VERTICAL AXIS WIND TURBINES

3/21/2015

INTRODUCTION

Vertical axis wind turbines are advocated as being capable of catching the wind from all directions, and do not need yaw mechanisms, rudders or downwind coning. Their electrical generators can be positioned close to the ground, and hence easily accessible. A disadvantage is that some designs are not self-starting.

There have been two distinct types of vertical axis wind turbines: The Darrieus and the Savonius types. The Darrieus rotor was researched and developed extensively by Sandia National Laboratories in the USA in the 1980's.

New concepts of vertical axis wind machines are being introduced such as the helical types particularly for use in urban environments where they would be considered safer due to their lower rotational speeds avoiding the risk of blade ejection and since they can catch the wind from all directions.

Horizontal axis wind turbines are typically more efficient at converting wind energy into electricity than vertical axis wind turbines. For this reason they have become dominant in the commercial utility-scale wind power market. However, small vertical axis wind turbines are more suited to urban areas as they have a low noise level and because of the reduced risk associated with their slower rates of rotation.

One can foresee some future where each human dwelling in the world is equipped with wind generators and solar collectors, as global peak petroleum is reached making them indispensable for human well being. They are well suited for green buildings architectural projects as well as futuristic aquaponics; where vertical farming in a skyscraper uses automated farming technologies converting urban sewage into agricultural products. Their cost will come down appreciably once they are mass produced on a production line scale equivalent to the automobile industry.

The economic development and viable use of horizontal axis wind turbines would, in the future be limited, partly due to the high stress loads on the large blades. It is recognized that, although less efficient, vertical axis wind turbines do not suffer so much from the constantly varying gravitational loads that limit the size of horizontal axis turbines.

Economies of scale dictate that if a vertical axis wind turbine with a rated power output of 10 MW could be developed, with at least the same availability as a modern horizontal axis turbine, but at a lower cost per unit of rated power, then it would not matter if its blade efficiency was slightly lower from 56 to about 19-40 percent.

Figure 1. Darrieus vertical wind turbine with the generator positioned at the base of the tower. The tower is reinforced with guy wires.

Figure 2. Hybrid Darrieus and Savonius self-starting Neoga turbine on top of a building.

Figure 3. Experimental concept for a vertical sail wind machine with a 3 kW rated output.

DARRIEUS VERTICAL WIND TURBINE

The first aerodynamic vertical axis wind turbine was developed by Georges Darrieus in France and first patented in 1927. Its principle of operation depends on the fact that its blade speed is a multiple of the wind speed, resulting in an apparent wind throughout the whole revolution coming in as a head wind with only a limited variation in angle. Cyclists will recognize that effect: if they go fast enough there is always a head wind.

From the perspective of the blade, the rotational movement of the blade generates a head wind that combines with the actual wind to form the apparent wind. If the angle of attack of this apparent wind on the blade is larger than zero, the lift force has a forward component that propels the turbine.

The angle of attack which varies in a revolution between -20 to +20 degrees should not exceed 20 degrees since at higher angles the flow along the blade is no longer laminar, which is a condition required for the generation of a lift force, but becomes turbulent causing stall.

An angle of attack between zero and 20 degrees requires a sufficiently high blade speed. A Darrieus turbine cannot be self starting; it needs to be brought to a sufficiently high blade speed by external means. However, the lack of a control system to point the turbine into the wind compensates for this shortfall.

The original Darrieus turbine suffered from some negative features such as violent vibrations leading to eventual fatigue blade failure, a high noise level and a relatively low efficiency, which severely limited its success.

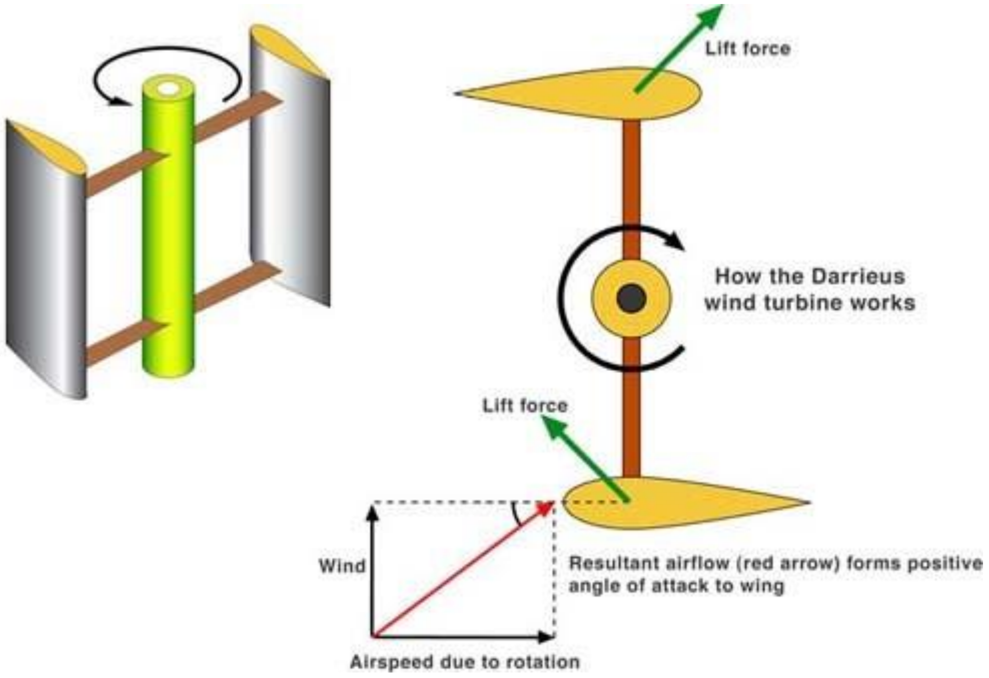

Figure 4. Darrieus vertical axis turbines principle of operation. The resultant of the wind speed and the air speed due to rotation forms a positive angle of attack of the lift force to the wing.

Figure 5. Experimental Department of Energy (DOE) and US Department of Agriculture (USDA) 34 meter diameter Darrieus wind turbine.

Figure 6. Blade end attachments in a Darrieus wind turbine.

VARIABLE GEOMETRY VERTICAL AXIS MACHINES

P. J. Musgrove in 1975 led a research project at Reading University in the UK whose purpose was to attempt to rationalize the geometry of the blades by straightening out the blades of a Darrieus type wind turbine. This led to the design of a straight bladed vertical axis wind turbine designated as the H rotor blade configuration.

At the time it was thought that a simple H blade configuration could, at high wind speeds, overspeed and become unstable. It was thus proposed that a reefing mechanism be incorporated into the machine design thus allowing the blades to be feathered in high winds. These earlier machines with feathering blades were known as Variable Geometry Vertical Axis Wind Turbines.

There were a number of these designs which had different ways of feathering their blades. During the late 1970's there was an extensive research program carried out. This included wind tunnel tests and the building of a few prototype machines in the 40-100 kW range. This work culminated in a final reefing arrowhead blade design for a large 25 meter, 130 kW rated machine, located in Carmarthen Bay in South Wales. This machine known as the VAWT 450, was built by a consortium of Sir Robert McAlpine and Northern Engineering Industries (Vertical Axis Wind Turbines Limited) in 1986. The project was funded by the UK government's Department of Trade and Industry.

Figure 7. Variable Geometry wind turbine machines.

H ROTOR STRAIGHT BLADED VERTICAL MACHINE

From the research carried out in the UK during the 1970-1980 time frame it was established that the elaborate mechanisms used to feather the blades were unnecessary. The drag/stall effect created by a blade leaving the wind flow would limit the speed that the opposing blade in the wind flow could propel the whole blade configuration forward. The fixed straight bladed or H Rotor configuration was therefore self regulating in all wind speeds reaching its optimal rotational speed, early after its cut in wind speed.

Figure 8. H Rotor wind turbine designs.

There have been a few commercial companies producing H rotor wind turbines since the 1980's. However turbine designs were aimed at niche areas of the small wind turbine market.

Due to the lower and more predictable stress loading on the blades of vertical axis wind turbines, they are the ideal type of machine for large scale electricity production. This potential for use for economic multi megawatt electricity production has not as yet been exploited. This is due partly due to earlier design failures and partly due to their slightly lower blade efficiency.

