Wind Turbine Technology Overview

An Online Continuing Education Course for Engineers

Course Number: R-1005

Credit: 1 Hour / 1 PDH / 1 CPD

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Introduction

This course explains how onshore wind turbines are designed and used, specifically for utility-sized applications. It discusses wind turbine technology for various applications and reviews turbine components along with their electrical implications. It also identifies the conditions for optimum turbine performance. Offshore turbines are outside the scope of this course.

Turbine Sizes

Wind generation equipment is categorized into three general classifications:

- Utility-Scale – Corresponds to large turbines (900 kW to 2 MW per turbine) intended to generate bulk energy for sale in power markets. They are typically installed in large arrays or 'wind energy projects,' but can also be installed in small quantities on distribution lines, otherwise known as distributed generation. Utility-scale development is the most common form of wind energy development in the U.S. As of 2011 the most powerful turbine was the Enercon E-126. With a hub height of 135 m (443 ft), rotor diameter of 126 m (413 ft) and a total height of 198 m (650 ft), it can generate up to 7.58 megawatts of power per turbine

- Industrial-Scale – Corresponds to medium sized turbines (50 kW to 250 kW) intended for remote grid production, often in conjunction with diesel generation or load-side generation (on the customer's side of the meter) to reduce consumption of higher cost grid power and possibly to even reduce peak loads. Direct sale of energy to the local utility may or may not be allowed under state law or utility regulations.

- Residential-Scale – Corresponds to micro- and small-scale turbines (400 watts to 50 kW) intended for remote power, battery charging, or net metering type generation. The small turbines can be used in conjunction with solar photovoltaics, batteries, and inverters to provide constant power at remote locations where installation of a distribution line is not possible or is more expensive.

The Technology

In North America, all commercially available, utility-scale wind turbines from established turbine manufacturers utilize the 'Danish concept' turbine configuration. This configuration uses a horizontal axis, three-bladed rotor, an upwind orientation, and an active yaw system to keep the rotor oriented into the wind. The drive train consists of a low-speed shaft connecting the rotor to the gearbox, a 2- or 3-stage speed-increasing gearbox, and a high-speed shaft connecting the gearbox to the generator. Generators are typically asynchronous, induction, and operate at 550–690 V (AC). Some turbines are equipped with an additional small generator to improve production in low wind speeds. The second generator can be separate or integrated into the main generator. Each turbine for utility-scale applications is equipped with a transformer to step up the voltage to the on-site collection system voltage. The on-site collection system typically is operated at medium voltages of 25 to 35 kV. Figure 1 shows the major turbine components for a wind turbine.

