Characteristic Study of Airborne Wind Energy Systems and its Types

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ABSTRACT

Wind Energy is a renewable form of energy available to us humans in abundance. Airborne wind energy systems (AWES) provide a solution to extract wind energy from altitudes that cannot be reached by general wind turbines. They utilize lightweight yet strong tether setup instead of a costly tower which gives an extra cost favorable position and lower add up to mass. This paper discusses mainly about different classifications of higher altitude wind energy conversion systems and Altaeros energies which are further classified as Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT) for small scale and large scale advantages based on their suitability and performance.

Keyword: - *Airborne Wind Energy Systems, Vertical Axis Wind Turbine, Horizontal Axis Wind Turbine, Airborne Wind Energy, Altaeros*

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1. INTRODUCTION

Wind vitality is a standout amongst the most plenteous types of sustainable power source. The normal size of wind turbines has been expanding ceaselessly amid the most recent couple of years. To reap high height wind, the airborne wind turbine is an option and inventive strategy which has a few favorable circumstances. There are few detriments of a three-bladed horizontal axis wind turbine. The height of the tower is constrained, as it must carry the mass of the rotor and drivetrain. Moreover, in offshore situation, the development and upkeep of a wind farm are not cost effective.

AWES is intended to achieve heights that are incapable for traditional turbines. This converts into higher potential vitality capture as wind speeds are faster and winds are less turbulent. Where the mean wind power density is appeared to be 4 times greater at a height of 500-1000 meters than that of 50-150 meters [1]. This is essential for remote zones that have constrained access to the framework, or for archipelagic nations that have numerous dispersed islands causing troubles in grid axis. The airborne HAWT is entrenched, there has been constrained consideration regarding the improvement of an airborne VAWT. This is on the grounds that the VAWT creates moderately low electrical power than the HAWT. Additionally, the plan of a device that can work on the vertical axis is challenging. In any case, the airborne VAWT has critical points of interest, particularly for Savonius idea that can self-start and work in low wind speed conditions [2]. Moreover, the airborne VAWT can catch the wind from any course due to its vertically arranged blades. Things being what they are for the most part airborne wind energy systems give out a critical power yield than traditional wind turbines

2. HIGHER ALTITUDE WIND ENERGY COVERSION SYSTEMS

High altitude wind energy conversion systems are mainly classified into two types ground-gen and fly-gen. Ground-gen is further classified into Fixed Ground Station and Moving Ground Station. Whereas Fly-Gen is classified into Crosswind and Non-Cross wind [3]. There is likewise a second rate class of systems that does not create electrical power but rather utilizes tether tension for vehicle propulsion. Some AWE systems have flexible wings while others have rigid wings. The wind turbines classified above are suitable at an altitude of 600 meters and above. They use the power of the jet stream available in the midst of troposphere and stratosphere which produces about jet velocity of 30 meter/second.

AWE systems are heavier than air and have therefore to depend on aerodynamic lift to remain airborne, however a couple of AWE systems are lighter than air and would thus be able to remain in the air inactively. Between every one of these ideas, numerous blends are conceivable, and a large number of these types are in fact realized

3. LIGHTER THAN AIR SYSTEMS

While most airborne wind energy systems relies upon aerodynamic lift in one shape or the other so as to keep the framework airborne, a couple of systems depend on aerostatic lift to stay on high, i.e. the airborne part of the system is lighter than air. The favorable position is that they can remain airborne without wind uncertainly, and without control utilization. Then again, they require a significant volume to repay the heaviness of rest of the airborne system. This volume is generally loaded with Helium. A fascinating certainty is that power generation joins critical tether tension and when the wind blows and power is created, the tether force, which is halfway coordinated in vertical way, generally dominates the heaviness of any airborne wind energy systems in this way, the upsides of lighter than air systems end up old when they do produce power. Two of the lighter than air systems that have been acknowledged as of late, the systems by Magenn power and Altaeros Energies said before, both utilize onboard power generation with the extra weight of the electrical generator.

3.1 Tether

There ought to be a total of three tethers situated at the front and toward the back sides of the shroud. The distinction in lengths of tether permits adds up to control over the roll and pitch of the shroud. Tension on the tethers is compelled to a minimum value to keep the shroud losing overall lift and keeping up a level of redundancy required for system stability. The tether requires a high strength to weight proportion, in addition to the diameter of the tether being as low as conceivable to lessen any drag. The incited tether drag will have a greater amount of an impact on the power generation of a kite or plane system since this system is relies on a high lift to drag proportion to boost the mechanical power yield [4]. However, in the Altaeros case one tether will be strengthened with either copper or aluminum to take into account electrical conduction. This will add weight to the system and increment the general cost contrasted with a kite or rigid plane design.

