

- 8 Read the following article and answer the questions that follow.

### Wind Turbines

From massive wind farms generating power to small turbines powering a single home, wind turbines around the globe generate clean electricity for a variety of power needs. The concept of harnessing wind energy to generate mechanical power goes back for millennia. As early as 5000 B.C., Egyptians used wind energy to propel boats along the Nile River. Windmills were also used to grind grain, pump water and cut wood at sawmills. Today's wind turbines are the windmill's modern equivalent -- converting the kinetic energy in wind into clean, renewable electricity.

Singapore's largest wind turbine located on Pulau Semakau taps wind energy to power the offshore island's energy needs. The turbine's three long-span rotor blades produce about 20 kWh of electricity per hour, depending on the wind conditions in Singapore. This turbine is one of up to seven that will generate power for hybrid microgrids on the landfill south of Singapore, as the nation steers itself towards developing sustainable energy. The turbine can generate power with a range of wind speeds.

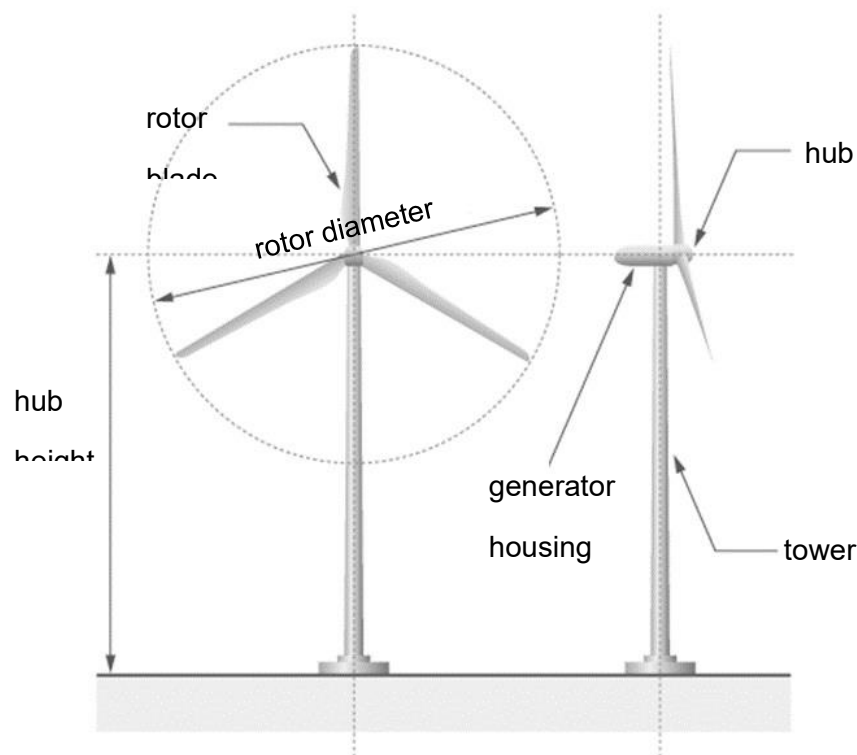
Source:

<https://www.straitstimes.com/singapore/wind-turbine-on-semakau-landfill-can-power-as-many-as-35-hdb-flats-a-year>

<https://www.straitstimes.com/singapore/singapores-largest-wind-turbine-built-on-semakau-island>

The majority of wind turbines consist of three blades mounted to a tower made from tubular steel. There are less common varieties with two blades, or with concrete or steel lattice towers. At 30 m or more above the ground, the tower allows the turbine to take advantage of faster wind speeds found at higher altitudes.

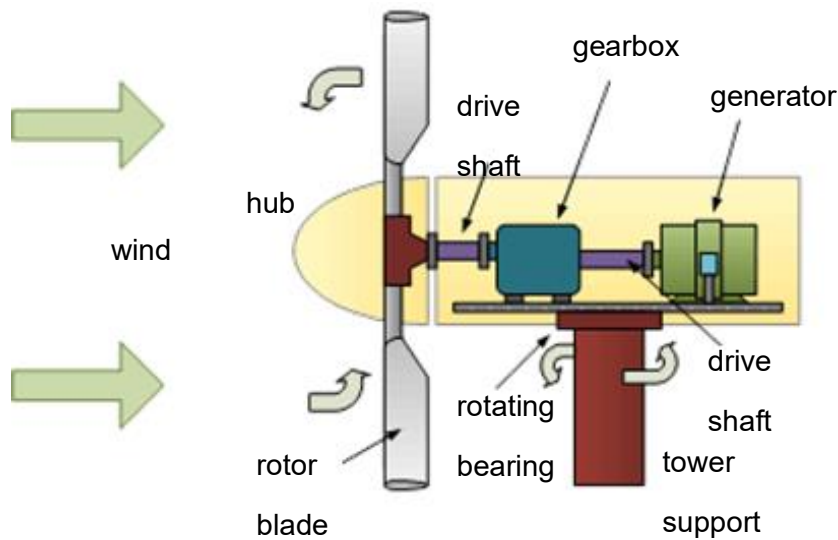
Fig. 8.1 illustrates one particular type of wind turbine.



**Fig. 8.1**

Source: <http://www.venti-japan.jp/en/windpoweren.html>

Fig. 8.2 below shows the basic components that go to the make up a typical wind turbine design.



