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Francisco Odécio Sales
(Organizador)

Conhecimentos pedagógicos e conteúdos disciplinares

das ciências exatas e da terra

2

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Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
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contato@atenaeditora.com.br

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APRESENTAÇÃO

A obra "Conhecimentos pedagógicos e conteúdos disciplinares das ciências exatas e da terra 2" aborda uma série de livros de publicação da Atena Editora, em seu I volume, apresenta, em seus 16 capítulos, discussões de diversas abordagens acerca do ensino e educação. As Ciências Exatas e da Terra englobam, atualmente, alguns dos campos mais promissores em termos de pesquisas atuais. Estas ciências estudam as diversas relações existentes da Astronomia/Física; Biodiversidade; Ciências Biológicas; Ciência da Computação; Engenharias; Geociências; Matemática/ Probabilidade e Estatística e Química. O conhecimento das mais diversas áreas possibilita o desenvolvimento das habilidades capazes de induzir mudanças de atitudes, resultando na construção de uma nova visão das relações do ser humano com o seu meio, e, portanto, gerando uma crescente demanda por profissionais atuantes nessas áreas. A ideia moderna das Ciências Exatas e da Terra refere-se a um processo de avanço tecnológico, formulada no sentido positivo e natural, temporalmente progressivo e acumulativo, segue certas regras, etapas específicas e contínuas, de suposto caráter universal. Como se tem visto, a ideia não é só o termo descritivo de um processo e sim um artefato mensurador e normalizador de pesquisas. Neste sentido, este volume é dedicado aos trabalhos relacionados a ensino e aprendizagem. A importância dos estudos dessa vertente, é notada no cerne da produção do conhecimento, tendo em vista o volume de artigos publicados. Nota-se também uma preocupação dos profissionais de áreas afins em contribuir para o desenvolvimento e disseminação do conhecimento. Os organizadores da Atena Editora, agradecem especialmente os autores dos diversos capítulos apresentados, parabenizam a dedicação e esforço de cada um, os quais viabilizaram a construção dessa obra no viés da temática apresentada. Por fim, desejamos que esta obra, fruto do esforço de muitos, seja seminal para todos que vierem a utilizá-la.

Francisco Odécio Sales

SUMÁRIO

CAPÍTULO 8

GENERATION OF WIND ENERGY WITH KITES: A REVIEW OF THE AIRBORNE WIND ENERGY TECHNOLOGY

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Laura Barros Cordeiro Peçanha
Dept. of Electrical Engineering, Instituto Federal Fluminense
Campos dos Goytacazes – RJ
http://lattes.cnpq.br/3676904945846007

Natalia de Souza Barbosa Oliveira
Dept. of Electrical Engineering, Instituto Federal Fluminense
Campos dos Goytacazes – RJ
http://lattes.cnpq.br/5085927822810487

Wagner Vianna Bretas
Dept. of Electrical Engineering, Instituto Federal Fluminense
Campos dos Goytacazes – RJ
http://lattes.cnpq.br/0842599 717842402

ABSTRACT: Use of clean and sustainable energy has gained distinction in the scientific community, given that the debate on sustainable development has been an agenda of utmost importance in a global level. Aiming to expand the existing technologies, the Airborne Wind Energy (AWE) system, which is based on capturing winds in altitudes and changing them into electric energy, was created. A review of the state of the art was made in this paper, including concepts and functioning methods, followed by two case studies of systems in operation, finishing with a proposal for the development plan of a didactic prototype based on the studies herein presented.

KEYWORDS: Alternative Energy Sources, AWE, Environmentally Sound Technologies, Sustainability.

GERAÇÃO DE ENERGIA EÓLICA COM PIPAS: UMA REVISÃO DA *AIRBORNE WIND ENERGY TECHNOLOGY*

RESUMO: O uso de energia limpa e sustentável tem ganhado destaque na comunidade científica, uma vez que o debate sobre o desenvolvimento sustentável tem sido uma pauta de suma importância no âmbito mundial. Com o intuito de ampliar as tecnologias vigentes, foi desenvolvido o sistema Airborne Wind Energy - AWE, que é baseado em captar ventos em altitudes e transformá-los em energia elétrica. Neste artigo é realizada uma revisão do estado da arte, incluindo conceitos e método de funcionamento, seguido do estudo de dois casos de sistemas em operação, finalizando com a prosposta do plano de desenvolvimento de um protótipo didático baseado nos estudos realizados.

PALAVRAS-CHAVE: Energias Alternativas, AWE, Tecnologias Ambientalmente Amigáveis, Sustentabilidade.

