Vertical Axis Wind Turbine

Vertical Axis Wind Turbines (VAWTs) have traditionally been relegated to a niche category in the overall wind turbine market.

From: Wind Energy Engineering, 2017

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Vertical Axis Wind Turbines

Robert Whittlesey, in Wind Energy Engineering, 2017

Abstract

Vertical Axis Wind Turbines (VAWTs) represent a unique form of power-generating technology. Historically, they have been relegated to fulfilling a small niche market in commercially available wind turbines due to their "yaw-less" design. Current VAWT designs lag behind their Horizontal Axis Wind Turbine (HAWT) counterparts in terms of efficiency, as measured by their power coefficient. However, new research suggests that these types of wind turbines may be better suited for wind farm installations than previously thought. In this chapter VAWT farm research will be reviewed and discussed. This will then be followed by an overview of different parameters for VAWT design, with an eye toward designs suitable for installation in an optimized wind farm.

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Wind energy in the built environment

M.A. Hyams, in Metropolitan Sustainability, 2012

20.4.2 Vertical axis wind turbines (VAWTs)

VAWTs are typically small wind turbines that are characterized by an axis of rotation that is perpendicular to the ground (see Table 20.6 for a selection of VAWTs). As a result, VAWTs can operate independently of wind direction, which is a major advantage for urban applications where wind direction can change rapidly. The two primary VAWT designs are derived from either the Darrieus (lift-driven) or the Savonius (drag-driven) rotors.

Table 20.6. Selected vertical axis wind turbines

Manufacturer, model	Swept area (m2)	Manuf. power rating (kW)	Rated wind speed (m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)	Noise emissions (dB)
WePower, Falcon 1.2	3.5	1.2	13.0	2.7	49.6	32.0
quietrevolution, qr5	13.6	3.3	11.0	4.5	19.0	58.0
Turby	4.9	2.5	14.0	4.0	14.0	N/A
Urban Green Energy, Eddy	2.1	0.65	12.0	3.5	32.0	36.0
Windspire Energy, Windspire	7.4	1.2	10.7	3.8	N/A	6.0 > background
Windside Oy, WS-4A	4.0	.24	18.0	1.9	None	N/A
Urban Green Energy, UGE-4 K	12.5	4.0	12.0	3.5	25.0	38.0

Source: All data from manufacturer websites or cut sheets.

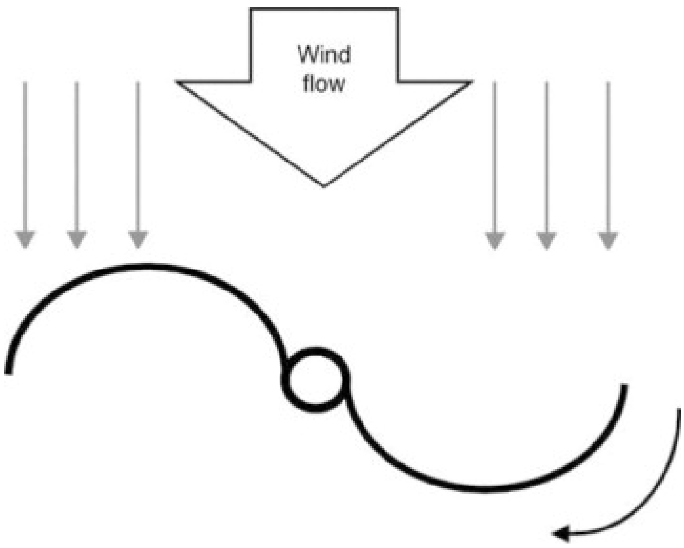
The lift-based Darrieus design looks like an eggbeater and uses long airfoil shaped blades (i.e. tapered like airplane wings) to extract energy as the wind strikes the blades perpendicularly. There are several variations on the Darrieus rotor, including some that have straight blades, which are often called Gyromills (e.g. the Windspire, Fig. 20.12) and more advanced designs including those by quietrevolution (Fig. 20.13) and Urban Green Energy. In ideal low-turbulence wind environments, Darrieus turbines tend to have lower efficiencies than HAWTs. But under the high-turbulence, directionally fluctuating wind conditions of an urban setting, Darrieus machines may run more smoothly and produce more energy than HAWTs (Mertens, 2006).

