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CONCEPT OF AUTONOMOUS TEXTILE FOIL KITE - WIND ENERGY GENERATOR

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Abstract: *This paper presents the starting phase of a research project that aims to develop the technological demonstrator of a wind power generator system using a wind sail to capture the high altitude wind energy. The sail will capture the wind energy and will be raised to an altitude of minimum 100-200 meters to capture the stronger and more constant winds at this altitude.*
Flight attitude control will be done via an active control hub named WCU (Wing Control Unit) attached to the cable at about 10m from the sail.
The ground station will be made up, at large, of a drum that will hold and wrap the push-pull towing and control cable, a flywheel for storing the mechanical energy, a centrifugal clutch coupled to an electric motor used in rewinding the towing cable on the drum and of course the electric generator.
The system will have an electronic command and control unit within the WCU. This control system will automatically launch the sail from the platform, guide the sail to the cruise altitude, control of the flight trajectory in the wind and on the return path, optimal landing on the platform in case of storm or other weather vagaries.
The demonstrator system will be sized to generate approximately 20kVA. Current calculations show the need of a sail area of about 25m^2 to achieve this power ratting.

Key words: *Foil Kite, Wind Energy, Electric Generator, Autonomous Flight, Technical Textiles*

1. INTRODUCTION

Among new technologies of producing electricity from renewable resources, a new type of wind energy generators have been in develpment. These systems are called Airborne Wind Energy Systems (AWE) and employ flying tethered kites to reach winds found at atmosphere layers that are inaccessible to traditional wind turbines. Research on airborne wind energy systems started in the mid-seventies.

The high level and the persistence of the winds that blow above 100m from the ground surface have attracted the attention of several research communities.

Among the different AWES concepts, there are Ground-Gen systems in which the conversion of mechanical energy into electrical energy takes place on the ground and Fly-Gen systems in which such conversion is done at the aircraft level such as depicted in fig.1.

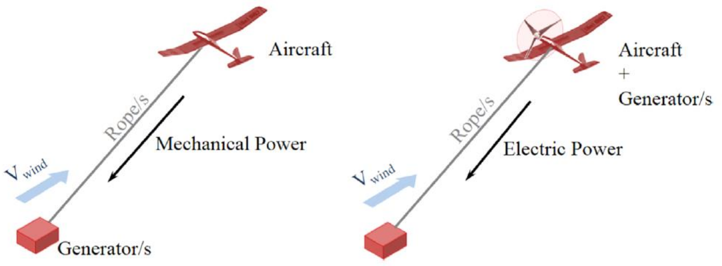

Fig.1: Examples of Ground-Gen and Fly-Gen.

Fly-Gen systems and Ground-Gen systems with fixed wing airborne unit (AU) are among the most successful technologies nowadays, however these suffer from a really bad scalability factor and higher costs as the weight and complexity of the airborne units is getting higher exponentially when targeting a higher power output.

This project however is not about fixed wing airborne units, what we trying to develop is an GroundGen AWESs that uses a foil kite as AU that can launch and land autonomously with the help of an WCU (Wing Control Unit) attached to the cable bellow the kite sail.

2. GENERAL INFORMATION

The GWA from IRENA website https://irena.masdar.ac.ae/gallery/#map/103 contains digital global maps of average wind speed and wind power density on 3 height levels (50, 100 and 200m) in raster format with a spatial resolution of about 1x1km. They cover all inland areas (onshore), as well as 30 km offshore. On https://globalwindatlas.info website, users can visualize wind speed and power density maps, as well as explanatory layers (including orography, roughness length and roughness index), and can download synthesis wind data for countries and regions within countries.

Based on these maps [1] we can observe and compare the wind power potential of Romania 100 to 200m, above this altitude we do not have exact measurements, mainly the eastern part of the country has marginal wind power density at 100m but at 200m its getting fairly good. The higher you get off the ground, the stronger the wind speeds and the more power can be obtained, thus we can harvest more power in a country that has marginal wind power density at the max wind turbine height of avg. 80m.