1 I INTRODUCTION

Given the relevance of electricity, the increasing demand for energy and the search for a more sustainable world, mankind started to show a rising need to develop energy sources that cause minimum harm to the environment (KUMAR; MISHRA; CHATTERJEE, 2017; REHMAN et al., 2019; TOLEDO et al., 2016).

Nevertheless, according to IEA data collection, the world energetic matrix is still tied to finite resources which are harmful to the environment (YANG; PARK; LEE, 2019). In order to change the way of producing energy, and seeking for production means that allow this resource to be greener and more accessible, mainly after UN (United Nations) recommendations which defined the Environmentally Sound Technologies, there has been a global effort to enable Alternative Energy Sources, especially biofuels, solar and eolic energy Concerning eolic energy, wind generation architectures started to be analyzed and spread due to the oil and gas crisis in the 1970s (FAGIANO; MARKS, 2015).

Since then, the traditional way of generating electric energy through wind uses wind turbines. However, in spite of all efficiency advance, reliability and cost reduction, the high power-to-weight ratio is still a significant issue, given that the higher the generator strength, the bigger are its dimensions, which implies additional production, operation and maintenance costs related to these turbines (CANALE; FAGIANO; MILANESE, 2007; FAGIANO; MILANESE; PIGA, 2011; TAIROV; AGNOLETTO, 2018).

Searching for new technologies capable to mitigate the previously mentioned issues concerning eolic turbines size and use of finite resources that harm the environment in the global energy matrix, Airborne Wind Energy (AWE) technology was identified as a possible answer for such matters. Therefore, this paper proposes a study concerning such matters. Therefore, this paper proposes a study concerning such technology and the design of an AWE generator didactic prototype.

2 I STATE OF THE ART

The so-called Airborne Wind Energy (AWE) technology consists of a system comprised by a kite, which captures wind from altitude, and a generator that transforms mechanical energy into electrical, and it can be either ground-based or suspended with the kite.

Studies regarding AWE systems have gained immense relevance within the academia. One of the reasons is the fact that conventional eolic turbines can only reach low-altitude winds. These winds, in turn, are weaker and less stable in proportion to the high-altitude ones (ARCHERA; MONACHE; RIFEC, 2014; DIEHL, 2013; FAGIANO; MILANESE; PIGA, 2011; FECHNER; SCHMEHL, 2012; MALZ et al., 2020).

Thefore, AWE systems prove to be an advantageous alternative, since they are able to reach higher altitudes and, consequently, higher speed winds – as altitude increases, the air masses speed intensity increases proportionally – and considering that these systems capacity of producing energy is proportional to the cube of the wind speed, AWE systems produce a more significant energy potential (LOYD, 1980; TUYTS et al,. 2015; YANG; PARK; LEE, 2019).

The most relevant academic research papers focusing on AWE systems will be addressed hereinafter, in order to explain the process of producing electric power through kites, strictly the Ground-Generator AWE system, seeking to understand how this recent innovative technology works.

A. Ground-Generator AWE system performance

AWE systems are comprised by two fundamental elements: the onshore system and the aircraft. Both must be mechanically connected through tethers (ANTONELLO et al., 2015; ARCHERA; MONACHE; RIFEC, 2014) , as shown in Figure 1:

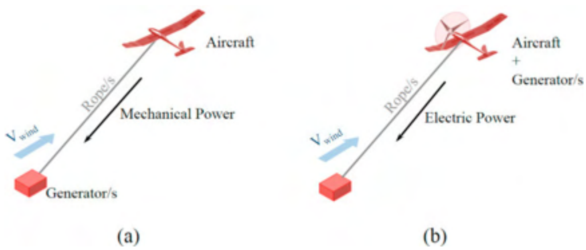

Figure 1. Examples of AWE systems (a) employing groundbased electric generator, and (b) employing on board electric generator.

(ANTONELLO et al., 2015).

The ground-based model system presented herein follows the model of Figure 1.b, consisting of an electric generator present at the station. In this model, energy conversion takes place on the ground. Due to this characteristic, it is referred to by some authors as Ground-Generator AWE system (ANTONELLO et al., 2015).

The aircraft, on the other hand, is recognized as a kite. This kite, presented in Figure 2, is responsible for delivering mechanical energy to the generator, which will be converted into electric energy afterwards.

Figure 2. Kite of Ground-Generator AWE systems.

(TAIROV; AGNOLETTO, 2018).

The performance of Ground-Generator AWE system is based on the access of energetic potential through conversion of tensile forces that the kite produces over a ground-based generator (FAGIANO; MILANESE; PIGA, 2011; FECHNER; SCHMEHL, 2012; LOYD, 1980; MALZ et al., 2020; RAPP et al., 2019; YANG; PARK; LEE, 2019; ZGRAGGEN; FAGIANO; MORARI, 2015).

