ANATOMY OF A

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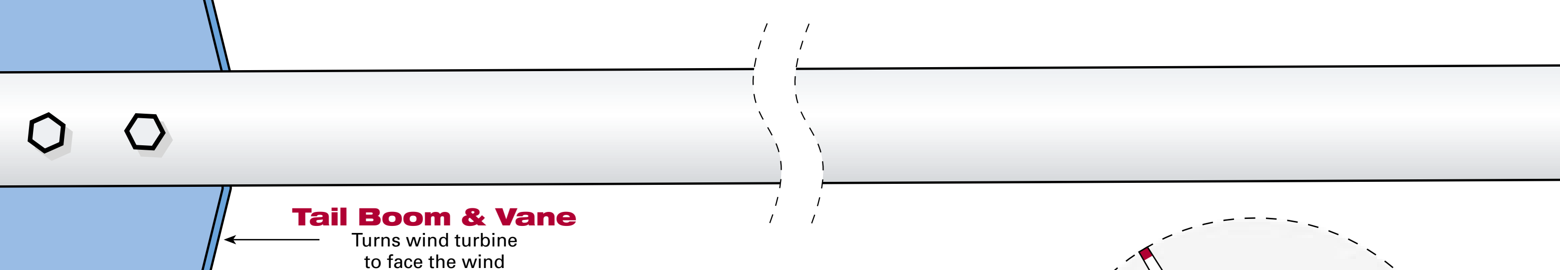
For thousands of years, people have been harnessing the energy of the wind. A fascination for wind energy has driven both of us to build, buy, install, and maintain our own machines for the last three decades. Chances are that the first wind-energy users were driven by the same maniacal glee that we experience when we grab energy out of thin air.

The design of home-scale wind-electric generators has been through many permutations and variations, with lots of circles and dead ends. But most of today's modern wind-electric generators are surprisingly similar. This article will help you understand each part of a typical wind generator, and how it functions in the overall design.



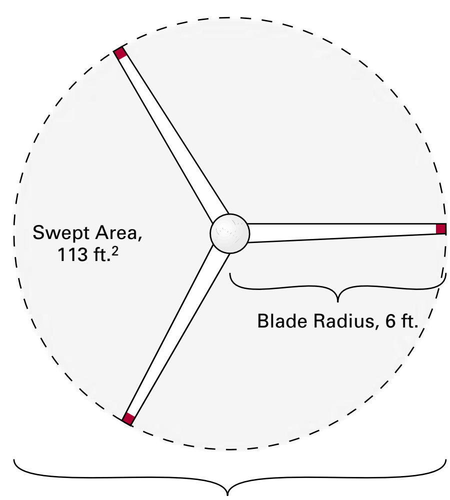
ROTOR (Blades & Hub)

"Rotor" is just a fancy word for a wind turbine's blade assembly—the part that rotates. (There are actually two rotors—the blade rotor, and the magnet rotor in the alternator or generator, which is driven by the blade rotor.) The wind generator's blades are the energy collectors. After the wind itself, the circular area that the rotor sweeps is the most important factor in determining how much power the machine can generate. The swept area of the rotor depends on the square of the diameter. Compared to a 5-foot-diameter rotor, a 10-foot one will be twice as wide, and twice as high. Doubling the diameter gives access to four times as much wind, and usually results in four times as much power.

Most modern wind turbines have three blades. Blades are usually made of plastic, often in a composite with fiberglass, or sometimes out of wood. Rotors with more than three blades have more start-up torque, but actually produce less power at high speeds. Two-bladed rotors can work at even higher speeds than their three-bladed counterparts, but can be noisy and also vibrate when the wind changes.

Mechanical power is a combination of speed and torque. Wind-electric generators need to spin at relatively high rpm and at low torque, unlike water-pumping wind machines, which need low rpm and high torque.

For home-scale wind generators, the blade rotor drives the magnet rotor directly. This design is the simplest and most efficient way to collect the wind's energy. Adding belts, pulleys, gearing, or any other indirect transmission will incur losses, as well as require more maintenance.

