Wind turbine

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Offshore wind farm using ⁵MW turbines REpower ⁵M in the North Sea off Belgium

This article discusses wind-powered electrical generators. See windmill for wind-powered machinery used to grind grain or pump water.

A **wind turbine** is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a **wind generator** or **wind charger**. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.

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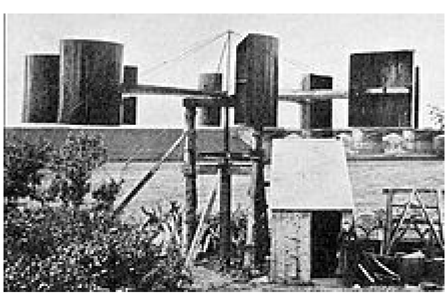
History

Main article: History of wind power

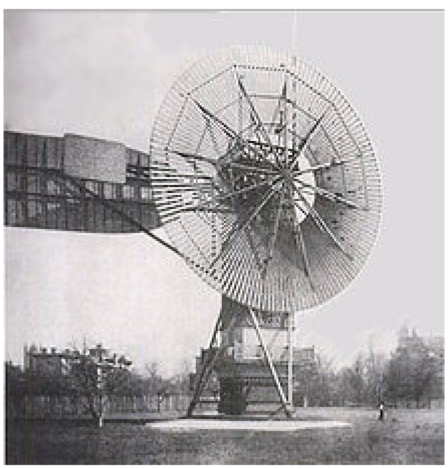


James Blyth's electricity generating wind turbine photographed in ١٨٩١

Windmills were used in Persia (present-day Iran) as early as ٢٠٠ B.C.[١] The windwheel of Heron of Alexandria marks one of the first known instances of wind powering a machine in history.[٢][٣] However, the first known practical windmills were built in Sistan, a region between Afghanistan and Iran, from the ٧th century. These "Panemone" were vertical axle windmills, which had long vertical driveshafts with rectangular blades.[٤] Made of six to twelve sails covered in reed matting or cloth material, these windmills were used to grind grain or draw up water, and were used in the gristmilling and sugarcane industries.[٥]

Windmills first appeared in Europe during the middle ages. The first historical records of their use in England date to the ١١th or ١٢th centuries and there are reports of German crusaders taking their windmill-making skills to Syria around ١١٩٠.[٦] By the ١٤th century, Dutch windmills were in use to drain areas of the Rhine delta.

The first electricity generating wind turbine, was a battery charging machine installed in July ١٨٨٧ by Scottish academic James Blyth to light his holiday home in Marykirk, Scotland.[٧] Some months later American inventor Charles F Brush built the first automatically operated wind turbine for electricity production in Cleveland, Ohio.[٧] Although Blyth's turbine was considered uneconomical in the United Kingdom[٧] electricity generation by wind turbines was more cost effective in countries with widely scattered populations.[٦]



The first automatically operated wind turbine, built in Cleveland in ١٨٨٧ by Charles F. Brush. It was ٦٠ feet (١٨ m) tall, weighed ٤ tons (٣.٦ metric tonnes) and powered a ١٢kW generator.[٨]

In Denmark by ١٩٠٠, there were about ٢٥٠٠ windmills for mechanical loads such as pumps and mills, producing an estimated combined peak power of about ٣٠ MW. The largest machines were on ٢٤-metre (٧٩ ft) towers with four-bladed ٢٣-metre (٧٥ ft) diameter rotors. By ١٩٠٨ there were ٧٢ wind-driven electric generators operating in the US from ٥ kW to ٢٥ kW. Around the time of World War I, American windmill makers were producing ١٠٠,٠٠٠ farm windmills each year, mostly for water-pumping.[٩] By the ١٩٣٠s, wind generators for electricity were common on farms, mostly in the United States where distribution systems had not yet been installed. In this period, high-tensile steel was cheap, and the generators were placed atop prefabricated open steel lattice towers.

