Current and Future Vertical wind Turbine

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Vertical axis wind turbines (VAWTs), and especially small VAWTs, have been used in urban lighting, homes, large outdoor billboards, telecommunication stations, oil fields, wind energy buildings, highway monitoring systems, boats and micro-generation stations, since they are omni-directional, noise-free, safe, reliable, esthetically pleasing and easy to maintain.

VAWTs in the markets come in various shapes and sizes due to the research concepts and practices of different manufacturers. Major wind turbine manufacturers, i.e. manufactures of MW-class horizontal axis wind turbines (HAWTs), have paid little attention to VAWTs, and the end users have had misunderstandings with VAWTs as the performances of most VAWTs can hardly compete with those of the HAWTs. However, VAWTs have become more and more popular thanks to their unique advantages, and in recent years more research efforts have been put into VAWTs than ever before.

Firstly, an introduction to the types of VAWTs:

1. Types of VAWTs

VAWTs can be divided into two major categories: drag-type that uses the drag of airflow to rotate and lift-type that uses the lift of airflow to rotate. Savonius VAWTs, or the S-type VAWTs, are typical drag-type turbines (See Fig. 1-1). Savonius VAWTs usually consist of two or three scoops, and looking down on the rotor from above, a two-scoop machine would look like an “S” shape in cross section. The advantage of Savonius VAWTs is bigger starting torque, while their drawbacks are vibration during rotation due to the sideway push produced by the asymmetric airflow, and low efficiency. Based on simplified calculations, the theoretical wind utilization rate can never exceed 2/27, and the actual utilization rate is lower than 2/27, making Savonius VAWTs difficult to commercialize.

Fig. 1-1

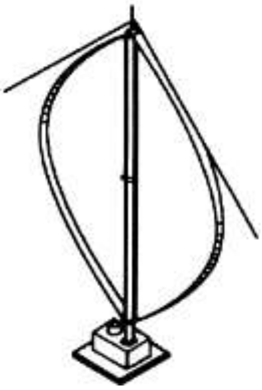


Fig. 1-2

Fig. 1-3

Lift-type VAWTs use the lift of airflow to rotate, and their blades are of aerofoil section, driving torque being created by resultant force when the air flows around the blades. Darrieus type (See Fig. 1-2) and H-shape type (See Fig. 1-3) are typical lift-type VAWTs.

Rotors of Darrieus turbines can be of Φ-shape or special Δ-shape, and usually feature two to three blades. They are simple in structure and low in cost, but are poor at self-starting, and to overcome this drawback, Darrieus tubines are sometimes combined with Savonius turbines.

H-shape VAWTs vary greatly in the conncetion methods of blades and the shaft, which influence the aerodynamic performance and mechanical structure. See Fig. 1-3 for the structure of a typical H-shape VAWT. H-shape VAWTs are able to perform well and achieve a wind utilization rate comparble to that of the HAWTs, provided specifications such as airfoil, angle of attack, number of blades, solidity of blades and structure are optimized.

2. Current situation of VAWTs

2.1 Current types of VAWTs

Two types of VAWTs are used nowadays, and the following is a brief analysis on their characters and applications.

2.1.1 Drag-type VAWTs

Figs 2-1, 2-2 and 2-3 show typical structures of drag-type turbines, which are easier to start, spins at lower speeds, but they cannot realize aerodynamic speed-regulation, and prone to damage by typhoons. Therefore, applications of drag-type turbines are limited to occasions where wind speeds are low, wind efficiency is not important and typhoons are rare.

Fig. 2-1

Fig. 2-2

Fig. 2-3

2.1.2 Lift-type VAWTs

Lift-type VAWTs, differing greatly in appearances, fall in the following categories:

Darrieus turbine. See Fig. 2-4 for a typical Darrieus turbine. Their blades, coming in two or three, have narrow chord, therefore self-strating is usually a problem and external forces are needed. However, the greatest drawback is its inability to relizing aerodynamic speed-regulation due to blade connection means, thus to avoid disintegration, the turbine must be shut down in high wind conditions. In-grid applications of Darrieus turbines are limited. The advantages of Darrieus turbines are: no need for towers, simple structure and low cost.