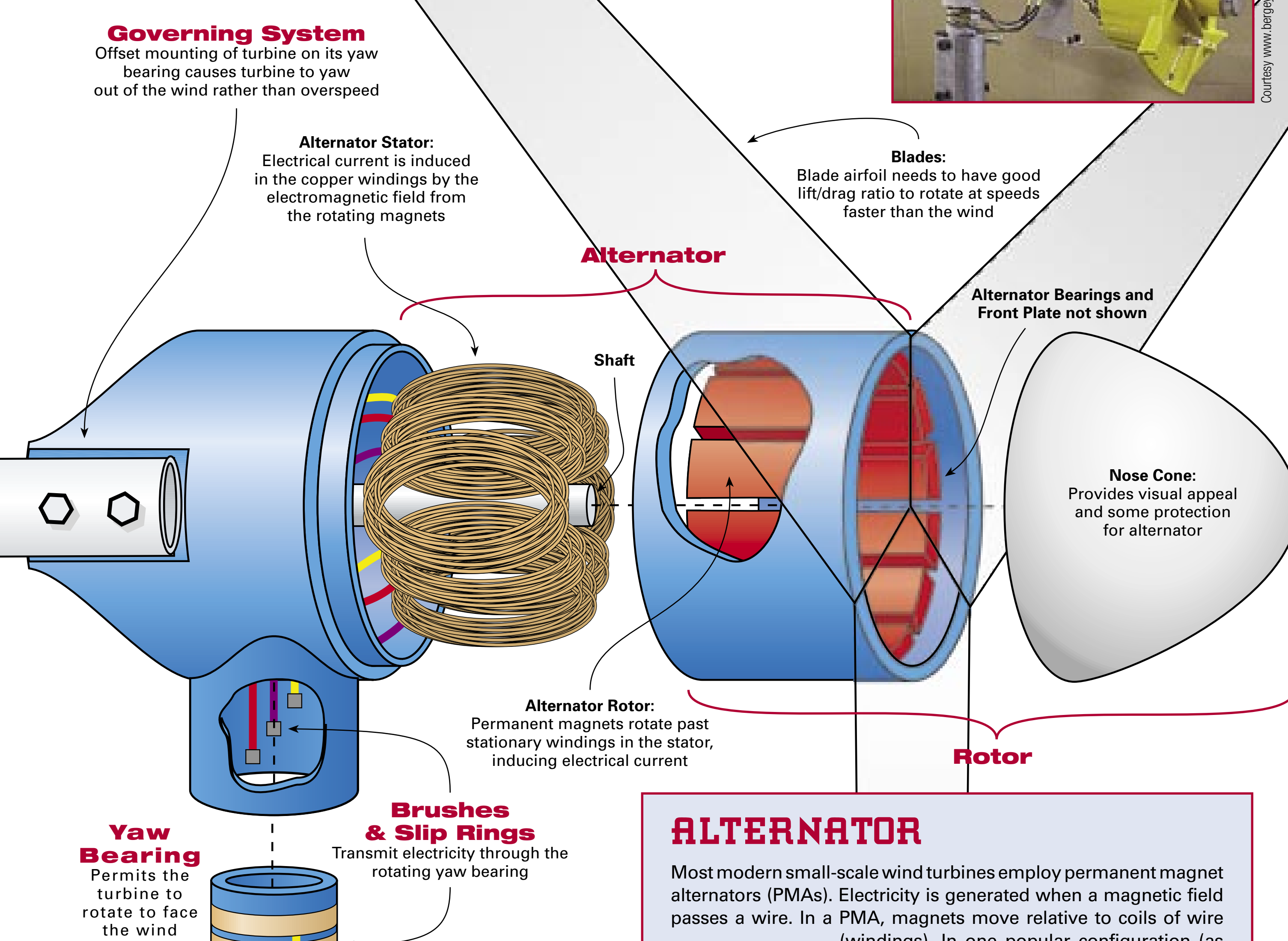


A cross-section of an extruded carbon-fiber blade shows the airfoil shape.

