Understanding Wind Energy

Understanding the basics of wind energy technology, equipment, and terminology.

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

Section Contents

Overview

In the United States, most wind energy is commercially generated for delivery and sale on the grid. Wind projects vary in size, configuration, and generating capacity depending on factors such as the wind resource, project area, land-use restrictions, and turbine size.

While wind turbines are most commonly deployed in large groups, they may also be installed as a single turbine or with just a few others connected directly to a distribution line. Common examples include installing one large turbine to offset electric purchases at a school, municipal building, or manufacturing facility.

Because wind is a variable resource with changing speeds, power production levels can vary. The energy output of a facility can be measured over time; however, expected yearly electricity production can be estimated. While turbines generate power, all other components of a wind plant aid in the transfer of that power to the grid.

1. Wind Turbine Technology

The major visible components of a utility-scale wind turbine are a rotor, nacelle, and tower; these and other components are illustrated in Figure 2-1.

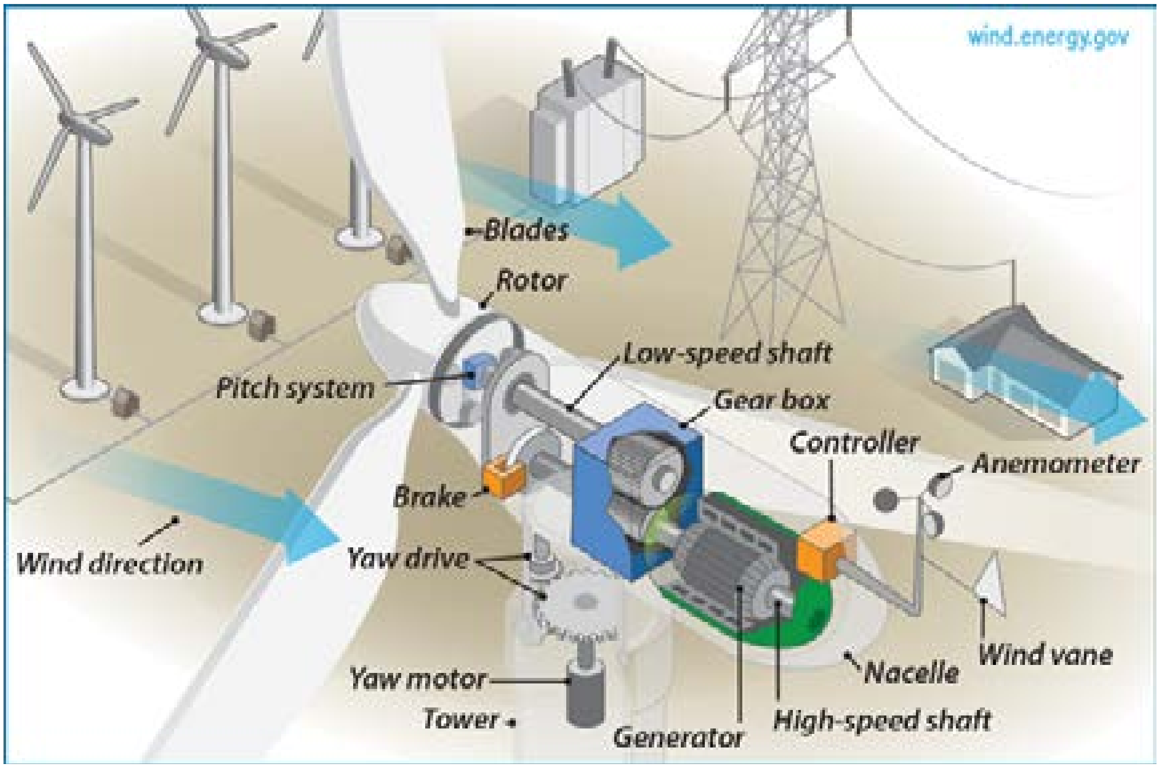
The **rotor** consists of blades (usually three, though some turbines feature two) and a hub (the mechanical link between the blades and the low-speed shaft). The turbine blades capture the kinetic energy from the wind and convert it into torque that is transmitted to the gearbox through a rotational shaft. A yawing mechanism allows the turbine to rotate on its vertical axis to orient the rotor into the direction of the wind, maximizing energy capture.