IMPULSE AND AERODYNAMIC VERTICAL TURBINES, TIP SPEED RATIO (TSR)

Aerodynamic wind turbines can be divided into two main classes: horizontal axis wind turbines and vertical axis turbines.

Large wind turbines up to a rated power of 5 MW are horizontal axis engines, much like the traditional Dutch windmills. This familiarity has given the development of horizontal turbines a higher priority than that of vertical turbines.

Modern horizontal axis wind turbines have a high efficiency but their capital cost is high. They have to be directed in the direction of the wind, either manually or by the use of a sensor based yaw-control mechanism, adding to their design complexity and cost.

Vertical axis turbines do not need such a control system; and can catch the wind from all directions.

Vertical axis wind turbines designs can be either impulse (drag) or lift (aerodynamic) devices. According to Betz’s equation, an aerodynamic turbine has a theoretical efficiency of 59 percent and an impulse type engine only 19-40 percent. Not all the energy in the wind can be extracted because if it were possible, the wind speed behind the turbine will be zero thus clogging any flow through the rotor. Part of the wind will flow through the rotor and part around it. The ratio of these two components determines the efficiency of the turbine.

It might appear counter intuitive that devices covering the whole swept area have such a low efficiency. However the ancient mariners have long realized that “Sailing before the wind’ is far less energetic than “Close hauled” or “Half wind.”

Without slip, the maximum rotor speed would be about the same speed as the wind speed. An example is the three cup anemometers commonly used for measuring wind speed.

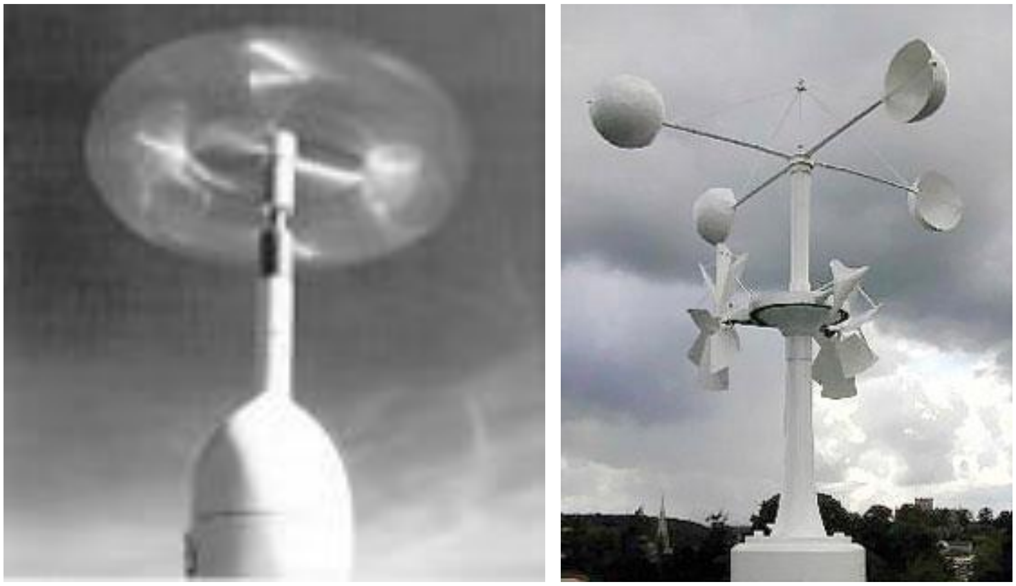

Figure 9. Rotating cup anemometer and drag cup wind turbine.

The tip speed ratio is defined as:

$$Tip\ speed\ ratio\ \alpha = \frac{V_{rotor}}{V_{wind}} \tag{1}$$

If the velocity of the cup is exactly the same as the wind speed, the anemometer has a tip speed ratio of unity. The ends of the cups can never go faster than the wind, thus:

$$\alpha_{anemometer} \leq 1 \tag{2}$$

A way of determining whether a vertical axis turbine design is based on impulse drag or aerodynamic lift is through its tip speed ratio α. An $\alpha > 1$ implies some amount of lift, while $\alpha < 1$ means primarily drag. Aerodynamic lift based designs can usually output much more power, more efficiently.

There have been multiple designs of vertical axis windmills. In fact there is evidence of the existence of vertical axis wind turbines, which can be traced back centuries before the more common horizontal axis designs. The vertical axis machines have evolved and now come in three basic types: the Savonius, the Darrieus, and the H-Rotor concepts.

THE SAVONIUS IMPULSE CONCEPT

The Savonius turbine is a vertical axis machine which uses a rotor that was introduced by Finnish engineer S. J. Savonius in 1922. In its simplest form it is essentially two cups or half drums fixed to a central shaft in opposing directions. Each cup or drum catches the wind and so turns the shaft, bringing the opposing cup or drum into the flow of the wind. This cup or drum then repeats the process, so causing the shaft to rotate further and completing a full rotation. This process continues all the time the wind blows and the turning of the shaft is used to drive a pump or a small generator. These types of windmills are also commonly used for wind speed instruments such as the anemometer.

Modern Savonius machines have evolved into fluted bladed devices, which have a higher efficiency and less vibration than the older twin cup or drum machines.

Figure 10. Evolution of the Savonius design for water pumping from half drums into the fluted spiral bladed design.

THE DARRIEUS AERODYNAMIC CONCEPT

In 1931 the French engineer George J. M. Darrieus introduced the Darrieus Vertical Axis Wind Turbine. The Darrieus type of machine consists of two or more flexible airfoil blades, which are attached to both the top and the bottom of a rotating vertical shaft. The wind blowing over the airfoil contours of the blade creates an aerodynamic lift and actually pulls the blades along.

Although nowhere near as much research has been carried out on these types of machine when compared with the horizontal axis machines, both the USA and Canada did have large research programs working on the Darrieus design in the 1970's and 1980's. This work culminated with the construction of a 4.2 MW machine designated as “Eole C” at Cap Chat, Québec, Canada.

Figure 11. Eole C 4.2 MW Darrieus vertical axis wind turbine, Cap Chat, Québec, Canada.

There were a number of commercial wind farms built in the USA using the Darrieus design, most of which were built by The Flow Wind Corporation. The machines proved to be efficient and reliable. However there was a problem with fatigue on the blades. The airfoil blades were designed to flex, allowing for the extra centrifugal forces in high wind and blade speeds. The flexing of the blades led to premature fatigue of the blade material, leading to a number of blade failures.

The vertical axis turbines built and tested in the 1970’s and 1980’s, used a symmetrical airfoil blade profile. Their theory was that, if the airfoil is symmetric then it will provide lift from both sides of the airfoil, therefore generating lift through more of the 360º path of the blades rotation. It was also believed at the time, that lift would only be created by the blade while traveling into the direction of the wind flow and that the drag created by the opposing blade traveling down wind was an undesirable although unavoidable effect.

A symmetrical airfoil is not the most efficient approach at providing lift. A design goal was to maximize lift at the same time as utilizing the inevitable drag created by the opposing blade. There have been a number of attempts using hinged blades attached to the end of the cross arm, therefore allowing the aerofoil section of blade to maintain its optimum angle of attack through the maximum portion of its arced rotation. An optimal blade profile and optimal fixing angle for the blade to the cross arm could achieve the same goal.

The wind flowing over the high lift and low drag blade profile, coupled with the blade areas solidity, gives the machine the initial power needed to overcome its inertia. Once momentum has been established, the forward movement of the blade through the air creates its own local wind flow over its contours, creating a varying amount of lift throughout the full 360º of its rotation. In its down wind stroke, the curved underside of the blade acts like the sail of a yacht therefore creating usable torque throughout its rotation.

The stalling of the blades at the top and bottom of their arc of rotation is also useful, as it regulates the speed of the blades rotation, implying that the blades accelerate up to a point of equilibrium at which they will not increase their speed no matter how hard the wind blows.

The more constant and predictable loadings on a vertical axis turbine blade, coupled with there not being any need for the blades to twist or taper, not only contribute to the possibility of scale increase, but will also enables their production in sections using mechanical mass production techniques.

