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High Altitude Wind Energy Harvesting Technologies

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Abstract. The environment is badly affected by use of traditional fossil fuels. To avoid these impacts there is a strong tendency toward renewable energy resources that are clean. Among renewable energy resources, wind is one of the most applicable ones. Usual horizontal axis wind turbines which are common in wind farms are designed to extract the energy of winds in low altitudes that are usually less than 150 meters. The point is that the stronger winds are always blowing in higher altitudes unreachable through towers of usual wind turbines. Recently some new technologies are developed to harvest the energy of these high altitude winds. These systems usually consist of a relatively light structure. Kite-gen and ground-gen are new classes of Airborne Wind Energy Systems (AWESs). These systems have aircraft or flying tethered wings to reach winds blowing at higher layers of the atmosphere that are not accessible by classic wind turbines. A variety of systems has been analyzed and tested and also some prototypes have been made. This paper introduces different technologies that have been developed to use the energy of high altitude blowing winds. A classification of these technologies is presented. Practical ideas are also proposed to be considered in the future researches to achieve more environmentally friendly systems.

Key words: environment, wind, high altitude.

1. Introduction

There have always been rising worries about power of energy in all around the world because energy plays a basic role in improvement of human life. Today, the main source of energy is fossil fuel (Kumar Y. (2015)). Due to the lack of fossil fuels for next generation majority of governments face problems with balancing between the supply and demand. Moreover, fossil fuel cause significant effects in the environment such as greenhouse effect (Saravanan S. (2015)). The factors of choosing an energy type mainly depend on different aspects such as being economical, accessible and environmentally friendly. Generation of electricity from renewable energy sources are called alternative method, instead of the fossil fuel. Renewable energy generation is gaining lots of attention and has become well-known in order to overcome the drawbacks of fossil fuel. Renewable energy sources include solar, wind, tidal, wave, and biomass. Since solar and wind energy are widely available in plenteous, they are used for power generation (Strantzali E. (2015)).

Wind energy generation is one of the most powerful and promising renewable and environmentally friendly energy sources with no fuel costs. According to American Wind Energy Association (AWEA), the efficiency of electricity from utility-scale wind systems has decreased more than 80% over the last 20 years (Argatov I. (2015)). The replacement of fossil fuels energy with clean technology such as wind energy systems is currently an important social subject matter and economic issue. As an example the wind turbine converts the kinetic energy from wind into the mechanical energy. The mechanical energy is converted to electrical energy by means of generator. It is well-known that the power available in the wind flow for the generation by traditional wind turbines does not merely increase linearly with wind speed, but rather by the cube of the wind speed (Hau E. (2006)).

The speed of wind increases with increase of the height from ground level. One of the problems of conventional wind turbines is the technical problems and also expensive costs of producing high towers and hard transportation of them. To avoid these limits and get some other advantages a category of new technologies are innovated that can extract the energy of high altitude strong winds.

In this paper all of these technologies are introduced. Advantages and disadvantages of them are studied and some new ideas are presented to improve the high altitude wind energy harvesters.

2. High altitude technologies

Most of high altitude wind energy harvesters are composed of a light weight floating structure that is connected to the ground with a tethered system. These are mainly classified in the two branches: ground-gen and fly-gen that are discussed as following.

2.1. Ground-gen

In Ground-Generator Airborne Wind Energy Systems (GG-AWES) electrical energy is produced exploiting aerodynamic forces that are transmitted from the air craft to the ground through one or more ropes(Cherubini A. (2015)). Some of these technologies can be put in a group and be called kite-gen.

2.1.1. Kite-gen

The first moving-ground-station architecture which is based on a vertical axis generator has been proposed back in 2004 by Sequoia Automation and acquired by KGR (Ippolito M. (2006)). This AWES concept is based on the architecture described (Cherubini A. (2015)).

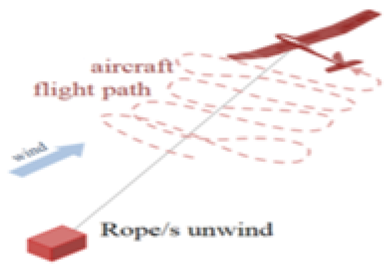

Figure 1. Scheme of the energy generation phase occurs during the unwinding of the ropes as the aircraft performs acrosswind flight. (Cherubini A. (2015))

Kite-Gen is the latest evolution of wind energy exploitation. It is a radically new and innovative concept that may be the most practical and effective solution, in the market of renewable sources, to the world's energy needs and problems. The main innovation is given by the fact that KiteGen can exploit an unexploited, virtually endless and almost universally available energy power.

The concept's operating principle is to mechanically drive a ground based electric generator using a tethered kite, instead of attempting to locate a wind turbine system at high altitudes. On the ground station the lower portion of the tether is wound around a drum connected to the generator. Energy is extracted from high altitude by letting the kite fly at a lying-eight orbit with high crosswind speed. During the fast crosswind motion the kite develops a large pulling force, and thus the generator generates electricity while the kite pulls the tether out of the ground station. Then the kite is controlled so, that the pulling force is reduced, and the lower part of the tether is wound back onto the drum using the generator as a motor. This cycle is repeated, and thus the system is called a pumping kite generator (Williams P. (2008)).