A forerunner of modern horizontal-axis wind generators was in service at Yalta, USSR in ١٩٣١. This was a ١٠٠ kW generator on a ٣٠-metre (٩٨ ft) tower, connected to the local ٦.٣ kV distribution system. It was reported to have an annual capacity factor of ٣٢ per cent, not much different from current wind machines.[١٠] In the fall of ١٩٤١, the first megawatt-class wind turbine was synchronized to a utility grid in Vermont. The Smith-Putnam wind turbine only ran for ١,١٠٠ hours before suffering a critical failure. The unit was not repaired because of shortage of materials during the war.

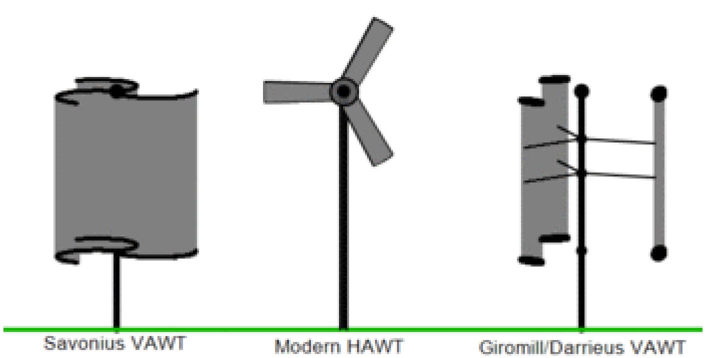
The first utility grid-connected wind turbine to operate in the U.K. was built by John Brown & Company in ١٩٥١ in the Orkney Islands.[٧][١١]

Resources

Main article: Wind power

A quantitative measure of the wind energy available at any location is called the Wind Power Density (WPD) It is a calculation of the mean annual power available per square meter of swept area of a turbine, and is tabulated for different heights above ground. Calculation of wind power density includes the effect of wind velocity and air density. Color-coded maps are prepared for a particular area described, for example, as "Mean Annual Power Density at ٥٠ Meters." In the United States, the results of the above calculation are included in an index developed by the U.S. National Renewable Energy Lab and referred to as "NREL CLASS." The larger the WPD calculation, the higher it is rated by class. Classes range from Class ١ (٢٠٠ watts/square meter or less at ٥٠ meters altitude) to Class ٧ (٨٠٠ to ٢٠٠٠ watts/square meter). Commercial wind farms generally are sited in Class ٣ or higher areas, although isolated points in an otherwise Class ١ area may be practical to exploit.[١٢]

Types



The three primary types:VAWT Savonius, HAWT towered; VAWT Darrieus as they appear in operation.

Wind turbines can rotate about either a horizontal or a vertical axis, the former being both older and more common.[١٣]

Horizontal axis

Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.[١٤]

Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount.

Downwind machines have been built, despite the problem of turbulence (mast wake), because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since cyclical (that is repetitive) turbulence may lead to fatigue failures, most HAWTs are of upwind design.

١١ x ٧,٥ MW E١٢٦ Estienne’s Wind farm, Belgium, July ٢٠١٠, one month before completion, with unique ٢ part blades.

Modern wind turbines

Turbine blade convoy passing through Eden field in the UK

Turbines used in wind farms for commercial production of electric power are usually three-bladed and pointed into the wind by computer-controlled motors. These have high tip speeds of over ٣٢٠ kilometres per hour (٢٠٠ mph), high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually colored light gray to blend in with the clouds and range in length from ٢٠ to ٤٠ metres (٦٦ to ١٣٠ ft) or more. The tubular steel towers range from ٦٠ to ٩٠ metres (٢٠٠ to ٣٠٠ ft) tall. The blades rotate at ١٠-٢٢ revolutions per minute. At ٢٢ rotations per minute the tip speed exceeds ٩٠ metres per second (٣٠٠ ft/s).[١٥][١٦] A gear box is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but more energy can be collected by variable-speed turbines which use a solid-state power converter to interface to the transmission system. All turbines are equipped with protective features to avoid damage at high wind speeds, by feathering the blades into the wind which ceases their rotation, supplemented by brakes.