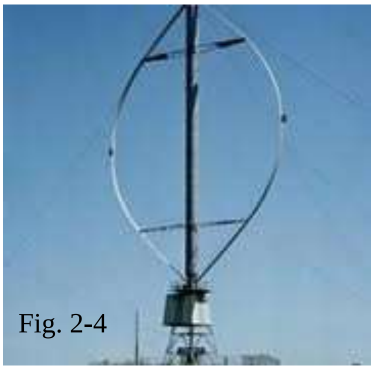


Fig. 2-4

VAWTs with helical blades. Straight blades H-shape VAWTs usually have two to five blades, and blade number influences the turbines' ability of starting - the fewer blades used, the more "dead points" (when the blades are situated in the dead points, no matter how fast the wind speed is, the turbines can not start) exist in the blades on starting. Turbines with two to three blades have the most "dead points", and turbines with four blades have less "dead points", while turbines with five blades are virtually "dead points"-free. To address the "dead points" problem in four or less bladed turbines, a new model of H-shape turbines have been developed, which employ helical blades (see Figs 2-5, 2-6 and 2-7). However, such turbines require greater cut-in wind speed, especially when the blades chords are narrow, since the torque produced in blades are small. Furthermore, the blade connections methods make the angle of attack fixed, rednering aerodynamic speed-regulation impossible. Damping resistors are the only option, making VAWTs with helical blades only suitable for hundred-watt turbines, not for middle or large turbines.

Fig. 2-5

Fig. 2-6

Fig. 2-7

Straight blade H-shape VAWTs (See Figs 2-8 and 2-9). With proper design, aerodynamic speed-regulation is possible for such turbines. Straight blade H-shape VAWTs vary in the means blades are connected to the shaft, resulting in different mechanical and aerodynamic performances.

a. the shaft connecting both ends of blades by supporting arms. During rotation, such turbines can maintain the air pressure inside of windmill as much as possible, therefore perform best aerodynamically. However, longer shaft experiences bigger bending moment, undermining the mechanical structure of the turbines.

Fig 2-8

b. turbines with a contracted shaft. In such turbines, supporting arms hold blades at the middle part. The shaft experiences less bending moment and load, facilitating the designing of shafts and cutting weight and cost. However, since the air pressures inside and outside the wind mill are different, such top-and-bottom open turbines will lose air pressure—this very pressure difference contributes most to the driving torque for lift-type turbines—in rotation. Such turbines are not efficient, the aerodynamic performance being compromised for structure purposes.


Fig. 2-9


Fig. 2-10

c. shortening the shaft to 1/2 of blade length (see Figs 2-11 and 2-12). Such designs, having balanced turbines' aerodynamic performance and mechanical structure, strengthened by other means that reducing inside-and-outside-windmill pressure difference lost, can achieve substantially the same aerodynamic performance as that of "shaft connecting both ends of blades by supporting arms", and the mechanical performance is also satisfying, facilitating the commercialization of the turbines.


Fig. 2-11


Fig. 2-12

2.1.3 Combined Darrieus-Savonius turbines

Combined turbines, i.e. put a Savonius turbine inside of a Darrieus turbine. Such turbines address the self-starting problem paluged Darrieus turbines. However, since the optimized tip-speed of Savonius turbine is 1/3 of the wind speed, the efficiency of the combined turbines depends on—not the efficiency of Darrieus turbine—the efficiency of Savonius turbine, as well as the diameter ratio between Savonius turbine and Darrieus turbine, and the closer the ratio to 1, the closer the efficiency of the combined turbines to the efficiency of Savonius turbine; in the contrary, if the ratio is small, the function of improving starting ability is losing. For such combined turbines, an improved design is to use a overrunning cluth to separate rotations of the two turbines, improving the mix turbine's wind utilization rate. However, the turbulences created by Savonius turbine will affect Darrieus turbine, making such combined turbines' efficency low. Further, such combination—same as Darrieus turbine—can not realiaze aerodynamic speed-regulation, narrowing its working wind speed range. The advantages are simple structure and low cost.