Energy conversion is obtained through two phases. The first one is generation, which produces energy. The second one is recovery, and unlike what happens in generation, energy is consumed. Thus, for the system to be efficient, the generation phase must surpass recovery (ANTONELLO et al., 2015; CANALE; FAGIANO; MILANESE, 2007; FAGIANO; MARKS, 2015).

In line with (TAIROV; AGNOLETTO, 2018), the generation phase is referred to as “reelout” (the kite movement is ascending), and the recovery phase is known as “reel-in” (the rope is lowered). While the kite is flying upwardly (reel-out), it tensions the rope, which is curled in winches. The winches, in turn, are connected to the generators axes (or shafts).

The tensioned rope will induce rotation of the electric generators during its uncoiling. When the rope is lowered (reel-in), the generators will rewind them and the kite will go back to its initial position (ANTONELLO et al., 2015; FAGIANO; MARKS, 2015).

More significant amounts of energy are obtained if the kite is not static, but if it flies perpendicularly to wind direction, that is to say, in the cross wind direction (TAIROV; AGNOLETTO, 2018).

The first movement is known as takeoff, in which the wing is positioned in the wind direction and the ropes are aligned with the air flow, creating a high attack angle, therefore increasing rope tension significantly. In this course of action, the wing must be controlled in order to fly rapidly and some direction adjustments must be done to ensure the wing flies in an upright trajectory. Thereafter, the kite movement in the air is actually obtained, also known as cross wind. Finally, there is the landing maneuver, a moment in which the line strength is too low and the kite is pulled back to its original position (FAGIANO; MARKS, 2015; DIEHL, 2013).

According to researches, it is possible to state that the “eight-shaped” one, because it favors better use of cross winds, trajectory in which the kite presents best efficiency levels is the which maximize electrical energy production, producing higher tensile forces, thus hindering the rope to go through torsion and to get coiled (TAIROV; AGNOLETTO, 2018).

In a nutshell, as the kite gets uncoiled from the generator and undergoes an ascending path, it is manipulated to perform “eight-shaped” maneuvers of cross flight, therefore providing higher tensile forces to the generator, which in turn will have higher electrical energy conversion rates. This process is called “reel-out”. However, when the maximum length is reached, the “reel-in” phase starts. In this phase the generator works as an engine and the kite starts to be pulled back to the ground using a minor amount of energy produced by the kite itself. Both processes are displayed in Figure 3 (DIEHL, 2013;

FECHNER; SCHMEHL, 2012; LUNNEY et al., 2016; RAPP et al., 2019).

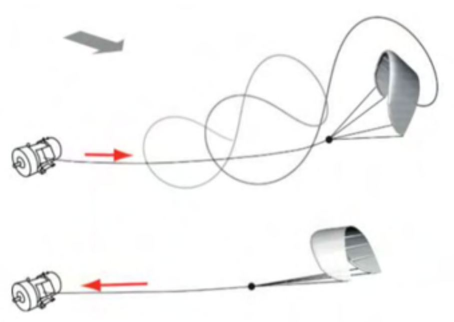

Figure 3. Reel out phase (top image) and reel in phase (lower image).
(FECHNER; SCHMEHL, 2012).

According to what has been previously stated, in order to amplify the generation power, the kites must develop an eightshaped path, which guarantees that the flight is always upright in relation to wind direction. To ensure the “eight-shaped” trajectory, control devices and methods must be used. Control plays a significant role concerning efficiency, meaning it acts as a collaborator for AWE Systems yielding (ZGRAGGEN; FAGIANO; MORARI, 2015).

Flight trajectories can be controlled through on board actuators, through control pods, by regulating the power cables, or by using diluent control cables (ANTONELLO et al., 2015).

Ground and aboard sensors that provide information such as azimuth angles, ground Global Positioning System (GPS) location, wind speed and direction, load values for each line, battery tension values, and engine currents are used to ensure better control. Some of these sensors can be attached to the main wing support (FAGIANO; MARKS, 2015; LUNNEY et al., 2016).

Besides the previously mentioned measures, the system needs a mechanism to perceive any parameters that may be inadequate or misfit, such as a failure detection mechanism. These tools will guarantee more reliability to the system (FAGIANO; MARKS, 2015).

3 | CASE STUDIES

Besides the state-of-the-art analysis, which encompasses the performance of electrical energy production through kites, the objective of this research was also to develop a study on the feasibility of building a prototype aimed at spreading knowledge on this subject, as well as to fill in the gap which is the difficulty to expand the technical and economic viability of the system (FAGIANO; MARKS, 2015).