ROPATEC VERTICAL WIND TURBINE

INTRODUCTION

The Ropatec wind rotors developed in Italy are neither proper Darrieus nor Savonius but a hybrid design. The wind rotors are made from airfoil sections like those of an airplane wing. A central panel between the wings referred to as the turtle back, acts as a diffuser and directs the wind flow toward the wings, turning the wind rotor at low wind speed.

Figure 12. Hybrid Darrieus and Savonius Ropatec vertical axis wind generator.

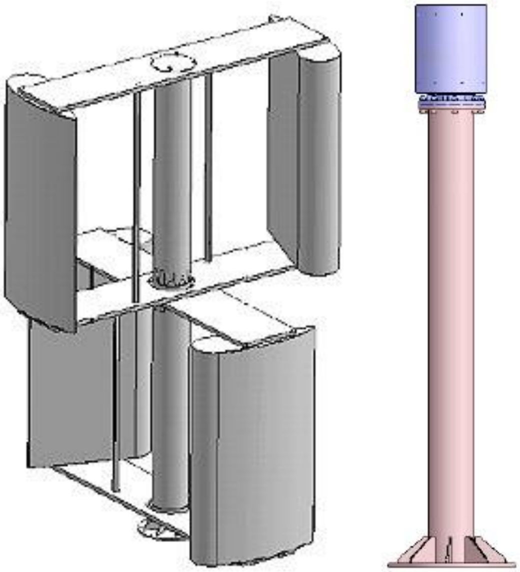

Figure 13. Ropatec rotors without turtle shell diffuser and the columnar tower with the generator on top.

DESCRIPTION

The Ropatec wind rotor is a vertically driven wind rotor that could be described as a hybrid building upon the Savonius and Darrieus principles. The WRE.060 model is associated with the MSP-Controller, an innovative CPU controlled charge regulator at 48 Volts with an incorporated SMD DC/AC inverter with 4,500 VA continuous output.

A central pole referred to as the axis has the electrical generator bolted to the top. The axis and generator are inserted into the wind rotor assembly and the generator is bolted to the inner tube. When the wind rotor turns, it also turns the generator.

The wind rotor will start to turn in a light breeze of about 7 km/hr or 4 knots. The maximum rpm is reached in winds of 50 km/hr or27 knots.

The wind rotor has a distinctive shape that creates an aerodynamic braking effect causing it to stall at high wind speeds. Winds stronger than 50 km/hr will not increase the wind rotor speed beyond its maximum rotational speed of 90 rpm.

The wind rotor is rated to produce power in winds up to 230 km/hr, the central wind speeds of a Category 2 hurricane or cyclone.

It is designed for a maintenance free operation of 15 years.

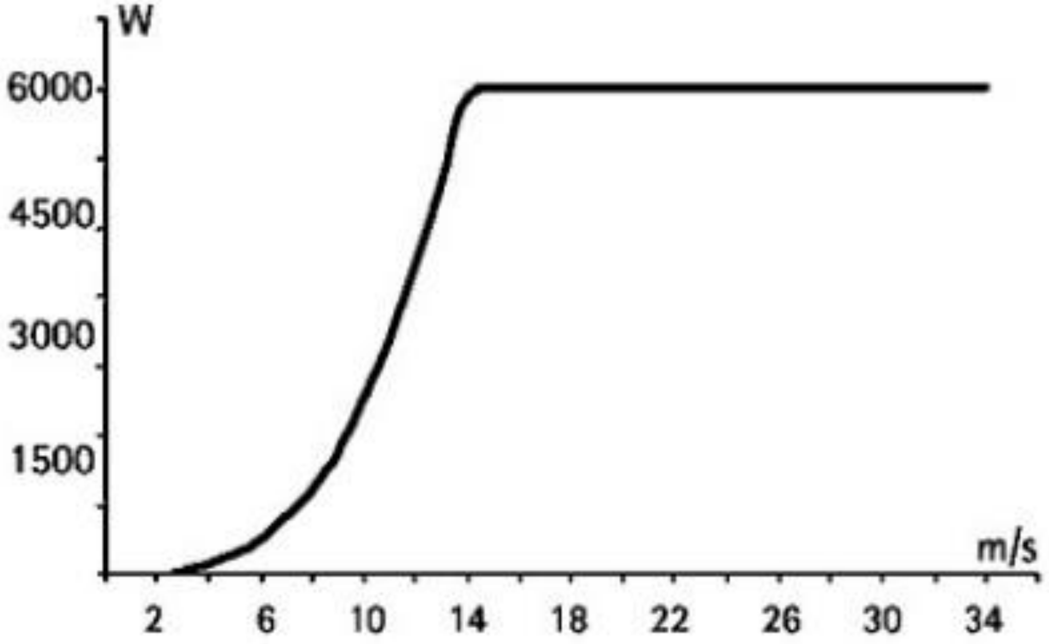

Figure 14. Power curve of Rotapec wind generator showing a low cut in wind speed around 3 m/s.

The Ropatec design possesses the following characteristics:

1. A low cut in wind speed at 2 m/s at every position.
2. Its operation is independent of the wind direction.
3. It is a low maintenance system.
4. It generates low noise even at high wind velocities.

5. It does not require a cut off wind speed.
6. It possesses an aerodynamically auto regulated rotational speed.
7. Its nominal power output is achieved at wind speeds of 14 m/s and higher.
8. It is not associated with an electromagnetic field built-up.
9. It has storm suitability up to 56 m/s, with practical experience up to 75 m/s.
10. It has a reliable, long product life time

The system can produce electricity directly or is expandable to a hybrid system including photovoltaic modules and/or diesel generator sets.

TECHNICAL SPECIFICATIONS OF WindRotor WRE.060

WindRotor	Rated output on axis (at 14 m/s)	6 kW
	Cut in wind speed	2 m/s
	Rated wind speed	14 m/s
	Rotor speed control	Aerodynamically auto regulated
	Over speed control	Not required
	Maximum revolutions/minute	90 rpm at14 m/s
	Cut off wind speed	None
	Rotor weight	700 kg
	Rotor blade type	Vertical Axis Wind Turbine (VAWT)
	Rotor diameter	3.3 m
	Swept area	14.52 m² (3.3 m x 4.4 m)
	Gear box type	No gear box, direct driven generator
	Brake system	Not required
Generator	Generator type	Permanent excited multi pole
	Electrical transmission	Brushless
MSP-Controller	Battery charger	48 VDC
	Output MSP on grid	2x 215VAC/ 230 VAC / 50Hz – 60
Typical performance Sea level, Weibull K 2	Average wind 5 m/s	Annual energy output 3.051 MW.hr
	Average wind 7 m/s	Annual energy output 7.608 MW.hr

Mast 10 m, anemometer 10m	Average wind 9 m/s	Annual energy output 12.861 MW.hr
	Average wind 11 m/s	Annual energy output 17.469 MW.hr

VERTICAL AXIS WIND TURBINE, SOLWIND

DESCRIPTION

The vertical axis wind turbine by Solwind in New Zealand is designed to start up at 1.5 m/s and start producing power at a wind speed of just 3.7 m/s and produce their rated output at 10 m/s.

These turbines are extremely quiet in operation. This is due to their special design where the blades do not create the usual coning noise that occurs with conventional horizontal axis wind turbines when the blades pass close to the mast at each revolution.

The blades are always at the same distance from the mast. The blades are made from composite fiber glass, stainless steel and lightweight aluminum, making them extremely strong yet flexible and easy to handle.

Figure 15. Four rotor vertical axis wind generator for remote sites.

A new Low Speed Magnetic Levitation Alternator (MLA), featuring only one moving part is used. This keeps the wearing components to a minimum, and so prolongs the longevity of the wind turbine.

At high wind speeds the turbine will start to stall, causing the machine to slow down at around 27 m/s. In the stalling mode, the turbine will automatically maintain its output speed.

This Darrieus based design lends itself to taking the wind from any direction and does not need a yawing mechanism.

Figure 16. Two and four rotor blades vertical wind generators.

GENERATOR

The generator is a low speed Magnetic Levitation Alternator (MLA). The output is 3/6 phase up to 415 volt AC.

