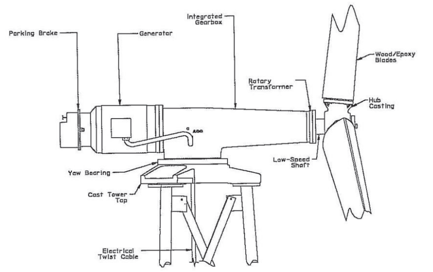
STEP 1

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

Steps in the Small Wind Series

E3A-SW.1
Printed October 2011

There are four main parts of a small wind system: 1) rotor, 2) generator, 3) tower, and 4) control system.



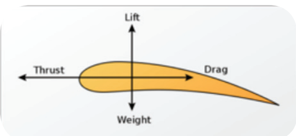
Courtesy of Wind Powering America

Rotor

The rotor includes the blades and the hub of a conventional horizontal-axis small wind system. The blades are designed to capture the energy in the wind and turn it into rotational torque. Rotational torque is the force that rotates the central shaft. The rotor hub connects to a central shaft, which drives a generator.

Turbine blades can be made of many different materials. Most blades are made of composites (fiberglass is common), because they are strong, lightweight, and cost less than other materials. You may find other blade types, although they are not common. Wooden blades can be strong, lightweight, and relatively cheap to produce. However, wooden blades are easier to nick and scratch, and need regular maintenance. Wooden blades can be difficult to balance since no two pieces of wood are identical. They can also absorb water, which can cause warping and balance problems. Severe vibration and wear on the turbine can occur when a rotor is out-of-balance. Aluminum blades are light-weight and less costly to manufacture, but are susceptible to damage. Steel blades are strong, but can be expensive, heavy and can rust. Aluminum and steel blades are no longer used for commercial turbines, but older turbines in the rural west were made of these materials. Be aware of the material characteristics of the blades before you buy a turbine so that you are able to plan for maintenance expenses.

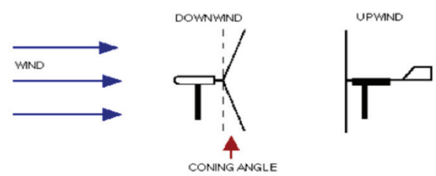
Blades are airfoil shape, like airplane wings. Airfoils are shapes which cause a force of "lift" when air flows around them just because of their shape. Lift is caused by air flowing around the airfoil shape. "Drag" is caused by air pushing against the blade. In "lift" machines, the blade is shaped to maximize the force of lift. The amount of lift depends on the angle at which the blade hits the wind. By angling the blade, the lift force can be raised and lowered and the turbine speed can be regulated. All commercially successful wind turbines are "lift" machines. Some turbines (including the historic 'windmills' common on farms and ranches decades ago) are "drag" machines. These turbines rely on drag forces to create rotary motion. Drag machine blades may be cupped or use a flap plate which use the wind's energy to push the blade, rather than lift the blade.



Forces of Lift and Drag on an Airfoil
Courtesy of Wikimedia Commons

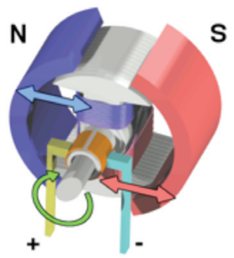
Turbines may be either "upwind" or "downwind" machines. Upwind machines use a tail fin or vane to place the blades into the wind upwind of the tower, whereas in a downwind turbine, the blades are downwind of the tower. Each type has certain advantages and disadvantages.

Blades are designed to twist and taper along the length of the blade. These design characteristics are needed to keep stresses uniform along the length of the blade: as the rotor turns, the tip moves at a faster speed than the root of the blade and requires a shallower angle and smaller blade cross-section to produce the desired lifting force. Some wind turbine's blades "pitch", so the blade changes angle as the wind speed increases. "Pitching" is standard on large, utility-scale wind turbines, but is less common for small wind turbines.



Upwind and Downwind Turbine
Courtesy Alternative Energy Institutte

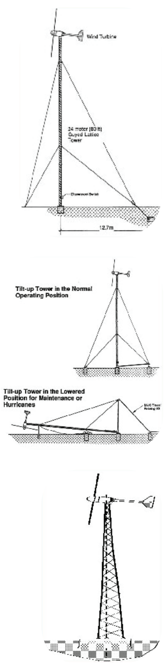
Generator



Courtesy of Wikimedia Commons

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

Tower


Courtesy of NREL

There are three basic types of towers: guyed towers, monopole, or latticed towers. Guyed towers are the least expensive. Guy wires do increase the footprint, or surface space occupied, of the turbine. The radius of a guyed system will be one-half to three-quarters the height of the tower. Most guyed towers are not designed to be taken down regularly, so turbine maintenance must be performed by climbing the tower. The guy wires also require maintenance, Livestock may rub on the guy wires which may be problematic. Tilt-up guyed towers are designed so that they can be laid down to perform maintenance, or if severe storms are expected. Tilt-up guyed towers are usually more expensive than conventional guyed towers. Latticed towers are permanent, free-standing and can be climbed to perform maintenance. Monopole towers are available in permanent free-standing or tilt-up designs. The towers are of a more robust design so they do not require guy wires, and there is an increased cost associated with this design. Additionally the tower foundation design is a critical part of the system and adds some expense.