20.12. Windspire VAWT).(courtesy of Claiborne Yarbrough (2010)

20.13. quietrevolution qr5 VAWT in Croydon, Greater London).(courtesy of quietrevolution (2010)

Darrieus designs are the most common VAWTs. Early examples, such as those made by FloWind and deployed in California's Altamont and Tehachapi passes in California, were built and operated in the 1980s. In fact, by the mid-1980s, FloWind had installed 95 megawatts (MW) of its VAWTs, which produced as much as 100 million kilowatt hours at their peak (Gipe, 2009). However, due to failing equipment and less-than- expected energy production, all of these systems were gone by the mid-1990s (Gipe, 2009).

Looking downward from the top, a turbine with a Savonius rotor would look like two spoons facing opposite directions and linked at the center to the rotor axis (creating an ‘S’ shape in cross section (Fig. 20.14)). Due to their curvature, the drag of the concave surface is higher than the convex surface, forcing the rotor to turn when the cups are exposed to wind (Mathew, 2006). In other words, the ‘scoops’ experience less drag when moving against the wind than when moving with the wind, which creates a differential that causes the turbine to spin.



20.14. View of a Sovonius rotor from above.

Compared with HAWTs and Darrieus VAWTs, Savonius designs turn slowly, but with high torque. The most successful drag-based VAWTs are cup anemometers, which are widely used to monitor wind speeds in many different types of applications (Gipe, 2009). Because they utilize drag forces, Savonius VAWTs have lower tip speeds and power coefficients than turbines utilizing lift forces. Although they have low cut-in speeds, drag-based turbines are generally not viewed as good for producing electricity. Also, Savonius turbines use more material than Darrieus machines and achieve a significantly lower aerodynamic efficiency than their lift-driven VAWT cousins (Mertens and van Bussel, 2005).

There are an increasing number of examples of VAWTs being deployed in cities. For example, quietrevolution has installed numerous of its qr5 turbines throughout cities in the UK. Another firm, Aerotecture, has developed a VAWT with a hybrid helical Darrieus–Savonious rotor that has been deployed at several sites in the USA. Aerotecture makes two models, the 610 V and 712 V, with rated capacities of 1000 W and 2500 W (at 14.2 m/s (31.8 mph)) respectively. The turbines have been installed on several buildings in the Chicago area as well as at the Randall Museum in San Francisco (Fig. 20.15).

20.15. Aerotecture VAWT at the Randall Museum).(courtesy of Myra Hyams (2010)

In 2008, in a particularly high-profile example, the manufacturer PacWind integrated 16 of its drum VAWTs into a Times Square billboard (Fig. 20.16). The project was supposed to save as much as $12000 to $15 000 per month in electricity costs and prevent 16.3 metric tons of carbon from being released into the air yearly (Collins, 2008). For unknown reasons, however, the turbines have been removed and replaced with solar panels.

20.16. Savonious VAWTs lighting a billboard in Times Square, New York City).(source: Michael Hyams (2008)

Proponents of VAWTs identify several advantages over HAWTs for urban applications. First, VAWTs are viewed as preferable for rooftop applications, because they can handle wind from all directions and perform better in turbulent conditions than HAWTs. Second, VAWTs tend to operate at lower rotating speeds and have fewer moving components, such as no yaw system to orient the turbine into the wind, which can theoretically reduce maintenance costs. Third, due again to lower rotating speeds,

VAWTs may emit less noise, which can be a problem for wind turbines close to residential populations. Finally, VAWTs are viewed as being more aesthetic and capable of being integrated into the built environment as an architectural enhancement (Stankovic, Campbell and Harries, 2009).

Despite these potential virtues, however, some wind industry analysts have cautioned against thinking that VAWTs represent a panacea for wind energy in cities. Most note that the designs are not new – Savonius and Darrieus – type VAWTs have been around for nearly 80 years (Sagrillo, 2010). The main reason these turbine designs are not as common as HAWTs today is that their lower efficiencies and relative costs hurt project economics (Gipe, 2009). Until VAWTs become more cost-effective, it is unlikely that they will occupy a major presence as distributed generation in cities.