A 3 /6 phase rectifier pack with regulator shunt type is available to suit the end user voltage such as 12 / 24 / 48 / 120 / 240 / 600 volts DC or any voltage required.

The generator is base mounted at the foot of the mast, and requires no slipping assembly, no dolly bearing assembly, no brush assembly and has no power cables running up the mast.

MAST ASSEMBLY

The stayed single pole mast assemblies have been designed for erection with out the aid of any extra lifting gear for remote area operation.

A complete self contained power generation system is accommodated within the base of the mast which will mean that only the 230/415 Volts AC will need to be connected to the end user via an underground or poled cable. The mast requires no guide wires and provides a smaller ground footprint than the stayed single pole mast assembly.

The mast is constructed from high tensile steel, and come in standard lengths of 6.5 meters for easy handling.

The maximum design wind speed is 190 km/hr. For coastal locations stainless steel fasteners are used throughout.

EUROWIND WIND TURBINE DESIGN

The concept aims at utilizing an innovative and unique adaptation which allows the turbine to be mounted on industrial chimneys and other similar tall structures without inhibiting their normal use.

The rotor blade design features an asymmetrical airfoil section selected for its high lift and low drag characteristics and is mounted to its supporting cross arm at a critical angle to optimize its performance. The blades are not twisted and their edges are parallel, unlike the twisted tapering blades of horizontal wind turbines. The simple, regular shape of the blade coupled with the lower blade stresses experienced by vertical axis turbines allow the blades to be produced mechanically in sections by extrusion or pultrusion.

A directly coupled slow speed alternator eliminates the need for separate generator sets, gearboxes and clutches.

Figure 17. Eurowind wind mill designs.

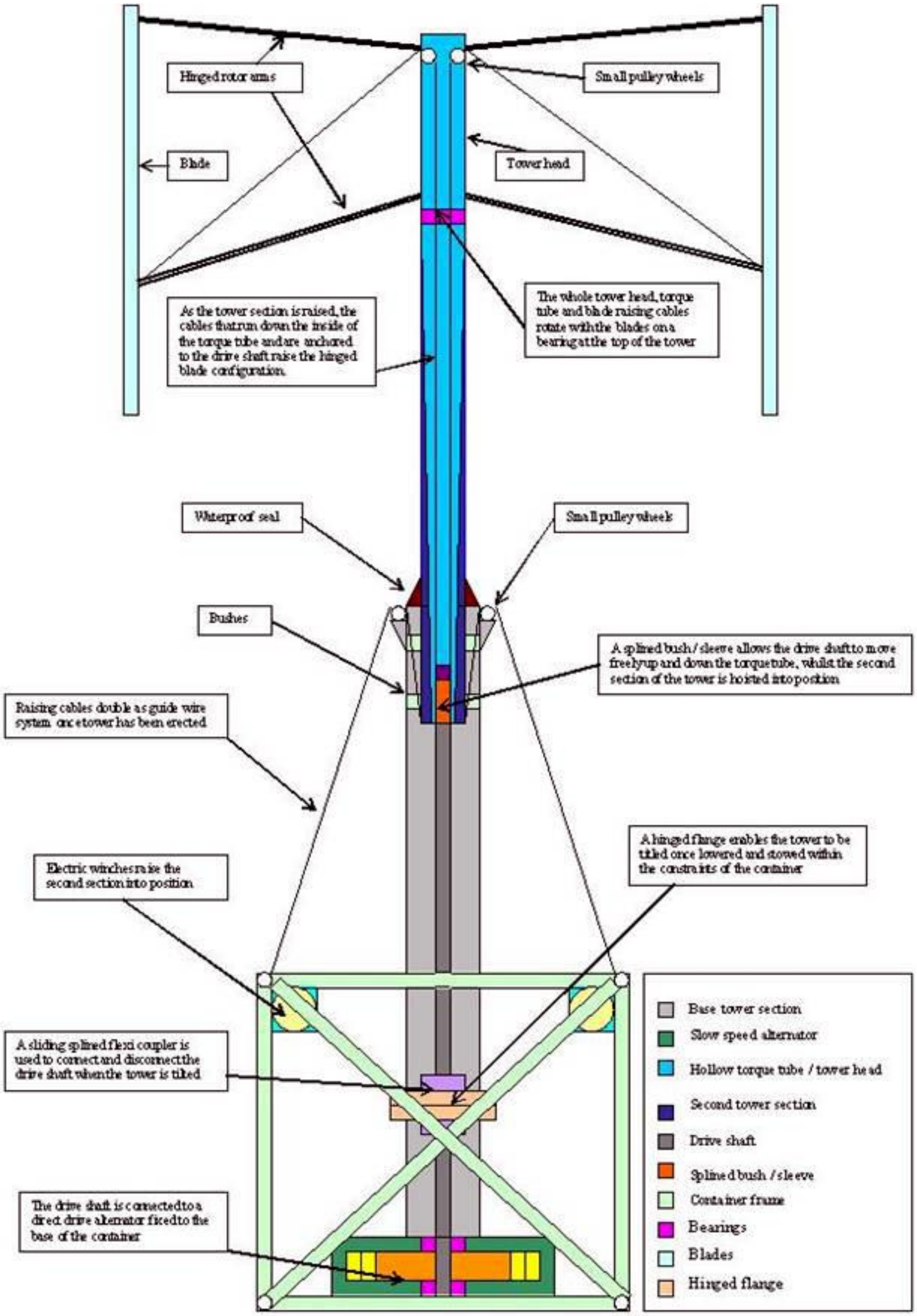

Figure 18. Large Eurowind modular vertical wind mill concept.

The main features of the Eurowind turbines designs are:

1. The turbine is self starting.

2. Vertical axis turbines are omni directional and do not require pointing in the direction of the wind.
3. The lower blade rotational speeds imply lower noise levels.
4. Perceived as being more aesthetically pleasing.
5. The increased blade configuration solidity and torque assists the machine in self starting.
6. Elimination the risk of the blades reaching equilibrium during start-up rotation by using 3 blades or more.
7. Reduced cyclic loading and power pulsation and fluctuation by using more than 2 blades
8. Easy access to all mechanical and structural elements of the machine.
9. A direct drive, permanent magnet generator is used and there are no gear boxes with the machine having only one moving part.

These machines have been adapted for use in the marine environment such as at harbors, on barges or oil rigs.

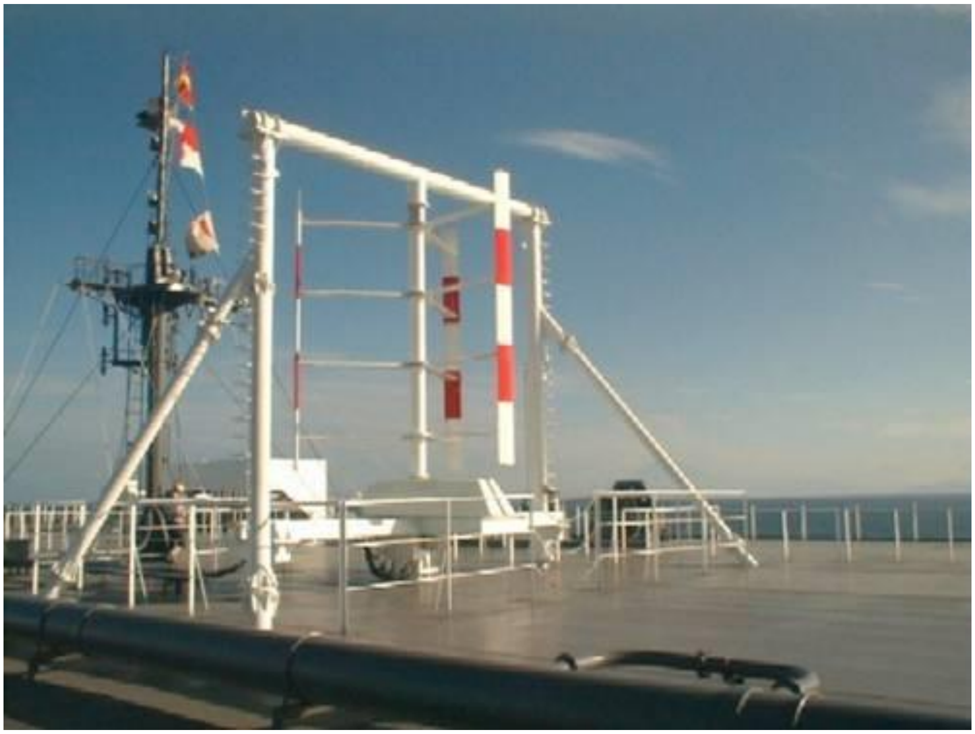

Figure 19. Vertical axis wind turbine in a marine environment.

