How a Wind Turbine Works

Course No: R01-011
Credit: 1 PDH

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This course was adapted from the Department of Energy website, Office of Energy Efficiency and Renewable Energy: https://www.energy.gov/eere/wind/how-wind-turbine-works-text-version.

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Wind Turbine Basics, Features, and Components

How a Wind Turbine Works?

Wind turbines work on a simple principle: instead of using electricity to make wind—like a fan—wind turbines use wind to make electricity. Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity.

Wind is a form of solar energy caused by a combination of three concurrent events:

1. The sun unevenly heating the atmosphere
2. Irregularities of the earth's surface
3. The rotation of the earth.

Wind flow patterns and speeds vary greatly across the United States and are modified by bodies of water, vegetation, and differences in terrain. Humans use this wind flow, or motion energy, for many purposes: sailing, flying a kite, and even generating electricity.

The terms "wind energy" and "wind power" both describe the process by which the wind is used to generate mechanical power or electricity. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases.

The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin.

The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity.

How a Wind Plant Works?

Wind power plants produce electricity by having an array of wind turbines in the same location. The placement of a wind power plant is impacted by factors such as wind conditions, the surrounding terrain, access to electric transmission, and other siting considerations. In a utility-scale wind plant, each turbine generates electricity which runs to a substation where it then transfers to the grid where it powers our communities.

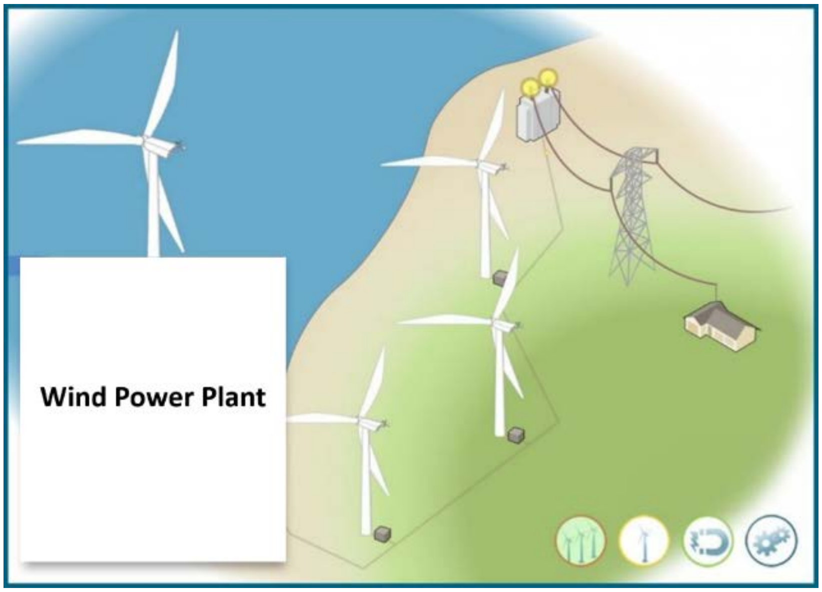

Figure 1. Wind Power Plant

Transmission

Transmission lines carry electricity at high voltages over long distances from wind turbines and other energy generators to areas where that energy is needed.

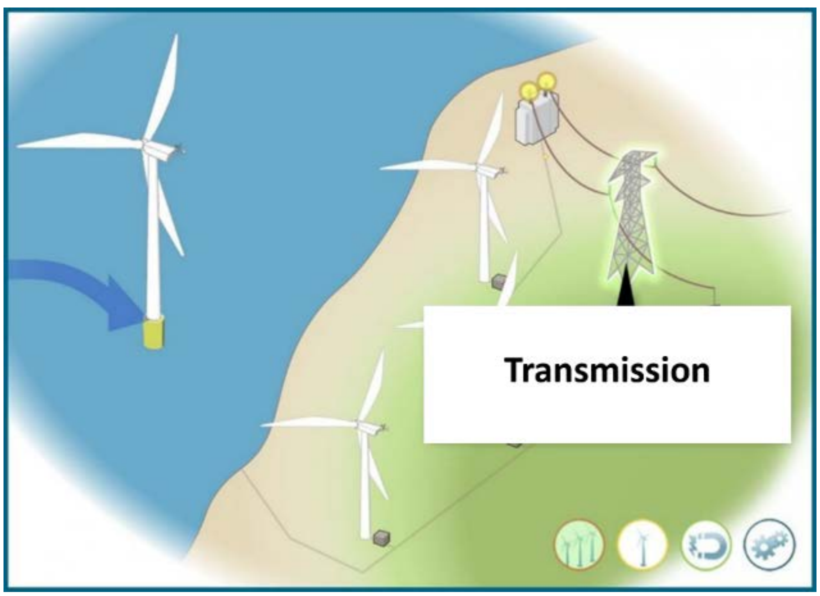

Figure 2. Transmission

Transformers

Transformers receive AC (alternating current) electricity at one voltage and increase or decrease the voltage to deliver the electricity as needed. A wind power plant will use a step-up transformer to increase the voltage (thus reducing the required current), which decreases the power losses that happen when transmitting large amounts of current over long distances with transmission lines.

When electricity reaches a community, transformers reduce the voltage to make it safe and useable by buildings and homes in that community.

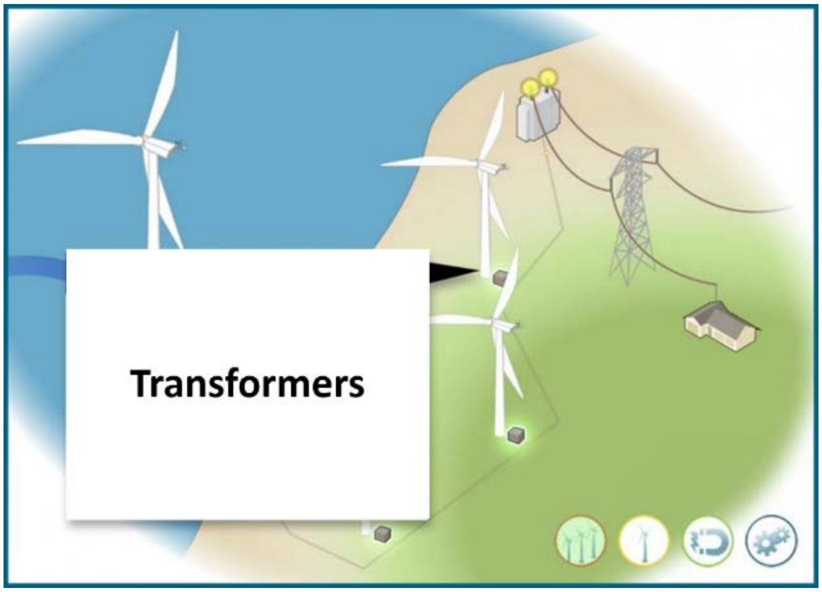

Figure 3. Transformers

Substation

A substation links the transmission system to the distribution system that delivers electricity to the community. Within the substation, transformers convert electricity from high voltages to lower voltages which can then be delivered safely to electricity consumers.