The **nacelle** houses major components, including a gearbox and generator. A low-speed shaft connecting the rotor to the gearbox and a high-speed shaft connecting the gearbox to the generator make up the turbine's drive train. Using a series of gears, the gearbox converts the low-speed, high-torque input from the rotation of the blades to a high-speed, low-torque rotational force that's transmitted to the generator. A transformer increases the voltage from the generator voltage level to the on-site collection-system voltage.

The rotor and nacelle sit atop a steel or concrete **tower** that is typically around 80 m to 110 m (262 ft. to 360 ft.) tall.

Distinct from the tower height, the vertical distance from the ground to the centerline of the rotor is often referred to as the turbine's **hub height**.

Figure 2-1. Major Turbine Components
(Source: www.wind.energy.gov)



2. Energy Production

2.1 Nameplate Capacity

The **nameplate capacity** (or rated capacity) of a wind turbine is the amount of energy the turbine would produce if it ran 100% of the time at optimal wind speeds. Wind turbines range in nameplate capacity from less than 1 MW to more than 4 MW.

2.2 Capacity Factor

To compare output across different generating facilities, **capacity factor** is used as a measure of the actual energy produced over a specified period of time, divided by the nameplate capacity. In other words, while wind turbines typically generate electricity during most hours of the day, they produce a varying percentage of the nameplate capacity in any given hour. Capacity factor represents the average generation over time. Capacity factors of wind plants may vary from 20% to 50% depending on the turbine type, location, and wind regime (see Power Curve).

Capacity factor can also be used to estimate the expected electricity production of a wind project, by multiplying nameplate capacity times 8,760 (the number of hours in a year) times capacity factor. For example:

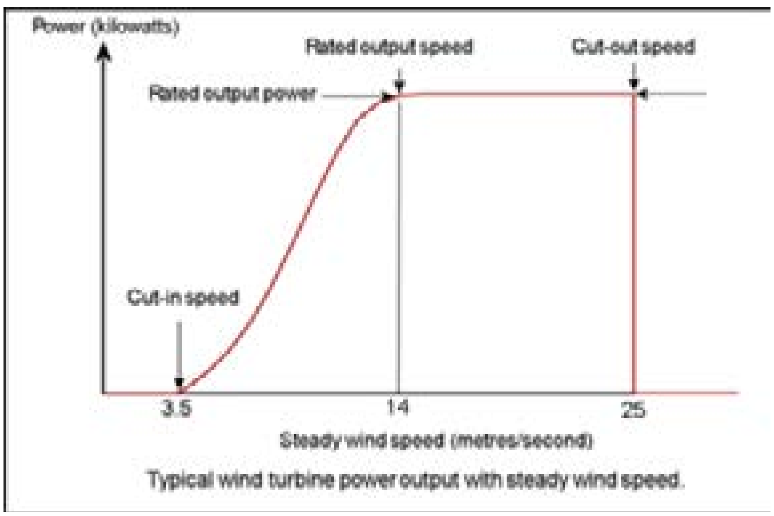
100 MW nameplate capacity x 8,760 hours x 35% capacity factor = 306,600 MWh expected annual generation.

2.3 Power Curve

Power production from a wind turbine is a function of wind speed. The relationship between wind speed and power is defined by a **power curve**, which is unique to each turbine model, and in some cases, unique to site-specific settings. Figure 2-2 illustrates a typical wind turbine power curve. Wind speeds are listed on the horizontal axis, in mph or meters per second (m/s). The turbine's power output is along the vertical axis in kilowatts (kW).

The cut-in speed, at the lower end of the curve, is the threshold that the hub-height wind speed must reach for the turbine to begin generating electricity. In general, wind turbines begin to produce power at wind speeds of about 6.7 mph (3 m/s). A turbine will achieve its nominal, or rated, power at approximately 26 mph to 30 mph (12 m/s to13 m/s); this value is often used to describe the turbine's generating capacity (or nameplate capacity). The turbine will reach its cut-out speed at approximately 55 mph (25 m/s). When wind speeds exceed this, the turbine will stop power production to protect itself from potentially damaging speeds. Variability in the wind resource results in the turbine operating at changing power levels. At good wind energy sites, this variability results in the turbine operating at approximately 35% to 40% of its total possible capacity over a year.