3.2 Actuators

The motor driven winches are situated on the base station controlling the reel out speed of the tethers. The maximum angular velocity at which the motor reels out the tether is restricted to avoid actuator limiting condition. On the shroud there are dynamic valves that can vent helium to increment and decrement of overall buoyancy of the shroud. Fins are available on the shroud which contribute streamlined lift and adjust the entire systems centre of pressure with the focal point of mass. A limitation on the most extreme pitch angle is set to keep the shroud entering stall and losing overall lift [4].

To stabilize the turbine in midair at an altitude of 30m from ground level, the elevator aerofoil NACA 0012 is inclined at -6o angle of attack at the leading edge [3]. To suspend the system in midair a helium balloon can be made according to its weight requirements. The wind turbine used is a direct drive system and the solar cells utilized for backup or support power generation is embedded into the main wing. A microcontroller can be utilized to control and transfer power without affecting the generator and solar cells. The generation system has DCDC power boosters to avoid transmission loss and also increase power generated. The system is designed to harvest energy at a micro level where it involves low speed winds varying from 8 m/s to 12 m/s [3].
The tension of a single tether is calculated as follows:

$$T_i = AE\varepsilon \quad \varepsilon = (l^i - l^i_u)/l^i_u \quad \ldots.\ (1)$$

Eq (1) defines the tension T at node 'i' of the system. As there are three tethers there are three nodes in this case. A is the cross-sectional area of the tether and E is young's modulus of the material. E denotes the difference in length between the stretched lengths of the tether, where l^i is the absolute length that the tether currently sits at. It is known as the un-stretched tether length and is regulated through the winch speed of independent motor 'i' located on the base station [5]. The tether moments are then calculated as a function of tether tension and the tether attachment points in relation to the shrouds center of mass and related to the inertial reference frame through appropriate rotation matrices. Note that during simulation tether tension is constrained to being positive at all times.

3.3 Ground System

Base station mainly contains winch, transformer, substation control house and power grid or batteries for storage of power. Winch can be multi rope or single rope. Two or more winch stations are placed in order to avoid tilting of shroud. The main conductive tether is connected to the transformer and substation control house in order to extract electricity and store in batteries for use.

At base station there are weight sensors, GPS, wind speed and direction sensors. Touch sensors are situated on the base station to give signs to successful landing and take-off while force transducers screen the traction force on the tether. On the shroud there are barometric pressure sensors, wind speed and direction sensors, accelerometers, magnetometers and three pressure transducers. Correspondence between the shroud and the base station is accomplished through a remote connection working at 2.4GHz. This takes into account exact situating, altitude and speed estimation of the shroud in respect to the base station [4].

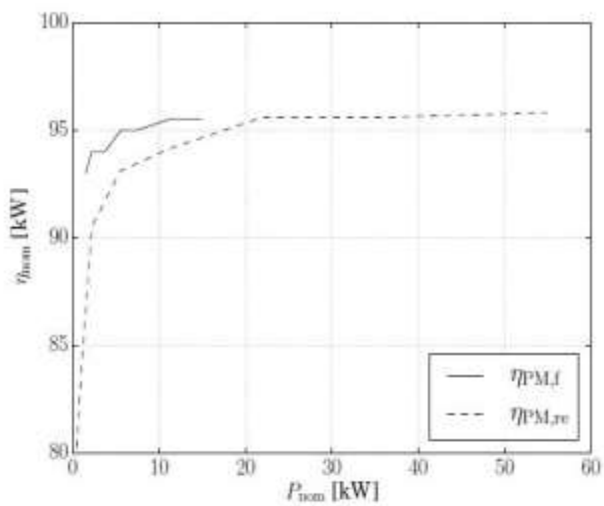

Fig -1: Efficiency of two types of permanent magnetic generators as a function of the nominal power rating [6]

The efficiency of a generator depends primarily on numerous parameters. Most critical is the sort of the generator. For a decent effectiveness in these investigations permanent magnets (PM) generators are considered. Two sorts of generators were researched: First, ordinary PM generators utilizing rear earth magnets and second, high productive PM generators, utilizing customary (and modest) ferrite magnets [6].