Thus, by establishing the elaboration of the prototype as the key part of this work, we sought to analyze research that brought models of AWE System generators, especially concerning their respective technical aspects.

For this purpose, two articles published on the IEEE platform were used: “Design of a small-scale prototype for research in Airborne Wind Energy” by Lorenzo Fagiano and Trevor Marks and “Design of a distributed kite power control system” by Uwe Fechner and Roland Schmehl. Both studies approach from the structural elements and the system design to the electrical/electronic part that includes actuators, sensors and power systems.

A. Design of a small-scale prototype for research in Airborne Wind Energy

For this purpose, two articles published on the IEEE platform were used: “Design of a small-scale prototype for research in Airborne Wind Energy” by Lorenzo Fagiano and Trevor Marks and “Design of a distributed kite power control system” by Uwe Fechner and Roland Schmehl. Both studies approach from the structural elements and the system design to the electrical/electronic part that includes actuators, sensors and power systems.

Lorenzo Flagiano and Trevor Marks’s article (2015) addresses the development of a low-cost AWE system, so that it allows simulations of this new model to be carried out, without necessarily focusing on the power generation capacity, but rather on the evaluation of sensors to actuators, design and materials. Overall, AWE systems aim to produce wind energy using a wing or an aircraft, connected to the ground by moorings, subjected to winds up to 1000 meters high, using different mechanisms. In the article mentioned in this section, AWE Systems work with generators at ground level (FAGIANO; MARKS, 2015).

The system modeled by (FAGIANO; MARKS, 2015) is composed by three lines, the external lines being named “direction lines” precisely because they give the kite a sense of direction, due to the fact that they have different sizes (the line on the right is longer than the left line). Due to this difference in size, when the air flow touches the kite, it performs a rotating movement that is perceived in the center of the line, as it can be seen in Figure 4.

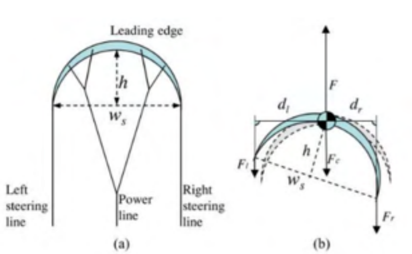

Figure 4. Air flow action in the kite. a) Front view diagram of a three-line curved flexible wing, showing the wingspan ws and the height of the wing h; b) Wing rotated during direction, and forces acting on the lines. F is the sum of all forces acting on the wing in the direction of the lines.

(FAGIANO; MARKS, 2015).

The center line ("power line"), in turn, is determined as the point of union of the two direction lines that come together forming a central line, which besides influencing the angle of inclination of the wing is also responsible to support the force exerted by the direction lines and to pass this twist on to the generator (FAGIANO; MARKS, 2015).

Regarding energy generation, it is the responsibility of the generator, which is located on the ground and often in a vehicle - such as a truck – to enable the transportation of this kitegenerator set to different regions, thus increasing the system mobility (FAGIANO; MARKS, 2015; DIEHL, 2013).

The generation process described by (FAGIANO; MARKS, 2015) applies previously discussed concepts, however with other meanings. The Power stage is herein equivalent to the reel-out phase and the Depower is equivalent to the reel-in phase.

To increase the project's efficiency, one of the most relevant mechanisms of this system corresponds to the automatic control of operation. It supervises and stores data through the sensors, in order to monitor input values and manipulate output values to reach the required set point (FAGIANO; MARKS, 2015).

This control mechanism has two main applications. The first is to maintain the wing in the air, ensuring a stable flight path. The second objective is to maximize the power generation cycle, maximizing the average produced power at the Power stage (reel-out) (FAGIANO; MARKS, 2015).

In addition to the concern with the design of the system in relation to the wing and lines, attention should be paid to other issues, such as fixing sensors, Linear Motion Systems - LMSs, anemometers, GPS, alarms and electric engines in the structure, as well as aligning the design for easy transportability and resistance of materials to corrosion (FAGIANO; MARKS, 2015).

Among these elements, it is worth noting the relevance of the LMSs in the prototype, since the direction lines give rise to the rotational movement in the wing. For such purpose, LMSs are used, which transform the rotation of electric engines into linear displacement, thus changing the length of the direction lines. In order to do so, screw mechanisms and a series of pulleys are used to redirect the lines (FAGIANO; MARKS, 2015).

That said, it is noticeable that an essential requirement for the dimensioning of the lines is the ability to withstand a sufficiently large change of linear position and be able to reduce the loads that must be supported by the electric engines (FAGIANO; MARKS, 2015).

