1

History of the Wind Energy Development

Wind has been a source of energy all along history. The ancient Egyptians discovered the power of wind, which led to the invention of sailboats around 5000 BC. Although no one knows exactly who invented the first windmill, archaeologists discovered a Chinese vase dating back to the third millennium BC that had an image resembling a windmill. By 200 BC, the Persian, Chinese, and Middle Easterners used windmills extensively for irrigation, wood cutting, and grinding grains. They were often constructed as revolving door systems with woven reed sails, similar to the vertical-axis wind system used today. By the eleventh century, people in the Middle East were using windmills extensively for food production. During the period from the eleventh century to thirteenth century, foreign merchants who traded with the Middle East, and the crusaders who invaded the region, carried the windmill technology back to Europe. Figure 1.1 shows a nineteenth-century renovated windmill in Europe. In Holland, windmills were also used to drain lands below the water level of the Rhine River. During this era, working in windmills was one of the most hazardous jobs in Europe. The workers were frequently injured because windmills were constructed of a huge rotating mass with little or no control on its rotation. The grinding or hammering sounds were so loud that many workers became deaf, the grinding dust of certain material such as wood caused respiratory health problems, and the grinding stones often caused sparks and fires.

In addition to producing mechanical power, windmills were used to communicate with neighbors by locking the windmill sails in a certain arrangement. During World War II, the Netherlanders used to set windmill sails in certain positions to alert the public of a possible attack by their enemies.

During the nineteenth century, the European settlers brought windmill technology to North America. They were mainly used to pump water from wells for farming. The first known windmill was built by Daniel Halladay in 1854. It was quite an innovative system, as it was able to align itself with wind direction. In 1863, he established the U.S. Wind Engine & Pump Company, Illinois, which was the first mass manufacturer of windmills in the United States. One of their designs is shown in Figure 1.2. During the nineteenth and early twentieth centuries, there were over 1000 factories building these very useful machines. Most, however, were weak designs that break due to over speeding during wind gusts.

Windmills were initially made out of wood, which limited their powers and speeds. Over time, iron and steel replaced wood, and systems with gearbox were introduced. They were much powerful systems, but much more expensive than wood. The first all-steel windmill was invented and designed by Thomas Osborn Perry in 1883.

In 1888, Charles Francis Brush of the United States made a major innovation by converting the kinetic energy in wind into electrical energy. These types of windmills are called "wind turbines." The first design, which is shown in Figure 1.3, was about 20 m in height and 36 ton in weight. This enormous structure produced just 12 kW. Because power grid did not reach farmlands in the United States until the second quarter of the twentieth century, farmers relied on these wind turbines for their electric energy needs. During the period from 1930 to 1940, thousands of wind turbines were used in rural areas not yet served

FIGURE 1.1
Renovated nineteenth-century windmill.

FIGURE 1.2
Halladay's windmill. (Courtesy of Billy Hathorn through Wikipedia.)

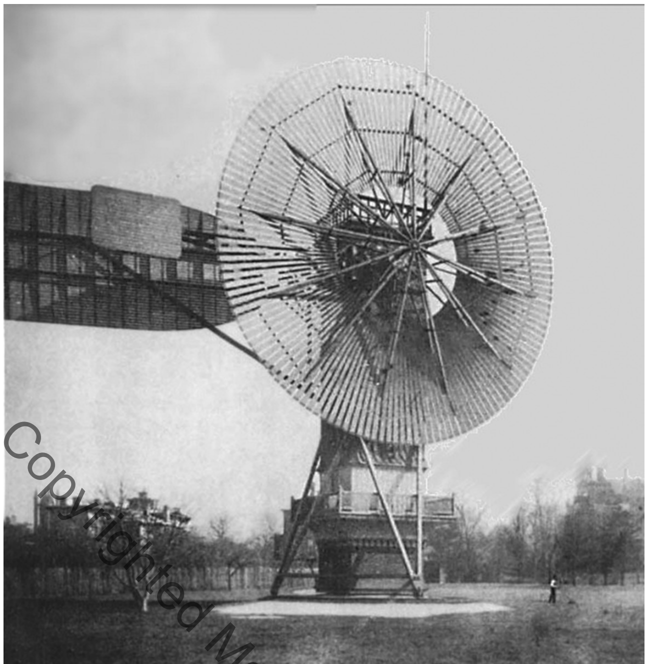

FIGURE 1.3
First electric wind turbine. (Courtesy of Robert W. Righter through Wikipedia.)

by the power grid. The Great Plains (west of the Mississippi River and east of the Rocky Mountains in the United States and Canada) had the majority of these machines.

In 1891, Poul La Cour of Denmark built the first wind turbine outside of the United States. In 1896, he tested small models of wind turbines in a wind tunnel. This was the first of such experiments in the world. Among his major contributions is the discovery of the power-capturing capability as a function of blade shape and number of blades. His primitive experiment in wind tunnel showed that eight blades can capture about 28% of the available wind energy, whereas 16 blades can capture about 29%. La Cour concluded that the number of blades and the energy-capturing capability are not linearly related. In addition, he showed that curved blades could capture more energy from wind. These are key factors that resulted in the designs of current wind turbines.