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The Development of a Straight-bladed Vertical-axis Wind Turbine

W.S. Bannister, S. Gair, in Energy for Rural and Island Communities: Proceedings of the Conference, Held at Inverness, Scotland, 22–24 September 1980, 1981

INTRODUCTION

Vertical axis wind turbines have been developed over recent years with a number of large Darrieus type turbines being built in America and with the Musgrove turbine being tested in England. Both types of turbine are now well known in the field of wind energy research.

At Napier College, work on wind energy has in the past, centred around student projects. The work on wind energy is complementary to the research work which is being carried out on solar energy. In 1978 work was started on a vertical-axis turbine. It was felt that there were possible alternatives to the basic Musgrove design. The alternative ideas were presented at the 1st Wind Energy Workshop of the British Wind Energy Association, in 1979. Similar ideas, for example, of increasing the solidity to improve performance, were arrived at quite independently by Musgrove and Mays (1978) and were subsequently developed to include the effects of low aspect ratio (1980). Small vertical axis wind turbines are not yet commercially available in any great number. Further work is required to improve the performance of the wind turbine, the electrical power conversion, reliability and overall economic viability. To this end, staff at Napier College are embarking on a research programme, funded by the Science Research Council, which will examine various possibilities which have been highlighted in recent investigations.

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Energizing Renewable Energy Systems and Distribution Generation

T. Adefarati, R.C. Bansal, in Pathways to a Smarter Power System, 2019

2.5.2.6 Vertical Axis Wind Turbines

The VAWT is designed to proliferate swept area and enhance power generation capacity and as well as to maintain the intrinsic beauty of the original design. It is designed with the incorporation of main motor shaft that is set to transverse with the wind speed. The advancement in the design of the VAWT permits the main components of the turbine to be located at its base. With this arrangement, it is very easy to carry out maintenance on the turbine since the main components such as generator and gearbox are located very close to the ground. This will reduce the maintenance cost. In addition to this, the VAWT is designed in such a way that it does not need to be pointed into the direction of the wind; as a result of this, it does not require the wind-sensing and orientation mechanisms. The wind turbines that have vertical axes are starting to become more popular as a way for generating localized electricity particularly for new constructions. The benefit of vertical axis turbines is that they can be placed much closer to the ground and are ideal for rooftop arrays.

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Wind energy

S.C. Bhatia, in Advanced Renewable Energy Systems, 2014

Vertical axis wind turbines

Vertical axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilise winds from varying directions. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten the service life.

However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50 per cent of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

> Read full chapter

Modeling and Characterization of a Wind Turbine Emulator

Imene Yahyaoui, Alvaro S. Cantero, in Advances in Renewable Energies and Power Technologies, 2018

3.1 Vertical-Axis Wind Turbines

This type of wind turbine has been the subject of much research. It has the advantage of not requiring a system for orienting the blades and possessing a mechanical part (multiplier and generator) at the ground, therefore facilitating the operations of maintenance. On the other hand, some of these wind turbines must be trained at start-up, which represents a drawback for the mat, because it receives strong mechanical constraints, making these types of wind turbines abandoned by manufacturers (except for the low power) in favor of horizontal-axis wind turbines [5].

Vertical-axis wind turbines were the first structures developed to produce the electricity, paradoxically in contradiction with the traditional windmill with horizontal axis. They have the advantage of having the control members and the generator at the ground level, which make them so easily accessible. Many variants have been tested since the 1920s, and many of them have been unsuccessful, but two structures have been well industrialized [5]:

- The Savonius rotor (named after its inventor) in which operation is based on the principle of “differential drag” used in anemometers: the efforts exerted by the faces of a hollow body are of different intensity, which then generates a motor torque making the assembly to rotate. The effect is reinforced by the circulation of air between two half-cylinders, which increase the motor torque [20].
- The cyclically variable wind turbines with the most widespread structure being that of Darrieus (French engineer who filed the patent in the early 1930s). Their operation is based on the fact that a profile placed in airflow according to different angles is subjected to forces with variable direction and intensity, which generates a motor torque causing the rotation of the device [21]. These forces are created by the combination of the proper displacement speed of the profile and the wind speed. This means that the rotation of the device cannot start on its own. When it is stationary, the wind turbine must be launched by an ancillary device (use of the generator as a motor, for example).