Vertical axis design

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, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the ٣٦٠ degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modelling the wind flow accurately and hence the challenges of analysing and designing the rotor prior to fabricating a prototype.[١٧]

With a vertical axis, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, hence improving accessibility for maintenance.

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 ٥٠% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. It should be borne in mind that wind speeds within the built environment are generally much lower than at exposed rural sites.[١٨]

Another type of vertical axis is the Parallel turbine similar to the crossflow fan or centrifugal fan it uses the Ground effect. Vertical axis turbines of this type have been tried for many years[١٩] The Magenn WindKite blimp uses this configuration as well, chosen because of the ease of running.[٢٠]

Subtypes

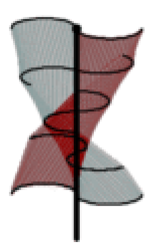
Darrieus wind turbine of ٣٠ m in the Magdalen Islands

Darrieus wind turbine

"Eggbeater" turbines, or Darrieus turbines, were named after the French inventor, Georges Darrieus.[٢١] They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.[٢٢]

Giromill

A subtype of Darrieus turbine with straight, as opposed to curved, blades. The cycloturbine variety has variable pitch to reduce the torque pulsation and is self-starting.[٢٣] The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a lower blade speed ratio; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. Straight, V, or curved blades may be used.[٢٤]



Twisted Savonius

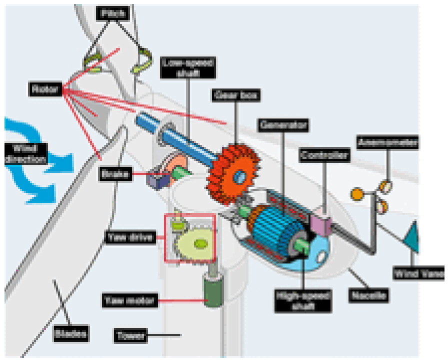
Savonius wind turbine

These are drag-type devices with two (or more) scoops that are used in anemometers, *Flettner* vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops.

Twisted Savonius

Twisted Savonius is a modified savonius, with long helical scoops to give a smooth torque, this is mostly used as roof windturbine or on some boats (like the Hornblower Hybrid).

Turbine design and construction



Components of a horizontal-axis wind turbine

Main article: Wind turbine design

Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamic modelling is used to determine the optimum tower height, control systems, number of blades and blade shape.

Wind turbines convert wind energy to electricity for distribution. Conventional horizontal axis turbines can be divided into three components.

- The rotor component, which is approximately ٢٠% of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
- The generator component, which is approximately ٣٤% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gearbox (e.g. planetary gearbox,[٢٥] adjustable-speed drive [٢٦] or continuously variable transmission[٢٧]) component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
- The structural support component, which is approximately ١٥% of the wind turbine cost, includes the tower and rotor yaw mechanism.[٢٨]

A ١.٥ MW wind turbine of a type frequently seen in the United States has a tower ٨٠ meters high. The rotor assembly (blades and hub) weighs ٤٨,٠٠٠ pounds (٢٢,٠٠٠ kg). The nacelle, which contains the generator component, weighs ١١٥,٠٠٠ pounds (٥٢,٠٠٠ kg). The concrete base for the tower is constructed using ٥٨,٠٠٠ pounds (٢٦,٠٠٠ kg) of reinforcing steel and contains ٢٥٠ cubic yards (١٩٠ cubic meters) of concrete. The base is ٥٠ feet (١٥ m) in diameter and ٨ feet (٢.٤ m) thick near the center.[٢٩]

Unconventional wind turbines

Main article: Unconventional wind turbines

One E-٦٦ wind turbine at Windpark Holtriem, Germany, carries an observation deck, open for visitors. Another turbine of the same type, with an observation deck, is located in Swaffham, England. Airborne wind turbines have been investigated many times but have yet to produce significant energy. Conceptually, wind turbines may also be used in conjunction with a large vertical solar updraft tower to extract the energy due to air heated by the sun.