Fig. 2-13

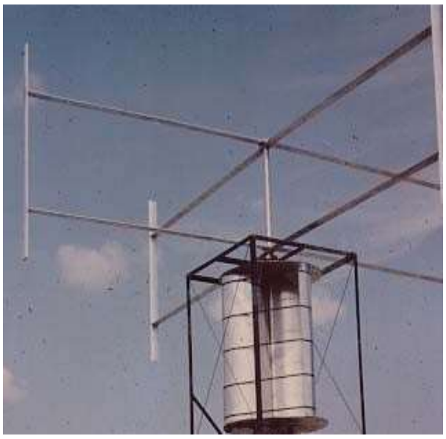


Fig. 2-14

The angle of attack—the angle between blade chord and the tangent of windmill orbit—of most lift-type VAWTs is fixed, and such turbines are simple in structure but not able to realize aerodynamic speed-regulation, resulting in limited applications and not in a position to compete with HAWTs. Most of the currently available small lift-type VAWTs employ damping resistance or short circuit to address over-speeding, in order to expand the work wind speed range. However, such over-speed regulation methods, based on wind tunnel experiments, are suitable only for hundred-watts VAWTs within certain wind speeds range, not for bigger VAWTs in high wind conditions.

Fig. 2-12 demonstrates a small VAWT with limited variable angle of attack feature, i.e. the angle of attack is able to change within limited range. Such feature, similar to variable pitch technology in HAWTs, can not only improve turbine efficiency, but also realize over-speed regulation, expanding the working wind speed range for VAWTs, and is suitable for KW-class VAWTs, hence greatly improving the commercial value of KW-class VAWTs and paving the way for the commercialization.

The double straight blade turbine has been developed based on the H type straight blade turbine (see Fig. 2-15). Double blades amount to increase the solidity of a turbine, thus improving its self-starting performance, and such design idea originates from double wing airplanes. However, the aerodynamic features between double wing in straight line motion and in rotation motion are highly different—in straight line motion, the influence of turbulence is comparatively small, while the influence of turbulence is comparatively big in rotation motion, and the turbulence caused by the inner blade will influence the aerodynamic performance of the outer blade, as well as decrease its efficiency in high speed rotation. Additionally, the different tip-speed ratios of the inner blade and the outer blade will further influence the turbine’s efficiency.

Fig. 2-15

2.2 Self-starting, number of blades and solidity of blades

Straight blade H-shape VAWTs usually use two to five or more blades, and blade number contributes greatly to VAWTs’ self-starting performance. Increasing baldes number amounts to improve the solidity of blades—measured by the sum of blades chord divided by circumference of wind mill, and when solidity of blades exceeds a certain dgree, the efficiency of the VAWTs begin to fall. While low solidity of blade can achieve higher rotational speed under load-free conditions, the loaded performance is poor. The optimized solidity of blade is around 0.2 to 0.25.

2.3 Relation between self-starting and efficiency

Drag-type VAWTs excel in starting performance, while lift-type VAWTs with fixed angle of attack are comparatively poor at starting performance. Starting performance and efficiency are not compatible in lift-type VAWTs with fixed angle of attack, and both factors shall be taken into consideration in designing.

2.4 Braking system for VAWTs

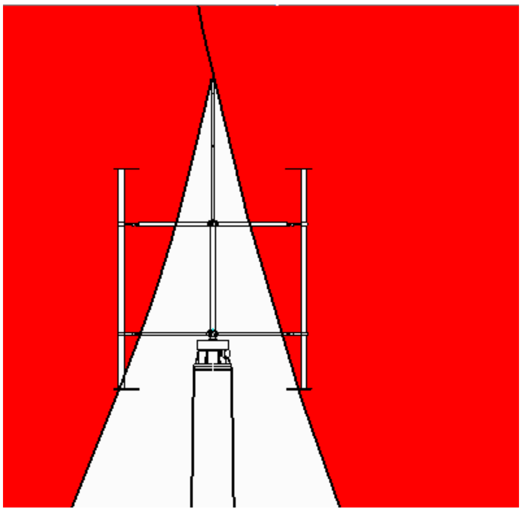
Low cut-in wind speed means higher driving torque, thus greater braking torque is needed to stop VAWTs. For VAWTs with only on stage brake, the braking torque shall be higher than the turbines' static torque at survival wind speed; For VAWTs with two stages brake, the first stage brake shall start to work at cut-out wind speed, and last for no more than three minutes. The desired braking torque is 1.5 time of the turbines' driving torque at cut-out wind speed, and the braking torque shall be applied gradually to protect the mechanical structure of the turbine. The second stage brake is a safety pin, which is used to block the turbine after braking.