With regard to the electric engines, it is essential to use two: one to activate the steering control and the second to activate the Power/Depower command, that is, the wing pitch (FAGIANO; MARKS, 2015).

In both cases, it is advisable to use brushed electric DC engines or non-brushed engines with incremental quadrature and position feedback encoders. The dimensioning of these engines must consider ventilation, heat dissipation, as well as shielded signal cables and real-time hardware to minimize the position feedback noise (FAGIANO; MARKS, 2015).

Regarding the power supply system, use of lead-acid batteries is recommended, as they are robust and have a fast operating time in relation to peak currents. This becomes essential since these prototypes must be prepared for the field adversities they may encounter, and they must also be able to supply the necessary energy to the engines at peak times, given that the system is subjected to high peak loads similar to those of a sinusoid (FAGIANO; MARKS, 2015).

To guarantee existence of some human control in the process, it is necessary to use a machine-human interface that needs to provide the operator with the ability to control the flight, the Power and Depower energy of the control system and also to control the LMSs position. In other words, two commands are required: one to control the position of the LMSs for the deviation of direction and the other for the Power/Depower setup of the center line (FAGIANO; MARKS, 2015).

Events such as excessive wind speed, low battery voltage or sensor failure must also be communicated to the human operator via bells or lights which shall be activated by the hardware in real time (FAGIANO; MARKS, 2015).

Regarding the line length, it must be chosen to match the space available at the established test site and it must comply with local airspace regulations. In addition, the line length must match the size of the kite and the wind connditions, in order to prevent the kite from sagging in the air (FAGIANO; MARKS, 2015).

B. Design of a distributed kite power control system

Despite the many advantages concerning energy production using kites, this generation model still comes up against technical resources such as the low availability of sophisticated control systems. Seeking to mitigate these difficulties, the University of Draft Technology has developed a power generator that operates an inflatable membrane - wing - tied in a generation cycle, in which the flight path is controlled by an actuator unit, suspended below the pipeline, and it communicates with the ground station control center via a wireless link (FECHNER; SCHMEHL, 2012).

In this research, particularly, scientists focused on the analysis of a distributed control system aiming at greater operational efficiency and flexibility. In practical terms, when having a flexible architecture, the kites of a wind farm should communicate with each other, thus avoiding collisions and optimizing the total production of the park (FECHNER; SCHMEHL, 2012).

In the prototype developed in this work, an aerial actuator (control pod) unit was chosen, which is hung under the wing (FECHNER; SCHMEHL, 2012) as shown in Figure 5:

Figure 5. Control pod hung under the wing.

(FECHNER; SCHMEHL, 2012).

According to Figure 5, the control pod is connected to the winches that control the steering lines, which are attached to the rear ends of the kite. In order to change the direction, one line is pulled while the other is released (FECHNER; SCHMEHL, 2012).

To change the angle of attack, the same movement is carried out on both lines, that is, they are pulled or released simultaneously (FECHNER; SCHMEHL, 2012).

The control pod minimizes the mechanical delay between activating the mini winches and the dynamic response of the wing. However, the system still requires a reliable communication link between the information captured by the sensors attached to the kite and the station on the ground and a power supply on board, in addition to its extra weight that generates a negative impact on the power capacity (FECHNER; SCHMEHL, 2012).

Dealing with these variables and expanding the project's viability became the crucial point of the research, which emphasized the production of knowledge for the development of a high-level kite generation control system.

Although it was originally designed for manual control between the ground station and the kite, each one having its operator coupled only mechanically, by the rope, the purpose of the project was automatic operation and for that matter it was essential to comply with hardware and software components that primarily aim at the integration of new control computers, sensors and actuators in a simple way. It is important to note that to achieve this goal, physical links between the control nodes can be used (FECHNER; SCHMEHL, 2012).

Given that the system designed by (FECHNER; SCHMEHL, 2012) was distributed, it was crucial to enhance the model so that it could achieve high control levels. In order to do so, it was chosen to carry out a synchronization between the clocks of the network nodes in less than 1ms, providing the links with the required reliability. In other words, it can be said that the software design contemplates the transfer of software components through distributed data processing.

The general structure of the control system is divided into four basic elements: the user interface (UI), the state machine (FSM), the path planner and the winch controller

(FECHNER; SCHMEHL, 2012).

The user interface, as the name already highlights, is responsible for providing information about the current position and altitude of the kite through a global satellite navigation system attached to the main wing support, as well as the displacement speed of the rope through a wind speed sensor suspended on the brake system between the kite and the pod control; in addition, it displays the amount of generated energy and other relevant aspects (FECHNER; SCHMEHL, 2012).