The preliminary estimates show that the net cost of wind energy generated by the small-scale KWG (kite wind generator) can be cheaper than that produced by a small-scale wind turbine of the same rated power(Argatov I. (2015)).

Advantages and disadvantages of kitegen versus wind turbine are as bellow: lower cost of initiation and installation, easy transportation, not filling much space, availability of achieving high altitude and without sonic or environmental contamination.

In order to exploit the vast amount of energy a radical change of perspective has been done: no more heavy and static structures but light and dynamic machines.

2.2. Fly-gen

In a Fly-Gen AWES (FG-AWES), electrical energy is produced on the aircraft and it is transmitted to the ground via a special rope which carries electrical cables. Electrical energy conversion in FG-AWESs is achieved using one or more specially designed wind turbines. A general classification of these systems can also be distinguished based on their flying principles that are: Wings lift, Achieved with a tethered flight of special gliders (Fig.3a) or frames with multiple wings (Fig.3b).

Buoyancy and static lift: Achieved with aerodynamically shaped aerostats filled with lighter-than-air gas (Fig.3c).

Rotor thrust: Achieved with the same turbines used for electrical power generation (Fig.3d) (Cherubini A. (2015), Ferguson F. (2006) and (2010)).

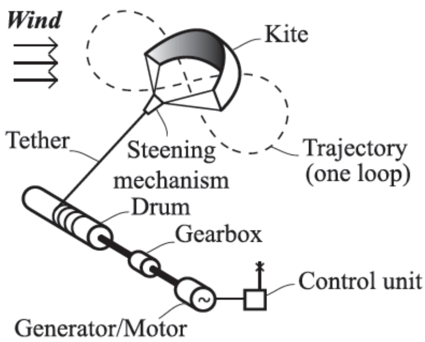

Figure 2. Pumping kite wind generator concept. (Argatov I. (2016))

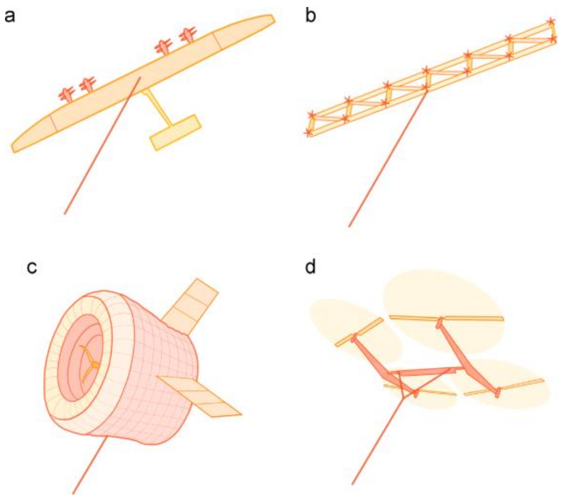

Figure 3. Different types of aircraft in Fly-Gen systems. (a) Plane with four turbines, design by Makani Power. (b) Aircraft composed by a frame of wings and turbines, design by Joby Energy. (c) Toroidal lifting aerostat with a wind

turbine in the center, design by Altaeros Energies. (d) Static suspension quadrotor in autorotation, design by Sky Wind Power. (Cherubini A. (2015))

2.2.1. Makani Powe

In nine years, Makani tested several AWESs concepts including Ground-Gen, single rope, multi- ple rope, movable ground station on rails, soft wings and rigid wings (Specter M. (2013)).

In the bimodal flight the AWT takes off with the wing plane in a vertical position, driven by propellers thrust. This flight mode is similar to a quad-copter flight and rotors on AWT are used as engines. Once all the rope length has been unwound, the AWT changes flight mode becoming a tethered flight airplane. In this second flight mode a circular flight path is powered by the wind itself and rotors on AWT are used as generators to convert power from the wind. During this phase the cable length is fixed. In order to land, a new change of flight mode is performed, and the AWT lands as a quad-copter (Griffith S. (2010) and Lind D.V. (2015)).

2.2.2. Joby Energy

Founded in 2008, Joby Energy Inc. is another US company which is developing a FG-AWES. The main difference between Joby and Makani is that the tethered airborne vehicle is a multi- frame structure with embedded airfoils. Turbines are installed in the joints of the frame (Joby Energy website (2014)) (as in Fig. 3b)

2.2.3. Altaeros Energies

In this case, instead of using wings lift to fly, they use a ring shaped aerostat with a wind turbine installed in its interior (as in Fig.3c). The whole generator is lighter than the air, so the take-off and landing maneuvers are simplified, and the only remaining issue is the stabilization of the generator in the right position relative to the wind (Vermillion C. (2013)). The aerostat is aerodynamically shaped so that the absolute wind generates lift that helps keeping a high angle of altitude together with the buoyancy force. After their energy production tests in 2012, Altaeros is additionally working on multiple rotor generators with different lighter-than- air craft configurations.