Although some major industrial projects have been carried out, vertical-axis wind turbines remain marginal and little used and currently abandoned. Indeed, the presence of the energy sensor near the ground exposes it to turbulence and wind gradient, which reduces its effectiveness. They are also exposed to aeroelasticity problems due to constraints they undergo. Finally, the surface they occupy on the ground is very important for high powers [22].

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Energy Production

Ibrahim Dincer, Muhammad F. Ezzat, in Comprehensive Energy Systems, 2018

3.4.3.1.2 Vertical-axis wind turbines

In the VAWTs the main rotor shaft is placed in a transverse position to the wind. The main component of this type such as the generator and the gearbox are positioned near to the ground. This type is used in the sites where the wind is usually varying its direction because the rotors are always directed into the wind. There are two subtypes in the VAWTs, the darrieus, and savonius wind turbines. Darrieus wind turbines are efficient but they require an additional power source to start the turbine rotation, and they may cause cyclic stress on the turbine tower. Savonius wind turbines do not require any external power source for the starting process, and they are frequently used in the areas where the turbulent wind occurs, and they are less efficient compared to darrieus wind turbines. The VAWTs have many advantages. For instance, they do not require any mechanisms to point the rotor blades toward the wind and the maintenance of the main parts is easier since they are close to the ground. Additionally, they are commonly utilized in the places where tall structures are not allowed, on mesas, and hilltops. The construction cost is low compared to HAWTs. However, they are less efficient compared to HAWTs, they might need an external power source to start up, and they do not take advantage of the higher wind speed at the higher elevations (Fig. 17).

(A) (B)

Fig. 17. Vertical wind turbines (A) Darrius wind turbine (reproduced from Dornier Darrieus 55–55,00 kW – Wind turbine, n.d. https://en.wind-turbine-models.com/turbines/93-dornier-darrieus-55 [accessed 31.07.17]) and (B) Savonius wind turbines (reproduced from Quiet Revolution Wind Turbine Photos, n.d. https://www.quietrevolution.com/photos/ [accessed 31.07.17]).

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Wind Power

D.G. Shepherd, in Advances in Energy Systems and Technology, Volume 1, 1978

2 Tracked-Vehicle Concept Analysis

Another VAWT type, the tracked-vehicle airfoil concept, has received significant attention by two investigators. One work is that of Powe and his co-workers, summarized in Powe (1977; and very similarly in Powe *et al.*, 1974), which presents an approximate performance comparison with the propeller type. The other is that of Lapin (1976), who also reports a parallel investigation of the Madaras concept utilizing the Flettner rotor and makes a comparison of these two systems.

Lapin presents his aerodynamic analysis in considerable detail following the general lines of the momentum and blade element approaches of propeller-type theory for the airfoil type and using a speed ratio □ = □*R*/*V* □ rotor spin velocity/wind velocity at the location of the rotor, corresponding to the equivalent of angle of attack, for the rotating Flettner rotor type. The analysis is made for aspect ratios of 4, 6, and 9, using the optimum incidence for maximum torque at each angular position chosen for calculation around the track. Wing data for C_L and C_D (including induced drag) are available and reliable for known airfoils but data for rotors are scarce and not reliable to the extent comparable with those for wings. Lapin uses what is available but emphasizes that more experimental values are needed. Most of the calculations are for a circular track but it is apparent that a linear track perpendicular to the wind will yield significantly greater output. Thus a flattened oval or race course track is better for a wind predominantly from one direction, as the propulsive effect is maintained at its greatest value over a longer fraction of the circuit. The loss of power due to rotors in tandem, i.e., differences of performance in upstream positions to downstream positions, is dealt with in detail. The analysis is based along the lines of the tandem actuator disk theory as outlined in Section II,B but the relationships are somewhat difficult to handle directly. However, a computational procedure is given and the procedure carried out semigraphically. Performance data are given for this loss of power and also for the case of no loss, i.e., assuming that mixing between upwind and downwind positions restores the freestream condition.