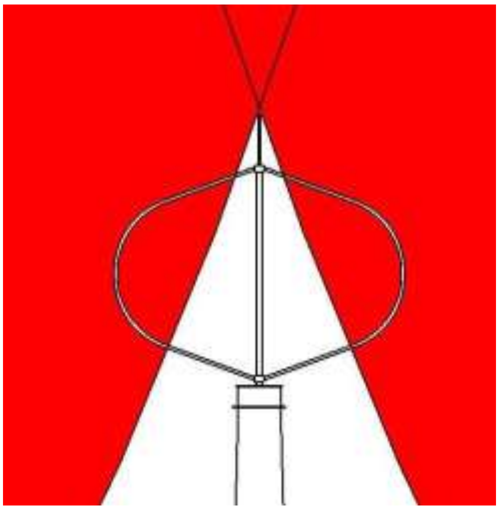
Two-stages braking system

One-stage braking system

2.5 Lightning protection for VAWTs

No matter level 2 or level 3 lightning protection standard is applied, the lightning-rods-on-top method is not ideal for VAWTs, while the desired method is making blades, supporting arms, shaft, shell of generator and tower conduct electric current well. Bearings in turbines are poor conductors since they usually lubricated. Therefore, to achieve desired lightning protection, shaft and shell of generator shall be connected by collecting rings.





2.6 On magnetic suspension technology

Magnetic suspension technology is different from maglev bearings, and in magnetic suspension technology, the wind mill is levitated by using the same-pole-repelling principle of permanent magnet. However, the loads turbines experienced are alternating, making non-contacted bearings not suitable. For regular deep groove ball bearings, they can normally stand axially 10% of their radial load, thus being fully able to bear small turbines' axially load. Even magnetic suspension technology is employed, traditional contacted bearings are indispensable and such extra feature contributes little to improve efficiency. For a wind turbine, the greatest resistance is from reluctance and bearings. Reluctance is indispensable for kinetic energy-power-conversion. Therefore, magnetic suspension technology can neither improve turbines' starting capability nor efficiency. Ways to improve starting capability include using lighter bearings and using permanent magnet generators without iron core.

3. Future development of VAWTs

The majority of currently available VAWTs have fixed angle of attack, and theoretically such VAWTs possesses efficiency slightly lower than that of HAWTs due to the fact that the VAWTs blades have various aerodynamic performance at various position during rotations. Therefore, the future trends for VAWTs are variable angle of attack and bigger turbines.

See Fig. 4-1 for a Norwegian designing concept for VAWT and Fig. 4-2 for a turbine manufactured by a Korean university based on the concept. By using an eccentric circle device to regulate the angle of attack during rotations and making the angle of attack optimized for different positions, this design is able to improve the VAWTs' efficiency. The diameter and center of the eccentric circle are regulated by a motor, making the angle of attack variable within a certain range. By the assistance of an anemoscope, the eccentric circle device is also able to shift the turbine' initial position and to make the turbine face the wind. Such technology is particular suitable for dozen-KW class VAWTs.

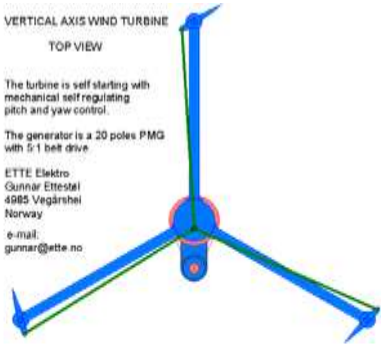


Fig. 4-1

Fig. 4-2

Fig. 4-3 shows a VAWT that uses hydraulic unit and stepping motor to regulate angle of attack continuously, and assisted by an anemoscope, the turbine is able to regulate angle of attack based on various wind speeds, wind directions, rotational speeds and rated powers. Such turbines have the advantages of excellent aerodynamic performance, higher efficiency, wider work wind speed range and limited impact on the grid, making such design suitable for dozen-KW and MW class VAWTs.

With more and more attention being attached to VAWTs, advantages such as excellent aerodynamic performance, higher wind energy utilization rate and wider work wind speed range will put VAWTs into wider applications.

