Article 2: Key Concepts and Vocabulary

We introduce a few underlying concepts and vocabulary for electricity and wind power.

2.1 The Watt and the Watt-Hour

The Watt (The Common Unit of Power)

The rate at which energy is produced or consumed is known as power and is measured in watts. For electrical devices, this energy is in the form of electricity. Some electrical devices (generators) produce electricity and others (loads) consume it. A 60-watt light bulb consumes electricity at the rate of 60 watts when turned on. A toaster making toast consumes electricity at a rate of about 1,000 watts, or 1 kilowatt. The largest jet aircraft engines can produce energy at a rate of about 100 million watts, or 100 megawatts.

We will use both kilowatts and megawatts in this distillate; remember that a megawatt is 1,000 times larger than a kilowatt. We will not use the "gigawatt," which is 1,000 times larger than a megawatt. We will avoid abbreviations: W, kW, MW, and GW, for the watt, the kilowatt, the megawatt, and the gigawatt, respectively.

A new, large land-based wind turbine today would typically be able to produce electricity at a maximum rate of three megawatts; it cannot produce electricity any faster, but in low winds it will produce electricity at a lower rate.

The Watt-Hour (The Common Unit of Energy)

The watt-hour is a unit of energy, which is commonly used to describe amounts of electricity produced or consumed over a period of time. The hyphen in watt-hour means that a multiplication is involved: a multiplication of a power unit (rate of energy production) and a time unit. A 60-watt bulb will consume 60 watt-hours when it is on for one hour and 120 watt-hours when it is on for two hours.

In this distillate, the energy units we will use are the kilowatt-hour and the megawatt-hour; we will not use the watt-hour or the gigawatt-hour. In the text, we will not abbreviate kilowatt-hour as kWh or megawatt-hour as MWh, but will always write them out. Where abbreviations do occur in figures, we remind the reader of their meaning in the caption.

Watts and watt-hours are frequently confused, in part because the watt is one of the few units describing a rate that has a name of its own.[1] If a home consumes 360 kilowatt-hours of electricity in 720 hours (a 30-day month), it consumes electricity at an average rate of half a kilowatt (500 watts).

2.2 Features of Wind and the Wind Turbine

Nomenclature for the Wind Turbine

Figure 2.1 labels the four main components of a wind turbine. The particular image shows a turbine sited offshore in Belgium. The blades are attached to the hub, which is part of the nacelle located at the top of the tower.

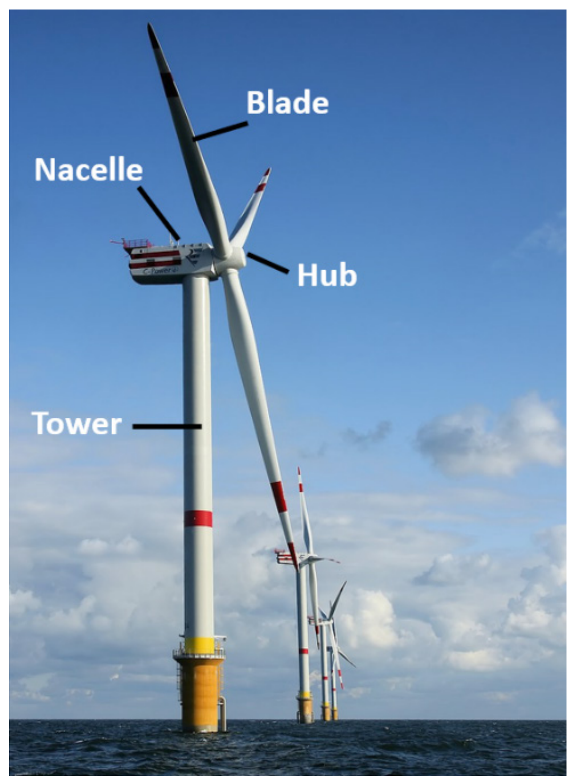

Figure 2.1: The principal parts of a wind turbine. Source: Hans Hillewaert, https://en.wikipedia.org/wiki/Wind_turbine#/media/File:Windmills_D1-D4_(Thornton_Bank).jpg.

[1]Other units that describe rates include the ampere (a rate of flow of electric current) and the knot (a measure of nautical speed).

Wind Speed

U.S. readers know intimately how to think about wind speed in miles per hour. Ordinary walking is more difficult at wind speeds of 30 miles per hour, and signs of the destructive force of wind on trees and structures are likely after winds at speeds of 60 miles per hour have moved through. However, most of the world discusses wind speeds not in miles per hour but in meters per second. We will always report wind speeds in meters per second, but we will not always provide the speed in miles per hour. The conversions between the two units are these:

2.22 miles per hour is 1 meter per second,

1 mile per hour is 0.45 meters per second.