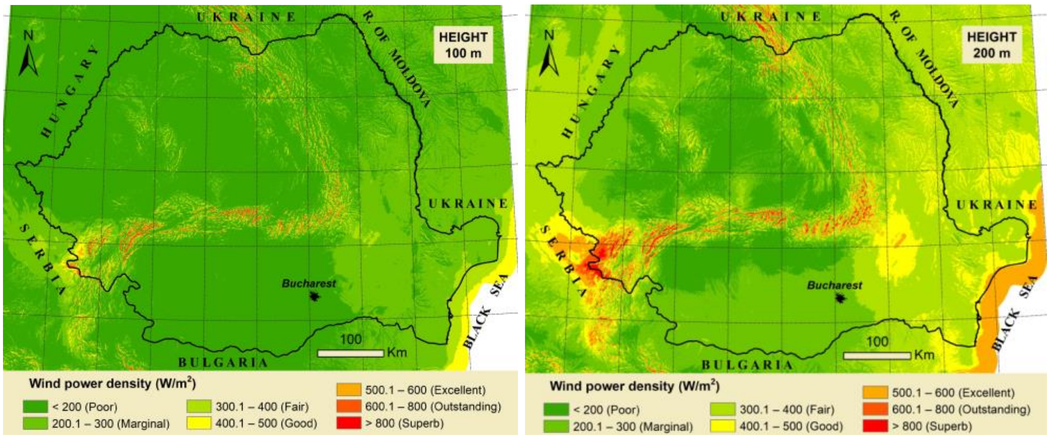

Fig.2: Wind power potential of Romania: 100 to 200m

The wind speed increases with height from the ground level up to the upper troposphere. There are several reasons that explain this. First, the pressure gradient increases with height. Second, and the main reason at the altitudes we operate in this project, the wind speed increase with height, is due to surface friction. Surface objects such as trees, rocks, houses, etc. slow the air as it collides to them. The influence of this friction is less with height above ground, thus the wind speed increases with height. A third reason is due to air density. The density of the air is higher at ground level and decreases with height. At higher altitudes, wind is also more constant, but building tall towers is not feasible, being much too expensive and massive in size. This is where AWE systems come into play.

The main principle of a kite power system is that the kite flight must be controlled to generate high drag in energy generation phase and low drag in recovery phase. By controlling the the kite trajectory, power is generated utilizing a drum that is capable of reeling the cable in-and-out. Power is generated when the cable is relled out and power is consumed when it is reeled back in. The kite is controlled in such a way that the cable tension must be lower during the reel-in phase than the reel-out phase. The larger the difference in power between these two phases, the greater the power will be generated. In order to maintain a proper cable tension, the kite must operate at a high angle of attack. The kite must have an aerodynamic drag sufficient to overcome the cable drag and the weight of the system including cable connected to the drum. Once the cable is pulled at its end it must be reeled back in. To have a positive energy generation, the cable tension must be reduced by lowering the angle of attack of the kite during reel-in phase [2].

The kite maneuveres in two ways: closed orbit and open orbit. In closed orbit both traction and recovery take place in the orbit's period where in the opened orbit the kite altitude increases during traction phase reaching its maximum and then it is reeled down during the recovery phase. For energy generation the kite is put in a closed orbit maneuvering that follows a lying-eight trajectory that minimises the risks of cable tangling and maximises the power generation time span [3].

This flight pattern differs from the ascending/descending circular motion (helical) as illustrated in before which is an opened orbit maneuvering system. However, researches are still being carried out to determine the types of trajectories that result in the optimal net average power produced per cycle [4].

During the first phase of the project we aim in establicshing the system components and dimensioning the experimental model of the system that can help us to better understand and optimise the final product. We started this with the kite and ground generator assemblies.

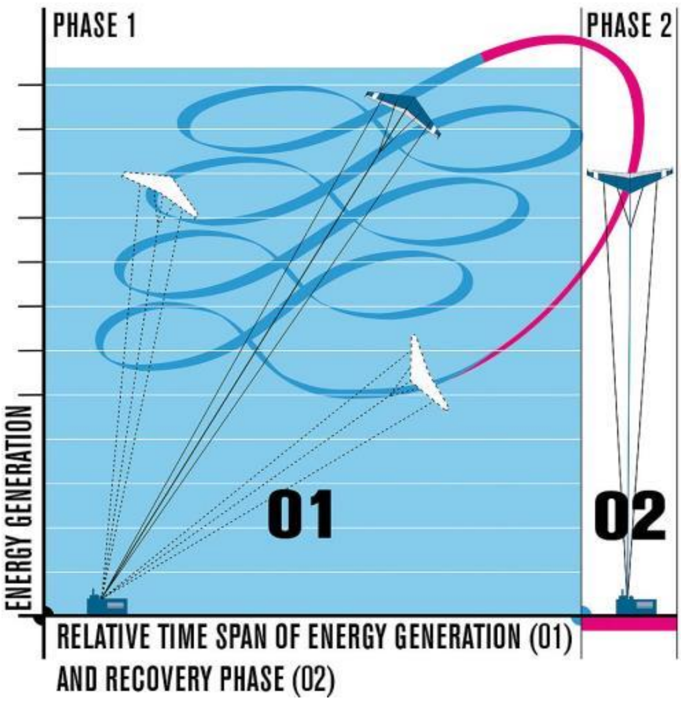

Fig.3: AWEs kite flight trajectory

3. SYSTEM COMPONENTS

Kites can be broken down into two categories based on their design (fig.4):
Leading Edge Inflatable Kites: SLE Kite (a); The C Kite (b); Hybrid Kites; Bow Kites;
Foil Kites: Classic Foil Kite (c); Valve Foil Kite