VENTURI WIND TURBINES

INTRODUCTION

In horizontal axis wind turbines the blades rotate and describe a circular surface. The rotor extracts the energy from the air flowing through this rotor surface and has a theoretical maximum efficiency of 59 according to Betz's law.

In the Venturi turbine concept, the rotor blades are attached to the hub at both ends. When rotating, a spherical surface is generated. Because of this aerodynamic behavior, Venturi effect turbines create a wind flow pattern that converges first, like rapids in a river. Within the sphere, a low pressure area is generated which attracts the air in front of the rotor towards the sphere. After the rotor has absorbed energy from the air, the energy poor air is swung radically outwards through the Venturi planes and is carried away by the surrounding airflow.

The air flowing through the turbine and the air surrounding the rotor are used more effectively, resulting into the efficiency of the Venturi turbine being higher than the efficiency of conventional wind turbines.

DESCRIPTION

Venturi turbines create a wind flow pattern that converges first like rapids in a river. This is induced by the unique aerodynamic Venturi characteristics. Therefore the turbine experiences a higher wind speed than other wind turbines would observe. This enables the Venturi turbine to generate electricity at very low wind speeds. Little gusts can be utilized for electricity generation where conventional turbines would use these to start rotating.

At inland locations, this characteristic enables the Venturi turbine to generate power during 80 to 90 percent of the time. Other turbines rotate just 50 percent of the time because they are designed for windy locations. Windy locations geographically cover only a small part of the land surface such as at mountain passes and sea sides.

When conventional wind turbines are placed inland, energy production is low and down times are long because they will rotate only about half of the time. Also, they are too noisy when they run. At such a location, the Venturi turbine will produce 2-3 times as much energy and down times are short.

Figure 20. Venturi wind turbines.

Figure 21. Visualisation of the Venturi Effect.

Wind tunnel measurements at the Technical University of Delft have shown that a three blade Venturi Turbine has a measured efficiency of 85 percent, which is 40 percent higher than the theoretical maximum efficiency of 59 percent in Betz's law.

ADVANTAGES OF VENTURI TURBINES

REDUCED SOUND EFFECT

The tips of conventional wind turbines are the main noise generators. Compared with it, the sound generated by a small Venturi turbine is virtually non existent because it does not have such a tip. Also, there is no gearbox and the number of blades reduces the speed of rotation.

LOW DOWN TIME

The six bladed rotor induces a high start up moment. This enables the turbine to run almost continuously, unless there is really no wind. The Venturi effect enables the Venturi turbine to generate a higher level of power at lower wind speeds, which is essential at an inland wind regime, where most of the applications will be found. This also minimizes the down periods to 10 to 20 percent of time where conventional turbines are known to stand still for 50 percent of the time. This results in a more constant power supply to a consuming system or a battery than conventional wind turbines would be able to deliver under the same circumstances.

At lower wind speeds the Venturi turbine will potentially generate three times more energy than comparable small wind turbines simply because the Venturi turbine will run and absorb energy from gusts while other wind turbines will require these gusts for their start up. This is of crucial importance for inland locations.

ATTRACTIVE DESIGN AND STYLING

Rotors create visual apprehension. Because the running small wind turbine is visually associated with a transparent sphere, this unrest is reduced and is recognized as attractive and pleasing to the eye.

The Venturi turbine is a fun object to be placed at locations that are meant to catch the eye, like billboards or attraction park entrances.

HIGH RELIABILITY

Because the blades of the Venturi turbine are attached to the hub at both ends, the feet of the blade and the flexible blade itself are subjected to non fluctuating tensile stresses only. Wind gusts and gyroscopic effects barely influence it. This way of rotor construction is so robust that it practically excludes the failure of the blades. In case a blade would fail, it is still attached to the turbine at its other end. The generator is integrated into the central hub of the Venturi turbine. The magnetic field is induced by permanent magnets. The generator dimensions are matched to the rotor characteristics thus making an expensive and problem prone gearboxes obsolete.

COST EFFECTIVENESS

Whist the theoretical background of the blade configuration is very complex, the manufacturing is utterly simple because the blade can be laser cut from a plate. Because normally the blades constitute a large part of the cost because special tooling like a mould is required, the Venturi turbine can be economically produced at relatively low volumes.

The cantilevered construction of conventional blades cause the foot of the blade to be subjected to strongly alternating bending moments caused by fluctuating wind gusts and gyroscopic effects. Additionally the unsupported tip end causes the blade as a whole to vibrate. The alternating stress loads are the main cause of blade failure.

TECHNICAL SPECIFICATIONS

Data	Cut-in wind speed	2 m/s
	Survival wind speed	40 m/s
	Rotor speed control	Not needed
	Rated output at 10 m/s	100 W
	Maximum output at 17 m/s	500 W
	Maximum rotational speed at 40 m/s	2,100 rpm
	Total weight	30 kg
	Number of rotor blades	6
	Rotor blade type	Flat blade polyester
	Rotor diameter	1.1 m
	Swept area	1 m_
	Rotor Volume	1 m^3
	Brake system	Electrical brake

	Gear box type	No gear box, direct driven
Generator	Electrical transmission	Four phase brushless
	Type	Permanent magnet generator
Battery charger	Output battery charger	12/24 VDC
Typical yearly output at sea level	Average windspeed 4 m/s	100 kW.hr
	Average windspeed 5 m/s	200 kW.hr
	Average windspeed 6 m/s	350 kW.hr
	Average windspeed 7 m/s	450 kW.hr

TURBY WIND TURBINE DESIGN

DESCRIPTION

This design is advocated for construction in an urban environment. The vibrations, high noise levels and the low efficiency characterizing the Darrieus turbine are caused by the flow of air around the blade. The angle of attack of the apparent wind is kept below 20 degrees. The rotational speed of the turbine is for all parts of the blades is constant. In a Darrieus turbine the distance between blade and shaft varies, accordingly, the blade speed also varies. On the blade parts near the shaft the self generated head wind is low, whereas at the curve of the blade, at the greatest distance from the shaft, its reaches a maximum. The low blade speed close to the shaft results in an angle of attack of the apparent wind that over large parts of a revolution exceeds the allowable limit with stall as a consequence.

Figure 22. Turby three bladed vertical axis turbine.

There are moments of laminar flow and moments of turbulence resulting in intermittent lift power and drag on the blades and this causes vibrations. The contribution of these blade parts to the driving force of the turbine is negligible. In the curve of the blade, the speed of the headwind is high. The angle of attack of the apparent wind is small, with the consequence that the component of the lift force in the direction of the rotation also nears zero. These parts of the blades do not contribute to the driving force. However given their high speed they do generate a high level of noise. This explains why the Darrieus turbine vibrates heavily, makes a lot of noise and has a low efficiency.

The blades of the Turby concept are designed with a fixed distance to the vertical shaft. To reduce the inevitable vibrations due to the change of the angle of attack between + 20 and – 20 degrees resulting in a change of the mechanical stress in the blade two times per revolution, its developers chose an odd number of 3 blades of a helical shape, making all changes occur gradually.

Figure 23. Turby triple blade wind turbine design on top of a building.