4 ALTAEROS

Altaeros Energies have built up a light airborne turbine (BAT) which has a standard wind turbine rotor settled inside a helium filled shroud. The framework is connected to ground through three tethers one situated at the fore and two situated at the toward the back starboard and behind port separately. One tether encourages the exchange of electrical vitality to ground. The tether lengths are managed through three DC engines situated on a turning base station [8]. They can be classified based on type of axis i.e., (HAWT and VAWT)

Fig -2: Altaeros Energies System During Testing

4.1 Horizontal Axis Wind Turbine

The design of Horizontal Axis Wind Turbine is similar to ordinary type of wind mill. Horizontal Axis Wind Turbine mainly contains yaw movement. Yaw movement is basically wind sensor coupled with servo motor to turn the turbine. The blades of HAWT are perpendicular to shaft axis. It has a rotor shaft and electric generator. BAT was the model which was already proposed by the Altaeros energies. Altaeros energies mainly focus on increasing the efficiency compared to the normal wind mill. It is developed in rural areas like Alaska in USA for experimental trails containing vast area of land. The electricity generated from Altaeros energies will be satisfying 10 to 15 families approximately. BAT is a propose HAWT design having inflatable shell of 35-foot-long. It covers the wind flow 8 times greater than the considerable wind (i.e., 1000-2000 feet above the ground). The power is supplied to the generator at the base station which is located on the ground through conductive tethers from the turbine. The working principle of BAT is combination of balloon and kite. The main working principal is by sending turbine to higher altitudes by using helium gas in inflatable shell. The power output is increased from 10% to 20% when the turbine is placed above the wind speed.

Three tethers associate the BAT to a turning ground station, automatically modifying its elevation to get the most strongest conceivable winds. It is named as kytoon (a packed name for kite and balloon) which is kept on high by consistent winds. Airborne wind turbines are secured to the ground utilizing electrically conductive tethers, which transmit energy to the ground.

The power output of HAWT can be calculated by using the following equations [3]

4.1.1 Power available in the wind

$P = 1/2 \times \rho \times A \times v^3$

Where, P = Power (W)

ρ = Density of air (kg/m^3)

A = Area the wind is passing through the wind mill - perpendicular to the wind (m^2)

v = Wind velocity (m/s)

4.1.2 Power extractable from the wind

$P = 1/2 \times \rho \times A \times C_p \times v^3$

Where, C_p = Power coefficient

The power coefficient is based on Betz limit. Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular – the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines.

4.1.3 Optimum Tip Speed ratio

λ max = $4\pi/n$
Where, λ = Tip Speed Ratio
n = number of blades on wind turbine

4.1.4 Lift force

$F_L = 1/2 \times C \times L \times \rho \times v^2 \times A$
Where,
F_L = lifting force (N)
C_L = lifting coefficient
ρ = density of fluid (kg/m^3)
v = flow velocity (m/s)
A = body area (m^2)

4.1.5 Drag force

$F_D = 1/2 \times CD \times \rho \times v^2 \times A$
Where,
F_D = drag force (N)
CD = drag coefficient
ρ = density of fluid (kg/m^3)
v = flow velocity (m/s)
A = body area (m^2)

4.1.6 Reynolds number

$Re = (\rho u^2) / (\mu u / L)$
$= \rho u L / \mu$
$= u L / \nu$
Where,
Re = Reynolds Number (non-dimensional)
ρ = density (kg/m^3)
u = velocity based on the actual cross section area of the duct or pipe (m/s, ft/s)
μ = dynamic viscosity (Ns/m^2)
L = characteristic length (m)
ν = kinematic viscosity (m^2/s)

For the balloon to lift the turbine, $1m^3$ of helium can lift 1099 grams. So by calculating the volume of the balloon by its shape the amount of helium required for the balloon to lift the turbine is calculated.

5 VERTICAL AXIS WIND TURBINE

The new and latest approach in wind turbine development is vertical axis wind turbine. The main advantages of VAWT are, maintenance cost is low and installation cost of a VAWT is easy which costs very less than HAWT. VAWT is self-initiating design. The main cons of VAWT are these types of wind turbines are suitable only for low wind speed areas and the blades which are developed in the rotor often breaks because of high centrifugal force caused by strong winds. But in the latest proposed model, wind energy is utilized by unique blade design. This model uses gas balloon to carry vertical axis wind turbine or the turbine itself is a gas balloon. Electrical generator is used to convert the wind energy into electrical energy. To retain the favorable conditions in performance of electrical generation, the design of the generator is made of a light weight material. The VAWT produces lower electricity when compare to HAWT. The designed and manufactured airborne VAWT was evaluated to supply low-power up to 0.4 W [2]. The drag type blades are used to produce a high amount of torque. The VAWT is only suitable for low wind speeds. There is no need of yaw movement in VAWT.