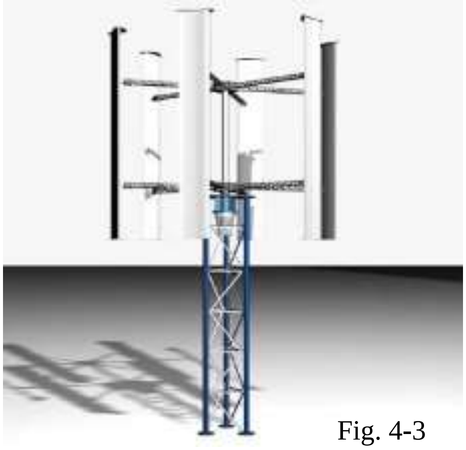
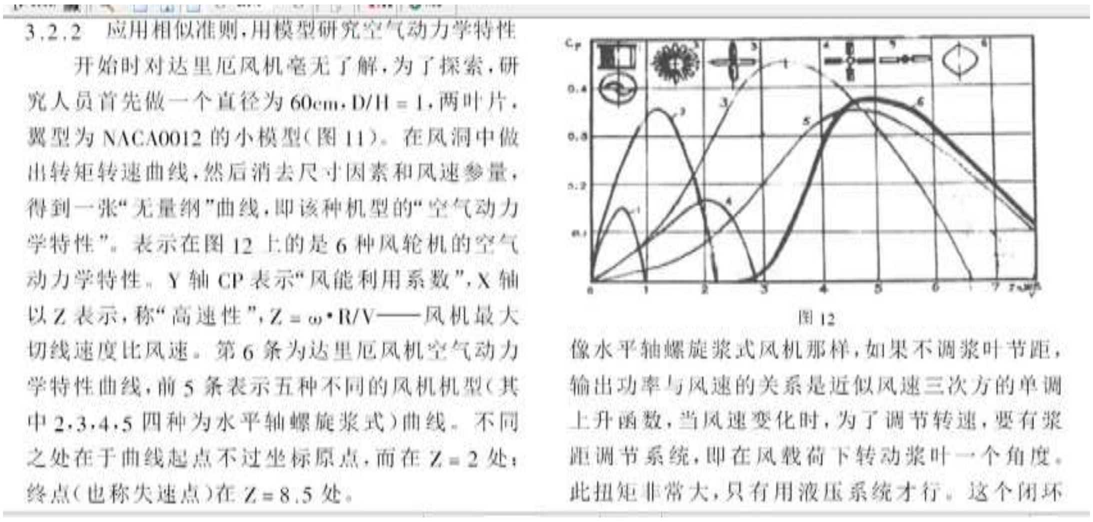


Fig. 4-3

4. Dimensionless graph

In the following figure, a dimensionless graph, curve 6 is based on wind tunnel experiments and calculations (Darrieus trubine, NACA0012 airfoil, certain chord and solidity of blades and smaller angle of attack). Wind tunnel experiments shows that the tip-speed ratio of VAWTs depends on airfoil, blade chord, number of blades, angle of attack and the like. Each wind mill has only one tip-speed ratio, and the ideal tip-speed ratio for straight blade H-shape VAWTs is 1.5-2. Further, wind mill of straight blade H-shape VAWTs passes two stall points in each rotation. However, in the wind tunnel experiments, the turbine has not experienced stall in rotation.



3.2.2　应用相似准则，用模型研究空气动力学特性

开始时对达里厄风机毫无了解，为了探索，研究人员首先做一个直径为60cm，D/H＝1，两叶片，翼型为NACA0012的小模型（图11）。在风洞中做出转矩转速曲线，然后消去尺寸因素和风速参量，得到一张“无量纲”曲线，即该种机型的“空气动力学特性”。表示在图12上的是6种风轮机的空气动力学特性。Y轴CP表示“风能利用系数”，X轴以Z表示，称“高速性”，Z＝ω•R/V——风机最大切线速度比风速。第6条为达里厄风机空气动力学特性曲线，前5条表示五种不同的风机机型（其中2，3，4，5四种为水平轴螺旋桨式）曲线。不同之处在于曲线起点不过坐标原点，而在Z＝2处；终点（也称失速点）在Z＝8.5处。

图12

像水平轴螺旋桨式风机那样，如果不调桨叶节距，输出功率与风速的关系是近似风速三次方的单调上升函数，当风速变化时，为了调节转速，要有桨距调节系统，即在风载荷下转动桨叶一个角度。此扭矩非常大，只有用液压系统才行。这个闭环

5. Application of VAWTs

VAWTs are noise-free and safe due to their low rotational speed and higher torque, and box girder structure of blades; VAWTs have less impact on the grid, because their rotational speed is less sensitive to changes of wind speed, and their rotational inertia is bigger—VAWTs are heavier than HAWT with similar capacity, thus the output voltage and power fluctuates mildly. For all their advantages, VAWTs can be widely used in off-grid condition such as buildings, telecommunication, outdoor billboards, islands, countryside power station and oilfield, and particularly suitable for in-grid systems.