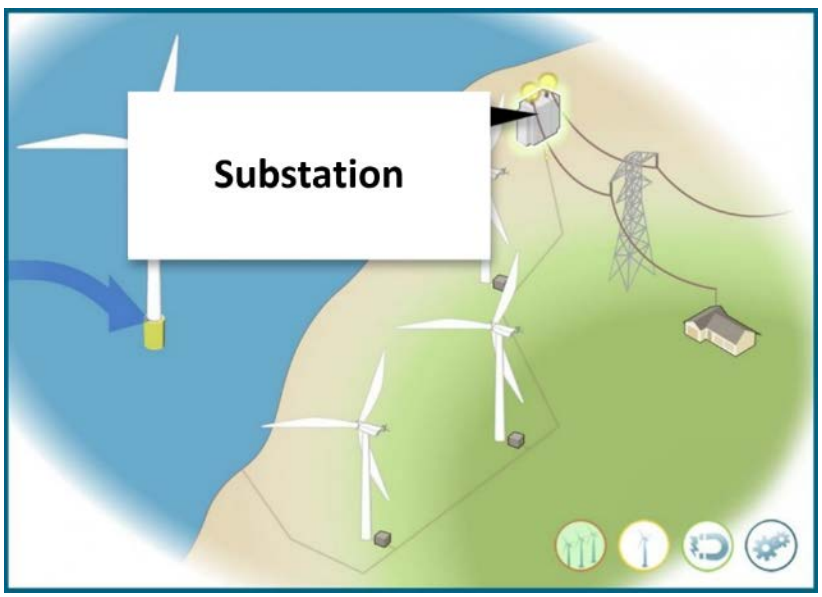

Figure 4. Substation

Wind Turbine Tower

Made from tubular steel, the tower supports the structure of the turbine. Towers usually come in three sections and are assembled on-site. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Winds at elevations of 30 meters (roughly 100 feet) or higher are also less turbulent.

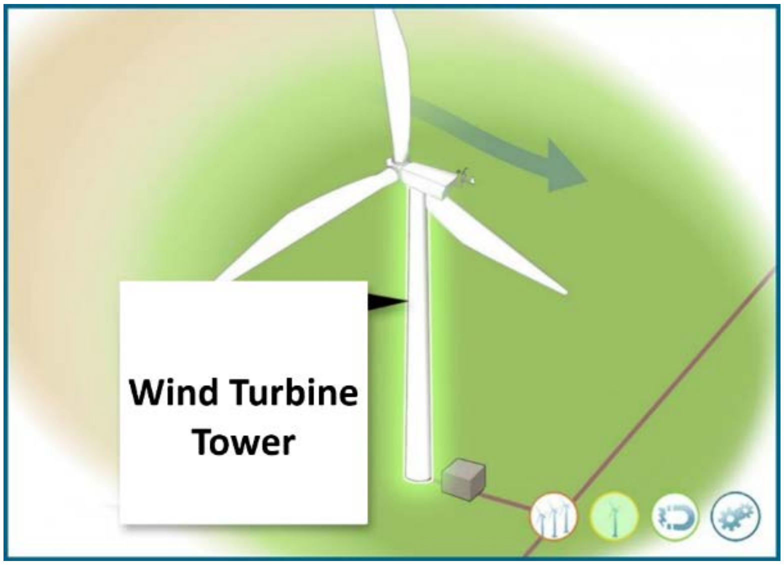

Figure 5. Wind Turbine Tower

Wind Direction

Determines the design of the turbine. Upwind turbines—like the one shown here—face into the wind while downwind turbines face away. Most utility-scale land-based wind turbines are upwind turbines.

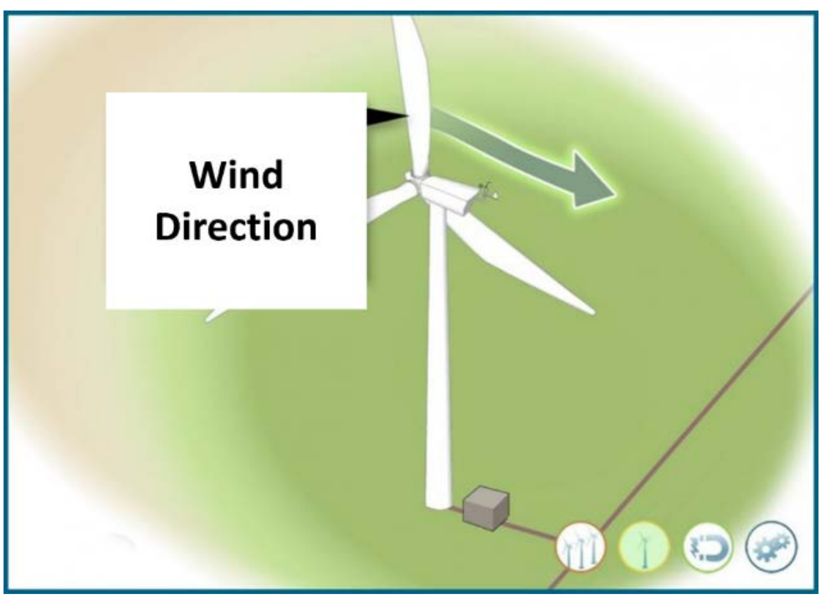

Figure 6. Wind Direction

Wind Vane

The wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

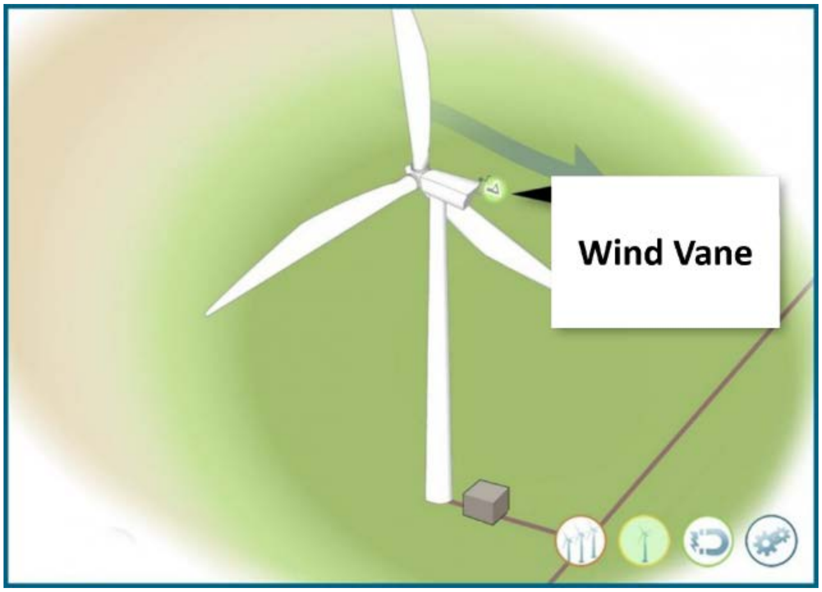

Figure 7. Wind Vane

Anemometer

The anemometer measures wind speed and transmits wind speed data to the controller.

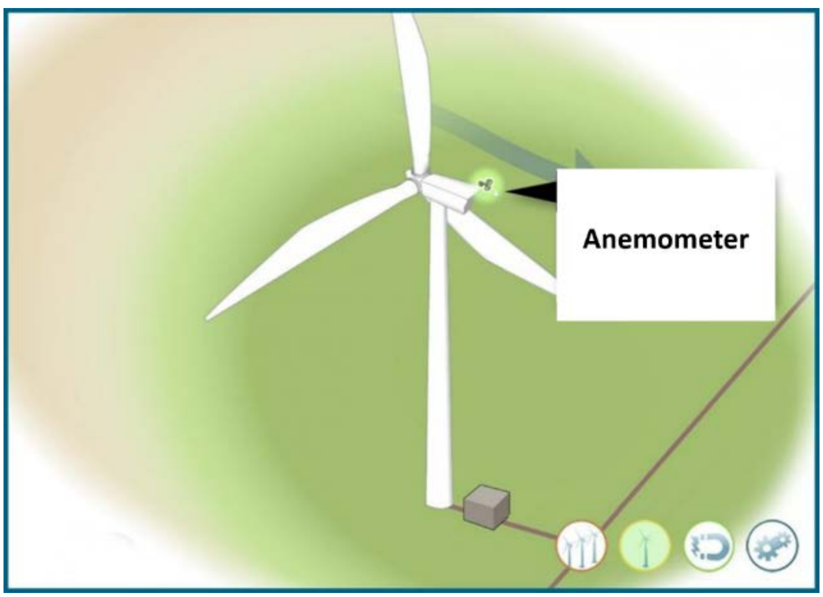

Figure 8. Anemometer

Blades

Most turbines have three blades which are made mostly of fiberglass. Turbine blades vary in size, but a typical modern land-based wind turbine has blades of over 170 feet (52 meters). The largest turbine is GE's Haliade-X offshore wind turbine, with blades 351 feet long (107 meters) – about the same length as a football field. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin.