Is a Tower Necessary?

Yes! Wind speed is greater as the height above ground increases and turbulent airflows are reduced - both are key factors in wind power production. A taller tower will enable the wind turbine to produce more electricity, but taller towers are also more expensive. Tower selection is limited by market availability and further limited depending on the turbine selected. In general taller towers produce more electricity which may improve the economics of the project. Tower height is dependent on the location and economics of the investment. Most towers range from 45 to 120 feet.

Roof-Mount Turbines

Can mounting a turbine on the roof save the cost of the tower? Before purchasing a roof-mount system, consider: a) Can the turbine be placed high enough above the roof to avoid turbulent air flows and to take advantage of wind shear? Wind shear is the increase in wind speed that occurs as the height above ground increases. Some experts state that the answer to this question is an unequivocal “no”. b) Is the roof strong enough for both the load (weight) and torque of the wind turbine? Remember that the wind turbine will be under significant pressure as the wind speed increases. c) Will the turbine cause unwanted noise for occupants of the structure. d)What are the possible problems caused by noise and vibration on the structure? Rooftops induce considerable turbulence at the turbine. The turbine cannot generate lift in turbulence. In addition, turbulence will increase the maintenance on the system and shorten its life expectancy. In general, rooftop installations have not performed well and are not recommended.

Control Systems

To account for changing wind directions, turbines must be able to “yaw” – that is, turn to face the wind. Most small wind turbine systems use a passive yaw control system, unlike the larger commercial-scale units that rely on active yaw control systems that utilize an electric motor to change the direction of the turbine. 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 can be done using the turbine’s yaw mechanism (turning to the side) or an angle governor, which will tilt the

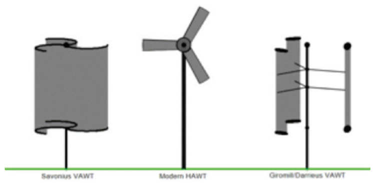

Courtesy of NREL

turbine up and away from the wind. Other systems reduce the lift generated by the blades pitching (changing the blade angle) or using turbine blades that bend back or fold. Other blades sweep back in a coning shape against the nacelle to reduce the amount of blade in the strong wind. Stalling systems (typically found on induction systems) or tip brakes can be used, but it is more common to find passive control systems to reduce the amount of blade surface area exposed to the wind resource.

Turbines should have a brake system, so the turbine can be shut down in a severe wind or when doing maintenance. Two brakes (also called redundant braking) are recommended for safety purposes.

Types of Turbines

There are two primary types of turbine – Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT).



Courtesy of NREL

In HAWTs, 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. Over years of testing, the three blade designs have had the highest power output. There are some two-blade designs on the market today, but these machines often experience "yaw chatter", or vibration caused when yawing. New spring plates are being tested to address this issue. Blade designs vary by manufacturer, ranging from curved blades and blades with weighted tips to blades with unique cuts and designs.

There are usually three designs of VAWT machines: Darrieus, Savonius, and Giromill. They are mounted with the 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 there is lower wind speed and a more turbulent wind resource. VAWT units tend to have poor self-starting abilities, and in some models the entire rotor must be removed to replace parts. 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 the power production formula:

$$P = \frac{1}{2}\rho v^3 \Pi r^2$$

ENERGY=(1/2) X (AIR DENSITY) X (VELOCITY)^3 X (SWEPT AREA OF ROTOR)*

What does the formula mean?

The formula tells us that the ability of a wind turbine to convert wind energy into electrical power depends on three factors: the density of the air, the swept area of the rotor, and the wind speed or velocity.

Why is the power production formula so important?

Wind turbines are all about producing power. The formula says that doubling the swept area creates four times the power (because it is a squared function). Increasing wind speed by two times will result in eight times the amount of power because it is a cubic function (2x2x2). On the other hand, if wind speed is cut in half there is only one-eighth the amount of power production! People learning about wind might think that a one- or two-mile per hour difference in wind speed is not a big difference, but because wind speed is a cubic function, a small difference in wind speed will make a big difference in the amount of power production.

This formula is important. There is a lack of industry standardization in small wind manufacturing. In 2009, the American Wind Energy Association developed industry standards. In 2010, the Small Wind Certification Council (SWCC) began testing turbines to those standards. However, testing is voluntary and it will take time for that process to result in good comparisons of performance. Therefore, consumers must often rely upon this formula to compare systems and make informed purchasing decisions. Other steps in this series will help you to understand when to use the formula to understand small wind.

**Note: This formula will calculate the kinetic energy available from the wind in watts. Other derivations of this formula as well as other formulas can be used to determine annual energy output in kilowatt hours, total available power, etc. This formula is presented in its simple form to help you understand the key determining factors in power output – air density, wind speed, and rotor diameter.*

Notes