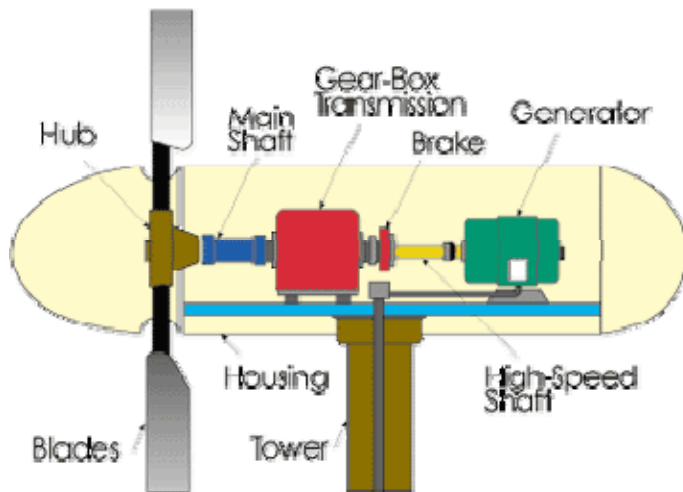


Main Components of a Wind Turbine



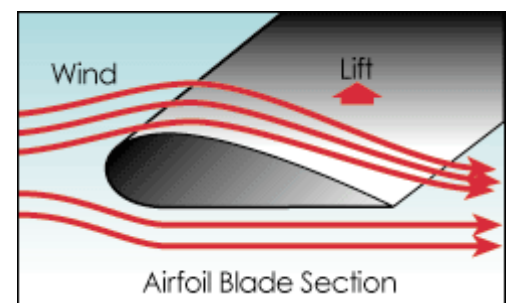
Rotor

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

Drag Design

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work that Dutch, farm and similar "work-horse" windmills perform. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

Lift Design enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.



Tip Speed Ratio

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed.

Electricity generation requires high rotational speeds. Lift-type wind turbines have

maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1. Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generators

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

It is important to select the right type of generator to match your intended use. Most home and office appliances operate on 120 volt (or 240 volt), 60 cycle AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC. Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correct voltage (120 or 240 V) and constant frequency (60 cycles) of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Towers

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the

stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top. This simplifies not only installation, but maintenance as well. Towers can be constructed of a simple tube, a wooden pole or a lattice of tubes, rods, and angle iron. Large wind turbines may be mounted on lattice towers, tube towers or guyed tilt-up towers.

Installers can recommend the best type of tower for your wind turbine. It must be strong enough to support the wind turbine and to sustain vibration, wind loading and the overall weather elements for the lifetime of the wind turbine. Tower costs will vary widely as a function of design and height. Some wind turbines are sold complete with tower. More frequently, however, towers are sold separately.

Basic Designs

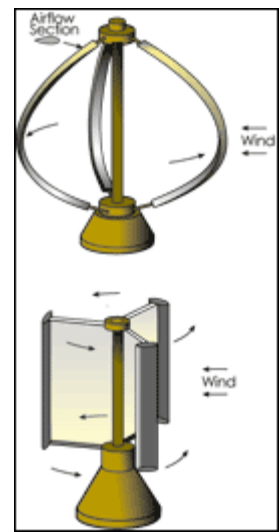
Wind turbines are classified into two general types: horizontal axis and vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commercially.

Horizontal Axis

This is the most common wind turbine design. In addition to being parallel to the ground, the axis of blade rotation is parallel to the wind flow. Some machines are designed to operate in an upwind mode, with the blades upwind of the tower. In this case, a tail vane is usually used to keep the blades facing into the wind. Other designs operate in a downwind mode so that the wind passes the tower before striking the blades. Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode. Some very large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction sensor mounted on the tower.

Vertical Axis

Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal



counterparts. The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines. The basic vertical axis designs are the Darrieus, which has curved blades, the Giromill, which has straight blades, and the Savonius, which uses scoops to catch the wind.

A vertical axis machine need not be oriented with respect to wind direction. Because the shaft is vertical, the transmission and generator can be mounted at ground level allowing easier servicing and a lighter weight, lower cost tower. Although vertical axis wind turbines have these advantages, their designs are not as efficient at collecting energy from the wind as are the horizontal machine designs.

Augmentors

Some experimental wind turbines have incorporated an added structural design feature, called an augmentor, intended to increase the amount of wind passing through the blades. However, these augmentors do not increase the energy capture of the machine enough to justify the added cost of employing them.