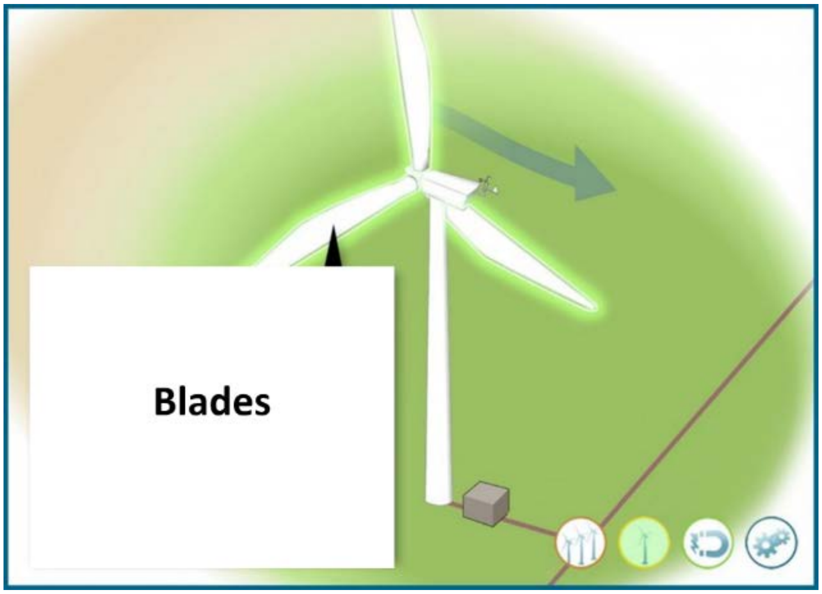

Figure 9. Blades

Land-Based Gearbox Turbine

The drivetrain on a turbine with a gearbox is comprised of the rotor, main bearing, main shaft, gearbox, and generator. The drivetrain converts the low-speed, high-torque rotation of the turbine's rotor (blades and hub assembly) into electrical energy.

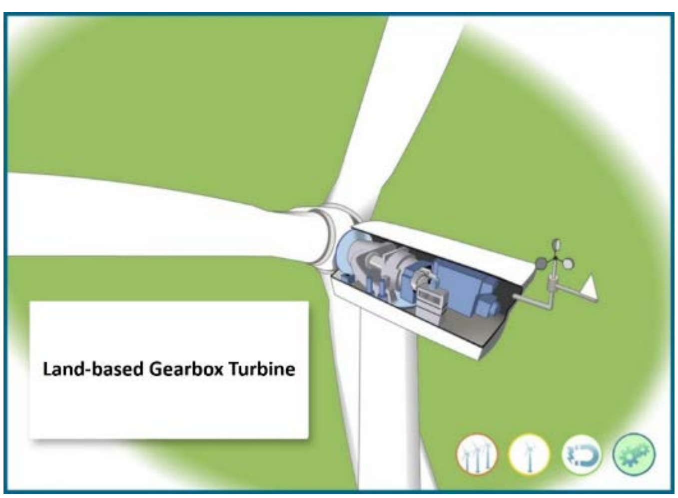

Figure 10. Land-based Gearbox Turbine

Nacelle

The nacelle sits atop the tower and contains the gearbox, low- and high-speed shafts, generator, and brake. Some nacelles are larger than a house and for a 1.5 MW geared turbine, can weigh more than 4.5 tons.

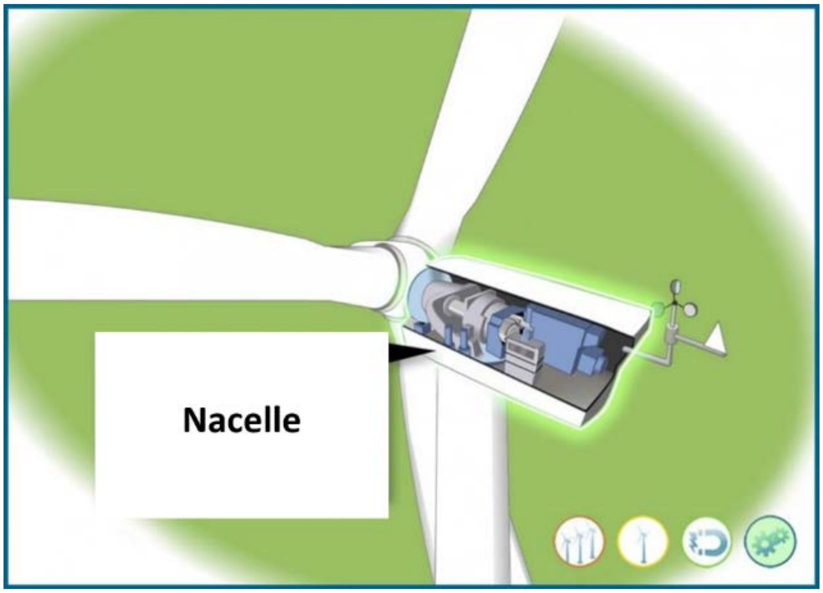

Figure 11. Nacelle

Yaw System

The yaw drive rotates the nacelle on upwind turbines to keep them facing the wind when wind direction changes. The yaw motors power the yaw drive to make this happen. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.

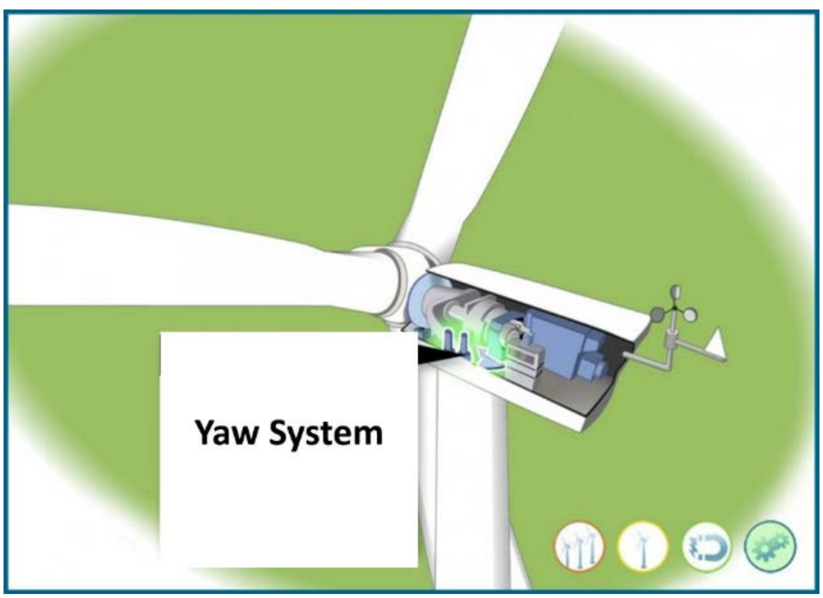

Figure 12. Yaw System

Pitch System

The pitch system adjusts the angle of the wind turbine's blades with respect to the wind, controlling the rotor speed. By adjusting the angle of a turbine's blades, the pitch system controls how much energy the blades can extract. The pitch system can also "feather" the blades, adjusting their angle so they do not produce force that would cause the rotor to spin. Feathering the blades slows the turbine's rotor to prevent damage to the machine when wind speeds are too high for safe operation.

