Efficiency of kite power systems in pumping operation

Uwe Fechner, Rolf van der Vlucht, Roland Schmehl, Wubbo Ockels
ASSET Institute, TU Delft
Kluyverweg 1, The Netherlands
E-mail: {U.Fechner,R.vanderVlugt,R.Schmehl,W.J.Ockels}@tudelft.nl

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INTRODUCTION
Airborne Wind Energy (AWE) systems are a novel way to harvest wind energy without the need for a heavy tower and foundation. During the last decade the number of companies and research groups involved in the development of AWE systems increased from three to sixty. AWE systems are expected to work with a very high capacity factor, because the wind-speed at increasing altitudes is higher and steadier. In many applications they also promise a substantial decrease of costs per kWh. However, the practical challenges to develop reliable AWE systems, which are operated automatically are high. The principle of operation of the AWE demonstrator of TU Delft will be explained. A simplified mathematical system and efficiency model will be presented.

PRINCIPLE OF OPERATION
Kite power systems combine one or more computer-controlled inflatable membrane wings with a motor-generator unit on ground using a strong and lightweight cable[1]. Each pumping cycle consists of an energy generating reel-out phase, in which the kites are operated in figure-eight flight manoeuvres to maximize the pulling force, and a reel-in phase in which the kites are depowered and pulled back towards the ground station using a small fraction of the generated energy (see figure 1).

Figure 1: Pumping Kite

To reach a high efficiency of the wind harvesting mechanism, a high reel-out and a low reel-in force are required. A high reel-out force is achieved by flying crosswind, a low reel-in force is realized by de-powering the kite. The current demonstrator achieves a harvesting efficiency of about 80%.

MEASURING RESULTS
In the upper diagram the mechanical and electrical power output of the generator is shown, and the quotient of them, the generator efficiency. In the lower diagram you can see the power consumption of the spindle motor and the brakes, that must be released, when the system is active.

Figure 2: Power during three cycles

MATHEMATICAL MODEL
A simplified mathematical model was developed to optimize the operation parameters and the winch. It combines an analytical framework with empirically derived performance factors. It takes into account the aerodynamic performance of the kite, the drag of the tether, the elevation angle of the tether and the increase of the wind-speed at higher altitudes. The most important mechanical performance factors are the duty cycle, the harvesting efficiency, the crest factor of the reel-out speed and the crest factor of the reel-out force. For the reel-in phase it takes into account, that the elevation angle of the kite rises, when the kite is depowered. By means of global optimization the optimal elevation angle, tether length, reel-out speed and reel-in speed as a function of the wind speed can be calculated.

CONCLUSIONS
The mean mechanical output of the system could be improved from about 2 kW to 6 kW in the time from June 2010 to June 2011. For a much higher mechanical power and a better electrical efficiency a new winch is currently in the design phase. The current goal is to increase the mean mechanical power to 25 kW and the mean electrical output to about 20 kW, using a kite with a size of 25 to 35 m².

REFERENCES