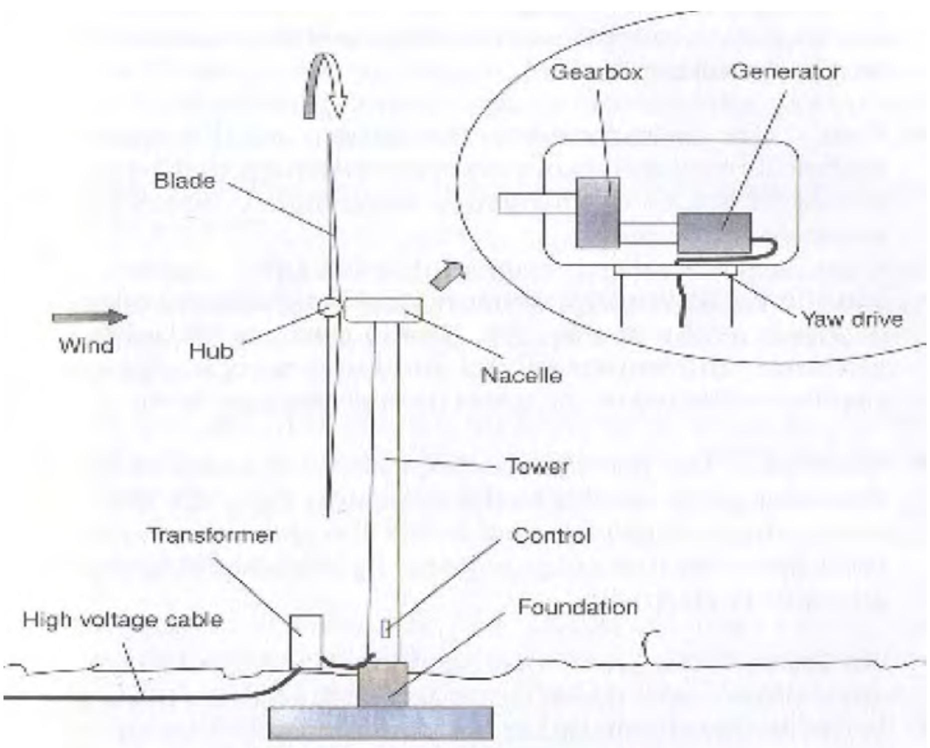

Figure 1. Major Turbine Components

As shown in Figure 2, 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. In general, most wind turbines begin to produce power at wind speeds of about 4 m/s (9 mph), achieve rated power at approximately 13 m/s (29 mph), and stop power production at 25 m/s (56 mph). Variability in the wind resource results in the turbine operating at continually changing power levels. At good wind energy sites, this variability results in the turbine operating at approximately 35% of its total possible capacity when averaged over a year.

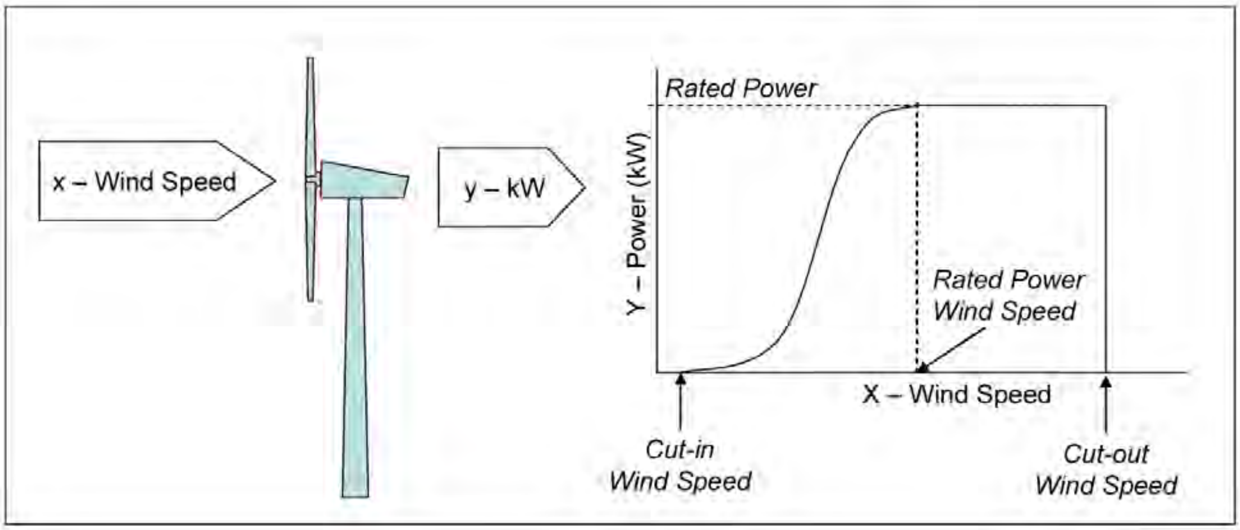

Figure 2. Relationship of Wind Speed to Power Production

Ratings and Rotor Size

The rotor diameters and rated capacities of wind turbines have continually increased in the past two decades, driven by technology improvements, refined design tools, and the need to improve energy capture and reduce the cost of energy. For comparison, the average turbine rating for turbines installed in the U.S. in 2001 was 908 kW, while turbines installed in 2005 had an average capacity of 1.5 MW to 1.8 MW. In 2009-2010, turbines with rated capacities of 1.75 MW or 1.77 MW presented the clear majority of the turbines sizes installed in North America. Figure 3 compares the height of a large wind turbine with other tall structures.