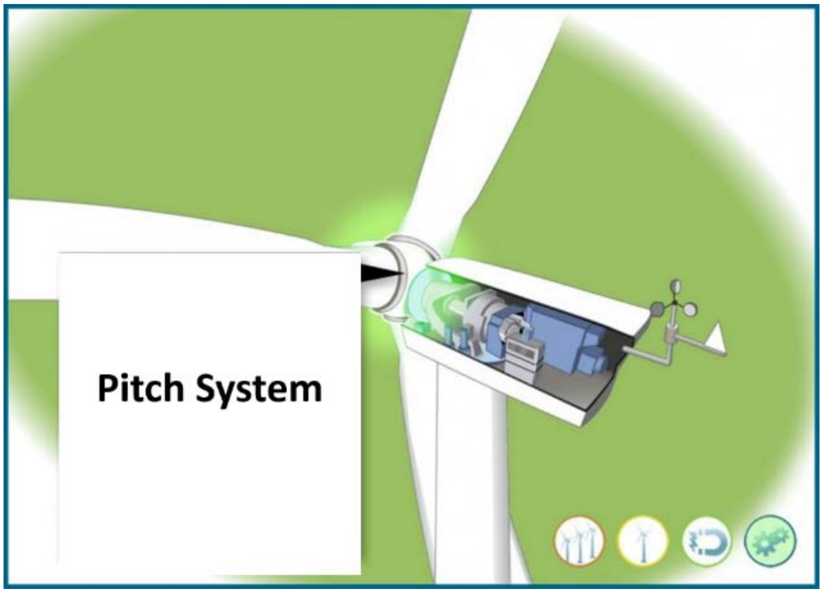

Figure 13. Pitch System

Hub

Part of the turbine's drivetrain, turbine blades fit into the hub that is connected to the turbine's main shaft.

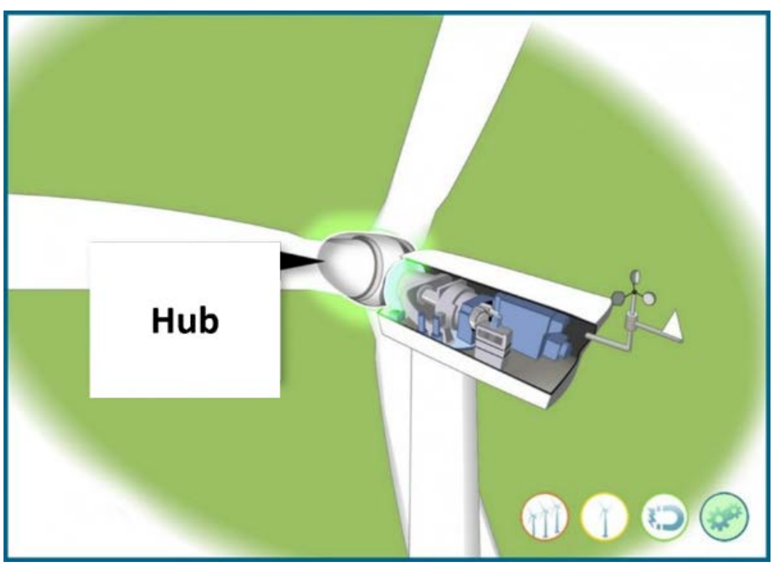

Figure 14. Hub

Gearbox

Part of the turbine's drivetrain, the gearbox connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 8-20 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity.

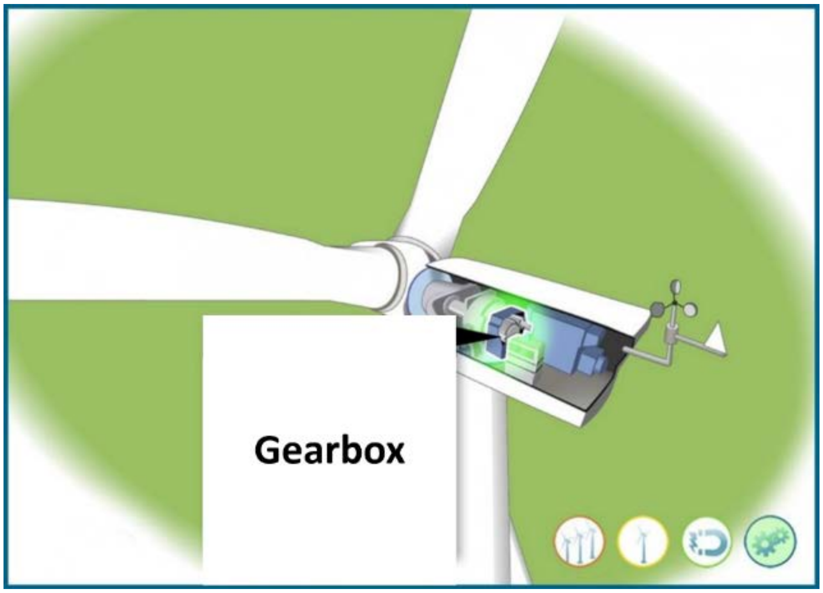

Figure 15. Gearbox

Rotor

The blades and hub together form the turbine's rotor.

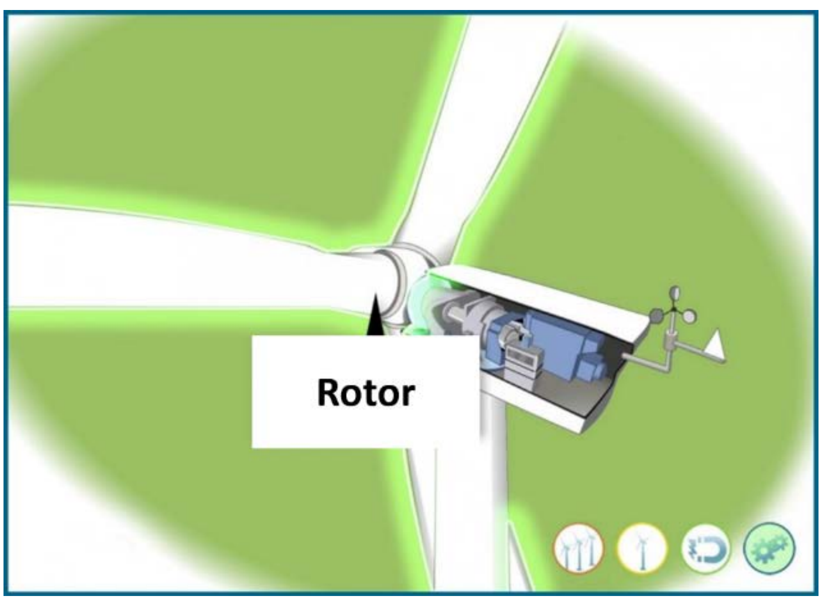

Figure 16. Rotor

Low-Speed Shaft

Part of the turbine's drivetrain, the low-speed shaft is connected to the rotor and spins between 8–20 rotations per minute.