Lapin takes into account the additional drag forces due to the unconventional system, which are significant. These are rolling friction forces due to (1) the weight of the rotor, cart, etc. and to (2) the cross-track force. Rolling friction coefficients from railroad freight car technology are used. The cross-track force is computed in terms of the aerodynamic force expressions, and thus varies with position. The maximum cross-track force is important for calculating structural stresses and the tipping moment. There is also cart drag, which is calculated with a drag coefficient equal to the aerodynamic equivalent flat plate area, taken as invariant with flow angle, and integrated around the circuit for varying angular position. He gives examples of overall power coefficients and power losses for a variety of system parameters. Lapin mentions the disadvantageous effect of the tracked-vehicle system having to operate in the lower wind speeds near the ground due to the boundary layer, but does not specifically include any factor for this in his data.

Powe (1977; Powe *et al.*, 1974) starts off with a momentum analysis of the control volume for an airfoil-type tracked-vehicle system, taking into account a velocity variation due to ground effect and indicates that theoretically this type of turbine would give about 19% more power than a propeller-type turbine with each unit having the midpoint of its overall blade span H at a height $H/2$ above ground. For systems with the midpoint of the blade elevated above this minimum height, the tracked-vehicle airfoil concept yields about 26% more power than the corresponding propeller type. This is his basis for an investigation of this type of WECS.

The analysis considers only a flattened oval (race course) type of track, with no power contribution being taken for the turns. In the two papers of Powe (1977; Powe *et al.*, 1974), the aerodynamic analysis is minimal and the problem of the value of the interference factor a and the actual value of the flow velocity of the disk is not discussed. Several airfoils from the NACA series were investigated, with the ubiquitous 0012 type being selected for the detailed calculations, using corrections for finite aspect ratio. The system resistances are categorized as the two rolling resistances due to the vertical and horizontal forces on the track, a resistance due to track curvature, and an aerodynamic resistance. A simple expression for rolling resistance was taken from railroad literature in terms of weight, with the weight being taken to include the aerodynamic forces of lift and drag which yield a moment giving rise to a vertical force acting on the track. Aerodynamic resistance of the cars was broken down into a value for the leading car as that of a streamlined locomotive, with the remainder as that for streamlined railroad cars, and a third value for unstreamlined cars being used for the turns.

The airfoil spacing was considered, with the evaluation being made with the vertical axes of adjacent airfoils being spaced one chord apart. This was based on a consideration of minimum spacing to minimize land area and track length, together with the fact that the airfoil axes have to be at least one chord apart to rotate in the turns. The effect of incomplete recovery was accounted for in one particular calculation by taking the downwind value of wind speed as 75% of the freestream values. The effect of variation of wind speed and direction in finding an actual energy output over a period of time was evaluated by using data from an Air Force Base in Montana, as detailed values were available over a 25-year period.

A computer program was compiled with the system parameters of geometry and weights, airfoil characteristics, and wind spectrum as input. Output is given in overall terms as energy per month, and as energy per month per unit area, with area as both total swept area including turns and as per unit blade area. A fourth output figure is energy per month per unit weight of the system. Other output data computed but not quoted are carriage velocities, angles of attack, etc., pertinent to analyzing component performance and operating conditions.

The performance of these tracked vehicle systems of both Lapin and Powe *et al.* will be discussed later.

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WIND ENERGY FOR PUMPING AGRICULTURAL WATER

R. NOLAN CLARK, in Energy, Resources and Environment, 1982

Mechanical Stand-Alone Pumping

A small, vertical-axis wind turbine has been mechanically coupled to a positive displacement pump for pumping from shallow wells or lakes. The 4-kW turbine is 5.5 m high and has an equatorial radius of 4.5 m. Power is transferred through an electric clutch, which allows the turbine to be started in a no-load condition (Fig. 8). The rotor operates between 160 and 250 rpm, with corresponding flows of 10 to 15 ℓ/s at a lift of 15 m. The wind turbine becomes overloaded when revolutions per minute drops below 160 and will stall. Stall occurs at windspeeds below 5 m/s. When operating near 20-m/s windspeed, aerodynamic brakes deploy and slow the turbine.