Operating Characteristics

All wind machines share certain operating characteristics, such as cut-in, rated and cut-out wind speeds.

Cut-in Speed

Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 7 and 10 mph.

Rated Speed

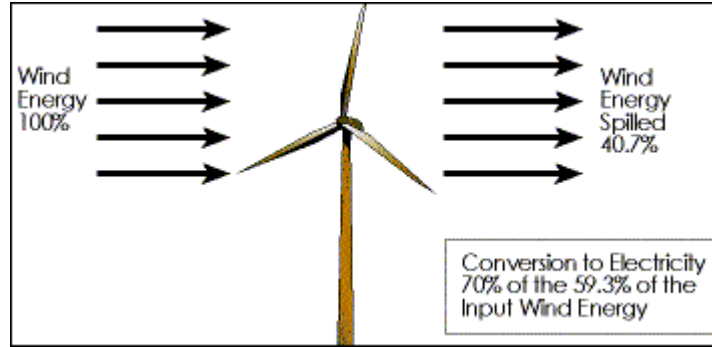
The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 25 mph. Rated speed for most machines is in the range of 25 to 35 mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.

Cut-out Speed

At very high wind speeds, typically between 45 and 80 mph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

Betz Limit

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59%. This value is known as the Betz limit. If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59%. A more typical efficiency is 35% to 45%. A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will (depending on the model) deliver between 10% and 30% of the original energy available in the wind.



Sizing Grid Connected Systems

The size, or generating capacity, of a wind turbine for a particular installation depends on the amount of power needed and on the wind conditions at the site. It is unrealistic to assume that all your energy needs can be met economically by wind energy alone. As a general rule, a wind system should be sized to supply 25% to 75% off your energy requirements. Most residential applications require a machine capacity of between 1 and 10 kW. Farm use requires 10 to 50 kW and commercial/small industrial uses typically require 20 kW or larger.

Because most buildings are connected to a utility line, many wind turbine owners have opted to interconnect their systems. In effect, they use the utility as a backup system. Excess electricity from the turbine is automatically fed to the utility and backup power is automatically supplied. While this does not constitute true storage, it provides power on demand at any time, in any amount. The process to obtain approval for interconnection from the utility company can be lengthy and complicated, and requires careful planning. The possibilities for interconnection should be investigated early in the process of researching a wind system.

The variability of your energy consumption and the amount of money you are willing to spend on a wind system should also guide your selection. For example, a user whose consumption is erratic or concentrated during short periods of the day should size a wind

turbine differently than a user with a fairly constant energy demand. In the former case, wind turbine size should be a function of off-peak or average energy demand.

Off-Grid Systems

Off-grid power systems can result in higher cost energy, but the high cost of extending a power line to a remote location often makes an independent energy system the most cost effective choice for remote homes and equipment. If the average wind speeds at a location are greater than 12 mph, a wind turbine may provide the least expensive form of energy.

Because wind is intermittent, it is often used in conjunction with batteries or with other energy sources, such as a gas generator or solar electric panels, to make a hybrid system. Battery systems can supply the owner with reserve power whenever energy demand exceeds that delivered by the wind turbine. This reserve power comes in handy during calm spells, but in situations where the storage capacity is taxed beyond its limits, a backup system, such as a portable gasoline or diesel generator, may be necessary. By combining two or more sources of energy, the size of energy storage can be decreased.

Energy Storage

Electrical Storage

Batteries are the most common form of electrical storage. Where heat, rather than electricity, is the desired end product of a wind turbine application, hot water is the usual storage medium. However, the advantageous economics of other heating systems make wind-powered heating a less attractive option.

Batteries can store and deliver only DC power. Unless an inverter is used to convert DC to AC, only DC appliances can be operated from the stored power. The battery voltage must be the same as the voltage needed to run the appliance. Standard battery voltage is 6 or 12 volts. For an appliance requiring 24 volts, two 12-volt or four 6-volt batteries connected in series are required. For a 120-volt application, you will need a series of ten 12-volt batteries.

The least costly batteries for wind applications are deep cycle, heavy-duty, industrial type lead-acid batteries, such as those used in golf carts and forklifts designed for high reliability and long life. They can be fully charged and discharged, while standard lead-acid batteries (e.g., automobile type) cannot. Gel-cell lead acid batteries have improved the safety of the traditional liquid acid battery by containing the hydrogen that can be produced during charging, and by preventing the liquid acid from spilling.