Courtesy www.bergey.com

WIND TURBINE

Rotor, stator, diode rectifier, slip rings, and bearings exposed on a Bergey XL.1 1 KW generator.



ALTERNATOR

Most modern small-scale wind turbines employ permanent magnet alternators (PMAs). Electricity is generated when a magnetic field passes a wire. In a PMA, magnets move relative to coils of wire (windings). In one popular configuration (as shown in the diagram above), the magnet rotor is a rotating "can" that spins outside the coils. The magnets are on the inside (facing the coils) and the blades attach directly to the front of the can. These PMAs usually generate wild three-phase AC, which is not usable by appliances directly. Instead, this energy is rectified (converted to DC electricity). After that, it can be used as DC or inverted to AC electricity for AC appliances. Traditionally, the energy has been stored in batteries, but in many modern wind-electric systems, it is fed straight into the household grid supply.

The stator from a 10 KW Bergey Excel showing multiple windings. A bearing in the center supports the rotor.

TAIL BOOM & VANE

The tail of a wind generator orients the turbine into the wind. When the wind changes direction, it pushes on one side of the tail, swinging the turbine around to face and collect wind energy. In tail-furling designs, the tail is also involved in protecting the turbine from high winds (see Governing Systems), and tail and boom length are designed carefully for weight and area. Changing these parameters can change the way the machine operates—so don't do it.

SHAFT & BEARINGS

The shaft of a wind turbine carries both rotors—the blades and the rotating part of the alternator. The shaft is suspended in bearings, which are usually sealed permanently. They need to be designed to withstand all the stresses of supporting the blade hub and any vibration from the alternator. Bearings typically last five to ten years.

SLIP RINGS & BRUSHES

Wind generators yaw to face the wind, but the transmission wiring is fixed to the ground. This can be a recipe for twisted wires, especially at turbulent sites where the yaw bearing is very free-moving. Most modern turbines use copper alloy slip rings to connect the turbine wiring to the fixed wiring. The slip rings are usually mounted in the part of the turbine that is fixed to the tower top. A set of graphite brushes is mounted on the yawing part of the turbine. The brushes ride on the rings as the turbine yaws, and serve to connect the alternator to the fixed wiring.

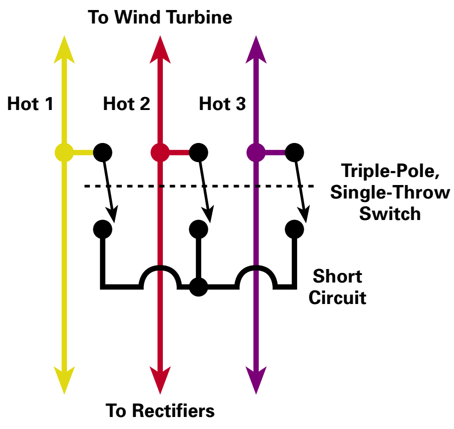
YAW BEARING

A wind turbine needs to be able to follow the wind, changing orientation each time the wind changes direction. The sealed bearing that supports the wind turbine as it swivels on its tower is called the yaw bearing, and the swiveling motion is called yawing.

Slip rings and brushes, and yaw bearing assembly from an ARE wind turbine.

BRAKING SYSTEM

Braking, as distinct from governing, is the ability to stop the turbine when you choose to. This can be useful when there is a problem with the machine, when you need to work on it, or when you simply don't need the energy. Manual braking is ideal, since it allows you to stop the machine in all conditions. Drum and disc brakes have been used in a few turbine designs, but most turbines use dynamic, or electrical, braking, where a big switch opens the connection to the grid or batteries, and shorts the three phases of the wind turbine together, making it very stiff to turn. Many wind turbines cannot be slowed by a short circuit once they are already running fast in high-wind conditions. Another method of control is manual furling—the ability to manually crank the tail over to furl the machine out of the wind.