Figure 2-2. Relationship of Wind Speed to Power Production
(Source: U.S. Department of Energy)



2.4 Trends in Nameplate Capacity and Hub Height

Over time, increasingly taller towers and longer blade lengths have helped wind turbines achieve economies of scale and higher capacity factors. Most new projects in the U.S. use turbines with a nameplate capacity between 2 MW and 3.6 MW—more than twice the average turbine capacity in 2000. At the same time, rotor diameters have nearly doubled, averaging close to 100 m. Hub heights have increased as well, ranging between 80 m and 110 m today versus 50 m to 70 m in 2000. The use of taller towers is driven by two factors: the accommodation of larger rotors, and the desire to tap stronger winds. In general, every 10 m increase in tower height means capturing winds that are 2% - 3% faster, yielding more energy. Wind manufacturers are developing even larger turbines, although their use in the Northeast may be limited by logistical and transportation challenges.[1]

3 Wind Project Layout

To achieve optimum exposure to the prevailing winds, while taking into account terrain variations, turbines are placed in groups or rows. Inter-turbine spacing (the space between the turbines) is chosen to maximize production while minimizing exposure to damaging rotor turbulence. Inter-turbine and inter-row spacing vary depending on the rotor diameter and the wind resource characteristics. Factors, such as cost and constructability, must be considered when designing the layout of a wind project. Wide spacing between wind turbines generally maximizes energy production but increases infrastructure costs (e.g., land, transmission, and road building). There is a trade-off between optimizing the turbine location for energy production (through wider spacing) and maintaining reasonable turbine interconnection and road costs, which increase with wider spacing. There is an additional tradeoff between the project's total capacity and the capacity factor. Experience, mathematical analyses, and cost are considered to determine the optimum configuration for the site conditions and proposed equipment.

4 Balance of Plant – Other Necessary Components

Wind turbines generate power, but several other components are needed to get the power from the turbine to the electric grid. These components are often referred to as **balance of plant** and typically address all aspects of the wind plant that are not the turbine itself.

4.1 Foundations

Having a properly constructed foundation is critical to the longevity of a wind plant. Foundations are designed specifically for each project, depending on the load and the type of soil at the site. Most foundations are made of concrete and are spread footing design. If the soil is loose, anchors may be used to further secure the turbine.

4.2 Electrical Power Collection System

Energy produced from turbines is generally collected in a medium-voltage (approximately 25 to 35 kilovolt) system consisting of underground cabling (wiring) and overhead power lines to a main substation. The point of interconnection (POI) with the utility line can be co-located in the substation or it can be physically separated and located adjacent to the utility line. In general, wind energy projects are positioned within 10 miles of a high-voltage transmission line to minimize the costs associated with interconnection. Greater distances may be economically feasible if the wind resource is sufficiently high. With some turbines, a pad-mounted transformer, generally located immediately adjacent to the base of each tower, is used to transform the low-voltage power produced by the turbine to the medium-voltage of the on-site electrical collection system. Some turbine designs incorporate the transformer into the nacelle, rather than placing it at the base of the tower.

4.3 Substation and Interconnection

For most wind energy projects, electrical energy produced by the turbines passes through a substation where it is metered, and the voltage is increased to match the voltage of the utility grid. Plant isolation breakers, power quality monitors, and protective equipment are present in the substation to protect both the electrical grid and the wind turbines. A system of switches and overhead infrastructure is used to connect the substation to the utility's power lines.

4.4 Control and Communications System

In addition to individual turbine control systems, a wind project typically includes a Supervisory Control and Data Acquisition System (SCADA). SCADA systems consist of a central computer with management capabilities for individual turbines and the ability to collect, analyze, and archive time-series data. Communication cables connecting the central computer with the individual turbine controllers are commonly buried in the same trenches as the electrical collection system.