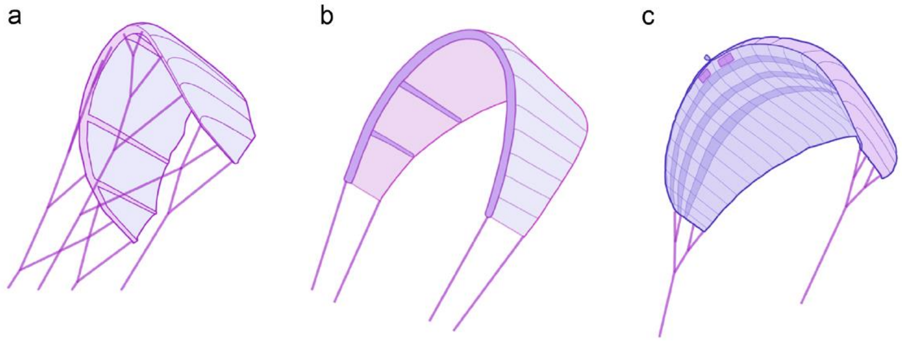

Fig.4: Types of kites

One drawback is that in the long term, the wind will fail, at least 5 percent of the time even in the best locations [5]. When the wind fails the kites must be taken down and put back up when wind is suitable for launch. This usually requires a human operator to properly launch the kites further increasing the time when the system does not generate power. The object of this proposal is to tackle this problem. One aspects of the problem can be solved by automating the take-off and landing of the kites.

Therefore we propose a system that uses as airborne unit a single sail foil kite construction with on-board capabilities to take off and land autonomously. We will use a single kite pulling force to generate power where the cable is reeled out from a drum and the rotation of the drum drives a generator. This process is known as the traction or power phase. After the cable is reeled out for several meters, the kite is configured to low drag force and winched back to its initial position. This process is known as retraction or depower phase. To control the kite’s flight a Kite Control Unit (KCU) is used which incorporates two powerful servos for steering and depowering of the kite.
The KCU is a small, remote-controlled copter suspended a few meters below the kite and is integral part of the launch/landing system. The KCU is basically a copter that will have propeller guards to will prevent accidental collision of the propellers with the kite risers or the kite tether. These guards will greatly reduce propellers efficiency but this is a non-issue as the KCU in active mode will be powered just briefly when needed.

Fig.5 explains the launch/landing sequence, were the kite (c) in collapsed/flaked position hangs bellow the KCU (a), a drogue chute (d) is used to position the kite canopy into wind and maintain the wind facing direction. The slider (b) is used to smooth line deployment and prevent line entanglements. A drum inside the KCU starts to un-reel the kite lines (stage I) causing the kite to catch more wind and consequently inflate until the actual drag cause by the kite equals the KCU lift (stage IIa). At this moment the KCU initiates a roll motion until the system positions upside down (stage IIb). From this time forward the KCU start to depower completely in order to permit the kite to fully inflate and slider to get in the lowest positon just above KCU (stage III).

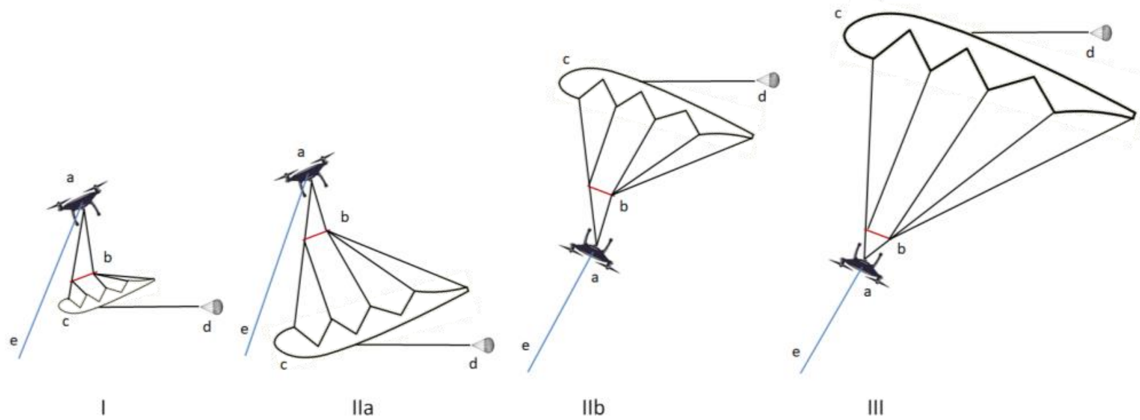

Fig.5: Kite launch/landing sequence

The landing phase will be done in reverse, starting with the lines reeling by the KCU; this will cause a decrease in kite surface area till it reaches the size were the reverse rolling action can be achieved followed by further reeling of the lines inside KCU until the kite is fully flaked bellow and thus the airborne unit can park in a specially designed area next to the ground station.