Connected to the user interface there is the state machine (Finite State Machine - FSM) that controls the operational mode of the system: start, landing, coiling and uncoiling, besides giving commands to the flight path planner and to the winch controller (FECHNER; SCHMEHL, 2012).

The flight path planner is responsible, as its denomination demonstrates, for calculating the ideal flight path, according to the wind speed parameters, the system situation, the instantaneous current force and the generator power. Its main objective is to minimize the error between the real and planned trajectories of the kite's flight, through an internal loop that controls the kite header and an external loop that controls its position (FECHNER; SCHMEHL, 2012).

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The winch controller, in turn, manages the drum/generator module, or in other words, a linear displacement module installed on a sled and driven by an axle engine, which ensures uniform supply of the cable at the drum. In low-speed air masses, this mechanism optimizes the combination of speed and strength to achieve maximum tractive power. In high-speed winds, this mechanism maintains the average force in the largest possible module without exceeding the maximum value supported by the structure. While in the coiling phase, it ensures that the rope tension does not decrease to the minimum value required for flight control (FECHNER; SCHMEHL, 2012).

In order to understand the working mechanisms of the control system, it is necessary to attach a grounding reference to the controller, which is then converted into a wind reference frame, where the kite's coordinates are projected in a unitary sphere around the frame's origin reference value of the wind that counts the position of the kite, which in turn is described by the azimuth angle and the elevation angle. Therefore, these angles can be used to guide the kite from its current position to the desired position, by sending a signal to the kite control pod (FECHNER; SCHMEHL, 2012).

These distributed control systems have sensors and actuators at different points in the structure that together form a critical control in a loop and which are usually connected by wireless systems. That way, it is possible to obtain a reliable control system, as Global Satellite Navigation System (GNSS) sensors can fail for different reasons. Therefore, to produce economically viable kite systems while minimizing the risk of failure, at least one additional position sensor is required, and this sensor must be able to measure elevation, as it is the case of angular sensors and also of display mechanisms that can carry out measurements exactly where the line is coming out of the winch, also known as azimuth angles (FECHNER; SCHMEHL, 2012).

For research and development purposes, the distributed control system with its controller on the ground has the main advantage of making testing and development processes easier, since using a desktop computer is easier than using a computer incorporated to the kite (FECHNER; SCHMEHL, 2012).

Since use of several computers for control and measurement purposes to communicate with each other is required, it is essential to use an Operating System, that is, a modular software structured with components that can be built independently and implemented in any part of the system to control the computers. Choice of the Operating System should include minimum latency during the loop, allowing the system to work as long as possible. For this purpose, Linux Operating System and “chrony” software were used due to their good performance for computers that do not have internet connection (FECHNER; SCHMEHL, 2012).

The software must contain additional tools, such as KitePFD, which has the function of displaying the power of the kite’s main flight, exposing particularities such as the position vector and the kite speed in top view as well as in front view; PodControl, which is responsible for displaying the position of steering winches and power/depower; and a clock capable of synchronizing the measurements of all sensors and calculating the new actor setup parameters (FECHNER; SCHMEHL, 2012).

In face of the use of different software systems, the communication between them can happen using a transport compatible with the different CPU architectures using a protocol player. For that purpose, multiple programming languages must be supported, such as Java, C or C ++. It was also possible to guarantee that it is more advantageous to use Standard Ethernet connections, since when compared to USB/serial adapters and serial numbers, wireless connections are considered more reliable and simpler (FECHNER; SCHMEHL, 2012).

Once having determined the project consents, the system can be successfully tested on more than 15 flights of approximately two hours each. It is important to highlight the convenience of keeping control during the flight, and to state that it is also possible to change the source code of any of the controllers, to recompile and run again.

Finally, the article (FECHNER; SCHMEHL, 2012) elucidates the reliability of the distributed control system, defining it as fast and capable of meeting all the requirements of a modular kite control system, being able to act in the research area, since several programming languages can be applied and different components can be developed independently, based on a common communication protocol. The distributed control system is also feasible for commercial control applications, due to the ease of adding redundant communication links and control components.

4 I PROTOTYPE DEVELOPMENT PLAN

The work whose feasibility is assessed in this paper targets at the development of a simple, low-cost and small-sized prototype which aims not necessarily to generate electricity, but to spread knowledge about this technology to groups that transcend the academic community, thus stimulating the interest of students and uninitiated people concerning the development of sustainable energy sources.