4.5 Access Roads

Access roads to each turbine location are usually crushed rock, and often wider than normal roads. In hilly or complex terrain, access roads are constructed to manufacturer specifications. Specific slopes and turning radii are necessary to allow delivery of large components, such as blades and tower sections. During the construction phase of a project, crane pads (flat, well-graded and compacted areas constructed of crushed rock) are installed along the access road and adjacent to the tower foundations. These serve as a base for specialized construction cranes to lift the tower sections and turbine parts. The crane pads remain in place during operation in the event a crane is required to replace large components that cannot be handled by the service crane in the turbine.

4.6 Operation and Maintenance Facility

Operation and Maintenance facilities for wind power plants generally consist of an office and maintenance shop. These spaces can be located on-site or off-site and may be in separate locations. An office houses plant-management staff, control computers, and communication systems. The maintenance shop is used to store vehicles and spare parts and provides a work space for component repair.

5 Transmission and Interconnection

Energy from generating plants is interconnected to the transmission system and subsequently travels to the distribution system, where it is delivered to end users. The bulk system of transmission lines and distribution lines in North America is referred to as the grid. The grid consists of high-voltage transmission lines that transmit large quantities of power; substations that convert electricity from one voltage to another; lower-voltage distribution lines that serve neighborhoods and individual customers; and safety and control systems to keep the grid operating safely.

Most of the power delivered to the grid comes from large, central power stations, such as coal- and natural gas-burning plants, with capacities of roughly 50 MW to 2,000 MW. The transmission system does not differentiate between electrons generated at a wind power plant and any other type of generating plant.

5.1 Intermittency and the NYISO Balancing Authority

The transmission system is balanced to match production with consumption. When a customer is using electricity, the adequate amount of production must be simultaneously occurring to balance the system. At any time, an instantaneous balance between production and consumption must be met. The New York Independent System Operator (NYISO) acts as the balancing authority for the New York State transmission system.

Wind energy is intermittent in nature, meaning wind power plants only produce power when the wind is blowing. By contrast, fossil-fueled power plants can control how much power they generate by increasing or decreasing how much fuel they burn. Integrating the intermittent nature of wind energy generation into the transmission system requires additional steps that aren’t needed in balancing energy from central power stations, such as coal or natural gas. As with all transmission system operators, NYISO is constantly studying and improving the system to integrate non-dispatchable resources, such as wind energy. NYISO’s requirements for wind energy plant interconnections ensure fair and open access to the transmission system while maintaining system reliability.

Wind energy plants interconnecting to the NYISO system are required to share meteorological data with NYISO to help forecast wind generation. The most accurate forecasting is available from permanently installed meteorological towers that track data at the same height as the operating turbines and from meteorological equipment on each operating turbine.

5.2 Interconnection

Because of the interconnected nature of the grid, proposed new facilities must undergo a series of grid impact studies before obtaining an Interconnection Agreement from NYISO and delivering energy. Improvements or protections to the transmission system may be required for the project to interconnect—usually paid for by the project developer. Proposed generation facilities of 20 MW or smaller are designated small generating facilities by NYISO and go through a streamlined interconnection application process. Regardless of project size, developers must also contact the local utility to complete the New York State Standardized Application for Attachment of Parallel Generation Equipment, and they must also comply with local utility requirements for interconnection.

Additional Resources

- NYISO 2020 Power Trends report: https://www.nyiso.com/documents/20142/2223020/2020-Power-Trends-Report.pdf/dd91ce25-11fe-a14f-52c8-f1a9bd9085c2

Questions?

If you have any questions regarding wind energy, please email questions to cleanenergyhelp@nyserda.ny.gov or request free technical assistance at nyserda.ny.gov/Siting. The NYSERDA team looks forward to partnering with communities across the State to help them meet their clean energy goals.

Section Endnotes

[1] "Supersized Wind Turbine Blade Study: R&D Pathways for Supersized Wind Turbine Blades" Lawrence Berkeley National Laboratory. 2019. https://emp.lbl.gov/publications/supersized-wind-turbine-blade-study