Wind turbines which utilise the Magnus effect have been developed.[٢]

The Ram air turbine is a specialist form of small turbine that is fitted to some aircraft. When deployed, the RAT is spun by the airstream going past the aircraft and can provide power for the most essential systems if there is a loss of all on–board electrical power.

Small wind turbines

A small wind turbine being used in Australia

Main article: Small wind turbine

Small wind turbines may be used for a variety of applications including on- or off-grid residences, telecom towers, offshore platforms, rural schools and clinics, remote monitoring and other purposes that require energy where there is no electric grid, or where the grid is unstable. Small wind turbines may be as small as a fifty-watt generator for boat or caravan use. The US Department of Energy's National Renewable Energy Laboratory (NREL) defines small wind turbines as those smaller than or equal to ١٠٠ kilowatts.[٣٠] Small units often have direct drive generators, direct current output, aeroelastic blades, lifetime bearings and use a vane to point into the wind.

Larger, more costly turbines generally have geared power trains, alternating current output, flaps and are actively pointed into the wind. Direct drive generators and aeroelastic blades for large wind turbines are being researched.

Wind turbine spacing

On most horizontal windturbine farms, a spacing of about ٦-١٠ times the rotor diameter is often upheld. However, for large wind farms distances of about ١٥ rotor diameters should be more economically optimal, taking into account typical wind turbine and land costs. This conclusion has been reached by research[٣١] conducted by Charles Meneveau of the Johns Hopkins University[٣٢] and Johan Meyers of Leuven University in Belgium, based on computer simulations[٣٣] that take into account the detailed interactions among wind turbines (wakes) as well as with the entire turbulent atmospheric boundary layer. Moreover, recent research by John Dabiri of Caltech suggests that vertical wind turbines may be placed much more closely together so long as an alternating pattern of rotation is created allowing blades of neighboring turbines to move in the same direction as they approach one another.[٣٤]

Accidents

Several cases occurred where the housings of wind turbines caught fire. As housings are normally out of the range of standard fire extinguishing equipment, it is nearly impossible to extinguish such fires on older turbine units which lack fire suppression systems. In several cases one or more blades were damaged or torn away.[٣٥] In ٢٠١٠ ٧٠ miles per hour (١١٠ km/h) storm winds damaged some blades, prompting blade removal and inspection of all ٢٥ wind turbines in Campo Indian Reservation in the U.S. State of California.[٣٦] Several wind turbines also collapsed.

Severe wind turbine accidents have had relatively low impacts on the communities where the accidents occurred. In comparison, nuclear accident sites such as the Chernobyl and Fukushima disasters have created emergency evacuation zones the size of Switzerland which will remain in place for many decades, if not centuries.

Place	**Date**	**Type**	**Nacelle height**	**Rotor dia.**	**Year built**	**Reason**	**Ref.**	**Other info**
Ellenstedt, Germany	October ١٩, ٢٠٠٢						[٣]	
Schneebergerhof, Germany	December ٢٠, ٢٠٠٣	Vestas V٨٠		٨٠ m			[٤]	
Wasco, Oregon, USA	August ٢٦, ٢٠٠٧						[٥]	١ worker killed, ١ injured
Stobart Mill, UK	December ٣٠, ٢٠٠٧	Vestas			١٩٨٢		[٦]	
Hornslet, Denmark	February ٢٢, ٢٠٠٨	Nordtank NKT ٦٠٠-١٨٠	٤٤.٥ m	٤٣ m	١٩٩٦	Brake failure	[٧]	Collapse was filmed [٨]
Searsburg, New Hampshire, USA	October ١٦, ٢٠٠٨	Zond Z-P٤٠-FS			١٩٩٧	Rotor blade collided with tower during strong wind and destroyed it	[٩]	
Altona, New York, USA	March ٦, ٢٠٠٩						[١٠]	
Fenner, New York, USA	December ٢٧, ٢٠٠٩						[١١]	
Kirtorf, Germany	June ١٩, ٢٠١١	DeWind D-٦	٦٨.٥ m	٦٢ m	٢٠٠١		[١٢]	
Ayrshire, Scotland	December ٨,						[١٣]	