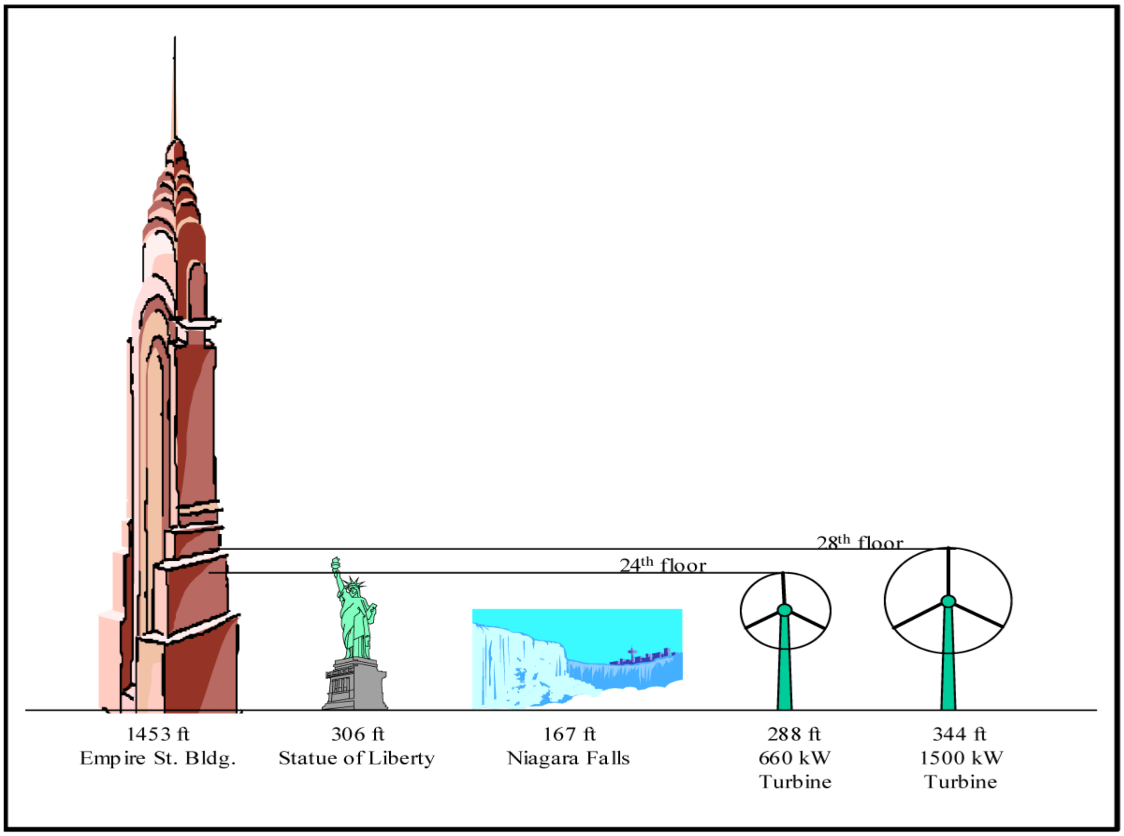

Figure 3. Large Wind Turbine Height Comparisons

Hub and Maximum Tip Heights

As the rotor diameters and rated capacities have increased, so has the hub height of the wind turbines. There is no standard hub height or ratio of hub height to rotor diameter. Wind resource characteristics, terrain, turbine size, availability of cranes, and visual impacts are a few critical items that are used to determine the most optimum hub height for a given project. But current wind turbines are typically 80 m (263 ft) at the hub height. The blades add another 30 m (100 ft), for a total approximate height of 363 ft.

Maximum tip heights (the highest point of the rotor) depend on the hub height and rotor diameter. One of the tallest wind turbines in the U.S., the Vestas V90-3MW, utilizes a 90-m (295-ft) rotor diameter with hub heights from 65 m to 105m (213ft to 344ft) and a potential maximum tip height of 125 m (410 ft). Figure 4 identifies these key physical features of a wind turbine.

Optimum turbine size is heavily dependent on site-specific conditions. In general, turbine hub heights are approximately 1 to 1.4 times the rotor diameter. Project analysis conducted to identify the optimum turbine equipment typically results in a compromise between rotor size, hub height, energy production, component handling logistics, and cost.