The model chosen to be developed was the GroundGenerator AWE System, consisted by a kite, lines and a generator on land. Figure 6 presents the model and elements that will be used in this project:

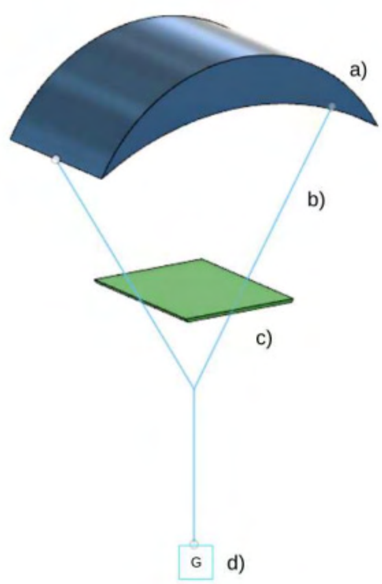

Figure 6. Schematic of the prototype using Fusion 360. a) Kite: responsible for the flight; b) Lines: responsible for interconnecting the kite with the drone and generator; c) Drone: Responsible for controlling the movement of the kite; c) Generator: Responsible for generating electricity.

A relevant factor is the material selection for the prototype construction, which needs to be light in order to favor the flight, in addition to being simple, low-cost and highly available on the market. Since it is a light material, displaying significant fluidity in the air, Styrofoam was used to represent the kite, which in turn, was connected to lines made of high density polyethylene fibers, ideal because of its low weight, resistance and flexibility.

According to Figure 6, a drone is attached to the lines, and this drone will be produced by the responsible academic team during the research. This device allows for manual control of the kite, and it is able to describe the trajectory of an eight in the air, a movement that is characteristic of AWE System. To ensure flawless control of the movements it is necessary to mention that the lines are perfectly connected to the drone in such a way that when manipulating the propellers maneuvers of this device, it is also possible to manipulate the lines resulting in the reel-in and reel-out movements.

The generator which is responsible for converting mechanical energy of the central rope traction into electrical energy must be located on the ground. In the previously described prototype, this mechanism will be represented by a mini generator installed in a replicate of a vehicle (car or boat), therefore explaining the mobility of this system that can be transported to different regions.

Another factor worth mentioning is the attachment of audible and light alarms to the structure, demonstrating the concern about having mechanisms that signal system failures.

5 I CONCLUSION

The state-of-the-art approach to technical aspects in the development of wind farms having AWE Systems as their main mechanism provided the acquisition of essential knowledge concerning the elaboration of a prototype of this energy production model, in such a way that this sample is able to represent the technologies and consents that involve this system, which in turn is in the ascendancy in the academic sphere, such as the “Design of a small-scale prototype for research in Airborne Wind Energy” (FAGIANO; MARKS, 2015) and the “Design of a distributed kite power control system” (FECHNER; SCHMEHL, 2012) mentioned in this paper and that helped in the elaboration of a method that represented the AWE Systems in an equivalent way.

Therefore, it was possible to clarify throughout this work that the use of materials such as styrofoam to represent the kite and the drone aiming at the replacement of the control system such as the POD control guarantee a satisfactory similarity, thus providing the development of prototypes with high similarity in relation to the models that are under analysis and development worldwide.

REFERENCES

A. L. Cristina, M. Luca Delle; R. L. Daran, **“Airborne wind energy: Optimal locations and variability,”** Renewable Energy, v. 64, p.180-186, apr. 2014. Elsevier BV. Available: http://dx.doi.org/10.1016/j.renene.2013.10.044

C. Antonello, P. Andrea, V. Rocco, F. Marco, **"Airborne Wind Energy Systems: A review of the technologies,"** Renewable And Sustainable Energy Reviews. nov. 2015. Elsevier BV. Available: https://doi.org/10.1016/j.rser.2015.07.053

C. Massimo, F. Lorenzo, M. Mario, **"Power Kites for Wind Energy Generation [Applications of Control],"** Ieee Control Systems, v. 27, n. 6, p. 25-38, dec. 2007. Institute of Electrical and Electronics Engineers (IEEE). Available: http://dx.doi.org/10.1109/mcs.2007.909465

C. Massimo, F. Lorenzo, M. Mario, **"High Altitude Wind Energy Generation Using Controlled Power Kites,"** Ieee Transactions On Control Systems Technology, v. 18, n. 2, p. 279-293, mar. 2010. Institute of Electrical and Electronics Engineers (IEEE). Available: http://dx.doi.org/10.1109/tcst.2009.2017933

D. Moritz, **"Airborne Wind Energy: Basic Concepts and Physical Foundations,"** Airborne Wind Energy, p.3-22, 2013. Springer Berlin Heidelberg. Available: http://dx.doi.org/10.1007/978-3-642-39965-7_1

