8 Wind energy is a renewable source of energy, harnessed from the kinetic energy of moving air. Since the late 1800s, windmills like the one shown in Fig. 8.1 have been used for milling grains.

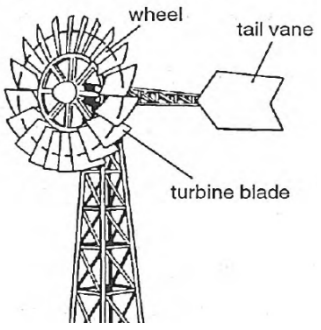


Fig. 8.1

Fig. 8.2 shows how the output power of these windmills varies with the overall diameter of the wheel for different wind speeds. The density of air is 1.3 kg m^{-3}.

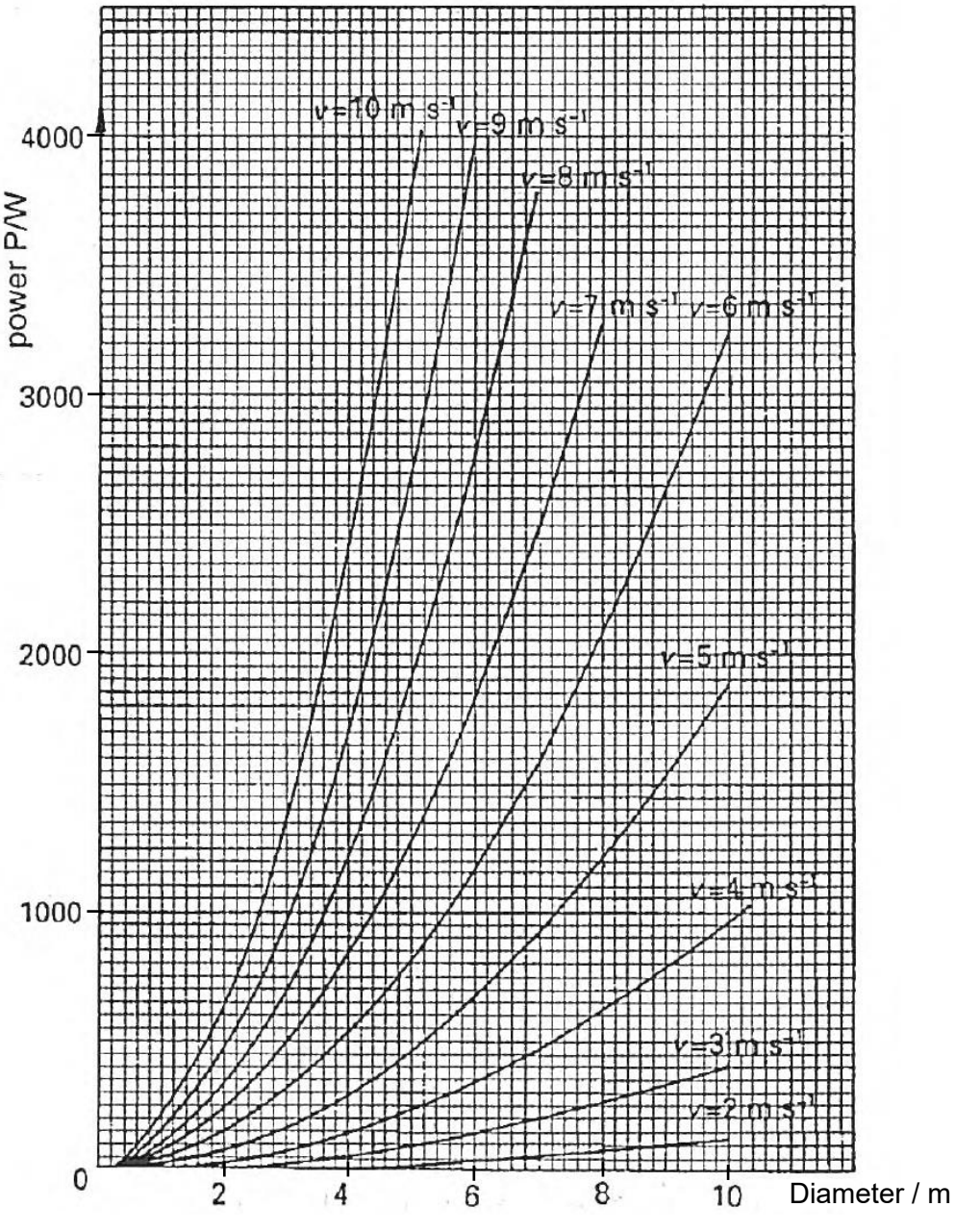
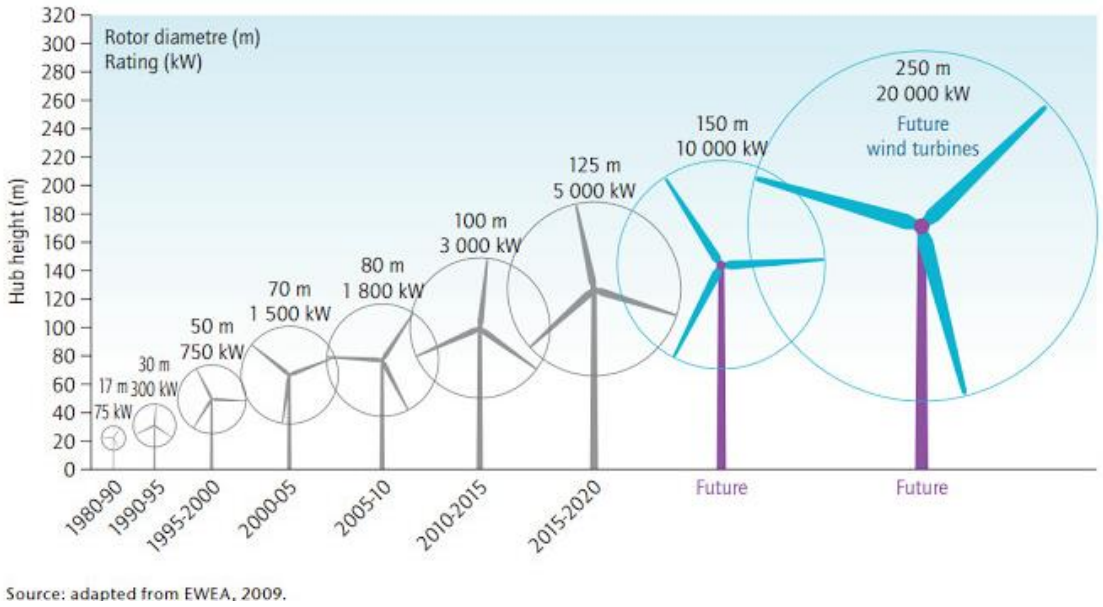


