E3A: Small Wind Energy Applications for the Home, Farm or Ranch

Understand small wind

There are four main parts of a small wind system: rotor, generator, tower and control system.

Rotor

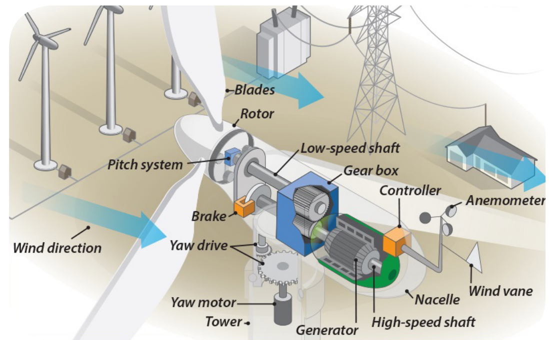
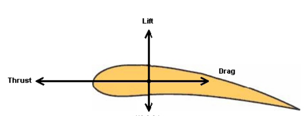


Photo credit: DOE

The rotor includes the blades and the hub of a conventional horizontal-axis small wind system. The blades are designed such that the wind causes rotational torque, which is the force that rotates the central shaft. The rotor hub connects to the central shaft that drives a generator.

Material characteristics of the blades make a difference in the performance and maintenance required for a system. Turbine blades can be made of many different materials, though most are made of composites, such as fiberglass, because they are strong, lightweight and cost less than other materials. Wooden blades can be strong, lightweight and relatively cheap to produce, but they damage easily and need regular maintenance. Wooden blades can be difficult to balance because no two pieces of wood are identical. They also absorb water, which can cause warping and balance problems. Severe vibration and wear on the turbine can occur when a rotor is off balance.

Blades are airfoils, which are shaped like airplane wings. Airfoils cause a force of lift when air flows around them due to their shape. The amount of lift depends on the angle at which the wind hits the blade. By angling the blade, the lift force can be increased or decreased and the turbine speed can be regulated. All commercial wind turbines are lift machines. Some turbines — including windmills common on farms and ranches decades ago — are drag machines. Drag is caused by air pushing against the blade. These turbines rely on drag forces to create rotary motion. Drag machine blades may be cupped or have a flap plate that uses the wind to push the blade rather than lift it.



Courtesy of Wikimedia Commons
Forces of lift and drag on an airfoil.

Turbines can be either upwind or downwind machines. Upwind machines use a tail fin or vane to face the blades upwind of the tower, whereas in a downwind turbine the blades face downwind of the tower. Each has its advantages and disadvantages.

Blades are designed to twist and taper along the length of the blade. These design characteristics are necessary to keep stress uniform along the length of the blade. Some blades pitch, so the blade changes angle as wind speed increases. Pitching is standard on large, utility-scale wind turbines but less common for small wind turbines.

Generator

Most small wind turbines are permanent magnet, direct-drive systems. There are also a number of induction generator designs used with small wind turbines. The rotor connects directly to a generator's central shaft. Permanent magnet generators produce electricity using copper wire coils and magnets. As the blades spin the rotor hub and shaft, the rotation turns copper coils on an axis between two magnets to create electrical current. The power created is variable-frequency alternating current (AC), which cannot be used without conditioning. A power converter changes variable-frequency AC power into direct current (DC) power. DC power can be used in some electrical appliances, or can be stored in batteries. DC power has to be converted to 60 hertz AC power, which is done using an inverter. Some turbines contain power conditioning systems within the nacelle, which is the housing for system components mounted on top of the tower. However, most use external power conditioning systems not housed in the turbine unit.

Tower

There are three basic types of towers: guyed, monopole and latticed.

Guyed towers are the least expensive, but guy wires increase the turbine's footprint, or surface area occupied. The radius of a guyed system should be 50 to 75 percent of the height of the tower. Most guyed towers are not designed to be taken down on a regular basis, so turbine maintenance requires climbing the tower. Guy wires also require maintenance. Tilt-up guyed towers are designed to be laid down to perform maintenance or in case of severe weather. Tilt-up guyed towers are usually more expensive than conventional guyed towers.

Latticed towers are permanent, freestanding and can be climbed to perform maintenance.

Monopole towers exist in two designs: permanent free-standing and tilt-up. Monopoles do not require guy wires because they are more structurally solid. With that stronger design comes a higher cost. In addition to the tower itself, foundation design is a crucial part of the system.