Place	Date	Type	Nacelle height	Rotor dia.	Year built	Reason	Ref.	Other info
	٢٠١١							

Record-holding turbines

Largest capacity

The Enercon E-١٢٦ has a rated capacity of ٧.٥٨ MW,[٣٧] has an overall height of ١٩٨ m (٦٥٠ ft), a diameter of ١٢٦ m (٤١٣ ft), and is the world's largest-capacity wind turbine since its introduction in ٢٠٠٧.[٣٨]

At least five companies are working on the development of a ١٠MW turbine:

- American Superconductor[٣٩]
- Wind Power Ltd are developing a ١٠ MW VAWT, the Aerogenerator X[٤٠]
- Sway AS announced the proposed development of a prototype ١٠ MW wind turbine with a height of ١٦٢.٥ m (٥٣٣ ft) and a rotor diameter of ١٤٥ m (٤٧٥ ft).[٤٠][٤١][٤٢]
- Astralux Ltd are developing vertical axis magneto levitated ١٠ MW turbine with ٢٣٠ m height and ٢٦٠ m rotor diameter[٤٣][٤٤]
- Clipper Windpower were developing the Britannia ١٠ MW HAWT, but terminated the project due to financial challenges.[٣٩][٤٠][٤١][٤٥]

Largest swept area

The turbine with the largest swept area is a prototype installed by Gamesa at Jaulín, Zaragoza, Spain in ٢٠٠٩. The G١٠X – ٤.٥ MW has a rotor diameter of ١٢٨m. [٤٦]

Tallest

The tallest wind turbine is Fuhrländer Wind Turbine Laasow. Its axis is ١٦٠ meters above ground and its rotor tips can reach a height of ٢٠٥ meters. It is the only wind turbine in the world taller than ٢٠٠ meters.[٤٧]

Largest vertical-axis

Le Nordais wind farm in Cap-Chat, Quebec has a vertical axis wind turbine (VAWT) named Éole, which is the world's largest at ١١٠ m.[٤٨] It has a nameplate capacity of ٣.٨MW.[٤٩]

Most southerly

The turbines currently operating closest to the South Pole are three *Enercon E-٣٣* in Antarctica, powering New Zealand's Scott Base and the United States' McMurdo Station since December ٢٠٠٩[٥٠][٥١] although a modified HR٣ turbine from Northern Power Systems operated at the Amundsen-Scott South Pole Station in ١٩٩٧ and ١٩٩٨.[٥٢] In March ٢٠١٠ CITEDEF designed, built and installed a wind turbine in Argentine Marambio Base.[٥٣]

Most productive

Four turbines at Rønland wind farm in Denmark share the record for the most productive wind turbines, with each having generated ٦٣.٢ GWh by June ٢٠١٠.[٥٤]

Highest-situated

The world's highest-situated wind turbine is made by DeWind installed by the Seawind Group and located in the Andes, Argentina around ٤,١٠٠ metres (١٣,٥٠٠ ft) above sea level. The site uses a type D٨.٢ - ٢٠٠٠ kW / ٥٠ Hz turbine. This turbine has a new drive train concept with a special torque converter (WinDrive) made by Voith and a synchronous generator. The WKA was put into operation in December ٢٠٠٧ and has supplied the Veladero mine of Barrick Gold with electricity since then.[٥٥]

Largest floating wind turbine

The world's largest—and also the first operational deep-water *large-capacity*—floating wind turbine is the ٢.٣ MW Hywind currently operating ١٠ kilometres (٦.٢ mi) offshore in ٢٢٠-meter-deep water, southwest of Karmøy, Norway. The turbine began operating in September ٢٠٠٩ and utilizes a Siemens ٢.٣ MW turbine[٥٦][٥٧]

Gallery of record-holders

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  Enercon E-١٢٦, highest rated capacity

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  Fuhrländer Wind Turbine Laasow, world's tallest

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  Éole, the largest vertical axis wind turbine, in Cap-Chat, Quebec

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Highest-situated wind turbine, at the Veladero mine in San Juan Province, Argentina

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