**Fig. 8.2 (not to scale)**

Kinetic energy from the wind causes the rotor blades to turn and these drive an electric generator. The electric generator is situated in the housing at the top of the tower. The available power in the wind that is available for harvesting depends on both the wind speed and the area that is swept by the rotating turbine blades. The faster the wind speed or the larger the rotor blades the more energy can be extracted from the wind. Therefore, wind turbine power production depends on the interaction between the rotor blades and the wind and it is this interaction that is important for a *wind turbine design*.

Source:

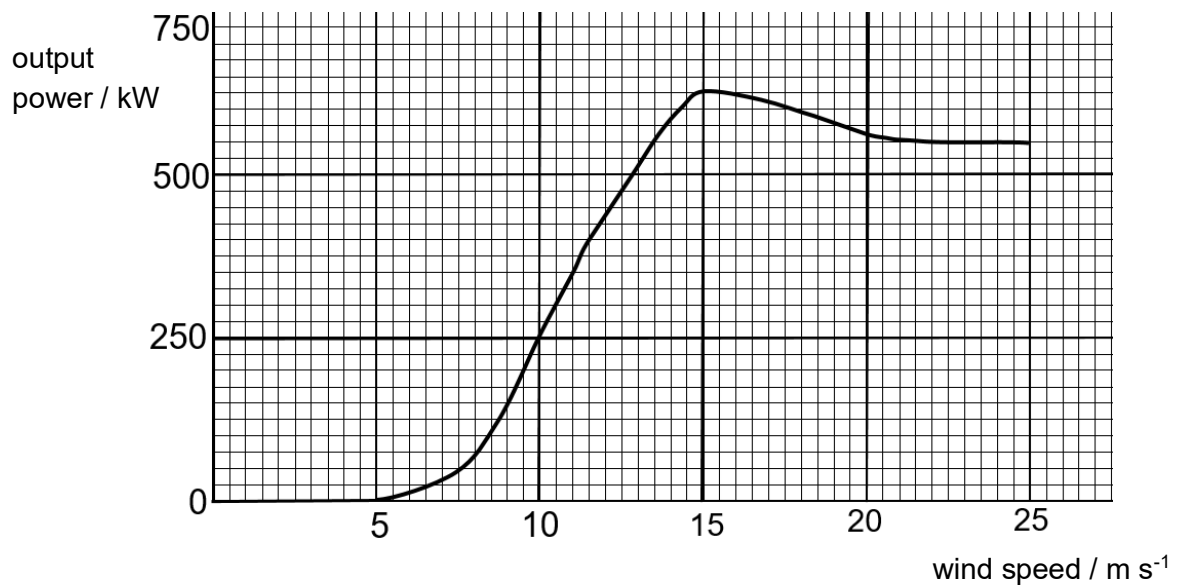
<https://www.alternative-energy-tutorials.com/wind-energy/wind-turbine-design.html>

<https://www.energy.gov/articles/how-wind-turbine-works>

Some information provided by the manufacturer of the wind turbines is given in the table in Fig. 8.3a and graph in Fig. 8.3b.

Height of tower from ground to hub	56 m
Rotor diameter	44 m
Number of blades	3
Nominal output	500 kW
Voltage	690 V
Frequency	50 Hz

**Fig. 8.3a**



**Fig. 8.3b**

- (a) Determine the minimum height of the tip of a rotor blade above ground level.

[1]

height = ..... m

**(b)** Using the manufacturer's data to give values of

**(i)** the maximum power output,

[1]

maximum power = ..... kW

**(ii)** the wind speed for this maximum power.

[1]

wind speed = .....  $\text{m s}^{-1}$

**(c)** Air of density  $\rho$  and speed  $v$  is incident normally on a rotor of radius  $r$ . The kinetic energy  $E_k$  of the air incident on the rotor in unit time  $t$  is given by

$$\frac{E_K}{t} = \frac{1}{2} \pi r^2 v^3 \rho$$

The air has density  $1.25 \text{ kg m}^{-3}$ .

- (i) 1. Calculate, for the wind turbine operating at maximum output power, the kinetic energy of air incident per second on the rotor (the incident wind power),

[2]

incident wind power = ..... W

2. the overall efficiency of generation of electric power.

[2]

efficiency = ..... %

- (ii) On Fig. 8.3c, sketch the graph to show how the input power of the air varies with the wind speed.

input power / kW



[2]

**Fig. 8.3c**

- (d) In addition to the incident wind power usefully transformed into electrical in the wind turbine, 10% of the incident wind power is lost.

Calculate the power of the wind after it passed through the rotor at the maximum output power.

[2]

power = ..... W

- (e) At high wind speeds, the turbine is 'cut out', that is, the generator is no longer turned by the blades.

- (i) Use Fig. 8.3b to determine this cut-out speed.

[1]

cut-out speed = .....  $\text{m s}^{-1}$

- (ii) Suggest one reason why it is necessary to have a cut-out speed.

.....

[1]

.....

- (f) (i) Suggest whether the generator produces direct current or alternating current, explaining how you came to your conclusion.

.....

.....

[2]

.....

.....

- (ii) Calculate the nominal current from the generator.

[2]

current = ..... A

- (g) The gearbox of the wind turbine consists of a series of gears that connect the rotor blade to generator. The gear ratio for the wind turbine is 90:1. For one revolution the blades make, the generator shaft spins 90 times. The speed that allows the turbine's generator to produce electricity is when it is moving at roughly 1500 revolution per minute.

Calculate the speed of the tip of the blade for the wind turbine when it produces electricity.

[3]

speed of blade = ..... m s<sup>-1</sup>

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