Fig. 8.2

Wind turbines are the modern evolutions of windmills. They have evolved from their multi-bladed predecessors to the modern 3-bladed version. Wind turbines have also increased in hub height and rotor diameter size in the last 45 years as shown in Fig. 8.3.



Source: adapted from EWEA, 2009.

Fig. 8.3

Wind turbines have rotor hubs that can change the angle of attack of the rotor blades, which allows it to vary the amount of wind it catches. The nacelle houses a low-speed shaft that is connected to a gearbox which is in turn connected to a high-speed shaft before being connected to a generator. Parts of the wind turbine are shown in Fig. 8.4 below.

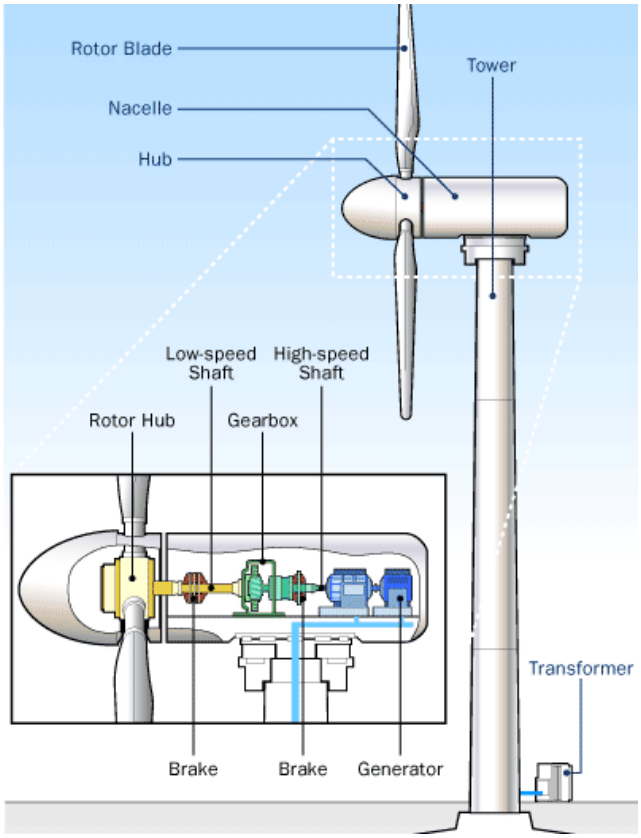


Fig. 8.4

The choice of location of wind turbines is an important factor to consider when building wind turbines. A table of average wind speed at various heights and locations are shown in Fig. 8.5.

Height above ground / m	Wind speed / m s^{-1}	
	On land	Offshore
20	2.43	3.52
50	3.86	4.51
80	4.11	5.96
100	5.29	7.27
120	6.43	9.51

Fig. 8.5

(a) The windmill is most efficient when the wheel and turbine faces the oncoming wind head-on. With reference to Fig. 8.1, explain how the tail vane works.

.....

.....[1]

(b) By considering the kinetic energy possessed by a cylindrical volume of air, prove that the input power P that can be harnessed by a windmill of cross-sectional area A is given by

$$P = \frac{1}{2}\rho A v^3 ,$$

where ρ is the density of air and v is the velocity of air. Explain your working.

[3]

(c) (i) For a windmill of diameter 9.0 m, state the power produced by the windmill when the wind speed is 6.0 m s^{-1}.

power = ... W [1]

(ii) Calculate the efficiency of a windmill of diameter 9.0 m when the wind speed is 6.0 m s^{-1}.

efficiency = ... % [2]

(iii) Suggest one reason for the loss in efficiency.

.....

.....[1]

(d) (i) For the 3-bladed wind turbines built between 2010 to 2015, each typical rotor blade has an effective area of 120 m^2 that faces the wind head on. The dynamic wind pressure p is given by

$$p = \frac{1}{2}\rho v^2$$

where ρ is the density of air and v is the speed of air.

1. State the hub height of a typical wind turbine built on land between 2010 to 2015.

hub height = ... m [1]

2. By considering the wind speed at the hub height in your answer in **(d)(i)1.**, estimate the moments acting on the wind turbine taken about the base of the tower when built on land.

moment = ... N m [2]

3. Hence suggest why modern wind turbines typically have only 3 blades even though a multi-bladed windmill ensures that more wind energy is harnessed.

.....

.....

.....[1]

(e) Explain how an increase in hub height and rotor diameter of wind turbines improves energy production.

.....

.....

.....

.....[2]

(f) **(i)** Wind turbines typically spin at a rate of 10 to 20 rounds per minute. For a wind turbine with a rotor diameter of 250 m, calculate the speed at the tip of the blade if it were to spin at 30 rounds per minute.

speed = ... $m\ s^{-1}$ [2]

(ii) Suggest why this rate of rotation is undesirable.

.....

.....[1]

(g) Explain, using the laws of electromagnetic induction, why there is a need to convert the rate of rotation of the shaft to a high rate before connecting to the generator.

.....

.....

.....[2]

[Total: 19]