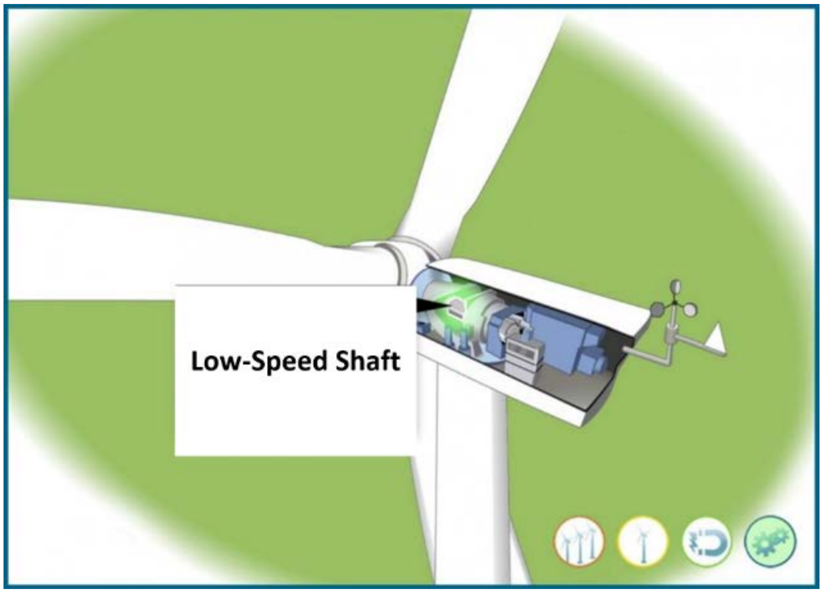

Figure 17. Low-Speed Shaft

Main Shaft Bearing

Part of the turbine's drivetrain, the main bearing supports the rotating low-speed shaft and reduces friction between moving parts so that the forces from the rotor don't damage the shaft.

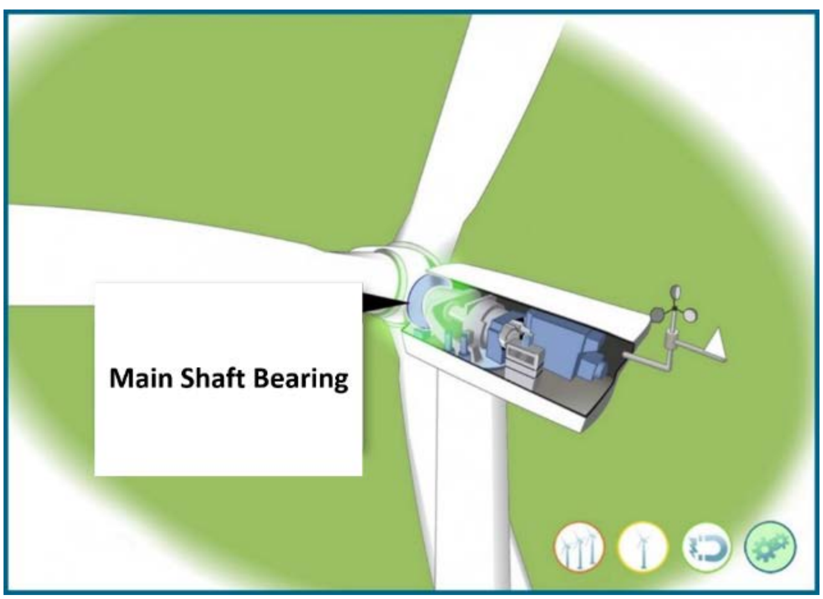

Figure 18. Main Shaft Bearing

High-Speed Shaft

Part of the turbine's drivetrain, the high-speed shaft connects to the gearbox and drives the generator.

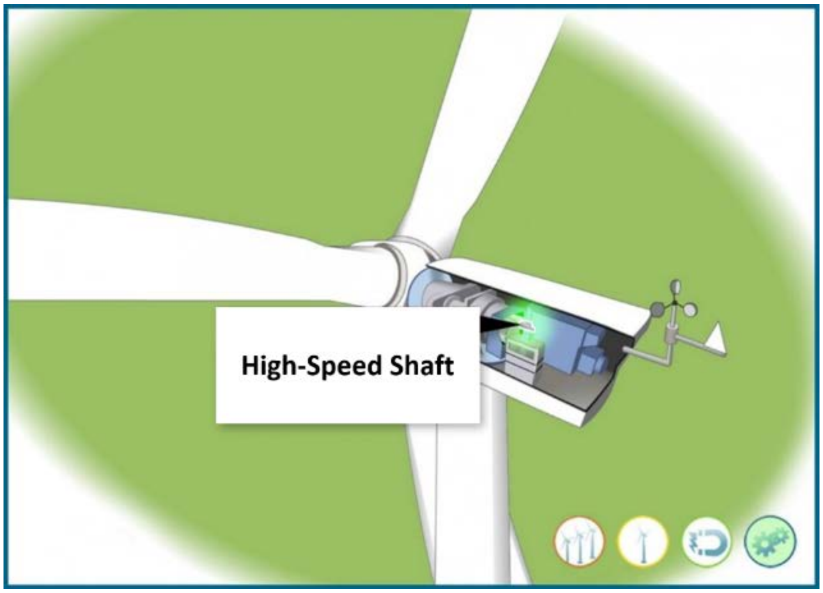

Figure 19. High-Speed Shaft

Generator

The generator is driven by the high-speed shaft. Copper windings turn through a magnetic field in the generator to produce electricity. Some generators are driven by gearboxes (shown here) and others are direct-drives where the rotor attaches directly to the generator.

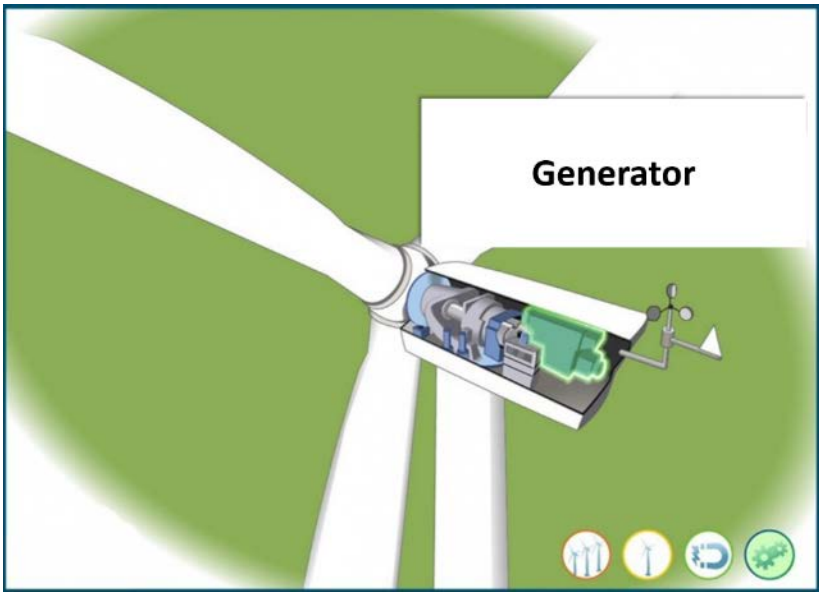

Figure 20. Generator

Controller

The controller allows the machine to start at wind speeds of about 7–11 miles per hour (mph) and shuts off the machine when wind speeds exceed 55–65 mph. The controller turns off the turbine at higher wind speeds to avoid damage to different parts of the turbine. Think of the controller as the nervous system of the turbine.

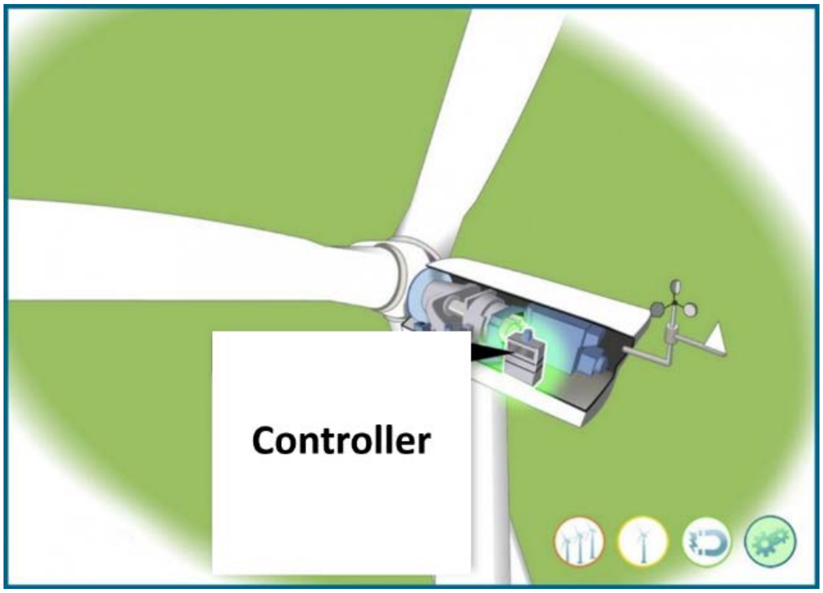

Figure 21. Controller

Brake

Turbine brakes are not like brakes in a car. A turbine brake keeps the rotor from turning after it's been shut down by the pitch system. Once the turbine blades are stopped by the controller, the brake keeps the turbine blades from moving, which is necessary for maintenance.

