weight and size should be minimal and all (electrical) connections have to be able to go through slip rings. The final mounting of this motor is shown in Figure 3.

The selection of the carousel motor is more based on ease-of-use and cost. This motor only has to rotate the carousel, which requires torque (about 400 Nm) to speed up fast enough and the ability to stop quickly and safely. The final mounting of this motor is shown in Figure 4.

The overlapping electrical system has to be able to safely supply power to the drives and to all peripherals (such as sensors, onboard computers, laptops, electrical tools etc.). An overview of the implemented electrical system is shown in Figure 5.

The control of the drives has three levels (prioritized): safety logic, a human controlled remote control and a control algorithm (running on a dedicated computer). These are interfaced with a PLC running custom code and the PLC is interfaced to the drives using PROFINET.

IV. Conclusions

The scope of this paper is the design and implementation of a complete electrical energy conversion system for a state-of-the-art experimental pumping airborne wind energy test set-up. The paper first describes in more detail the mechanical design of the set-up, from which the requirements of the electrical energy conversion system follow. That system is divided in: a drive system (2 motors with inverters, active front-end and peripherals), an advanced safety system, a drive control system and an overlaying electrical system.

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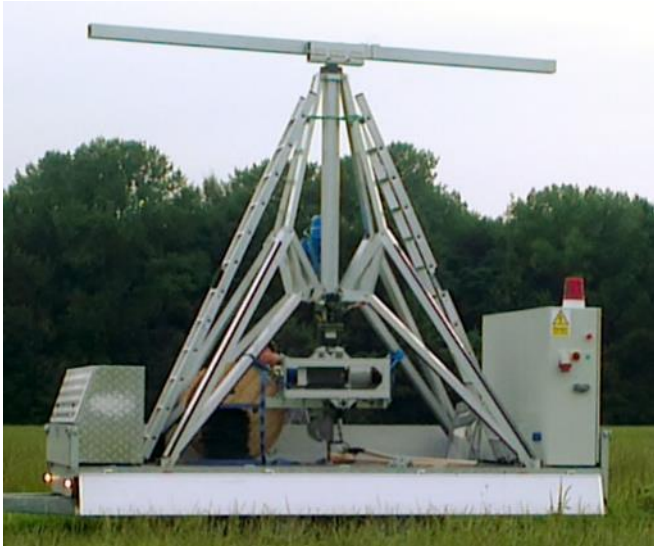

Figure 5: Overview of the entire outdoors setup

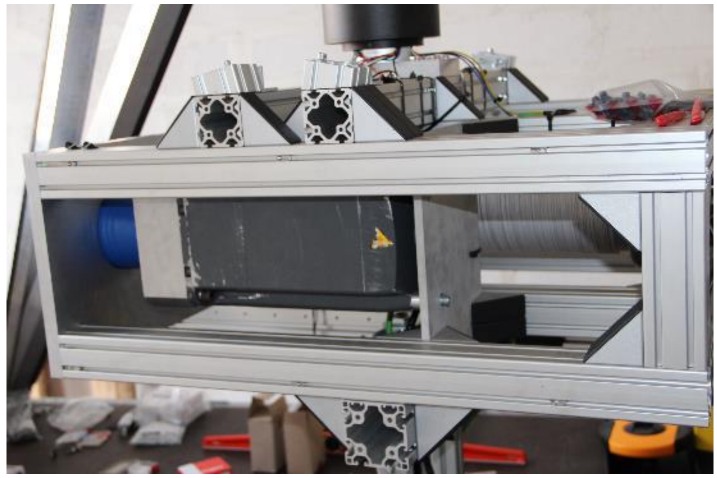

Figure 5: Mounting of the winch motor

Figure 5: Mounting of the carousel motor

Figure 5: Overview of the electrical system

V. LEARNING OBJECTIVES

Pumping airborne wind energy is an interesting alternative to the traditional wind turbine but requires a very complex system behind it. This paper gives an overview of how to design an electrical system for such a system, what is important and what to take into account. The selection of the drives is based on the mechanical requirements. Based upon the mobility and reliability of the drives, an overlaying electrical system is designed. A distributed drive control scheme is then combined with an extensive safety system in order to allow safe operation at all time. All these aspects are crucial when designing an electrical system for such an advanced test set-up. The described topics can serve as a basis to design such a system or similar advanced drive systems yourself.

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