After the invention of the steam engine and the expansion of power grids to rural areas, interest in wind turbines declined. The interest was only renewed during the oil crisis of the 1970s, mainly because the generous tax credits by the U.S. government. Consequently, several wind farms were built in the United States in the 1970s and 1980s. These wind turbines, unfortunately, were very expensive and high-maintenance machines. They also created electrical problems to the grid such as voltage flickers and voltage depression due to the high and cyclic demand for reactive powers.

Interest in wind energy declined again in the 1980s because of the following four reasons:

1. Oil prices dropped substantially around 1985.
2. U.S. tax credits were provided for anyone who had installed wind turbines instead of the actual energy production. Because of this shortcoming, wind turbines were afflicted with low productivity and frequent failures. It was not unusual

to find a wind farm with less than 10% of their turbines producing electricity. This investment tax credits expired in 1986.

3. Designs of wind turbines were fragile and required extensive maintenance.
4. Cost of electricity generated by wind turbines were several times higher than those provided from conventional resources.

To address the declining interest in wind energy, the United States issued a new type of tax credit in 1992 based on the production of electricity rather than cost of installation, known as federal production tax credit (PTC). PTC encouraged major improvements in wind turbine research and designs, and encouraged developers to maximize their electricity production. As a result, nowadays, the cost of wind energy dropped to a level comparable to fossil-fuel power plants.

1.1 Wind Turbines

Modern wind turbines are much larger in size and much more reliable than the 1970s–1980s versions. The power rating of wind turbines, as shown in Figure 1.4, has increased from just a few kilowatt to up to 8 MW for a single unit in 2013. Because the air density is low, these machines are large in size, as seen in the figure. Keep in mind that the height of the Statue of Liberty is 93 m and that of the Great Pyramid is 140 m.

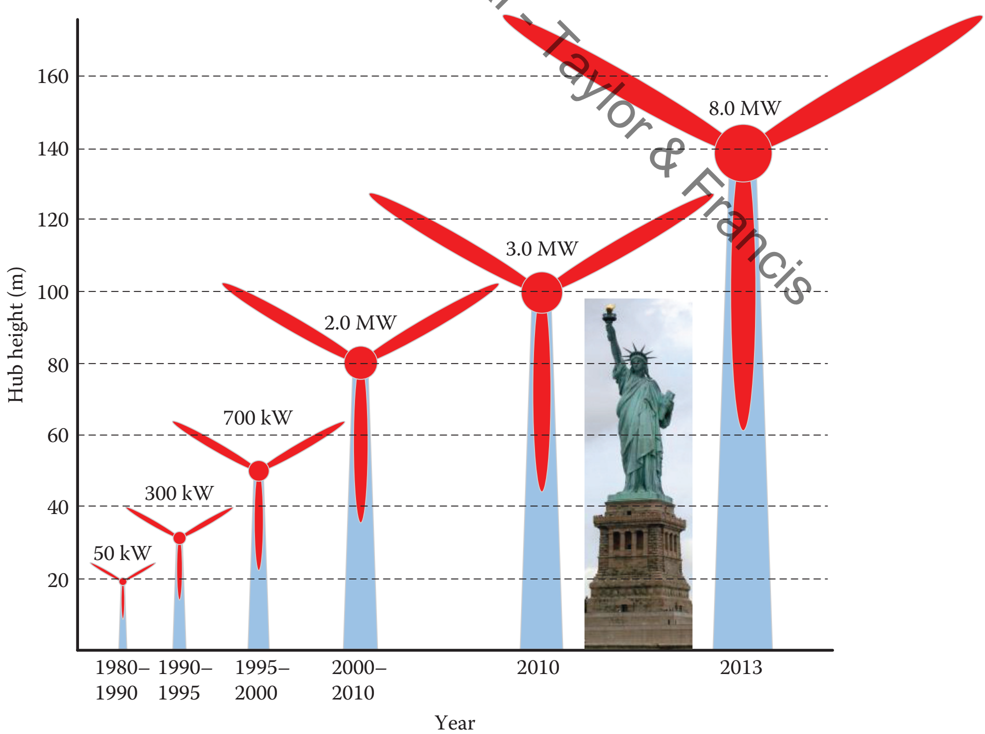

FIGURE 1.4
Average height of wind turbines.

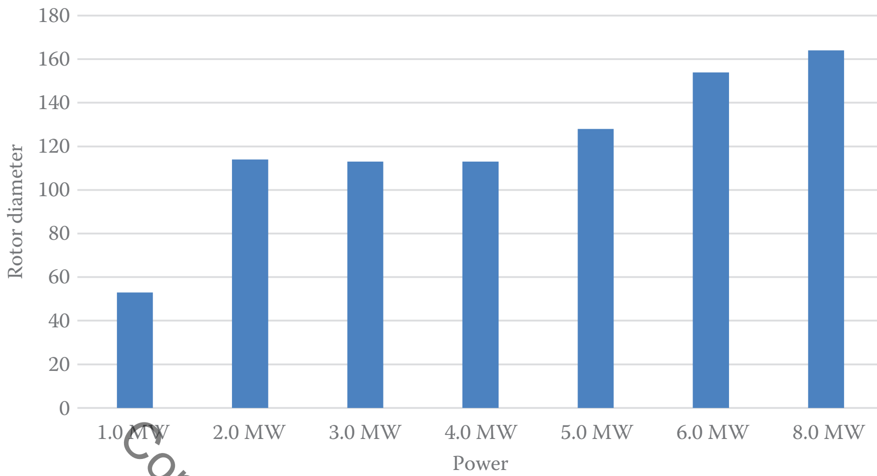

FIGURE 1.5
Typical rotor diameter.