Here a gas balloon was used as the main body of the turbine. Ideally, the airborne VAWT should be positioned vertically to work in any wind direction. However, the swing movement of the gas balloon due to total drag force generated by wind (F_W) might occur, which reduces the output wind energy. This problem is a main challenging issue in designing the airborne VAWT. The problem can be solved by placing a balloon (head) at the top of the body with suitable volume Fig. 3a. Figure 3b shows free body diagram of the airborne VAWT without head component

[2]. Here total drag force, tie force (F_T), lift force (F_L) and gravitational force (F_G) are coincident in the center of gravity point. Fig 3c shows the head component of airborne VAWT. The moment force (F_L X L) is generated due to shifting. The additional F_L causes the shift of centre of gravity. This helps the VAWT to maintain the vertical position. The drag coefficient of blades and gas balloons differ, the drag coefficient of the blade should be more than balloon. The type of blade design is also an important consideration. The half round shape of the blade is selected because the quantity of air is more, when compared to normal ones, so a lot of pressure is created. This also maximizes the drag force.

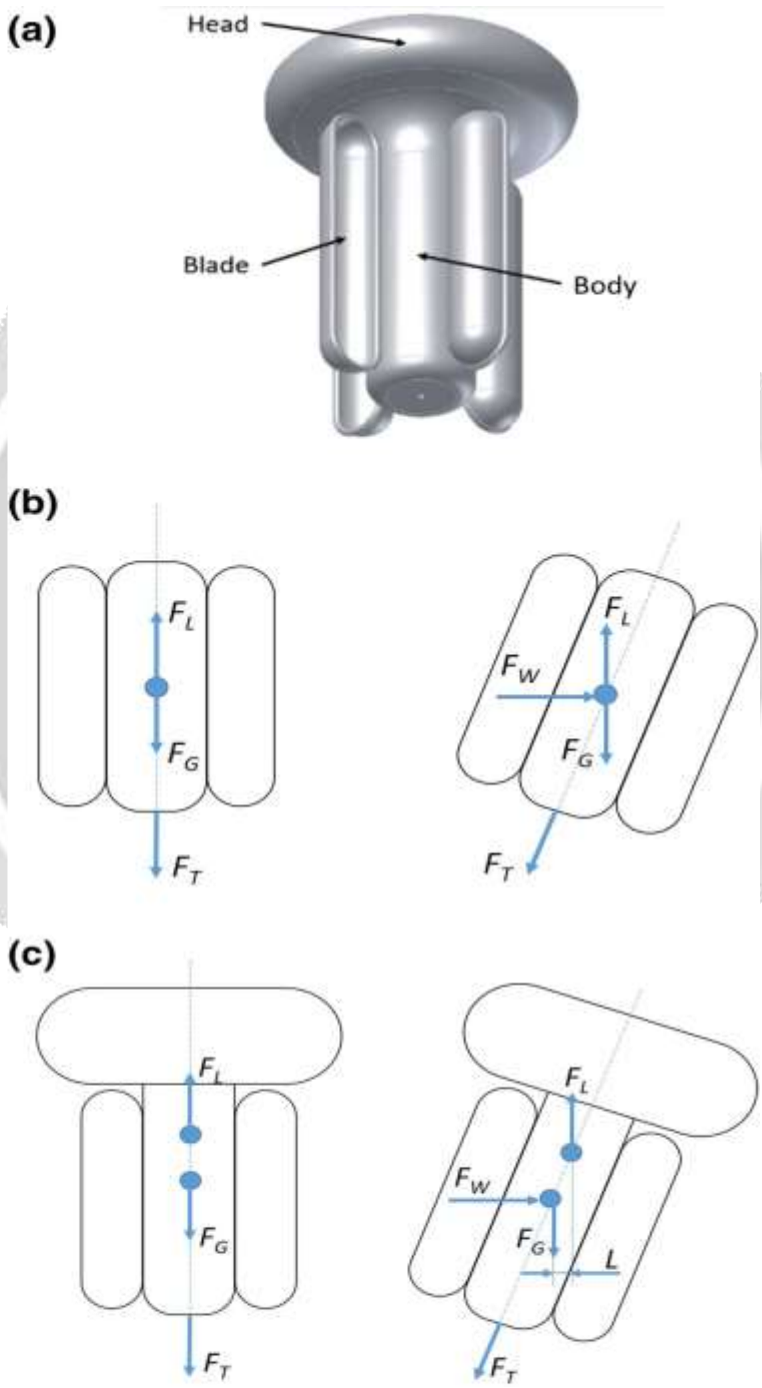

Fig -3: (a) The proposed design of the airborne VAWT, (b) free body diagram without head component and (c) with head component.