Thus, 30 miles per hour is 13.5 meters per second, and 60 miles per hour is 27 meters per second.[2]

The "Turbine" and the "Farm"

The word "turbine" is used in two ways in the wind industry. In this distillate, the "wind turbine" is the entire system that converts incoming wind to electricity, including the foundation, the tower, and the blades, as well as the mechanical and electrical machinery, mostly located at the top of the tower. The "turbine" sometimes refers, instead, just to the rotating machinery that produces electricity from the mechanical energy of the slow-rotating shaft attached to the blades. The wind turbine viewed as a system used to be called a "windmill," because its principal function was to mill grain by turning a millstone; the change from "mill" to "turbine" emphasizes that its objective now is to generate electricity.

Although the word "windmill' is disappearing, the words used for a collection of wind turbines at a single site still evoke the industry's agricultural origins: it is called a "wind farm." Figure 2.1 shows an offshore wind farm.

Rated Wind Speed and Rated Capacity for a Wind Turbine

Every wind turbine has a specific wind speed, the "rated" speed, which is the lowest wind speed at which it generates power at its full capacity (its "rated" capacity). The turbine is deliberately operated so as to prevent the production of extra power when the wind blows faster than the rated speed. The rated speed is a compromise between capturing as much wind as possible and keeping the cost of the turbine as low as possible.

Capacity Factor, A Performance Index for a Turbine at a Site

The "capacity factor" is a generic concept, applicable to any power plant. It is the actual amount of electricity produced at a power plant, divided by the maximum amount of electricity the plant could have produced if it had run continuously at its rated capacity (over some common period such as a year). In the case of the wind turbine, the capacity factor, as noted above, is tied to the rated wind speed and the actual distribution of wind speeds at a site.

The capacity factor of a wind turbine is affected by the variability of the wind speed at the site: an ideal wind would blow at the rated speed all the time. The capacity factor is reduced as a result of times of low or non-existent winds, downtime for maintenance, and any deliberate reduction in power generation (curtailment) imposed by a grid manager to prevent excess supply.

The capacity factor can also characterize a wind farm, or all the wind in a utility's portfolio, or an entire geographic region. For example, the capacity factor for the entire world's wind power (an average over all the wind power plants) in 2015 can be calculated from estimates that global installed capacity (the total rated capacity for all the turbines licensed to run) was 435,000 megawatts (435 million kilowatts) and global wind production was 834 billion kilowatt-hours.[3] Since there were 8,760 hours in 2015, it follows that 3,810 billion kilowatt-hours of electricity would have been produced if the turbines had run at full capacity all year. Dividing 834 by 3,810, the capacity factor for the world's wind power in 2015 was 22 percent.

Another way to express this result is to note that 22 percent of the 8,760 hours in a year is about 1,900 hours. Therefore, global production was equivalent to production at full capacity for about 1,900 hours, and no electricity production during the rest of the year.

Capacity factors are much higher than 22 percent for recently installed turbines, excellent sites, and well-functioning electricity markets.

Efficiency, A Performance Index for a Turbine Determined by the Device

The efficiency of a turbine is a measure of its performance that is complementary to the concept of capacity factor. The efficiency quantifies how well the incoming energy in the wind is converted into electricity, while the capacity factor is largely determined by the

[2]One hour is 3,600 seconds, and one mile is 1,609 meters (1.609 kilometers). Dividing (3,600 seconds per hour) by (1,609 meters per mile) equals (2.22 miles per hour) per (meter per second).

[3]World Energy Council - World Energy Resources Wind | 2016

characteristics of the wind where the turbine is located. A typical efficiency for a large modern turbine is about 40 to 50 percent. To state this in other words, imagine a circle traced by the tips of the blades of a wind turbine as they turn. A 40 percent efficient wind turbine produces an amount of electricity equal to 40 percent of the kinetic energy in the wind that would strike the area within that circle if the blades weren't turning.

Pitch and Yaw

A wind turbine can change its output by changing the angle between the blades and the incoming wind (the "pitch" of the blades). It can respond to a change of wind direction by turning the nacelle to face the wind using its "yaw" motors.

Curtailment

A grid operator can require that the power output of a wind turbine be reduced when total electricity production from the whole system would otherwise exceed total consumption and contractual or other barriers constrain the reduction of production from the other resources on the grid. These "curtailments" can arise when turbines are built ahead of transmission capacity or when the rules of a grid prioritize other sources ahead of wind. Curtailments also result when wind forecasting has under-predicted actual production and the grid cannot accommodate the excess. Because of the low marginal cost of wind power, grid operators and wind power developers seek to minimize curtailments.