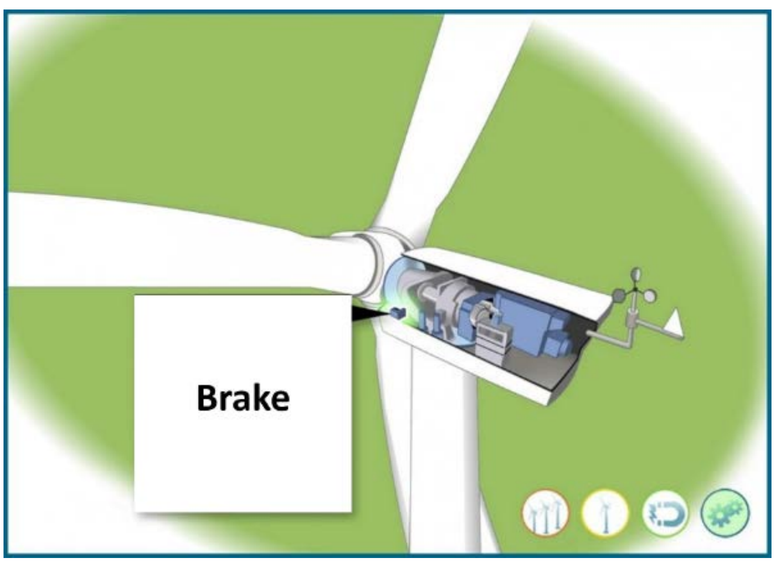

Figure 22. Brake

Direct-Drive Offshore Wind Turbine

Direct-drive turbines simplify nacelle systems and can increase efficiency and reliability by avoiding gearbox issues. They work by connecting the rotor directly to the generator to generate electricity.

Figure 23. Direct-Drive Offshore Wind Turbine

Direct-Drive Offshore Wind Vane and Anemometer

The wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind. The anemometer measures wind speed and transmits wind speed data to the controller.

Figure 24. Direct-Drive Offshore Wind Vane and Anemometer

Direct-Drive Yaw System

The yaw motors power the yaw drive, which rotates the nacelle on upwind turbines to keep them facing the wind when the wind direction changes.

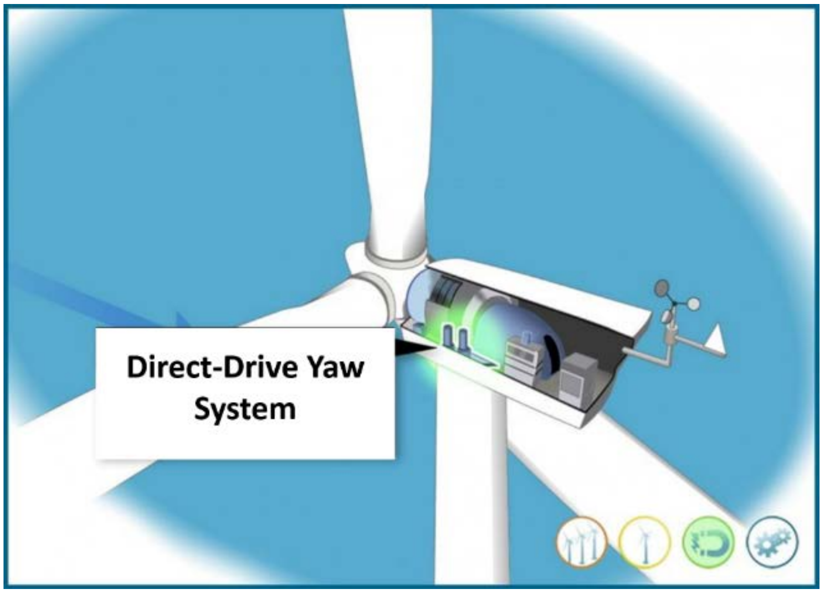

Figure 25. Direct-Drive Yaw System

Direct-Drive Generator Blades

Most turbines have three blades which are made mostly of fiberglass. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. Blades on GE's Haliade X turbine are 351 feet long (107 meters) – about the same length as a football field!

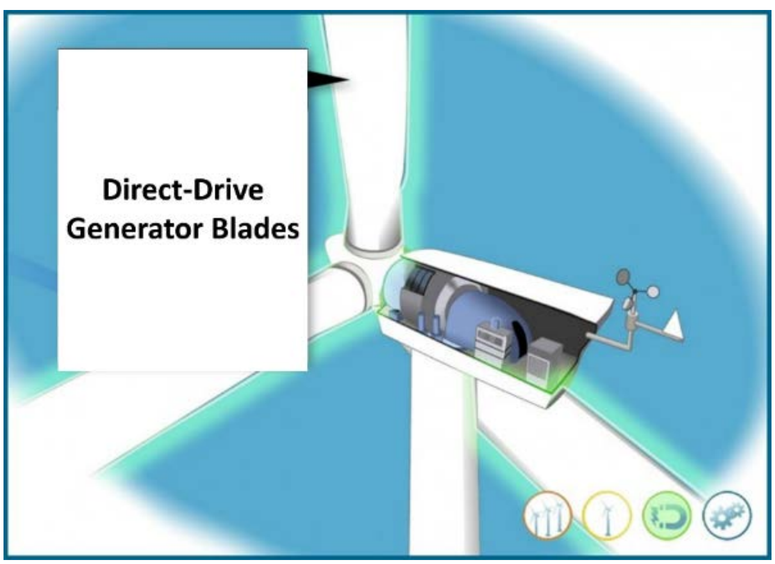

Figure 26. Direct-Drive Generator Blades

Direct-Drive Pitch System

The pitch system adjusts the angle of the wind turbine's blades with respect to the wind, controlling the rotor speed. By adjusting the angle of a turbine's blades, the pitch system controls how much energy the blades can extract. The pitch system can also "feather" the blades, adjusting their angle so they do not produce force that would cause the rotor to spin. Feathering the blades slows the turbine’s rotor to prevent damage to the machine when wind speeds are too high for safe operation.

Figure 27. Direct-Drive Pitch System

Direct-Drive Hub

Turbine blades fit into the hub that is connected to the turbine's generator.

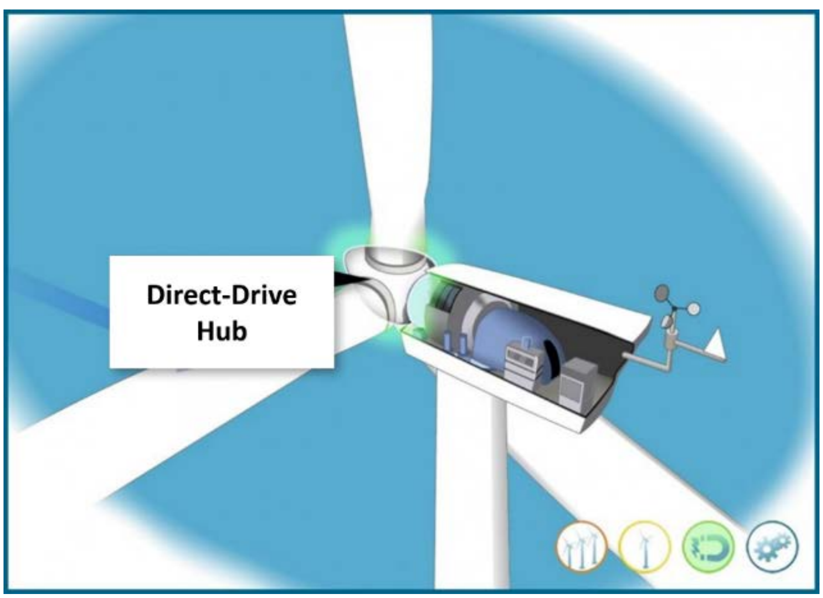

Figure 28. Direct-Drive Hub

Direct-Drive Rotor

The blades and hub together form the turbine's rotor.