TECHNICAL SPECIFICATIONS

Operation	
Cut-in wind speed	4 m/s
Rated wind speed	14 m/s
Cut-out wind speed	14 m/s

Survival wind speed	55 m/s
Rated rotational speed	120 - 400 rpm
Rated blade speed	42 m/s
Rated power at 14 m/s	2.5 kW

Turbine	
Overall height	2890
Weight (inc. blades)	136 kg
Base flange	
Diameter	250
Bolt circle	230
Bolt holes	6 x M10
Rotor	
Diameter	1999
Height	2650
Rotorblades	
Number	3
Material	composite
Weight (3 blades)	14 kg

Converter			
Type	4 -quadrants AC-DC-AC		
Rated power	2.5 kW		
Peak power	3.0 kW		
Output	220-240 V	50 Hz	60 Hz under development
Weight	15 kg		
Integrated functions			
Control	Maximum Power Point tracker		
Start	Starting is achieved by the generator in motor operation.		
Brake	Electrical, short circuiting of the generator.		
Protection	Grid failure, anti islanding, system faults, short circuit, mechanical faults, vibrations, blade rupture, imbalance.		
Overspeed protection	Two independent detection systems each triggering an independent brake action: 1. Generator frequency measurement in the converter. 2. Generator voltage measurement on the generator terminals.		

Generator		
Type, rated voltage, rated voltage	250 V 6.3 A, 3 phase synchronous permanent magnet	
Peak brake current, rated power	60 A, 2.5 kW	During 250 ms

Overload	20 percent	120 min
	50 percent	30 min
	100 percent	10 min

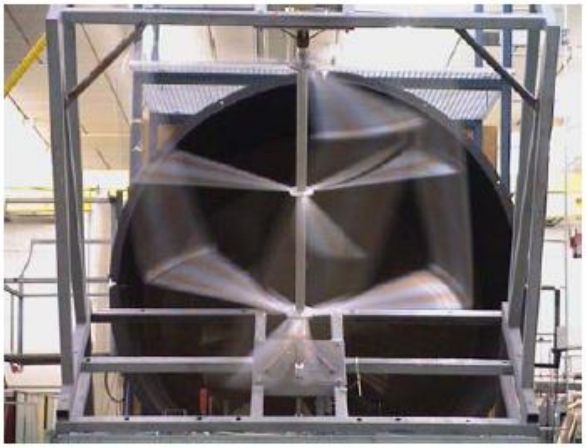

Figure 24. Wind tunnel testing of Turby wind turbine design.

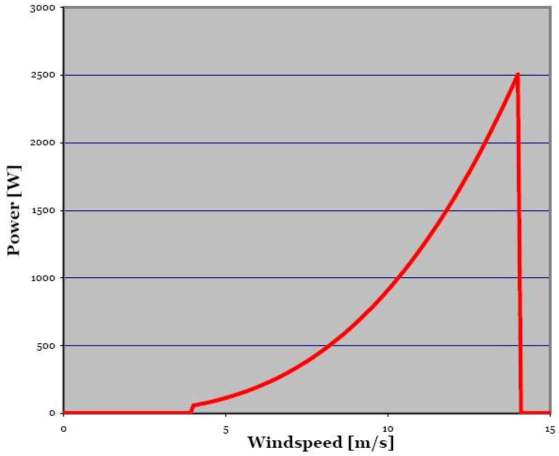

Figure 25. Turby turbine power curve.

POLES DESIGNS

Two different mast types depending on the required height can be considered. Up to 6 m height, spring supported masts. From 7.5 m and higher, freestanding tubular masts are used. Both types could be either made of stainless steel or galvanized steel.

HELICAL WIND TURBINES

DESCRIPTION

The Windside Wind Turbine developed in Finland is a vertical wind turbine whose design is based on sailing engineering principles. The turbine rotor is rotated by two spiral formed vanes. It is intended for both inland and marine environments. Designs are for use in wind speeds of up to 60 m/s.

Figure 26. Helical wind turbine with generator at its base.

Figure 27. Manufacturing of helical wind blades. The generator is at right.

These designs for battery charging are a unique and ecological solution for energy production in harsh environments under cold or hot conditions, violent storms, as well as low wind speeds.

These turbines generate almost no noise and are safe to use in population centers, public spaces, parks, wildlife parks and on top of buildings. They are also aesthetically appealing and in many cases have been used to combine art and functionality.

QUIETREVOLUTION QR5 WIND TURBINE

DESCRIPTION

The QR5 is a wind turbine designed in response to increasing demand for wind turbines that work well in the urban environment, where wind speeds are lower and wind directions change frequently.

It possesses a sophisticated control system that takes advantage of gusty winds with a predictive controller that learns about the site's wind conditions over time to further improve the amount of energy generated. If the control system determines that sufficient wind exists for operation, the turbine is actively spun up to operating conditions at which point it enters the lift mode and starts extracting energy from the wind. It will self-maintain in a steady wind of 4.0-4.5 m/s. The turbine will brake in high wind events of speeds over 12 m/s and shut down at continuous speeds over 16 m/s.

The blade tip speed is much lower than on a similarly rated horizontal axis wind turbine so less noise is produced. The helical blade design results in a smooth operation that minimizes vibration and further reduces acoustic noise.

It is constructed using a light and durable carbon fiber structure and is rated at 6kW and has an expected output of 9,600 kWhr per year at an average annual wind speed of 5.9 m/s. This would provide 10 percent of the energy for a 600 m^2 office building. Its design life is 25 years.

Figure 28. Quiet revolution QR5 wind turbine.

Figure 29. A direct drive in line electrical generator has auto shut down features and peak power tracking. It is directly incorporated into the mast. The helical design of the blades captures turbulent winds and eliminates vibration.

As a safety feature, it is designed with a high tensile wire running through all its component parts, to minimize the risk of any broken parts being flung from the structure in the unlikely event of structural failure.

TECHNICAL SPECIFICATIONS

Physical dimensions	5m high x 3.1m diameter
Generator	Direct drive, mechanically integrated, weather sealed 6 kW permanent magnet generator
Power control	Peak power tracking constantly optimizes turbine output for all sites and wind speeds
Operation mode	Max wind speed: 16m/s; Min wind speed: 4m/s
Design lifetime	25 years
Rotor construction	Carbon fiber and epoxy resin blades and connection arms
Brake and shutdown	Overspeed braking above 14 m/s wind speed Auto shutdown in high wind speeds above 16m/s
Roof mounting	Minimum recommended height above buildings: 3 m
Tower mounting	Minimum mast height: 9m to bottom of blades
Remote monitoring	Event log can be accessed via PC. Remote monitoring stores operation and kW hours of electricity generated

AEROGENERATOR VERTICAL OFFSHORE WIND TURBINE CONCEPT

The 144 meters high and V-shaped structure would be mounted offshore and capable of generating up to 9 MW of electricity, roughly three times as much power as a conventional turbine of equivalent size.

Instead of being mounted on a tower with egg whisk blades that bow outwards and meet at the top like a typical Darrieus design, it has two arms jutting out from its base to form a V-shape, with rigid sails mounted along their length at intervals. As the wind passes over these they act like airfoils, generating lift which turns the structure as a whole at roughly 3 rpm.

No matter how high the two main structures are made it is relatively simple to make them with a center of gravity at its bottom. Because of this the technology lends itself to large engineering projects, which is what is needed with wind power.

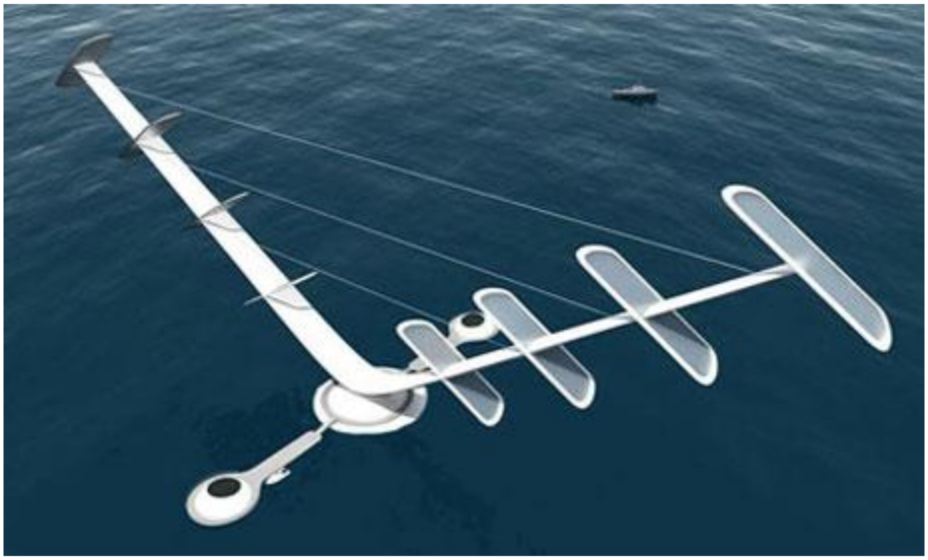

Figure 30. Offshore vertical Aerogenerator concept. Photo: Grimshaw Architects.