ENERGY TRANSMISSION

Wiring routed down the tower carries the electricity generated by the turbine to the control room, usually as wild (varying voltage) three-phase AC. A few turbines rectify the output at the tower top, and transmit it as DC. Using thick copper wire reduces the risk of fire and limits power lost as heat. Where the wire run is very long, high-voltage AC transmission to a step-down transformer at the control room can be used to save on wire cost and energy losses. Batteryless grid-tied inverters work with higher voltages than most battery-based systems, so they lose less energy in transmission.

One feature of Southwest Windpower's controller is to rectify the turbine's AC output to DC for battery charging.

Courtesy www.windenergy.com

NACELLE

Some wind turbines use a plastic cover (cowling) spaced away from the alternator, which protects it from rain but allows airflow over the alternator for cooling. Many turbines have a separate nose cone, which serves an aesthetic purpose, as well as streamlines the turbine.


Courtesy www.windenergy.com

Governing Systems

To a novice, high winds seem like a bonus. But to seasoned wind-energy users and turbine designers, once the wind turbine is already going flat out, stronger winds become a cause for concern. Doubling the wind speed makes *eight times* as much power available, and also increases the thrust force on the turbine and tower by a factor of four.

A turbine should be able to shed excess force, or it will overspeed, burn out, or self-destruct in some way. Protection from strong winds, called governing, can be accomplished either by furling or by blade pitch-control. The most common governing system is a furling tail that steers the rotor out of the wind. Some machines twist the angle (pitch) of their blades toward stalling, which decreases their efficiency and prevents overload. Both of these systems are passive, in the sense that they are driven by the force of the wind, or by the speed of the blade rotor. Very recently, electrical braking also has been introduced to automatically control a turbine's speed.


As the wind approaches this turbine's rated speed for maximum power, the rotor begins to swivel out of the wind to prevent overspeed.

Courtesy www.windenergy.com

Putting It All Together

In an effective wind generator design, all of these systems and components are carefully matched to each other. For example, the alternator must produce power at the best rotational speed (rpm) to get the most power from the blade rotor. Too slow and the rotor will stall; too fast and the machine will be noisy and ineffectual in low-speed winds.

Of course, a complete wind-electric system is much more than just the turbine. Other major components are the tower, rectifier, charge controller and dump load, battery bank (if needed), inverter, and metering. Several of these components can be more expensive than the turbine, and all of them need to be considered as you design a complete system.

The bottom line is to buy a turbine that is robust, simple, low speed, and reliable. Talk with experienced wind-energy users to find out which turbines stand the test of time. Heavier wind turbines with larger swept areas are usually more expensive, but more durable.

Focus on the energy the turbine makes, not its peak power. The energy will depend on the swept area and the average wind speed at the tower top. A small rotor on a short tower will not generate much energy. Remember that low and medium wind speeds are the most frequent, and therefore the most important. Do it right and you can share our glee in wind energy.

Access

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Major U.S. Turbine Manufacturers/Importers:
Abundant Renewable Energy • 503-538-8298 • www.abundantre.com

Bergey WindPower Co. • 405-364-4212 • www.bergey.com

DC Power Systems • 800-967-6917 • www.dcpower-systems.com

Pine Ridge Products LLC • 406-738-4283 • www.pineridgeproducts.com

Southwest Windpower • 866-807-9463 • www.windenergy.com

Wind Turbine Industries Corp. • 952-447-6064 • www.windturbine.net

Additional Reading:
"Apples & Oranges: Choosing a Home-Sized Wind Generator," by Mick Sagrillo in *HP90*

"Wind Generator Tower Basics," by Ian Woofenden in *HP105*

"Wind-Electric Systems, Simplified," by Ian Woofenden in *HP110*

Wind Power: Renewable Energy for Home, Farm, and Business, by Paul Gipe, 2004, Paperback, 496 pages, ISBN 1-931498-14-1, $50 from Chelsea Green Publishing Co. • 800-639-4099 or 802-295-6300 • www.chelseagreen.com