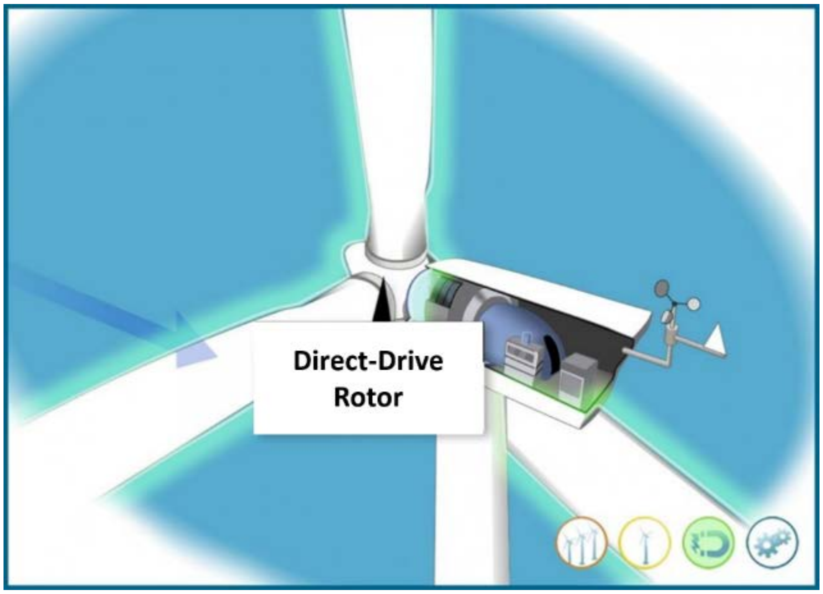

Figure 29. Direct-Drive Rotor

Direct-Drive Generator

Direct-drive generators don't rely on a gearbox to generate electricity. They generate power using a giant ring of permanent magnets that spin with the rotor to produce electric current as they pass through stationary copper coils. The large diameter of the ring allows the generator to create a lot of power when turning at the same speed as the blades (8–20 rotations per minute), so it doesn't need a gearbox to speed it up to the thousands of rotations per minute other generators require.

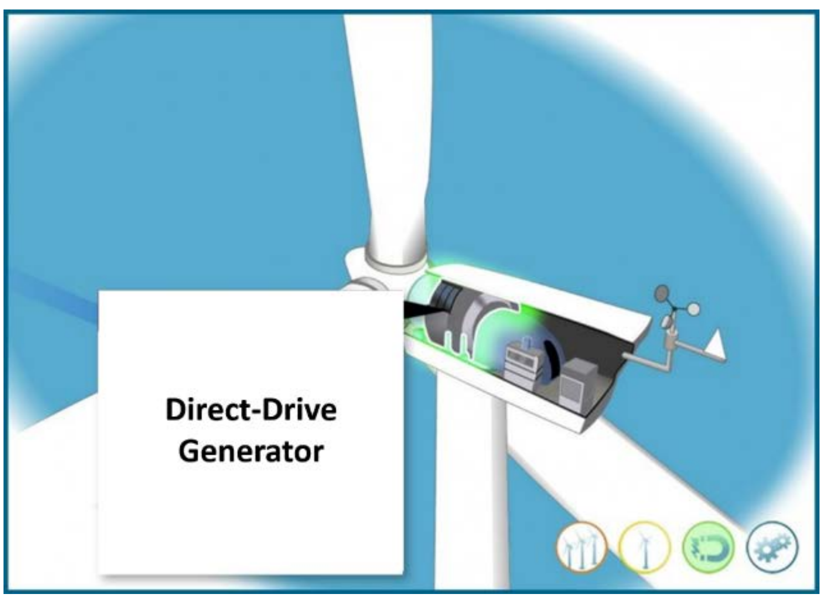

Figure 30. Direct-Drive Generator

Direct-Drive Controller

The controller allows the machine to start at wind speeds of about 7–11 miles per hour (mph) and shuts off the machine when wind speeds exceed 55–65 mph. The controller turns off the turbine at higher wind speeds to avoid damage to different parts of the turbine. Think of the controller as the nervous system of the turbine.

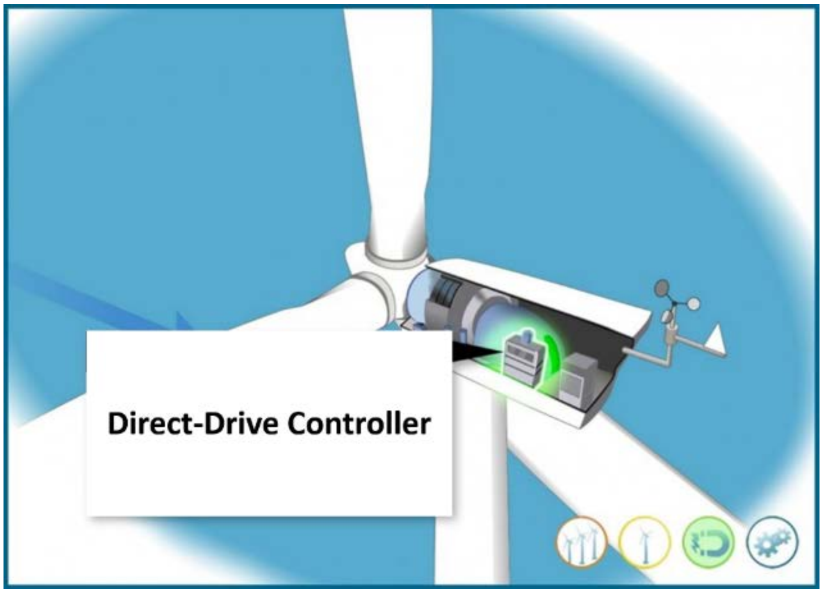

Figure 31. Direct-Drive Controller

Direct-Drive Brake

Turbine brakes are not like brakes in a car. A turbine brake keeps the rotor from turning after it's been shut down by the pitch system. Once the turbine blades are stopped by the controller, the brake keeps the turbine blades from moving, which is necessary for maintenance.

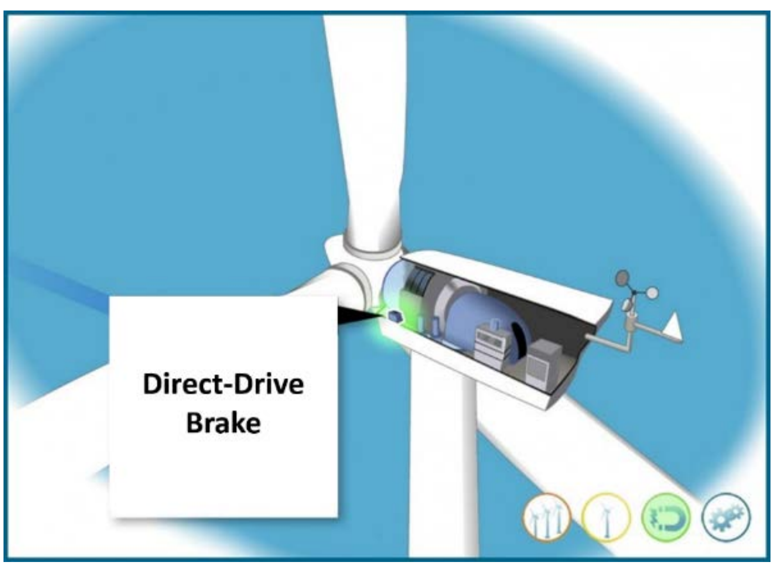

Figure 32. Direct-Drive Brake

Direct-Drive Rotor Bearing

The rotor bearing supports the main shaft and reduces friction between moving parts so that the forces from the rotor don't damage the shaft.