E. C. Malz, F. Hedenus, L. Göransson, V. Verendel, S. gros, **"Drag-mode airborne wind energy vs. wind turbines: An analysis of power production, variability and geography,"** Energy, v. 193, feb. 2020. Elsevier BV. Available: http://dx.doi.org/10.1016/j.energy.2019.116765

E. Lunney, M. Ban, N. Duic, A. Foley**, "A state-of-the-art review and feasibility analysis of high altitude wind power in Northern Ireland,"** Renewable and Sustainable Energy Reviews (2016). Available: https://doi.org/10.1016/j.rser.2016.08.014

F. Lorenzo, M. Mario, P. Dario, **"Optimization of airborne wind energy generators,"** International Journal Of Robust And Nonlinear Control, v. 22, n. 18, p. 2055-2083, 29 sep. 2011. Wiley. Available: http://dx.doi.org/10.1002/rnc.1808

F. Lorenzo, M. Trevor, **"Design of a Small-Scale Prototype for Research in Airborne Wind Energy,"** Ieee/asme Transactions On Mechatronics, v. 20, n. 1, p.166-177, feb. 2015. Institute of Electrical and Electronics Engineers (IEEE). Available: http://dx.doi.org/10.1109/tmech.2014.2322761

F. Uwe, S. Roland, **"Design of a distributed kite power control system. 2012 Ieee International Conference On Control Applications,"** 6f, oct. 2012. IEEE. Available: http://dx.doi.org/10.1109/cca.2012.6402695

K. Dipesh, M. Anirban, C. Kalyan, **"Power and frequency control of a wind energy power system using artificial bee colony algorithm,"** 2017 Third International Conference On Science Technology Engineering & Management (iconkstem), mar. 2017. IEEE. Available: http://dx.doi.org/10.1109/iconstem.2017.8261385

L. L. Miles, **"Crosswind kite power (for large-scale wind power production),** Journal Of Energy, v. 4, n. 3, p. 106-111, may 1980. American Institute of Aeronautics and Astronautics (AIAA). Available: http://dx.doi.org/10.2514/3.48021

R. Ateekh Ur, A. Mustufa Haider, U. Usama; U. Yusuf Siraj, **"MultiCriteria Decision-Making Approach for Selecting Wind Energy Power Plant Locations,"** Sustainability, v. 11, n. 21, 2 nov. 2019. MDPI AG. Available: http://dx.doi.org/10.3390/su11216112

R. Sebastian, S. Roland, O. Espen, S. Sture, H. Thomas, M. Johan, **"A Modular Control Architecture for Airborne Wind Energy Systems,"** Aiaa Scitech 2019 Forum, 6 jan. 2019. American Institute of Aeronautics and Astronautics. Available: http://dx.doi.org/10.2514/6.2019-1419

S. Jeroen, H. Greg, V. Wouter, D. Johan, D. Moritz, **“Effect of the Electrical Energy Conversion on Optimal Cycles for Pumping Airborne Wind Energy,”** Ieee Transactions On Sustainable Energy, v. 6, n. 1, p.2- 10, jan. 2015. Institute of Electrical and Electronics Engineers (IEEE). Available: http://dx.doi.org/10.1109/tste.2014.2349071

T. Stanislav, A. Daniel, **“Geração de energia por pipas,”** Revista Brasileira de Ensino de Física, v. 40, n. 2, 6f., 1 feb. 2018. FapUNIFESP (SciELO). Available: http://dx.doi.org/10.1590/1806-9126-rbef-2017-0263

T. Sergio, R. Marco, G. Raul, R. Jorge, C. Leonardo, **“Predictive current control with reactive power minimization in six-phase wind energy generator using multi-modular direct matrix converter,”** 2016 Ieee Andescon, p. 213-233, oct. 2016. IEEE. Available: http://dx.doi.org/10.1109/andescon.2016.7836229

Y. Hoseong, P. Hyeonsoo, L. Youngho, **“The design of combined energy generation using airborne and ocean current kites in offshore,”** 2019 Offshore Energy And Storage Summit (oses), jul. 2019. IEEE. Available: http://dx.doi.org/10.1109/oses.2019.8867204

Z. U. Aldo, F. Lorenzo, M. Manfred, **“Real-Time Optimization and Adaptation of the Crosswind Flight of Tethered Wings for Airborne Wind Energy,”** Ieee Transactions On Control Systems Technology, v. 23, n. 2, p.434-448, mar. 2015. Institute of Electrical and Electronics Engineers (IEEE). Available: http://dx.doi.org/10.1109/tcst.2014.2332537

ÍNDICE REMISSIVO

A

B

C

D

E

F

G

I

K

L

M

P

R

S

T

U

W

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