The power captured by the turbine is proportional to the sweep area of its blades. This makes the power proportional to the square of the blade length, as seen in Chapter 2. The diameter of the sweep area is known as the "rotor diameter," which is twice the length of a single blade. Some typical rotor diameters is given in Figure 1.5. To put the number into perspective, the diameter of a 2 MW turbine is more than the length of a Boeing 747 airplane or an Airbus 380.

Figure 1.6 shows a 1.8 MW turbine blade. Note the length of the blade with respect to the extended-load truck. Such a large length poses a transportation problem as most roads cannot allow drivers to negotiate turns. This is why larger turbines are built offshore.

The drive shaft of wind turbines can rotate horizontally or vertically. A horizontal-axis wind turbine (HAWT) is shown in Figure 1.7. This is the most common type of wind turbine system used today. Its main drive shaft, gearbox, electrical generator, and, sometimes, the transformer are housed in the nacelle at the top of a tower (see Figure 1.8). The turbine is aligned to face the upwind. To prevent the blades from hitting the tower at high wind conditions, the blades are placed at a distance in front of the tower and tilted up a little. The tall tower allows the turbine to access strong wind. Every blade receives power from wind at any position, which makes the HAWT a high-efficient design. The HAWT, however, requires

FIGURE 1.6
Blade of a 1.8 MW wind turbine.

FIGURE 1.7
A 1.8 MW horizontal-axis wind turbine.

FIGURE 1.8
Nacelle of a 1.8 MW wind turbine.

massive tower construction to support the heavy nacelle, and it requires an additional yaw control system to turn the blades toward wind.

The other design is the vertical-axis wind turbine (VAWT) shown in Figure 1.9. It is known as “Darrieus wind turbines” and it looks like a giant upside down eggbeater. The VAWT was among the early designs of wind turbines because it is suitable for sites with shifting wind directions. This design does not require a yaw mechanism to direct the blade into wind. The generator, gearbox, and transformers are all located at the ground level, making the VAWT easier to install and maintain as compared with the HAWT. The cut-in speed of the VAWT is generally lower than that for the HAWT. However, because of its massive inertia, VAWT may require external power source to startup the turbine, and extensive bearing system to support the heavy weight of the turbine. Because wind speed is slower near ground, the available wind power is lower than that of HAWT. In addition, objects near ground can create turbulent flow that can produce vibration on the rotating components and cause extra stress on the turbine.

The VAWT is also popular in small wind energy systems. One of them is shown in Figure 1.10. This small VAWT is intended for individual use (home or office), and several units with design variations are installed all over the world.

FIGURE 1.9
Vertical-axis wind turbine. (Courtesy of U.S. National Renewable Energy Lab.)

FIGURE 1.10
Small wind turbine. (Courtesy of Anders Sandberg through Wikipedia.)

1.2 Offshore Wind Turbines

With the continuous demand for larger wind turbines, researchers envisioned the offshore wind turbines. This is because of several reasons; a few among them are as follows:

- Size of wind turbines will eventually reach a level where roads cannot accommodate the transportation of the blades.
- Offshore wind is stronger than onshore.
- Offshore winds are often strong in the afternoon, which match the time of heavy electricity demand.
- Most densely populated areas are near shores. Thus, offshore systems do not need extensive transmission systems. For example, 28 states in the United States have coastal lines. These states consume 78% of the national electric energy.
- Offshore turbines are not normally visible from shores. This reduces the public concern with regard to the visual impact of wind farms.
- Noise and light flickers are less of a problem for offshore turbines.

FIGURE 1.11
Offshore vertical-axis wind turbine. (Courtesy of Leonard G. through Wikipedia.)

With today's technology, most of the offshore installations are in relatively shallow water (up to 50 m deep) (Figure 1.11). The first offshore wind turbines were installed in Denmark in 1991. By early 2014, 70 offshore wind farms were in operation with a capacity of about 7 GW. Offshore wind is expected to dominate the large turbine market for the foreseeable future.

Exercise

1. What is the difference between a wind mill and a wind turbine?
2. What is a Halladay windmill?
3. Who invented the first wind turbine?
4. Where was the first wind turbine invented?
5. State one of the major contributions of Poul La Cour.
6. What is the average blade length for a 6 MW wind turbine?
7. What are the advantages and disadvantages of HAWT?
8. What are the advantages and disadvantages of VAWT?
9. What are the advantages and disadvantages of offshore wind turbines?