Is a tower necessary?

Higher off the ground, wind speeds increase and turbulent airflows are less common; both key factors in wind power production. Market availability and type of turbine limit tower selection. Taller towers generally produce more electricity, which may improve the economics of a project. Tower height depends on the location and economics of the investment.

Roof-mount turbines

Before purchasing a roof-mounted system, consider several factors:

Can the turbine be placed high enough above the roof to avoid turbulent airflows and take advantage of wind shear? Wind shear is the increase in wind speed that occurs higher off the ground. Some experts say the answer to this question is unequivocally no.

Is the roof strong enough for both the weight and torque of the wind turbine? The wind turbine will be under significant pressure as wind speed increases.

Will the turbine cause unwanted noise for occupants of the structure? What are the possible problems caused by noise and vibration on the structure? Rooftops create considerable turbulence at the turbine, which prevents it from creating lift. Turbulence will also increase the maintenance necessary for the system and shorten its life expectancy. Rooftop installations generally have not performed well and are not recommended.

Control systems

To account for changing wind directions, turbines must be able to yaw, or turn to face the wind. Most small wind turbine systems use a passive yaw control system. Passive control systems are designed to cause the rotor to slow down when the wind speed exceeds a certain level. Small wind turbines protect themselves from damage caused by severe wind in one of three ways: stalling, turning out of the wind or using tip brakes.

The most common method is turning out of the wind, or furling. Furling uses the turbine's yaw mechanism or an angle governor, which tilts the turbine up and away from the wind. Other systems reduce lift generated by changing the blade angle or using turbine blades that bend back or fold. Other blades sweep back in a conical shape against the nacelle to reduce the amount of blade in strong wind conditions. Stalling systems, typically found on induction systems, or tip brakes can be used, but passive control systems are the most common way of reducing the amount of blade surface area exposed to the wind.

Turbines should have a brake system, so the turbine can be shut down in a severe wind or to perform maintenance. For safety purposes, two brakes — also called redundant braking — are recommended.

Types of turbines

There are two types of turbines: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT).

In a HAWT, the nacelle sits on top of the tower parallel to the ground. They are the most common type of turbine, and most are upwind lift machines. HAWTs are usually two- or three-blade designs. Years of testing have shown that three-blade designs have the highest power output. Two-blade designs often experience "yaw chatter," or vibration caused by yawing. New spring plates are being tested to address yaw chatter in two-blade designs. Blade designs vary by manufacturer, ranging from curved blades



Photo credit: DOE NREL

and blades with weighted tips to blades with unique cuts and designs.

There are usually three designs of VAWT machines: Darrieus, Savonius and Giromill. VAWT machines are mounted with turbine components perpendicular to the ground. The components sit at ground level, making some maintenance tasks easier. Many use lighter weight towers. However, VAWTs have struggled to gain commercial acceptance due to various design, performance and reliability issues. VAWT rotors are often near the ground where wind speed is lower and turbulence is greater. There has not been a commercially successful VAWT in the United States.

Converting wind to electricity

Many of the purchasing decisions consumers make on small wind systems are based on this power production formula:

$$\tfrac{1}{2}(\text{Air density}) \times (\text{Wind speed})^3 \times (\text{Swept area of rotor})^2 = \text{Energy}$$

This formula will calculate the kinetic energy available from the wind in watts. Other derivations of this formula can be used to determine annual energy output in kilowatt-hours or total available power. This formula is presented in its simplest form to help you understand the key determining factors in power output — air density, wind speed and rotor diameter.

What does the formula mean?

The formula shows that doubling the swept area creates four times the power, because that variable is squared. Doubling wind speed results in eight times the power generated, because that variable is cubed. People learning about wind might think a one- or two-mile per hour change in wind speed is negligible, but a small change in wind speed makes a big difference in the level of power production.

Why is the power production formula so important?

The small wind industry lacks standardization. In 2009, the American Wind Energy Association developed industry standards. In 2010, the Small Wind Certification Council began testing turbines to those standards. However, testing is voluntary and it will take time to get good performance comparisons. Therefore, consumers must often rely on this formula to compare systems and make informed purchasing decisions. Other guides in this series help you understand when to use the formula to understand small wind.

Notes

Original work created by Montana State University Extension and the University of Wyoming.
Adapted with permission by University of Missouri Extension.

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