The ground station of this system consists of a drum, a variable speed electric drive that operates as a generator during the power phase and as motor during de-power phase, a battery module to balance the electrical energy over these alternating or pumping cycles and power electronics.

A simulation model is developed to investigate the power transmission system of the kite power unit, which reflects the torque, speed and power behavior of the modeled ground station transmission line. An overview of the system simulation model is as shown in fig.6.

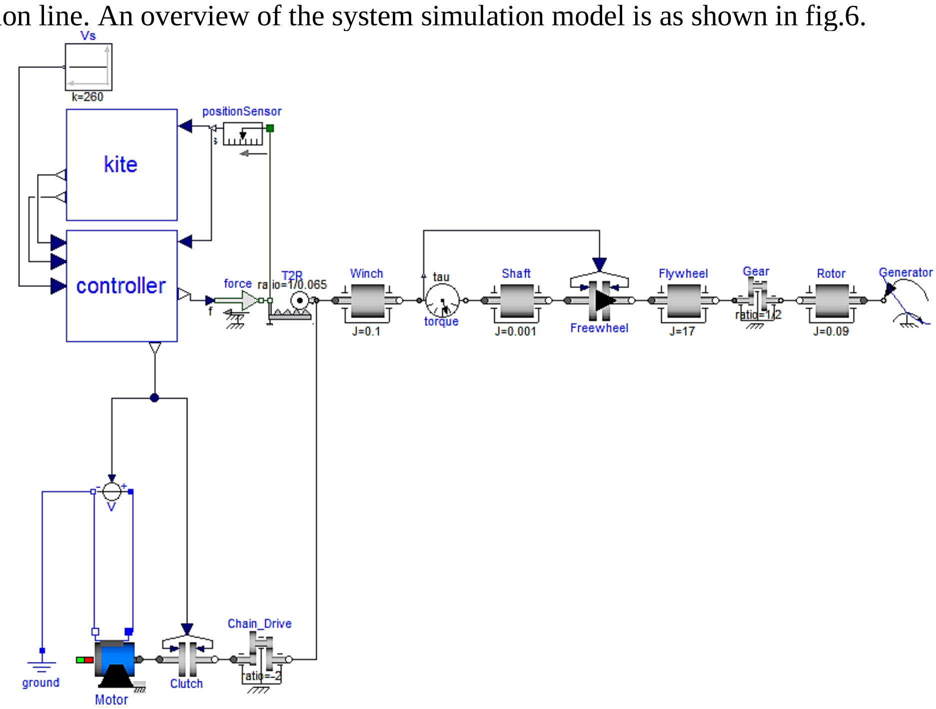

Fig.6: Illustration of the proposed AWEs simulation model

5. CONCLUSIONS

During the starting phase of the project a digital model was developed for kite (1), ground station (1) and control module (1). This model will be further applied further in the process of digital and experimental design of the functional model.

The numerical model reflects the behavior of the torque, speed and power of the transmission designed for the ground station as expected. The kite power unit was designed for a nominal power of 20.5 kW, and from the simulation results a maximum power of 18.5 kW is obtained. A simple control strategy for the kite's open-loop maneuvering system is adopted here to demonstrate the high-altitude wind generation capability. Several factors were not considered while analyzing the simulated results, such as optimal kite trajectories for efficient power generation, friction losses of the cable on the winch, exact kite dynamics, wind speed variations, etc.

It should be noted that the model in question refers to a medium-sized kite of 25 m^2 that generates a maximum theoretical power of 20.5 kW. A conventional wind turbine of the same nominal power weighs about 6 tons and costs about 70,000 euros [6]. The expected weight and cost for the designed system is of around 500-750kg and costs less then that.

To achieve good performance and efficient power production, however, a robust system control adaptable to changing wind conditions must be implemented. To achieve fully automated operation, the kite's flight path, elevation angle, and power delivery modes must be automatically adjusted in real time based on optimal set points. The use of high-efficiency airfoils can lead to further improvements in performance.

It is proposed to continue the project with the development of the digital and experimental design phase of the functional model, which will also include the prototype of the WCU active control system for the automatic control of the launch and landing sequence of the kite.

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