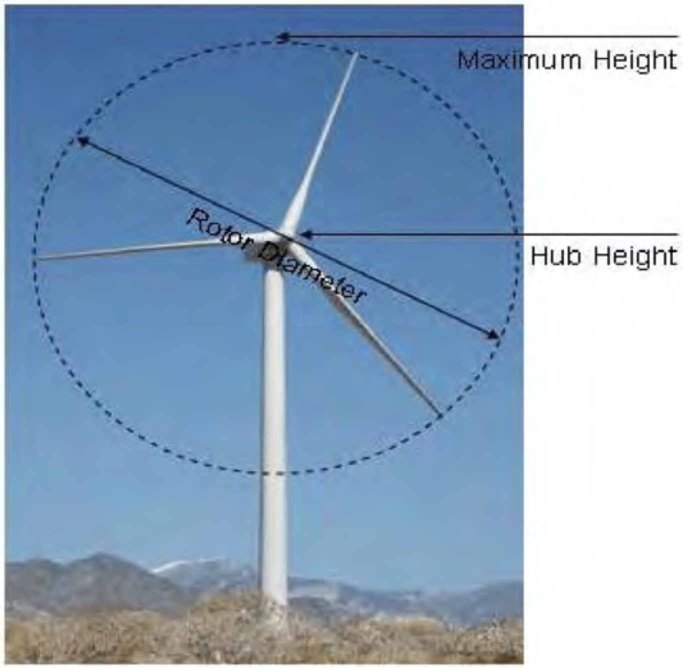

Figure 4. Wind Turbine Features

Specific Rating

The ratio of a turbine's rotor swept area to the rating of the turbine is known as the specific rating. No 'best' relationship between rotor diameter and generator rating exists. Designers of modern turbines appear to have settled on a range of specific ratings from 0.32 to 0.47 kW/m^2, as this range presents the best compromise between energy capture, component loading, and costs. Turbines at sites with lower wind speeds (such as 7.0 to 7.5 m/s annual average at hub height) tend to have larger rotors and lower specific ratings to improve energy capture.

Turbines at high-wind-speed sites (exceeding 9 m/s) tend to have smaller rotors and higher specific ratings. The smaller rotor helps to reduce loads on components and thus improves reliability in these aggressive wind sites. As the speed increases above the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the *cut-out speed* and is usually around 25 m/s.

Control Scheme

The control scheme employed to operate the turbine to produce grid-quality electricity varies among turbine manufacturers. No one control scheme is the 'best.' Each has advantages and disadvantages; however, they all successfully deliver energy into utility grids. Variable-speed turbines produce energy at slightly higher efficiencies over a wider operational range of wind speeds than constant-speed turbines. The power electronics necessary in variable-speed turbines to produce grid-quality electricity consume slightly more energy than capacitors used to condition the power from constant-speed turbines. Variable-speed turbines also provide the ability for the turbine to supply reactive power to the grid ... nically control the reactive
power supply (power factor) to the ... geous to the operation of the
transmission system pa... on system where voltage
control can be difficult ... . Typically, reactive power
and its effects are mana... nks and special reactive
power supply equipment ... ce or consume reactive
power with either a static ... equipment on the
transmission system. Tur... logy provide close to
unity power factor by usi... me cases, at the project
substation. The effect of c... e consumption of
reactive power. This react... ssion system resources.
Transmission system opera... ely located wind energy
projects to assist in providi...

Fixed-pitch turbines genera... ex than variable- pitch
turbines, resulting in lower ... turbines can optimize blade pitch
and adjust it for changes in ... contamination. For these and other reasons, the energy output from variable-pitch turbines is somewhat higher than fixed-pitch turbines, thus offsetting the higher system costs. In locations with large variations in temperature, and thus air density, fixed-pitch turbines can experience difficulties with excessive power production during periods of high air density if the blades are pitched in a manner that optimizes production throughout the year. The specific wind and climate characteristics at a given site ultimately determine which type of control scheme generates energy most cost effectively.

Small Turbines

A small wind turbine is a wind turbine used for microgeneration. Most small turbines are much less sophisticated than industrial-scale and utility-scale turbines.

Figure 5 presents a comparison of small wind turbines with common structures.