5.1 Methodology

5.1.1 Number of Blades

The number of blades used for the airborne wind turbine must be determined to obtain a maximum drag force [2]. Typically, increasing the number of blades installed to the VAWT can achieve high drag force from any direction of the wind [7]. However, there must be no blade which is covered by another blade whilst facing the wind. Figure 4a shows a schematic of the blade positions for the gas balloon. A covered blade is defined as when the outer part of a blade (point A) overlaps the tangential line of the inner part of another blade. The number of blades, while maintaining that there is no blade covered by another blade, reaches a maximum when point A is in line with the tangential line. At a maximum number of blades (n), point OAC will form a right triangle as shown in Fig. 4b. n can be then calculated from Eq. (2):

$n = 2\pi/\theta$ .... (2)

where θ is the angle of the nearest two blades. It can be calculated using the following equations

$\cos\theta = (D/2)/((D/2)+d)$ ….(3)

where D and d are the outer diameter of the gas balloon and the diameter of the blade, respectively. Substituting Eq. (3) into Eq. (2), n as a function of diameter ratio (D/d) can be calculated using Eq. (4):

$n = 2\pi/\cos{-1}\{(D/2)/(D/d^2)\}$ ….(4)

Note that n is an integer number, the decimal number appearing from calculations should be rounded down.

5.1.2 Generated Torque on the Blade

The total torque generated by the blades (T) is generated when the blades are facing the wind. Hence, it can be calculated using Eq. (5)

$T = \sum F_D R$ ….(5)

where R is the length between the center of the main gas balloon and the center of blade and F_D is the drag force generated by the blade. FD in stationary condition can be calculated using Eq. (6)

$F_D = 1/2 C_D \times \rho \times A \times (v\cos(\alpha))^2$ ….(6)

where ρ, A, v, α, and C_D are air density, the frontal area of the blade, wind speed, the angle between the wind speed direction and the normal direction of the blade surface, and drag coefficient, respectively. It is important to note that the blades of an airborne VAWT consist of front and back shapes. The value of C_D depends on the blade shape facing the wind. Forward torque is generated by the front shape of the blades facing the wind, whereas an opposing torque is generated by the back shape of the blades facing the wind. Torque generated at rest condition

$$T_{sta} = 1/2 \times \rho \times A \times R\ \{\sum C_{D1} \times (v\cos(\alpha_1))^2 - \sum C_{D2} \times (v\cos(\alpha_1))^2\}….(6)$$

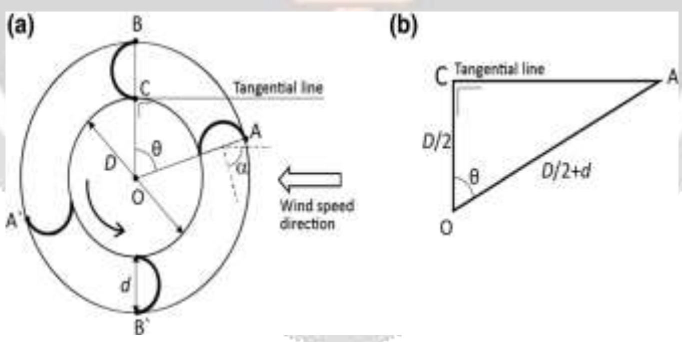

Fig -4: (a) Schematic of blade position, b(a) right triangle used to calculate the maximum blade number condition

where C_{D1} and C_{D2} are the drag coefficients of the front and back blade surfaces.

5.1.3 Operating rotational velocity

The operating rotational velocity of an airborne VAWT (x) can be predicted by modifying Eq. (6) for steady state rotation. In steady-state rotation, the available wind speed which can generate a torque at the blade (Tcycle) is the relative speed between the wind speed and the circumferential speed of blade. F_D generated from the available wind is used to maintain the rotation of the airborne VAWT. Further, Tcycle can be expressed by Eq. (7)

$$T_{cycle} = 1/2 \times \rho \times R \times (\sum C_{Di} \times (v\cos(\alpha_i) - \omega \times R)^2 - \sum C_{D2} \times (v\cos(\alpha_j) + \omega \times R)^2 …..(7)$$

6 CONCLUSION

Most airborne systems are still at working and implementing stage. Altaeros Energies combines state aerodynamic theory to produce a system that has the potential rival a wind turbine. This paper presents a guide into the design and operation of the Altaeros system and some classifications. A brief description about HAWT and VAWT has been discussed. This shows that if these above mentioned systems are implemented more amount of energy can be extracted from renewable source of energy.

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