WINDSPIRE WIND TURBINE

The Windspire design is 30 feet tall and 2 feet in radius. It is equipped with a high efficiency generator, integrated inverter, hinged monopole, and wireless performance monitor.

The slender vertical axis design allows it to operate with a low tip speed ratio, with the edges of the rotor spinning at 2 - 3 times the speed of the wind, making it virtually silent.

ROTOR

The rotor is a low speed gyromill or a straight-bladed Darrieus design optimized for energy capture efficiency by the Ecole Polytechique de Montréal. The rotor has modified the Darrieus high efficiency configuration into a size and form optimal for small scale power generation. The changes lowered the operating speed, making it nearly silent, while also improving its self-starting capabilities. Constructed from aircraft grade aluminum, the rotor is both high strength and low cost.

At 10 mph wind, the noise level is imperceptible, and it is 8.8 dB above the ambient level in a 50 mph wind; compared with 65-100 dB of other turbine designs.

The installation includes a poured concrete foundation without the need for guy wires.

Figure 31. Winsdspire vertical straight blade or gyromill Darrieus wind turbine design.

GENERATOR

Double Rotating Air Core motors and generators provide the highest achieved efficiencies ever attaining 98 percent. New manufacturing technology allows them to be produced with both the highest possible efficiency at low cost.

The Windspire generator technology was dynamometer tested and its performance verified by Oregon State University and the University of Nevada, Reno, under a program sponsored by the National Renewable Energy Laboratory (NREL).

Figure 32. Air core generator used with the Windspire turbine.

INVERTER

The design has its own integrated inverter to convert the raw electrical power from the generator into regulated electricity that ties in with the grid. The high efficiency inverter was designed to optimize operation with the rotor and generator over the encountered range of wind speeds.

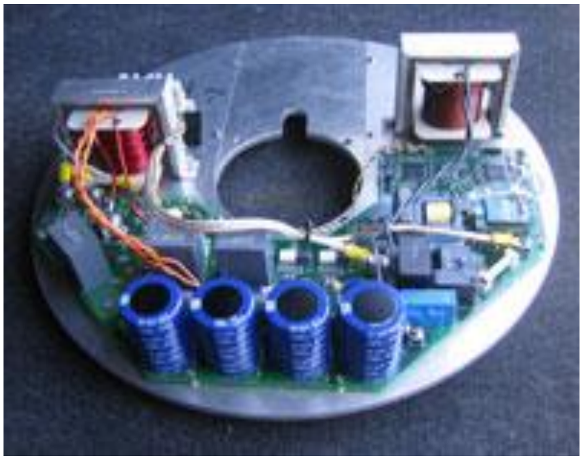

Figure 33. Inverter for the Windspire vertical wind turbine design.

WIRELESS MONITORING

The Windspire concept is equipped with a wireless modem that is continuously transmitting the power production information. With the Zigbee dongle modem unit, similar to a flash drive, plugged into a computer's USB drive, one can monitor the performance of the turbine.

Figure 34. USB connection of wireless modem for monitoring the performance of the Windspire design.

TECHNICAL SPECIFICATIONS

The Annual Energy Production, AEP is based on a Raleigh wind speed distribution and a sea level air density.

Annual Energy Production (AEP)	2,000 kW.hr
Instantaneous Power Rating (IPR)	1.2 kW
Standard Unit Height	30 ft , 9.1 m
Total Weight	600 lb , 273 kg
Color	Soft Silver
Sound	imperceptible at 10 mph 8.8 dB above ambient at 50 mph

Rotor Type	Vertical Axis Darrieus Low Speed Gyromill
Rotor Height; Radius	20 ft , 6.1 m 2 ft radius , 0.6 m
Swept Area	80 sq ft , 7.43 sq m
Maximum Rotor Speed	500 rpm
Peak Tip Speed Ratio	2.8
Speed Control	Dual Redundant: passive aerodynamic; electronic
Wind Tracking	Instantaneous

Generator	High Efficiency Brushless Permanent Magnet
Inverter	Custom Integrated Grid Tie 120 VAC 60 Hz
Inverter Certification	ETL: Meets IEEE 1547.1; UL 1741
Performance Monitor	Integrated Wireless Zigbee Modem

Cut in Wind Speed	9 mph , 4 m/s
AEP Average Wind Speed	12 mph , 5.4 m/s
IPR Rated Wind Speed	25 mph ,11.2 m/s
Survival Wind Speed	100 mph , 45 m/s

Foundation	Poured Concrete
Foundation Size	2 ft diameter by 6 ft base
Rotor Material	Aircraft Grade Extruded Aluminum
Monopole/Structure Material	Recycled High Grade Steel

Coatings	Corrosion resistant industrial grade paint

POWER CURVE

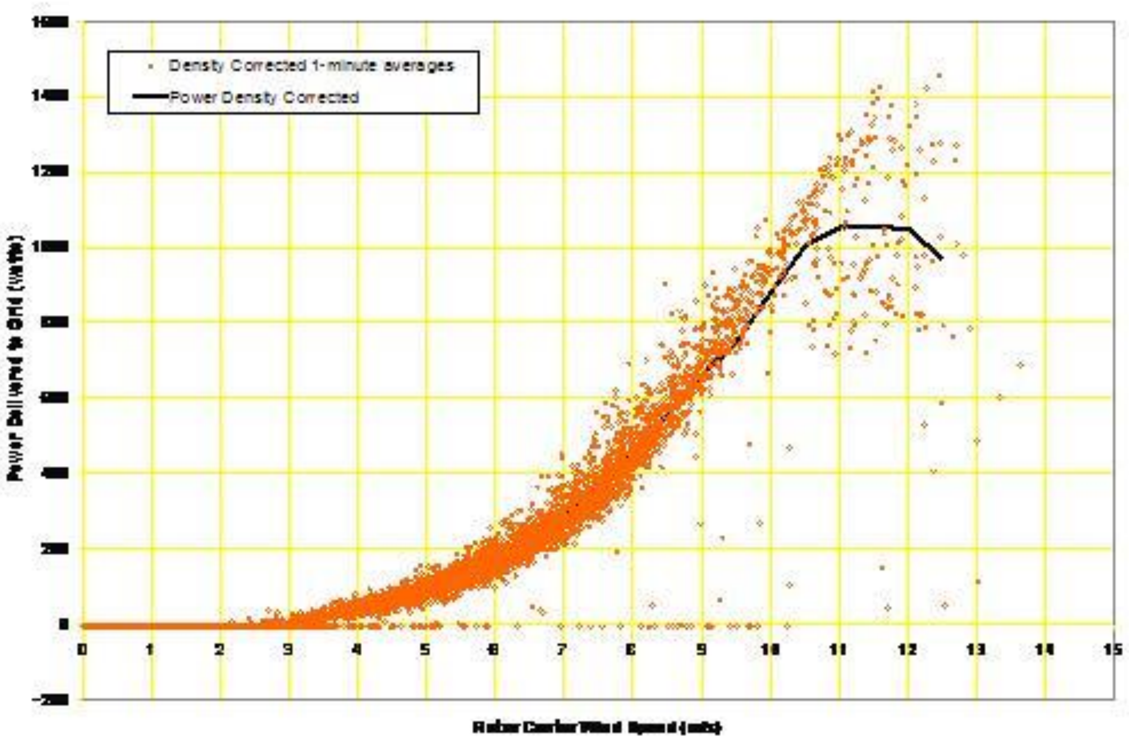

Figure 35. Power curve of the Windspire flat blade Darrieus turbine.

Figure 36. The Beacon: a conceptual design of vertical wind turbines providing power for green buildings.

REVOLUTION AIR WIND TURBINES

Pramac, an Italian power generation equipment manufacturer offers wind turbines aimed at domestic use. A quadrangular 400 WT model with a rated power of 400 Watts, and a helical shape 1kW WT with a rated power of 1,000 Watts are produced and offered at a price of $3,500.