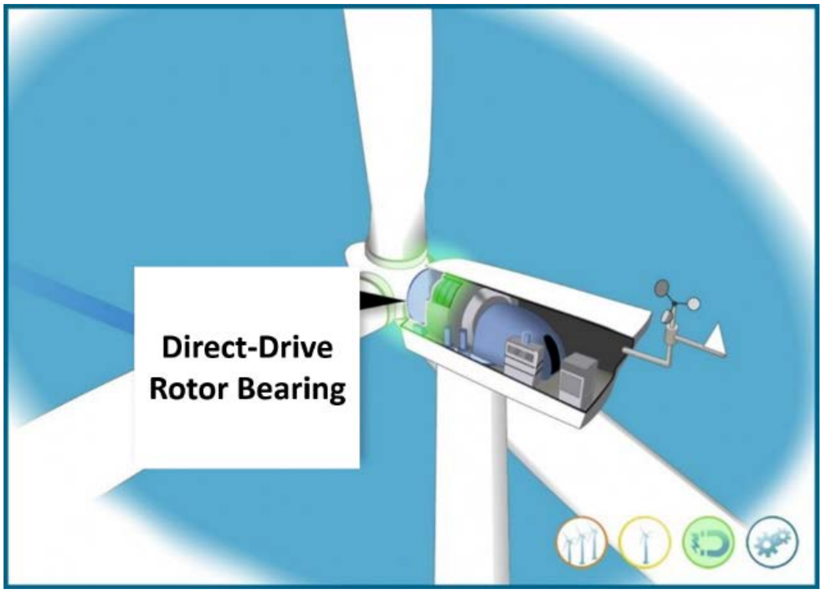

Figure 33. Direct-Drive Rotor Bearing

Types and Applications of Wind Turbines

Types of Wind Turbines

The majority of wind turbines fall into two basic types:

Horizontal-Axis Turbines

Horizontal-axis wind turbines are what many people picture when thinking of wind turbines. Most commonly, they have three blades and operate "upwind," with the turbine pivoting at the top of the tower so the blades face into the wind.

Figure 34. Horizontal-Axis Turbines
Source: Dennis Schroeder | NREL 25897

Vertical-Axis Turbines

Vertical-axis wind turbines come in several varieties, including the eggbeater-style Darrieus model, named after its French inventor. These turbines are omnidirectional, meaning they don't need to be adjusted to point into the wind to operate.

Wind turbines can be built on land or offshore in large bodies of water like oceans and lakes. The U.S. Department of Energy is currently funding projects to facilitate offshore wind deployment in U.S. waters.

Figure 35. Vertical-Axis Turbines
Source: Mike Van Bavel | 42795

Applications of Wind Turbines

Modern wind turbines can be categorized by where they are installed and how they are connected to the grid.

Land-Based Wind

Land-based wind turbines range in size from 100 kilowatts to as large as several megawatts. Larger wind turbines are more cost effective and are grouped together into wind plants, which provide bulk power to the electrical grid.

Figure 36. Land-Based Wind Turbines
Source: WINDExchange

Offshore Wind

Offshore wind turbines tend to be massive, and taller than the Statue of Liberty. They do not have the same transportation challenges of land-based wind installations, as the large components can be transported on ships instead of on roads. These turbines are able to capture powerful ocean winds and generate vast amounts of energy.

Figure 37. Offshore Wind Turbines
Source: Dennis Schroeder | NREL 40484

Distributed Wind

When wind turbines of any size are installed on the "customer" side of the electric meter, or are installed at or near the place where the energy they produce will be used, they're called “distributed wind”. Many turbines used in distributed applications are small wind turbines. Single small wind turbines—below 100 kilowatts—are typically used for residential, agricultural, and small commercial and industrial applications.

Small turbines can be used in hybrid energy systems with other distributed energy resources, such as microgrids powered by diesel generators, batteries, and photovoltaics. These systems are called hybrid wind systems (explained below) and are typically used in remote, off-grid locations (where a connection to the utility grid is not available) and are becoming more common in grid-connected applications for resiliency.

Figure 38. Distributed Wind

Hybrid Wind and Solar Electric Systems

According to many renewable energy experts, a small "hybrid" electric system that combines home wind electric and home solar electric (photovoltaic or PV) technologies offers several advantages over either single system.

In much of the United States, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. Because the peak operating times for wind and solar systems occur at different times of the day and year, hybrid systems are more likely to produce power when you need it.

Many hybrid systems are stand-alone systems, which operate "off-grid" -- that is, not connected to an electricity distribution system. For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional fuels, such as diesel. If the batteries run low, the engine generator can provide power and recharge the batteries.

Adding an engine generator makes the system more complex, but modern electronic controllers can operate these systems automatically. An engine generator can also reduce the size of the other components needed for the system. Keep in mind that the storage capacity must be large enough to supply electrical needs during non-charging periods. Battery banks are typically sized to supply the electric load for one to three days.

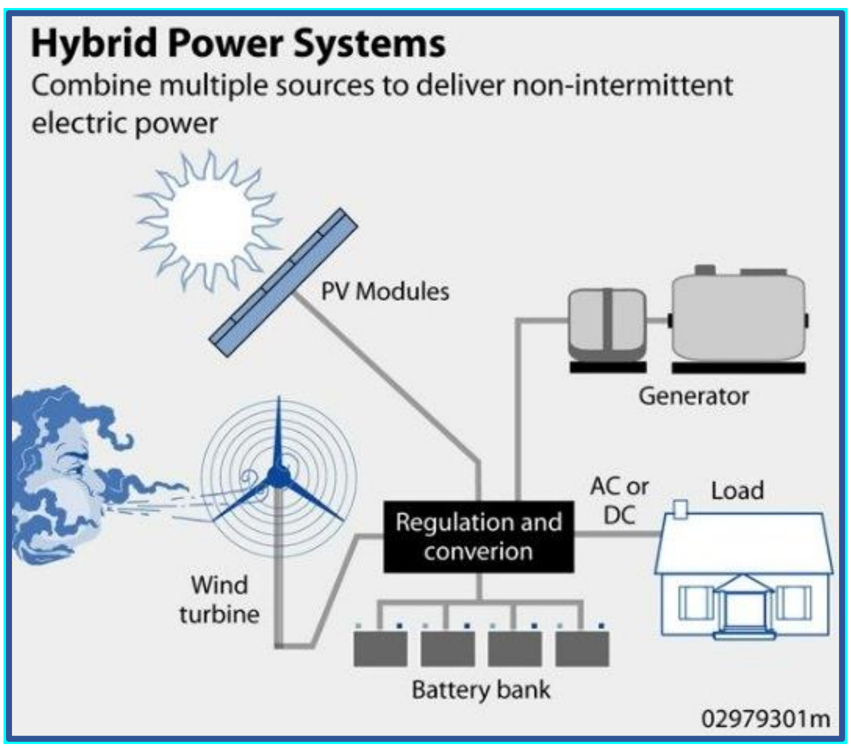

Figure 39. Hybrid Power Systems

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