2.2.4. Sky Wind-power

Sky Wind-power Inc. (Bevirt J. (2011)) proposed a different kind of tethered craft called ‘Flying Electric Generator’ (FEG) (as in Fig. 3d) which is similar to a large quad-rotor with at least three identical rotors mounted on an airframe that is linked to a ground station with a rope having inner electrical cables (Roberts B.W. (2004), (2009) and (2011)). Their concept was the first AWES to be tested in 1986 at University of Sidney (Diehl M. (2013)) (Roberts B.W. (2015)). Take-off and landing maneuvers are similar to those of Makani's and Joby's generators, but FEG operation as generator is different. Once it reaches the operational altitude, the frame is inclined at an adjustable controllable angle relative to the wind (up to 50 deg) and the rotors switch the functioning mode from motor to generator. At this inclined position, the rotors receive from their lower side a projection of the natural wind parallel to their axes. This projection of wind allows autorotation, thus generating both electricity and thrust. Electricity flows to and from the FEG through the cable. Sky Wind-power tested two FEG prototypes (Cherubini A. (2015)). As a new idea Makani system can be composed by frame of wings and turbines. Frame of wings can be installed on an air craft to increase rate of energy harvesting.

3. Conclusion

The energy of high altitude wind is a very interesting resource for the sustainable production of electricity now a days. In the recent years, some companies tried to patent AWESs and diverse principles and to find technical solutions for their implementation. Current research explained the developed technologies in terms of different concepts, systems and trends are introduced and compared. In this work a new idea is also presented that can be tested experimentally. In the near future, an acceleration of research will be experienced in the airborne wind energy field.

References

Argatov I. and Shafranov V. (2016), Economic assessment of small-scale kite wind generators, Renewable Energy, 89,125-134.

Bevirt J. (2011), Tether sheaths and aerodynamic tether assemblies, *US Patent Application* US20110266395A1.

Cherubini A., Papini A. and Fontana M. (2015), Airborne Wind Energy Systems: A review of the technologies, Renewable and Sustainable Energy Reviews, 51, 1461-1476.

Diehl M. (2013), Airborne wind energy: basic concepts and physical foundations, In: Ahrens U., Diehl M., Schmehl R., editors, *Airborne wind energy Berlin: Springer*, 3–22 [Chapter 1].

Ferguson F. (2006), Systems and methods for tethered turbines, *PCT Patent Application* WO2006117593.

Ferguson F. (2010) Systems and methods for tethered turnes. PCT Patent Application WO2010007466. Hau E., Wind Turbines: Fundamentals, Technologies, Application, Economics, Springer, Berlin (2006).

Griffith S., Lynn P. and Hardam C. (2010), Wind power generation, *US Patent Application* US7847426B1.

Ilzhofer A., Houska B. and Diehl M. (2007), Nonlinear MPC of kites under varying wind conditions for a new class of large-scale wind power generators, Int. J. Robust, Nonlin Control, 17,1590-1599.

Ippolito M. (2006), Vertical axis wind turbine with control system steering kites, *European Patent Application EP1672214*.

Joby Energy website, http://www.jobyenergy.com/ (accessed on 30.12.14)

Kumar Y., Ringenberg J., Shekara Depuru S., Devabhaktuni V.K., Lee J.W., Nikolaidis E.,Andersen B. and Afjeh A. (2016), Wind energy: Trends and enabling technologies, *Renewable and Sustainable Energy Reviews,***53**, 209–224.

Lind D.V. (2015), Developing a 600 kW airborne wind turbine, *Abstract submitted to the airborne wind energy conference*. TU Delft.

(Roberts B.W. (2004), Windmill kite, *US Patent Application*, US6781254B1

Roberts B.W. (2009), Control system for a windmill kite, *PCT Patent Application*, WO2009126988A1

Roberts B.W. (2011), Tethered airborne wind-driven power generator, *US Patent Application*, US2011057453.

Roberts B.W. (2015), Quad-rotorcraft to harness high altitude wind energy, *Abstract submitted to the airborne wind energy conference*,TU Delft.

Saravanan S. and Ramesh Babu N. (2016), Maximum power point tracking algorithms for photovoltaic system: A review, *Renewable and Sustainable Energy Reviews*, **57**, 192-204.

Specter M. (2013), Inherit the Wind, *The New Yorker*,⟨http://www.newyorker.com/magazine/2013/05/20/inherit-the-wind⟩.

Strantzali E. and Aravossis K. (2016), Decision making in renewable energy investments: A review, *Renewable and Sustainable Energy Reviews*, **55**,885-898.

Vermillion C., Glass B. and Goessling A. (2013), Systems and methods for attitude control of tethered aerostats, *PCT Patent Application* , WO2013043586.

Williams P., Lansdorp B. and Ockels W. (2008), Optimal crosswind towing and power generation with tethered kites, J. Guid, *Control Dyn.* , **31**, 81-93.