Figure 37. Two and three bladed vertical axis wind turbines. Source: Pramac.

COUNTER ROTATING TURBINES ARRAYS

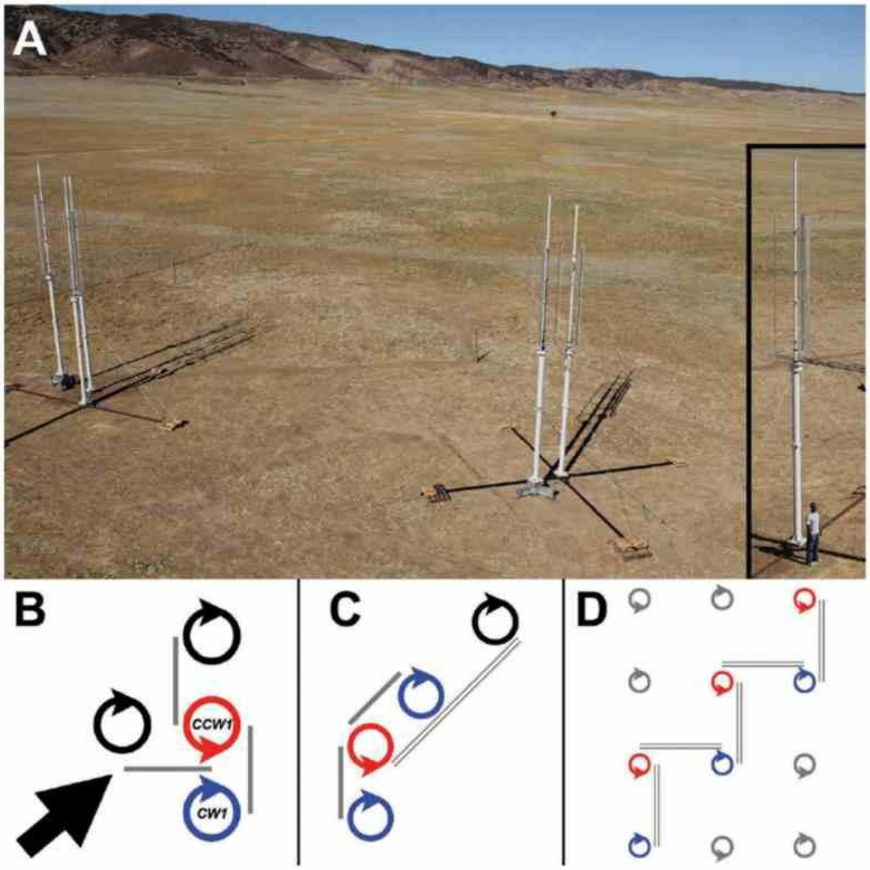

Figure 38. Array of counter-rotating vertical-axis wind turbines 10 m tall and 1.2 m in diameter relative to a person 1.9 m in height. Turbine spacing is 1.6 turbine diameters [2].

Horizontal axis wind turbines need a lot of space to operate. To avoid interference through turbulence, the spacing between the towers has to be wide. Turbines have to be made larger and taller and built in high places in order to catch more of the wind. All this adds to the cost and it impacts heavily on the visual landscape.

An array of counter-rotating Vertical Axis Wind Turbines allows the use of a configuration has been identified that yields twice as much power per acre as with a Horizontal Axis Wind Turbines.

Averaged over all incident wind directions, the close proximity of the turbines slightly improved their performance relative to the turbines in isolation. This is in contrast to typical performance reductions between 20-50 percent for HAWTs at a similar turbine spacing. The result is consistent with the predictions of simple numerical models which anticipated that closely-spaced VAWTs can reciprocally enhance the wind field of the adjacent turbines.

The wind farm power flux for a VAWT farm given by:

$$P_{wind\ farm} = \frac{PC(1-L)}{\frac{\pi}{4} D_{\text{footprint}}^2} [W / m^2]$$

$where: D_{\text{footprint}}$ = footprint diameter [m] = $\sqrt{SD}$

S = wind turbines spacing [m]

D = wind turbine diameter [m]

C = Capacity factor

P = Electrical power generated [W]

L = Wind farm aerodynamic loss factor

(1)

is approximately 18 W / m^2. The footprint diameter represents the area around a turbine where other turbines are excluded. This performance is 6–9 times the power density of modern wind farms that utilize HAWTs.

The counter-rotation of the adjacent VAWTs is important because it ensures that the airflow induced by each of the turbines in the region between them is oriented in the same direction. The creation of horizontal wind shear or velocity gradient, which leads to turbulence and energy dissipation in the region between the turbines, is reduced relative to adjacent turbines that rotate in the same direction. Since the remaining wind energy between the turbines is not dissipated by turbulence, it can be subsequently extracted by VAWTs located further downwind. This process is most effective for VAWTs operating at higher tip speed ratios greater than 2, since in this regime the turbine rotation can suppress vortex shedding and turbulence in the wake in a manner similar to that observed in studies of spinning cylinders. At lower tip speed ratios, the VAWTs likely create a larger wake akin to that of a stationary cylinder with a corresponding reduced performance [2].

This approach is different from current practices in wind energy harvesting. In this case, a large number of smaller VAWTs are implemented instead of fewer, large HAWTs. The higher levels of turbulence near the ground, both naturally occurring and induced by the VAWT configuration, enhance the vertical flux of kinetic energy delivered to the turbines, thereby facilitating their close spacing. This could alleviate many of the practical challenges associated with large HAWTs, such as the cost and logistics of their manufacture, transportation, and installation by using less expensive materials and manufacturing processes and by exploiting greater opportunities for mass production and general acceptance by local communities.

The optimal configuration of the array can be determined using the analog of vortices generated in a horizontal water tank with a stream flow simulating the wind stream.

SMALL VERTICAL AXIS WIND TURBINES ARRAYS

As the wind passes around and through a wind turbine, it produces turbulence that buffets downstream turbines, reducing their power output and increasing wear and tear. Vertical-axis turbines produce a wake that can be beneficial to other turbines, if they are positioned correctly. Since the blades are arranged vertically, the wind moving around the vertical-axis turbines speeds up, and the vertical arrangement of the blades on downstream wind turbines allows them to effectively catch that wind, speed up, and generate more power.

Small vertical axis wind turbines that are 10 meters tall and generate3-5 kWs are easy to manufacture and cost less than conventional ones if produced on a large scale. The maintenance costs could be less because the generator sits on the ground, rather than at the top of a 100-meter tower, and thus is easier to access. The noise of horizontal axis wind turbines has led some communities to campaign to tear them down. These small turbines are almost inaudible and are less likely to kill birds.

Their use on military bases is contemplated because they are shorter and interfere less with helicopter operations and with radar.

Vertical-axis wind turbines are less efficient than horizontal axis wind turbines since half of the time the blades are actually moving against the wind, rather than generating the lift needed to spin an electrical generator. As the blades alternatively catch the wind and then move against it, they create wear and tear on the structure. Adding half a shield against the return stroke would solve the problem.

Figure 39. Vertical axis wind turbines, Los Angeles County, California [3].

DISCUSSION

The idea for Vertical Axis Wind Turbines (VAWTs) has been blowing around for decades, but despite many advantages the technology has so far attracted little interest.

A Darrieus turbine becomes unstable above a certain height. The largest Horizontal Axis Wind Turbines (HAWTs) are capable of producing 6 MW of power and stand just short of 100 meters tall, but if made any bigger they start to become less efficient. One reason is that the weight of the turbine blades becomes prohibitive. As they turn, this places the blades under enormous stress because gravity compresses them as they rise and stretches them as they fall. The larger you make these structures, the more robust they must be in order to withstand these forces. In addition, the cost and difficulty of building the increasingly large towers needed to keep this top-heavy structure stable lead to a major engineering challenge.

An advantage of VAWTs is that they can catch the wind from all directions eliminating the need for a yaw mechanism. In addition, they can be built lower, so they are less visible and can withstand much harsher environments and do not need to be shut down when wind speeds exceed 64 mph, and even then the structures are claimed to withstand speeds of up to 110 mph.

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