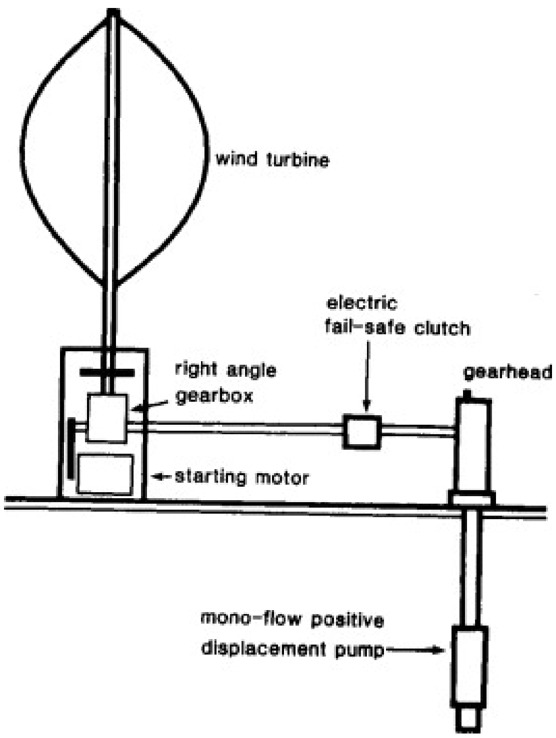

Fig. 8. Schematic of stand-alone mechanical pumping system.

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Energy Fundamentals

Craig MacEachern, İlhami Yıldız, in Comprehensive Energy Systems, 2018

1.16.6.3.2.5 Savonius rotor

Another popular design for VAWTs is the Savonius rotor invented by Finnish architect and inventor Sigurd Johannes Savonius. The rotor incorporates two large cylindrical blades each with a large concave and convex side. An overhead diagram of the device can be seen in Fig. 12.

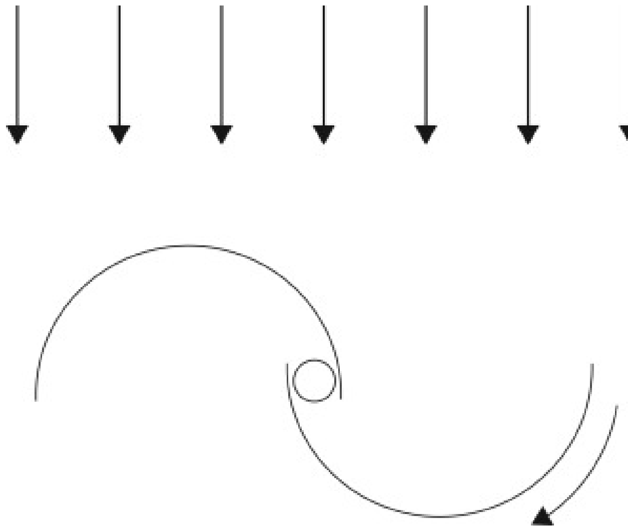

Fig. 12. Rotational principles of the Savonius rotor.Reproduced from Mathew S. Wind energy: fundamentals, resource analysis and economics. Heidelbeg; Berlin: Springer; 2006.

Unlike the Darrieus rotor, the driving force in the operation of the Savonius rotor is drag. In taking basic physical principles into account, it is well known that the drag coefficient on a concave surface is much greater than that of a convex surface given they have the same surface area. As such, when the oncoming wind contacts the rotor, the concave side experiences a greater drag force than does the convex side. This causes the rotor to spin and drive the turbine. This effect can be observed clearly in Fig. 12. While it has been established that lift is preferential to drag for wind turbines, there are some approaches, which can be taken to improve efficiencies. One of these approaches is to orient two or more Savonius rotor atop one another offset at 90 degree angles. This has the effect of limiting the torque fluctuations experienced by the rotor resulting in more consistent and reliable energy conversion. A second way in which the process can be optimized is by placing deflector augmenters in front of the convex side of the rotor. This will limit the drag on the convex side, while simultaneously directing more wind toward the concave side and subsequently increasing the drag. As they are drag devices, they have lower power coefficients along with equally low tip speed ratios. With that being said they are simple to construct and can even be fashioned from a halved oil drum. Savonius rotors also have a high solidity and starting torque. Based on these characteristics, Savonius rotors are perfect for high torque, low speed application such as water pumping [14].

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