Battery conversion efficiency is approximately 60% to 80%. A battery's capacity is rated in amp-hours, a measure of its ability to deliver a certain amperage for a certain number of hours. For example, for a rating of 60 amp-hours, 3 amps can be delivered for 20 hours. Batteries should be routinely inspected for fluid level and corrosion. The storage

room should be well ventilated. If allowed to accumulate, the hydrogen gas produced by some batteries can explode.

Substantial research on battery technology has taken place since 1990, when the Federal Clean Air Act Amendment prompted new battery research for electric vehicles. Much of this research has focused on developing batteries that can be rapidly charged and are lighter in weight. Many new types of batteries are being developed. Two examples of near-future alternatives to lead-acid batteries are nickel-cadmium batteries and nickel-iron batteries. Both types generally provide good low-temperature performance and long life, but they are still more expensive than lead-acid batteries.

Heat Storage

When heat is the desired end product, hot water is an alternate way to store energy. It is well suited to northern climates where the heating season coincides with the windy season. There are two basic ways to produce heat from a wind turbine. Electricity can be sent to resistance heaters immersed in water, or the wind turbine's rotor shaft can be mechanically coupled to a paddle or pump that agitates water, thereby heating it.

Resistance Heaters

The first method of heat storage involves electrical resistance heaters which can be DC or AC powered with unregulated voltage and frequency levels. Thus, the buyer has considerable flexibility in choosing a machine without the need for additional complex and expensive control or conditioning devices. The conversion efficiency of a resistance heater is nearly 100%, and heat loss is minimized if the water storage tank is well-insulated. Resistance heaters can also be used directly to heat air, as with baseboard electric home heaters.

Mechanical Heating

The second method of heating water is by mechanically agitating it, using either a pump or a paddle. The heat is produced by the large frictional losses that are produced by agitation. This method of heating does not require an electrical generator. Instead, the power from the rotating rotor shaft is used directly. Theoretical conversion efficiencies are nearly 100%, but practical considerations can reduce this considerably. As yet, only a few experimental models of this type of wind system have been tested.

Sizing of Off-Grid Systems

Sizing remote systems is substantially different than sizing a wind system for utility interconnection because remote systems must be designed to supply the entire electrical demand. Before one can size the components of a remote system, one must determine the load requirements of the site. This means quantifying the power demand on a daily and seasonal basis. The goal is to compare the amount of energy needed at different times of the day and year to when it is available on average from the wind. After taking into account the wind's intermittence, you can determine the size and type of energy storage or other energy sources needed to meet your total demand.

Battery storage should be sized large enough to handle at least three windless days. Backup generators are often included in remote electrical systems as a supplemental backup.

They help to power large, infrequently used loads and to preserve the life of the batteries by minimizing the number of times they are completely discharged. Also, they run most efficiently at full load. For these reasons, generators are often sized larger than the average expected load of the system so that they can also charge the batteries at the same time, keeping run time and fuel consumption to a minimum. Many wind system dealers are familiar with remote system designs and can assist you in selecting an optimum, cost-effective system.

Installation, Maintenance and System Life

Many dealers will sell and install a complete package, including wind turbine, tower and electrical work. Wind turbines should be installed by qualified, experienced people. Local codes should be checked to determine if contractors must be licensed. The local building inspector may be required to inspect the completed work. For utility interconnected systems, a utility-designated inspector probably will make an inspection.

By their very nature, wind turbines are subject to extreme physical forces. The tips of a wind turbine rotor can reach speeds of up to 300 mph. Hail, dirt and insects contacting the blades at these speeds can cause wear to the blade edges. Bearings that support the rotor or other moving parts are also subject to wear. The lifetime of these bearings depends on the wind conditions and level of maintenance care.

The manufacturer usually specifies what is required for the maintenance of a wind turbine. The entire wind system, including the tower, storage devices and wiring should be inspected at least once a year. Routine maintenance might include changing the transmission oil, greasing the bearings and visually inspecting the condition of the blades, tower and electrical connections. Instead of doing the maintenance work yourself (which may require climbing the tower), you can arrange a maintenance contract with the dealer.

According to manufacturers, the expected lifetime of wind turbines is 20 to 30 years. Although few manufacturers have been around that long, this prediction is not unrealistic. Some electricity-generating wind turbines built more than 50 years ago are still working today. Just like automobiles and washing machines, wind turbines have to be properly and routinely maintained to maximize their life. Do not be surprised if minor repair work is needed soon after initial operation. A reputable company will make such repairs quickly and at no charge.